School of Psychology and Speech Pathology

The effectiveness of PROMPT therapy for children with Cerebral Palsy

Roslyn Ward

This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University

April 2012

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Roslyn Ward

Signature………………………………….

Date………………………………………

Acknowledgements

> *"intellectual development and personal growth do not occur if there is no disequilibrim in a person's current thinking or feeling"(Panicucci, 2007).*

The undertaking of this thesis was made possible by the support and contributions of many, to whom I owe much gratitude. Each person has played a unique and vital role.

To My Academic Team

Supervisor: Suze Leitão - I feel privileged to have completed this thesis under your supervision. Thank you for your time, support, guidance and insights. I have sincerely appreciated your adeptness at keeping me on track, dedication to evidence-based practice, and editorial expertise.

Co-supervisor: Geoff Strauss - The kinematic analysis would not have been possible without your expertise. Thank you for your assistance, guidance and attention to detail. I have valued your patience, particularly in explaining some of the key principles.

Research Assistant: Paul Davey - Thank you for your instruction in the Peak Motus system, writing the programs that enabled the kinematic analysis; and the creation of the visual animations. I also want to acknowledge your persistence in problem solving glitches along the way.

Statistician: Peter McKinnon - Thank you for your assistance and willingness to repeatedly answer my questions with such patience and humour.

Thanks also go to Associate Professor Anne Ozanne and Dr. Beverly Joffe at LaTrobe University, where this journey commenced.

To My Colleagues

Elizabeth Barty - You have been a great source of support and mentoring. Thank you for being instrumental in facilitating the availability of resources that made the intervention study possible.

Georgina Jones - Thank you for undertaking and completing the practical aspects of this study: from logistics to data preparation and de-identification. I am most grateful for your commitment to rigor and exactness.

Michael Chan - Thank you for inspiring me to pursue a deeper understanding of movement disorders.

The Therapists at the Centre for Cerebral Palsy - Thanks go to the therapists who administered the PROMPT intervention protocols. Their commitment to undertake the PROMPT training and dedication to administering the therapy protocols is gratefully acknowledged.

Deborah Hayden (PROMPT Institute) – Thank you for your support throughout the process, in particular for conferring on the participant intervention protocols and priorities, providing therapist training during the mentoring day and fidelity protocol.

Linda Orton and Meg Houghton - Thank you for your professionalism, commitment and attention to detail. I would like to express my gratitude for the vital roles you fulfilled as independent scorers, thus allowing me to remain blinded during the analyses.

Marie Blackmore - Thank you for support and assistance during the early phases of this thesis when the study design and methodology were in development. Your knowledge and expertise in single subject research design was invaluable.

To The Families Who Participated in This Study

Sincere and deep thanks go to the participants and their families who gave so generously of their time with such dedication and commitment.

To My Friends and Family

Finally, I wish to thank family members and friends who shared the journey. Special mention goes to my husband Russell and my daughter April - Your encouragement, practical support and understanding were instrumental to seeing this thesis across the finish line.

Peer Reviewed Presentations and Publications arising from the Thesis

Ward, R. (2009, Sept). *The effectiveness of PROMPT therapy for children with cerebral palsy*. Poster presented at the 63rd American Academy of Cerebral Palsy and Developmental Medicine (AACPDM) Annual Meeting, Arizona, USA.

Ward, R., Leitão, S., & Strauss, G. (2009). The effectiveness of PROMPT therapy for children with cerebral palsy [Abstract]. *Developmental Medicine and Child Neurology, 51(S5):* 76.

Ward, R. (2011, June). *Kinematic changes in jaw and lip control of children with cerebral palsy following participation in a motor-speech (PROMPT) intervention*. Poster presented at the 6th International Conference on Speech Motor Control, Groningen, The Netherlands.

Ward, R., Strauss, G., & Leitão, S. (2011). Kinematic changes in jaw and lip control of children with cerebral palsy following participation in a motor-speech (PROMPT) intervention [Abstract]. *Stem, Spraak en Taalpathologie, 17:* 59

Ward, R., Strauss, G., & Leitão, S. (2011). Kinematic changes in jaw and lip control of children with cerebral palsy following participation in a motor-speech (PROMPT) intervention. *Manuscript in review.*

Abstract

The purpose of this study is to evaluate the effectiveness of a motor speech treatment approach (PROMPT) in the management of motor-speech impairment in children with cerebral palsy. Two main objectives were addressed: (1) to evaluate changes in speech intelligibility and, (2) evaluate changes in kinematic movements of the jaw and lips using three dimensional (3D) motion analysis.

A single subject multiple-baseline-across-participants research design, with four phases: Baseline (A1), two intervention phases (B and C) and maintenance (A2), was implemented.

Six participants, aged 3-to-11-years (3 boys, 3 girls) with moderate to severe speech impairment were recruited through The Centre for Cerebral Palsy, Western Australia (TCCP). Inclusion criteria were: diagnosis of cerebral palsy, age 3 – 14 years, stable head control (supported or independent), spontaneous use of at least 15 words, speech impairment ≥1.5 standard deviations, hearing loss no greater than 25dB, developmental quotient ≥70 (Leiter-Brief International Performance Scale R) and no previous exposure to PROMPT.

Thirteen typically-developing peers were recruited to compare the trend of kinematic changes in jaw and lip movements to those of the children with cerebral palsy.

Upon achievement of a stable baseline, participants completed two intervention phases both of 10 weeks duration. Therapist fidelity to the PROMPT approach was determined by a blinded, independent PROMPT Instructor.

Perceptual outcome measures included the administration of weekly speech probes, containing trained and untrained vocabulary at the two targeted levels of intervention plus an additional level. These were analysed for both perceptual accuracy (PA) and the motor speech movement parameter.

End of phase measures included:

1. Changes in phonetic accuracy as measured using a measure of percentage phonemes correct;

2. Speech intelligibility measures, using a standardised assessment tool; and
3. Changes to activity/participation using the Canadian Occupational Performance Measure (COPM).

Kinematic data were collected at the end of each study phase using 3D motion analysis (Vicon Motus 9.1). This involved the collection of jaw and lip measurements of distance, duration and velocity, during the production of 11 untrained stimulus words. The words contained vowels that spanned the articulatory space and represented motor-speech movement patterns at the level of mandibular and labial-facial control, as classified according to the PROMPT motor speech hierarchy.

Analysis of the speech probe data showed all participants recorded a statistically significant improvement. Between phases A1-B and B-C 6/6 and 4/6 participants respectively, recorded a statistically significant increase in performance level on the motor speech movement patterns (MSMPs) targeted during the training of that intervention priority (IP). The data further show that five participants (one participant was lost to follow-up) achieved a statistically significant increase at 12-weeks post-intervention as compared to baseline (phase A1).

Four participants achieved a statistically significant increase in performance level in the PA of the speech probes of both IP1 and IP2 between phases A1-B. Whilst only one participant recorded a statistically significant increase in PA between phases B-C, five participants achieved a statistically significant increase in IP2 between phases A1-C. The data further show all participants achieved a statistically significant increase in PA on both intervention priorities at 12-weeks post-intervention.

All participants recorded data that indicated improved perceptual accuracy across the study phases. This was indicated by a statistically significant increase in the percentage phonemes correct scores $F(3,18) = 5.55$, $p<.05$.

All participants achieved improved speech intelligibility. Five participants recorded an increase in speech intelligibility greater than 14% at the end of the first intervention (phase B). Continued improvement was observed for 5 participants at the end of the second intervention (phase C).

All participants achieved a statistically significant improvement in activity/participation subsequent to intervention. The analyses showed a statistically significant improvement in performance on all four items of the sensory-motor domain and item 12 in the social-emotional domain (ability to express emotions and feelings to family members and friends) subsequent to intervention.

All participants demonstrated significant changes in specific movement characteristics of the jaw and lips. Phases B and A2 were characterized by positive changes towards the movement characteristics of the age-matched peers. Phase C showed evidence of regression in some measures, for some participants.

It is concluded that the PROMPT intervention was effective in supporting changes to the motor-speech patterns of children with CP. These changes were associated with improvements in phonetic accuracy and speech intelligibility across the therapy phases.

The significant changes observed in the speech outcome measures of the participants of this study indicate compensatory motor speech patterns can be modified; and contribute to improved speech intelligibility. Prior to intervention, all participants presented with speech movement patterns that suggested impaired mandibular control.

Post-intervention data indicate all participants recorded significant changes in the jaw and lip measures that reflected those targeted across the phases of the study. Whilst kinematic analysis was not used to establish intervention priorities, the continued improvement in some measures between phase C and A2 highlight the need for further research to not only evaluate performance and stability within intervention priorities, but also the timing between and across intervention priorities. This may make a contribution to further refining therapy protocols aimed at improving motor speech control.

Although our understanding of how the central nervous system uses sensory information for motor-speech acquisition is not clear, the results obtained in this study provide some support for the use of PROMPT in managing motor speech disorders associated with CP. Further research evaluating the use of this technique with a larger sample size and participants with differing levels of impairment is

recommended to further develop our understanding of using this approach with children with CP.

List of Abbreviations

2SD band	Two Standard Deviation Band
AM	Attention and Memory
ANOVA	Analysis of Variance
BLC	Inter-lip Distance during Bilabial Contact
CDC	Conservative Dual Criterion
CELF	Clinical Evaluation of Language Fundamentals
C-L	Cognitive-Linguistic
COPM	Canadian Occupational Performance Measure
CNS	Central Nervous System
CP	Cerebral Palsy
CSIM	Children’s Speech Intelligibility Measure
DST	Dynamic Systems Theory
EBP	Evidence-Based Practice
HAPP	Hodson Assessment of Phonological Processes
EMG	Electromyographic
GMFCS	Gross Motor Function Classification System
ICF	International Classification of Functioning, Disability and Health
ICF-CY	International Classification of Functioning, Disability and Health – Children and Youth
IP	Intervention Priority
J/L Vel	Jaw/Lip Opening Velocity
JG	Jaw Grading
JHP	Jaw Height Position
JLDM	Jaw Lateral Distance from Midline
JOD	Jaw Open Distance
JPD	Jaw Path Distance
LCL	Lower Confidence Level
LL	Lower Lip
LME	Linear Mixed Effect Model
LRR	Lip Rounding/Retraction Distance
MC	Motor Coaching

MSH	Motor Speech Hierarchy
MSMPs	Motor Speech Movement Patterns
NDT	Neurodevelopmental Treatment
PA	Perceptual Accuracy
PPC	Percentage Phonemes Correct
PROMPT	Prompts for Restructuring Oral Muscular Phonetic Targets
PPT	Phonetic Placement Therapy
P-S	Physical-Sensory
SAO	Systems Analysis Observation
S-E	Social-Emotional
SPC	Statistical Process Control
SSRD	Single Subject Research Design
TCCP	The Centre for Cerebral Palsy
TD	Typically Developing
TMS	Transcranial Magnetic Stimulation
UCL	Upper Confidence Level
UL	Upper Lip
VMPAC	Verbal Motor Production Assessment of Children
WD	Word Duration
WHO	World Health Organisation

Table of Contents

List of Tables

List of Figures

CHAPTER 1 INTRODUCTION

Cerebral Palsy (CP) is a neurodevelopmental condition that includes a group of non-progressive movement and posture disorders that are a result of lesions or dysfunction to the central nervous system. The worldwide incidence is reported to be approximately 2 to 2.5 per 1000 live births (Ashwal et al., 2004; J. Lin, 2003; Siebes, Wijnroks, & Vermeer, 2002; Workinger, 2005) making it one of the most prevalent childhood disorders.

The literature identifies at least 40% of children with CP present with communication impairment (Kennes et al., 2002). Due to the complex interaction between multiple systems (e.g., physical, cognitive, sensory and communicative) in CP, children with motor speech disorders are at increased risk of social and educational limitations, and participation restrictions (Bult, Verschuren, Jongmans, Lindeman, & Ketelaar, 2011; Palisano et al., 2011; Voorman, Dallmeijer, Van Eck, & Schuengel, 2010).

Given this, one of the primary objectives of speech intervention is to improve communicative function and increase speech intelligibility by “maximizing the ability to speak within neurological limits”, thereby improving an individual’s quality of life (Workinger, 2005).

Decision making regarding the evaluation and selection of an appropriate intervention requires the use of a conceptual framework. This provides a structure for gathering and assessing relevant information for the selection of appropriate intervention protocols (Shumway-Cook & Woollacott, 2012; van der Merwe, 2009).

Two broad components are essential in the development of a conceptual framework: 1. evidence-based practice, and 2. the identification of a model of disablement.

Evidence based practice is an approach for clinical practice that requires the “…conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence-based-medicine means integrating individual clinical expertise with the best available external evidence from systematic research” (Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996, p. 71).

The integration of evidence-based practice into clinical practice requires the application of a step-by-step process that includes the formulation of a specific question, a search for the *best available evidence*, and critical evaluation of the validity and usefulness of that evidence (Speech Pathology Australia, 2010; Clark, 2003; Williams, McLeod & McCauley, 2010; Reilly, others).

Clark (2003) states two broad strategies are available to clinicians in the search for the best available evidence. The first strategy requires a clinician to consult, identify and critically evaluate the peer reviewed literature for documented quality experimental evidence that supports the effectiveness/efficacy of an intervention approach.

Critical evaluation of the literature requires some knowledge as to the type of study design (e.g., randomised controlled trial, case-cohort study) that will most suitably answer the specific question under investigation (Glasziou & Vandernbroucke, 2004).

Typically, randomised control trial studies have been heralded as the gold standard for best available evidence with other types of study designs excluded from systematic reviews because of failure to meet the level of evidence assigned to randomised control trials (Grossman & Mackenzie, 2005; J. P. T. Higgins & Green, 2011; Moher, Schulz, Altman, & Group, 2001; Palmer & Enderby, 2007; P. Rosenbaum, 2010). However, a judgement on the basis of *level* alone does not inform a clinician regarding the *quality* of the evidence (Guyatt et al., 2008). As stated by Booth (2010), a “bad randomised controlled trial is not superior to a good cohort study” (p. 84). Further, “the five phase model of clinical-outcome research” (Robey, 2004; Robey & Schultz, 1998) for communication disorders indicates control trial studies, in the absence of early phase (e.g., I and II) research is inappropriate. Therefore, disregarding early phase treatment studies on the basis of “low level” evidence is premature.

A review of the literature pertaining to motor speech disorders associated with CP indicates that whilst many treatment strategies (instrumental, medical, compensatory and behavioural) for the management of motor speech disorders associated with CP have been reported, the experimental evidence base to support these treatment approaches is lacking (Pennington, Goldbart & Marshall, 2003; Palmer & Enderby, 2007; Pennington, Robson & Miller, 2009, Hodge & Wellman, 1999).

To date, there is only a small body of phase I experimental research for the management of speech disorders associated with CP. Phase I and II research is exploratory in nature and typically focused on detecting a treatment effect using a small sample size. In these phases, hypotheses are generated, tested and intervention protocols refined (Robey, 2004).

This early phase research supports a subsystems approach to intervention in children with moderate-to-severe speech impairment associated with CP. A hierarchical subsystems approach to intervention was described by Dworkin (1991). This approach advocates that intervention focus on establishing adequate control at the lower levels (i.e., first order: resonation and respiration; and second order: phonation) before addressing higher levels (i.e., third order: articulation and prosody) of complexity.

Research studies that have adopted a subsystems approach have focused principally on the subsystems of phonation and respiration (Fox, 2002; Pennington, Miller, & Robson, 2009; Pennington, Smallman, & Farrier, 2006) with mixed outcomes regarding improved speech intelligibility. For example, Pennington (2006) reported no significant change to speech intelligibility, whilst Pennington (2009) reported a mean performance increase of 15% using a similar approach.

Two studies, utilising single subject research design, targeted the subsystem of articulation but did not meet all criteria for experimental control, as evaluated using the Single-Case Experimental Design (SCED) Scale (Tate et al., 2008) and the guidelines developed by Logan et al. (2008) for the critical review of single subject research design.

The first of these studies evaluated the effects of a motor-based approach and a linguistic based approach in two children with CP (Wu & Jeng, 2004). One child was assigned to each treatment condition and pre-post intervention data provided. Unfortunately, the control phase (i.e., baseline) data were not provided so it was difficult to determine what change in trend direction, slope or variability occurred subsequent to the initiation of the intervention phase. Further, a cross-over design was not utilised so it is not possible to determine whether one approach was more effective than the other. Despite this, the authors report the pre-post testing data indicate the therapy was effective in improving production of the speech sounds targeted during intervention.

In the second study, Marchant, McAuliffe and Huckabee (2008) used a single subject research design to compare the effects of phonetic placement therapy (PPT) and biofeedback relaxation therapy (using sEMG) in a 13-year-old child with spastic CP. The authors report a significant increase in single word intelligibility post PPT. Whilst the authors report visual inspection of the data was undertaken to examine the trends of the intervention phases, only the means and standard deviations of the pre and post data is provided. This contributes to the difficulty in interpreting the effects of the relaxation therapy. As the relaxation therapy was administered two weeks post PPT it is not possible to determine if the gains were due to the relaxation therapy or represented continued off-line learning from the PPT.

In addition to evaluating treatment studies on the basis of experimental control, evidence-based practice also requires an evaluation of adherence to the principles and processes of the intervention approach (Chambless & Hollon, 1998; Kaderavek & Justice, 2010). Kaderavek and Justice (2010) highlight the obligation of researchers to not only report treatment fidelity measures but also provide documentation that defines fidelity to the procedural and qualitative aspects of the treatment approach under investigation. Without fidelity measures a clinician is unable to evaluate whether the treatment was effective or ineffective. Further, it also impedes future research due to insufficient provision of documentation required for replication studies. The authors recommend the provision of manuals, expert training and supervision and documentation as a means to enhance treatment fidelity.

In summary, speech pathologists working with children with a motor-speech disorder associated with CP are challenged by the lack of strong scientific evidence on which to base intervention decisions. This conclusion is supported by a systematic review completed for the Cochrane Collaboration in 2003 and updated in 2011. Pennington, Goldbart and Marshall (2003) concluded there is insufficient data to demonstrate speech/language therapy provided to children with communication impairments associated with CP is effective. In addition, the literature also indicates there is no evidence base to support or disprove the effectiveness of speech/language interventions for the most common motor speech disorder associated with CP, that of dysarthria (Sellars, Hughes, & Langhorne, 2005).

In the absence of documented evidence, the second strategy proposed by Clark (2003) requires a clinician examine the theoretical soundness of an intervention approach. In order to do this successfully, a clinician needs to have “a clear understanding of *both* [italics added] the nature of the targeted impairment and the therapeutic mechanism of the selected treatment technique” (Clark, 2003, p. 400).

Thus, implementation of this second strategy requires a clinician to structure and define critical information needed for understanding not only the targeted impairment but also the impact on quality of life issues such as activity limitations and participation restrictions. The framework to achieve this second strategy is found within the International Classification of Functioning, Disability and Health (ICF) model of disablement. This model is currently driving intervention practices in the field of CP (Mutlu, Akmese, Gunel, Karahn, & Livanelioglu, 2010; Rosenbaum & Stewart, 2004; Wright, Rosenbaum, Goldsmith, Law, & Fehlings, 2008).

Acceptance of the ICF model of disablement has contributed to a “phase shift” away from developmental models of intervention towards ecological models, such as dynamic systems theory. Ecological models view development as a result of the complex interaction between a number of components operating both within and external to an individual. Emphasis is placed on the “emergence” of behaviours across differential time scales as opposed to a top-down model where behaviours development is viewed to occur through an unfolding of developmental milestones (Darrah, Wiart, & Magill-Evans, 2008).

The shift towards ecological models has further been driven by technological advances that have enabled the refinement of data collection and analysis techniques. This is especially evident in the field of neuro-anatomy where empirical data has made a substantial contribution to our knowledge base regarding motor learning and neural plasticity.

In particular, new research has highlighted that active task-specific coupling of sensory input to motor output can enhance skill acquisition (Atchy-Dalama, Peper, Zanone, & Beek, 2005; Ito & Ostry, 2010). These results are particularly relevant to the field of CP, where neuroimaging techniques have also highlighted that the motor impairments associated with CP are attributable to both impairment of the descending corticospinal tracts and changes in white matter projections to and from the sensory cortex (Hoon et al., 2009; Sanger & Kukke, 2007).

Both the ICF and EBP resonate with a systems approach to intervention, which is consistent with the increased reporting of intervention approaches founded on dynamic systems theory (Darrah & Bartlett, 1995; Darrah et al., 2008; Heriza, 1991; Papavasiliou, 2009; Whinnery & Whinnery, 2007).

The aim of this thesis is to make a contribution to the evidence base for the effective management of motor speech disorders associated with cerebral palsy (CP), through the evaluation of an intervention approach that utilises tactile-kinaesthetic input. The key principles that underpinned the search for, and ultimate selection of the PROMPT approach for evaluation in this thesis, included:

1. A philosophy consistent with the current-evidence based literature regarding the ICF framework.
2. An approach that supported the application of dynamic systems theory to the motor control of speech.
3. The availability of intervention techniques grounded in principles of neural plasticity that focused on enhancing motor learning through active task-specific augmentation of sensory information, and
4. A sufficiently detailed approach that would enable a number of clinicians to administer the intervention with adherence to fidelity that was measurable.

The specific objectives of this thesis are to evaluate:

1. The effectiveness of PROMPT in facilitating change in speech production accuracy in children with a motor speech disorders associated with CP;
2. Changes to motor speech movement patterns in children with CP subsequent to PROMPT intervention, through the use of three dimensional (3D) motion analysis; and
3. Changes to the Activity and Participation domains of the ICF subsequent to PROMPT intervention.

A single subject research design (SSRD) was implemented based on the heterogeneity and small number of available participants for the study as well as the lack of existing efficacy studies. This thesis is consistent with a phase I intervention study (Beeson & Robey, 2006).

The thesis contains the following chapters:

1. Chapter 2: A review of the literature.

In this chapter the key principles that resulted in the selection of the PROMPT approach are explored, as detailed below:

1.1 The ICF framework.

1.2 The definition of CP. This is described within the context of the ICF model, with a focus not only on the impairments of structure and function, but also activity and participation limitations.

1.3 Motor speech control. This section details the subsystems of motor speech control, early development of these subsystems and impairment in children with cerebral palsy.

1.4 The PROMPT approach. This entails a description of the theoretical basis, principles that define the intervention procedures, and evidence to support the evaluation of this approach in children with motor speech disorders associated with CP.

2. Chapter 3: Rationale and research aims of the thesis.

Chapters 4, 5 and 6 document the three main research questions addressed in this thesis, as follows:

3. Chapter 4 examines the effectiveness of PROMPT in facilitating change in speech production accuracy in children with a motor speech disorders associated with CP. This chapter includes a detailed description of the six participants who completed the PROMPT intervention, the procedures and instruments, the intervention protocol, outcome measures and results obtained. The chapter concludes with a discussion of the findings.

4. Chapter 5 examines changes in the motor speech movement patterns of these same children through the use of three dimensional (3D) motion analysis. A cohort of typically developing children was recruited to compare the trend of changes in jaw and lip movements to those of the children with cerebral palsy. This chapter details the procedures and instruments; results obtained and concludes with a discussion of the findings.

5. Chapter 6 examines changes to the Activity and Participation domains of the ICF subsequent to PROMPT intervention. This entailed an evaluation of changes to speech intelligibility using a formalised measure; and parent evaluation of changes in performance and satisfaction with changes to the daily routine.

The thesis concludes with a general discussion of the findings, limitations and strengths, consideration for further research and conclusion.

CHAPTER 2 LITERATURE REVIEW

The ICF Model of Disablement

> *…disability is a 'universal' phenomenon and is regarded as a general feature of the human experience (McDougall, Wright, & Rosenbaum, 2010, p. 208).*

The ICF is a conceptual framework, proposed by the World Health Organisation (WHO) that expresses disability from a health perspective as opposed to impairment (WHO, 2002). More recently, the ICF Children and Youth (ICF-CY) version was derived from the ICF to more accurately reflect the dynamic inter-relationship of the child within the context of a family system (WHO, 2007).

The ICF-CY has two parts, as illustrated in **Error! Not a valid bookmark self-reference.**:

Part 1. Function and Disability.

a. Structure and Function. These two components are further divided into 8 subdomains that include voice and speech functions, neuromuscular and movement-related functions, and sensory functions.

b. Activity. Within the ICF, activity is defined as "the execution of a task or action by an individual".

c. Participation. This is defined as a child's "involvement in a life situation" (WHO, 2007, p. 9).

The Activity and Participation domains are further divided into 9 subdomains that include learning and applying knowledge, general tasks and demands, communication, mobility, self-care, domestic life, interpersonal interactions and relationships, major life areas, and community, social and civic life.

Part 2. Contextual Factors. These describe the subdomains of the environmental and personal factors (WHO, 2002). The ICF-CY concept of environment reflects transitions (e.g., entering and leaving school) and increasing independence across the ages (infancy, childhood and adolescence).

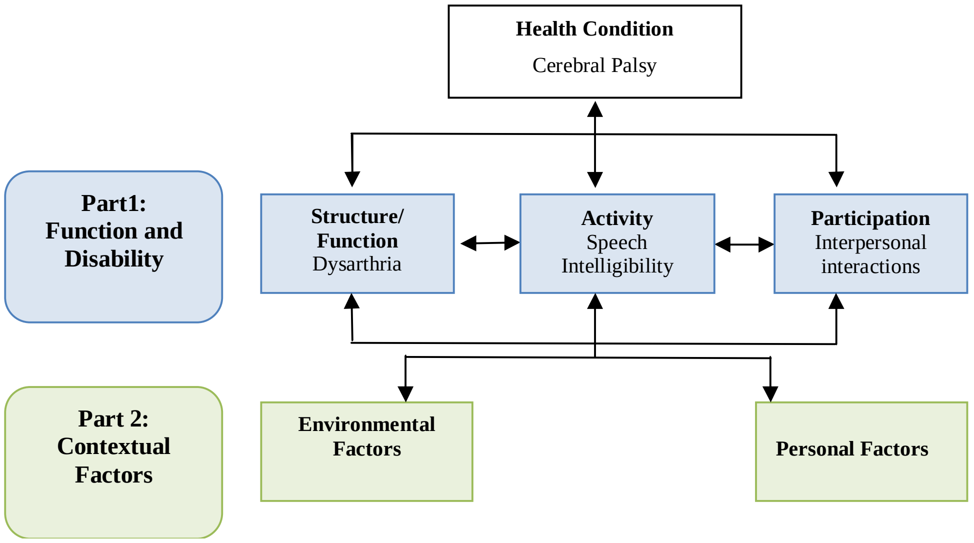


Figure 2.1. Representation of Cerebral Palsy within the ICF Framework (WHO, 2002).

The ICF has been described as a biopsychosocial model because of the shift in focus from the structural/functional limitations and attributes of an individual to an emphasis on the impact of the disability on independent participation within the community (Ibragimova, Lillvist, Pless, & Granlund, 2007; McConachie, Colver, Forsyth, Jarvis, & Parkinson, 2006; McLeod, 2004; Rosenbaum & Stewart, 2004; Threats & Worrall, 2004). The ICF also reflects a dynamic systems perspective. That is, the interactions occurring between and within the individual subsystems represent a bi-directional non-linear relationship influenced by contextual factors and environmental factors.

The influence of the ICF framework to the field of CP is evident in the implementation of service delivery models. For example, the well-established service delivery model of family centred practice acknowledges the central role of the family in working together with service providers to make informed service delivery decisions for both the child with CP and the family (King, Teplicky, King, & Rosenbaum, 2004).

More topical is the shift away from theoretical models that have historically underpinned intervention approaches and outcome measures. Specifically, there is increasing evidence of a shift away from neuromaturation models that have focused traditionally at the level of impairment towards an ecological systems perspective which addresses the domains of activity and participation (Darrah et al., 2008). Whilst this theoretical shift is evolving, the most appropriate tools for evaluation of the intervention effectiveness require further development to fully reflect the multidimensional framework of the ICF (Majnemer & Mazer, 2004; McConachie et al., 2006; McDougall et al., 2010).

Cerebral Palsy

Cerebral Palsy (CP) is an umbrella term that describes a lifelong neurodevelopmental condition. It includes a group of non-progressive movement and posture disorders that are a result of lesions or dysfunction to the central nervous system. It is the most common childhood disability with a reported worldwide incidence of approximately 2 to 2.5 per 1000 live births (Ashwal et al., 2004; J. Lin, 2003; Siebes et al., 2002; Workinger, 2005). In Western Australia, the prevalence rate for the period 1995 – 1999 was reported to be 1.54 per 1000 live births (Watson, Blair, & Stanley, 2006).

Until recently, the most commonly cited definition was that of Bax who described CP as “a disorder of movement and posture due to a defect or lesion of the immature brain” (Bax, 1964, p. 295). In 2005, a revised definition was proposed to acknowledge the associated impairments of sensation, cognition, communication, perception, behaviour, and seizure:

> CP describes a group of disorders of the development of movement and posture, causing activity limitations that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder (Bax, Goldstein, Rosenbaum, & Paneth, 2005, p. 572).

The significance of this diagnosis is the acknowledgement that CP is associated with other conditions in addition to the disorder of movement and posture.

The classification of cerebral palsy is based on the type of deformity or abnormality (spastic, dyskinetic, ataxic or mixed), anatomical distribution (hemiplegia, monoplegia, diplegia or quadriplegia) or location of injury (periventricular, brainstem, pyramidal or extrapyramidal). The most common clinical pattern is spastic CP, with 70% to 80% of individuals presenting with this pattern. Approximately 10% to 20% present with athetosis and 5% to 10% present with ataxia (Krigger, 2006).

Classification Based on Motor Abnormality

Classification of the motor abnormality is based on the predominant type of motor disorder: spastic, dyskinetic (further differentiated by dystonia and choreoathetosis) or ataxic. However, it is acknowledged that children may present with symptoms whereby no one type dominates and in this instance a category of ‘mixed’ may be assigned (Bax et al., 2005).

Spastic Cerebral Palsy.

Spastic CP is a result of an injury to the upper motor neurons resulting in decreased input to the reticulospinal and corticospinal tracts (Koman et al., 2004). This produces abnormal muscle control, weakness and spasticity.

Due to the abnormal muscle control, musculoskeletal changes occur that include alterations in muscle fibre size and type, increased muscle cell and muscle tissue stiffness, and inferior mechanical properties of the extracellular material (Foran, Stienman, Barash, Chambers, & Lieber, 2005). Movement patterns are characterised by slow movement or paucity of movement due to difficulty initiating, sustaining or terminating movement (Stamer, 2000).

Dyskinetic Cerebral Palsy.

Dyskinetic CP (also known as athetosis) is a result of injury to the thalamus and basal ganglia. The basal ganglia control the flexion and extension of voluntary movement as well as the timing of movements and intensity of muscle contractions. It is also sends sensory information to the pre-motor cortex and plays a role in the initiation of movement (Stamer, 2000).

The clinical signs and symptoms associated with athetosis are variable as damage to different parts of the basal ganglia and thalamus will result in different movement patterns. In general, children with athetosis will present with difficulty initiating and terminating movement.

Ataxic CP.

Children with ataxia associated with cerebral palsy show disorganised movements as a result of injury to the cerebellum. They are reported to show delayed initiation of movement, intention tremor and poor adjustments to sensory discrepancies or proprioceptive information (Stamer, 2000).

Location of the lesion.

Advances in technology (e.g., magnetic resonance imaging and diffusion tensor imaging) have allowed for greater diagnostic sensitivity for locating lesions in the brain. Reported aetiologies include decreased cortical gray matter volumes, abnormalities to the basal ganglia, thalamus and cerebellum, injury to subplate neurons; and periventricular leukomalacia (Hoon et al., 2009). Periventricular leukomalacia (PVL) has been identified as the leading known cause of cerebral palsy. Whilst PVL presents with different aetiologies, neuropathological studies have shown that it is associated with lesions in the corticospinal, thalamocortical, optic radiation, superior occipitofrontal and superior longitudinal pathways (Hoon et al., 2009; Korzeniewski, Birbeck, Delano, Potchen, & Paneth, 2008; Thomas et al., 2005).

Activity and Participation

Children with CP are at increased risk of experiencing poorer activity and participation outcomes than any other disability group due to the complex interaction between the physical impairment, cognitive and communicative functioning. McConachie et al. (2006) report three aspects of activity and participation to be essential for typical development: social interaction, opportunity for play, and exploration and mobility. The literature indicates all three of these aspects are impaired in children with CP and this impairment has the potential to increase with age (Garvey, Giannetti, Alter, & Lum, 2007; Imms, Reilly, Carlin, & Dodd, 2009; Majnemer et al., 2008; Pirila et al., 2007; Van Agt, Verhoeven, Van Den Brink, & De Koning, 2010; Voorman et al., 2010; Wichers, Hilbrink, Roebroeck, van Nieuwhuizen, & Stam, 2009).

McCormack et al. (2010) noted that five of the nine ICF activity and participation domains were problematic for children with a primary diagnosis of speech and language impairment. These included, difficulty in the domains of communication (e.g., conversation), learning and applying knowledge (e.g., focusing attention), general tasks and demands (e.g., managing one’s own behaviour), interpersonal relationships (e.g., basic interpersonal interactions) and community, social and civic life (e.g., play).

Further, the literature specifically identifies speech impairment in general as a potential educational risk factor, with speech production identified as one of the most important early predictors of reading success (Nadeau & Tessier, 2009; Peeters, Verhoeven, de Moor, & van Balkom, 2009). Thus, children with motor speech disorders associated with CP are at a further increased risk of educational limitations and participation restrictions.

Motor Speech Control

"Communication will make use of, and will be bound by, the system states available in production" (Porter & Hogue, 1998, p. 110).

Speech Subsystems Coordination

> *"Normative data and function are essential prerequisites for determining the severity of dysfunction as well as selecting and sequencing treatment goals and procedures" (Netsell, 2001, p. 416).*

Coordination of the speech subsystems involves precise, rapid and complex goal-oriented behaviours with many potential degrees of freedom of movement. For example, the motion of the mandible is characterised by three orientation angles and three positions (Ostry, Vatikiotis-Bateson, & Gribble, 1997). The lips and tongue have limitless possibilities as they consist of soft tissue with muscles running in different directions. This means that in addition to being independent of a skeletal structure, during motion of the lips and tongue, compression in one plane will result in expansion in another (Stone & Murano, 2007).

Though speech production is a complex process, the literature indicates the coordination of motor units or muscles for a complex motor task is achieved through the formation of functional synergies that act to reduce the potential degrees of freedom of movement (Latash, Levin, Scholz, & Schöner, 2010; Shumway-Cook & Woollacott, 2012; Vereijken, van Emmerik, Whiting, & Newell, 1992). Functional synergies have been defined as fundamental units of control organised to achieve functional goals that "… consist of collectives of muscles or motor neurons that in turn control muscle contractions” (A. Smith, 2010 p.275). Thus synergies are regarded as a way of organising the speech system to reduce the potential degrees of freedom of movement, and give rise to preferred movement patterns. They are also considered dynamic in the sense that they are open to modification through changes in the central nervous system, specific task requirements and changes associated with motor learning and development. As such, synergies are expected to emerge, disappear and change.

The speech science literature provides data that support the existence of hierarchical sequences in speech motor control (specifically mandibular and labial coordination) that unfold over an extended developmental period. Individual articulators exhibit non-uniform developmental time paths that are differentiated by changes in the composition of inter-articulator relationships (Cheng, Mudoch, Goozée, & Scott, 2007; Grigos, Saxman, & Gordan, 2005; Riely & Smith, 2003; A. Smith, 1992; A. Smith & Zelaznik, 2004; Terband, Maassen, Van Lieshout, & Nijland, 2010).

The Development of Early Motor Speech Control

Within the hierarchy of motor-speech development, the mandible has been identified as foundational to the development and integration of more complex movements of the lips and tongue. For example, Green, Moore and Reilly (2002) found the mandible is the predominant contributor in early development, with engagement of the lips independent from the mandible increasing with age. That is, early lip movements occur as a result of excessive mandibular displacement in the open phase creating excessive lip compression upon completion of mandibular closure. With development, differentiation between the mandible and lips is observed through decreased jaw displacement and increased upper lip and lower lip movements (Green, Moore, Higashikawa, & Steeve, 2000; Green et al., 2002; Walsh, Smith, & Weber-Fox, 2006).

In addition to the developmental trends observed in labial-mandibular coupling, there is also evidence to suggest the presence of developmental differences in muscle activation patterns of the mandible (Ruark & Moore, 1997; Steeve & Moore, 2009; Steeve, Moore, Green, Reilly, & McMurtrey, 2008). In a recent longitudinal electromyography (EMG) study, Steeve and Moore (2009) examined the developmental differences in the coordinative muscles of the mandible in speech and non-speech tasks, in a typically developing single male infant from 8 to 22 months. They found organisational differences in muscle group activation for babble and true words across the developmental ages of their study. For example, during vowel babble there was increased EMG activity in synergistic muscle groups whilst greater coupling of the antagonistic muscle groups was observed in multi-syllabic vocalisations. These findings are in support of earlier work by Ruark and Moore (1997).

Smith and Zelaznik (2004) further examined the development of inter-articulator relationships by investigating two speech synergies – the mandible/lower lip and the lip (upper lip - lower lip) aperture synergies. Their data indicate the lower lip/mandible synergy develops before the lip aperture (upper lip - lower lip) synergy.

Finally, whilst the tongue/jaw synergy has been less researched there is emerging literature that suggests tongue movements become increasingly dissociated from the mandible with increasing developmental age (Cheng et al., 2007; Terband et al., 2010).

In summary, early developmental changes in individual articulators and composition of functional synergies occur due to extensive changes in neuromotor pathways associated with maturation, anatomical/biomechanical composition, experience and practice.

Speech Subsystem Control In Children with Cerebral Palsy

> *"Motor control abnormalities due to the initial neurological insult give rise to atypical movement patterns, which in turn give rise to atypical development"(Deffeyes, Harbourne, Kyvelidou, Stuberg, & Stergiou, 2009, p. 564).*

The prevalence of speech disorders in individuals with CP is not well described, and estimates vary between 31% and 88% (Ashwal et al., 2004; Havstam, Buchholz, & Hartelius, 2003; Watson et al., 2006; Whitehall, 2009). Whilst the most commonly reported speech disorder associated with cerebral palsy (CP) is dysarthria (Hodge & Wellman, 1999; Pennington, Miller, & Robson, 2009), recent work has suggested that even children who do not present with explicit symptoms of dysarthric speech may experience underlying motor control deficits (Hustad, Gorton, & Lee, 2010).

The motor speech impairments associated with CP may impact an individual's ability to produce speech efficiently and accurately, due to impairments in timing and coordination across the speech subsystems. The literature describes impairment to different subsystems of speech control including respiration, phonation, resonance and articulation. Reduced speech intelligibility has been associated with poor breath quality, inappropriate voicing, slower speech rate, reduced vowel space, excessive or reduced movements and articulatory imprecision (Hustad, Gorton, & Lee, 2010; E. L. Lin, Chen, & Lee, 2007; Soloman & Charron, 1998; Workinger, 2005). Whilst the Mayo classification system has been used to describe the perceptual characteristics observed in children with dysarthria, more recent research indicates classification on the basis of severity and disease type may be more appropriate (Y. Kim, Kent, & Weismer, 2011).

Two possible explanations for impaired motor control in individuals with CP have been postulated: aberrant activation of muscle synergies (Neilson & O'Dwyer, 1981); and/or a poor relationship between the motor command and the resulting perceptual consequences of the movement (Kent & Netsell, 1978).

Examination of the work of early researchers investigating the articulatory precision of speakers with cerebral palsy suggests a pattern of articulatory imprecision related to the physiological complexity (integration of jaw, lip and tongue control) of articulation (Byrne, 1959; Clarke & Hoops, 1980; Clement &

Twitchell, 1959; Hixon & Hardy, 1964; Ingram & Barn, 1961; Love, 1992; Milloy & Morgan-Barry, 1990; Platt, Andrews, Young, & Quinn, 1980; Workinger, 2005; Workinger & Kent, 1991). For example, in a study conducted by Irwin (1972), as cited by Love (1992), production of labial phonemes and nasals were reportedly the easiest, whilst dentals, glottals, fricatives and glides were the most difficult. These findings support those reported by Byrne (1959) who also stated the acquisition of the bilabial stops (p, b) and nasals (m, n) in speakers with CP are the easiest to produce.

Recent data reported by Kim, Martin, Hasegawa-Johnson, and Perlman (2010) support the pattern of articulatory errors recorded in the data by early researchers. These authors suggest speakers with low speech intelligibility substitute complex sounds with sounds that required lower complexity. This supports the notion that error patterns can be attributed to the motor complexity of the phoneme (Bartle-Meyer, Goozée, Murdoch, & Green, 2009; R. D Kent, 1992; A. Smith & Goffman, 2004). For example early bilabial (p, b) can be produced through the mechanical motion of the jaw, whilst tongue tip sounds require integration and coordination of the jaw, lips and tongue.

Whilst empirical data on the speech-movement patterns of children with CP are limited, there is evidence to suggest children with CP present with underlying mandibular instability. For example, Kent and Netsell (1978) report excessive mandibular displacement with lip and tongue blade movements highly dependent on the mandible in four children with athetoid CP. Yokuchi (2004) reported impaired motor speech movement patterns that included limited jaw opening, lip asymmetry, and inappropriate labial contraction for rounding and retraction. More recently Ortega et al. (2008) reported significantly decreased mouth opening and increased lateral deviation in children with spastic CP when compared with typically developing peers.

Most recently, a kinematic study by Hong et al. (2011) evaluated labiomandibular coupling in mono-syllabic and poly-syllabic speech tasks in twelve Mandarin-speaking children with spastic CP. They reported a significant difference in the temporal coupling between the lower lip and jaw movements using a cross-correlation analysis, for children with CP, as compared to the age matched peers. In addition, increased jaw open distance was also reported. These results support the findings of Kent and Netsell (1978).

Research findings indicate the enhancement of somatosensory input during speech can not only affect change in the coordination of movement synergies but also influence learning that can be maintained across time. These findings suggest potential therapeutic value in enhancing tactile-kinaesthetic input to children with CP (Mefferd & Green, 2010, Kelso et al., 1984; Estep & Barlow, 2007).

One intervention approach that has been developed specifically to facilitate articulatory control for improved speech production; and has been indicated in the literature to be of "specific relevance to the remediation of dysarthria of childhood for children" is PROMPT (Murdoch & Horton, 1998, page 401).

PROMPT

> *The scientific principles of a theoretical model need to "play an informing role inside programme construction" (Lettinga et al., 1999, p. 488).*

PROMPT (Prompts for Restructuring Oral Muscular Phonetic Targets) is an intervention approach that was developed for the management of speech production disorders, in children. Hayden (2006) describes PROMPT as "a tactually grounded sensory-motor, cognitive-linguistic model and approach" (p. 265).

Since its initial conception, PROMPT has evolved to have 4 components that both define and structure the assessment and intervention processes:

1. Philosophy*:* The tenets of dynamic systems theory (DST) form the foundation of the PROMPT philosophy, as expressed within conceptual model shown in Figure 2.2. This model provides the context for "conceptualising and approaching communication breakdown across the multiple domains" (Hayden, 2003, p.7).

2. Approach: The PROMPT conceptual model provides a clinician with a systematic way to interpret the dynamic interaction between and within each of the domains that influence and affect communication (e.g., motor-sensory, cognitive-linguistic, physical-sensory, behavioural and environmental) in order to assess the communication breakdown.

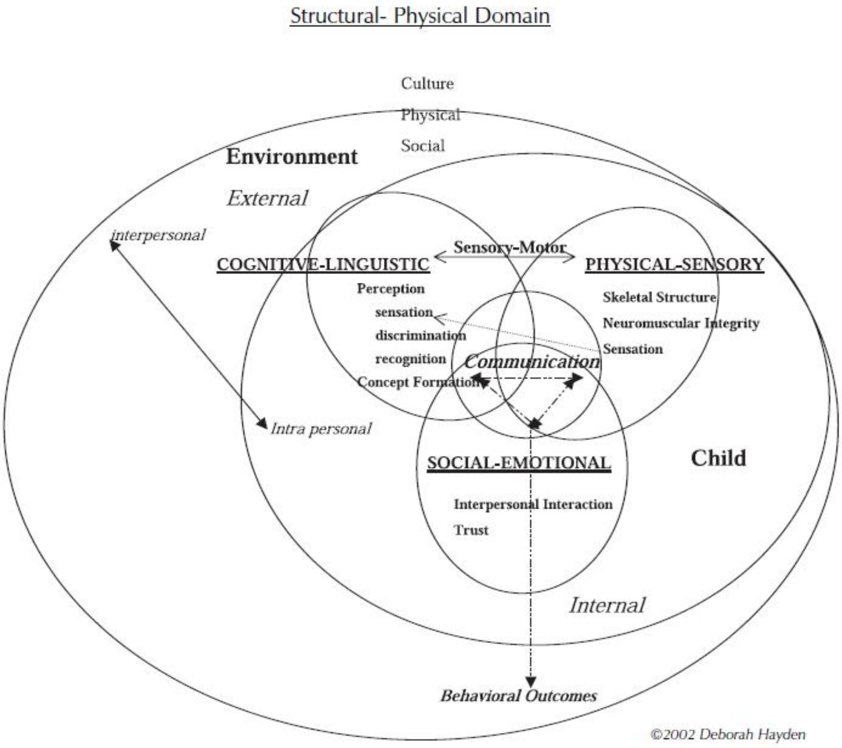


Figure 2.2. The conceptual model for the PROMPT approach. From The PROMPT Introduction to Technique Manual by Hayden (2003). Copyright 1994 by the PROMPT Institute. Reprinted with permission.

The PROMPT Global Domain Analysis is used to structure the evaluation of a child’s strengths and weaknesses within each of the communication domains, which is completed using both formal and informal assessments (Hayden, 2003).

Evaluation of the motor speech system (respiration, phonation, articulation, prosody), within the physical-sensory domain, is assessed and interpreted using the PROMPT Motor Speech Hierarchy (MSH) (Hayden & Square, 1994). The MSH is based upon the hierarchical sequence of motor speech development, (that is, the jaw provides the foundation for the integration of lip and tongue movements) and consists of seven levels, as depicted in Figure 2.3. The first two levels focus on postural support for speech and the ability to produce sound for at least two to three seconds. Levels three to five focus on training the appropriate movement patterns for speech of the jaw, the lips and the tongue. The last two levels address the sequencing of movements seen in speech and prosody.

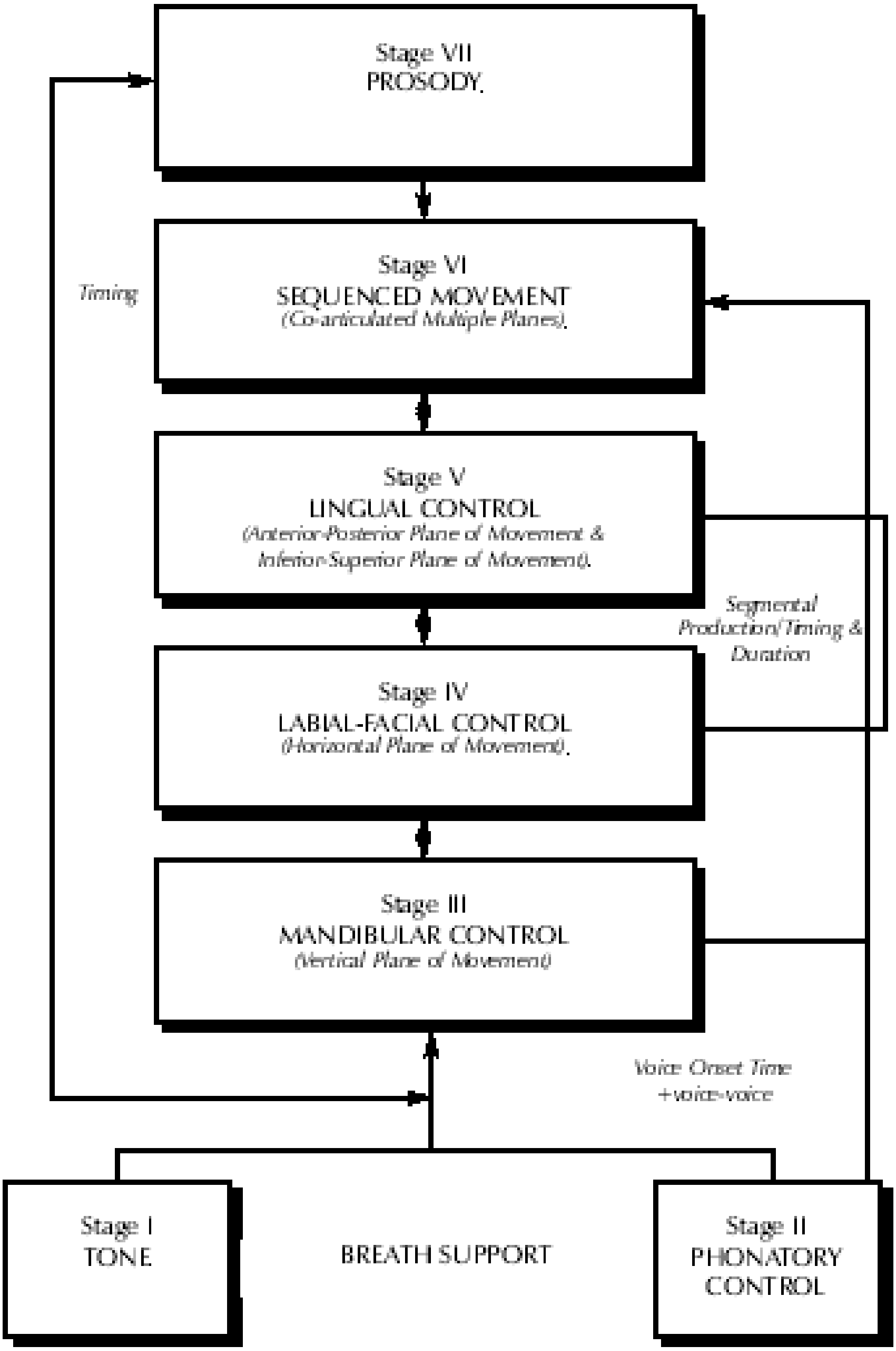


Figure 2.3. Motor Speech Hierarchy. From The PROMPT Introduction to Technique Manual by Hayden (2003). Copyright 1986 by the PROMPT Institute. Reprinted with permission.

3. A System: Provides the context and principles that enables a clinician to "plan and organise the direction and type of treatment needed for the specific type of speech production delay or disorder" (Hayden, 2003, p. 7).

The PROMPT therapy session is structured around principles of motor learning to optimise the establishment and consolidation of more efficient motor patterns to achieve improved speech intelligibility.

Hayden (2006) describes ten core elements that form the foundation of a PROMPT treatment session. Many of these key elements are based on the premise that the brain is plastic and capable of reorganisation. For example:

- Each session is structured to provide the opportunity for massed and distributed practice.
- The PROMPT lexicon is designed to facilitate immediate use and transfer into activities and the natural environment;
- Specific types of prompts are used dependent on the level of support needed to facilitate speech-motor control;
- Therapy goals and tasks are structured to limit competing resources; and
- Tactile-kinaesthetic input is used to integrate cognitive-linguistic, social-emotional and motor behavior;

4. The Technique: The PROMPT approach uses tactile-kinaesthetic-proprioceptive input *during speech* to train appropriate degrees of freedom of movement (for example, limit or increase) for the integration of jaw, lip and tongue movements (Chumpelik, 1984). The fundamental assumption is that the tactile-kinaesthetic input will facilitate modifications to the orofacial movements of speech (i.e., improvements in timing and coordination as measured through changes in distance, velocity and duration) thus resulting in improved speech intelligibility. The theoretical support for the use of tactile-kinaesthetic input is found in the literature examining proprioceptive mechanisms in speech (Barlow, 1999; Connor & Abbs, 1998; Loucks & De Nil, 2001; Trulsson & Johansson, 2002). Bosma (1970) as cited by Barlow (1999) states "the mouth's sensory experiences are generated principally by its own actions, and its actions are responsive to sensory experiences" (p. 144). The central nervous system (CNS) requires signals from the orofacial mechanoreceptors for the sensory motor regulation of oral behaviours to achieve

normal speech production (Trulsson & Johansson, 2002). In addition, the CNS needs to monitor the consequences of motor speech output through information from the auditory, proprioceptive, kinaesthetic and cutaneous systems.

The type of prompt selected depends on the level of support required by the child to produce a sound or sound sequence. For example ‘Parameter Prompts’ provide information about large muscle movements (e.g., degree of mouth opening), ‘Syllable Prompts’ provide information regarding the shape of a word, ‘Complex Prompts’ provide as much information as possible regarding the components of a sound (e.g., tongue tension and mouth shape), and ‘Surface Prompts’ provide information regarding the place and timing of production (e.g., air through the nose for ‘m’, lips together for ‘p’, back tongue elevation for ‘k’). Figure 2.4 illustrates the placement for the facial surface prompts.

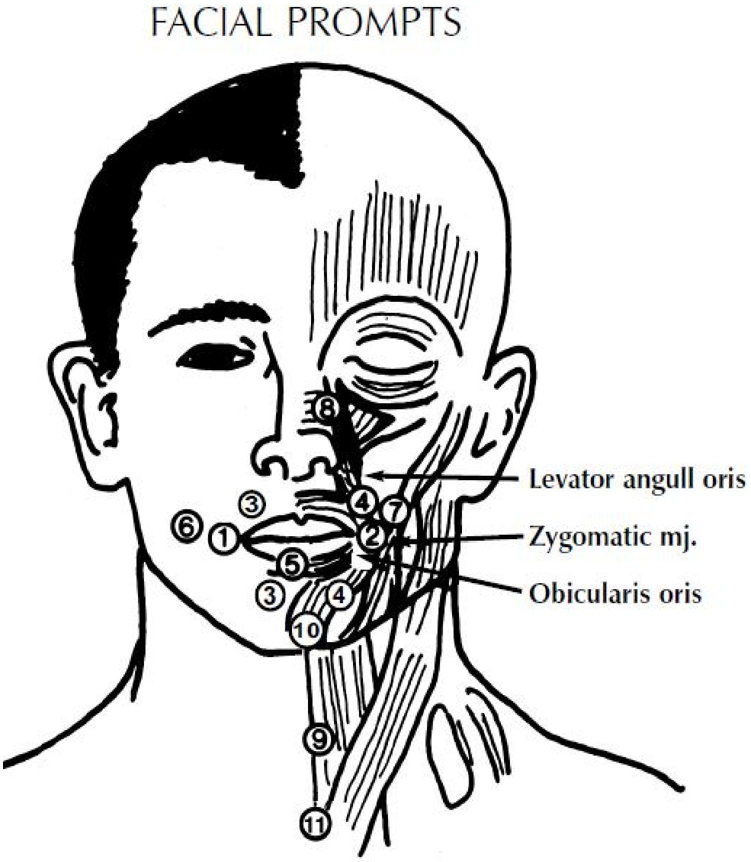


Figure 2.4. Finger placement for facial surface prompts.
Taken from PROMPT Introduction to Technique manual (2003) by Hayden.
Copyright 1994 by the PROMPT Institute. Reprinted with permission.

Clark (2003) suggests the theoretical foundations of an intervention approach and its components need to be examined individually, as part of the evidence-based process of critical evaluation. In this section the components of PROMPT will be investigated as follows:

1. An overview of the theoretical basis that informs the philosophy and approach of PROMPT, and
2. Examination of the principles of neural plasticity and motor learning that inform the intervention protocol.

This section will conclude with an examination of the current research undertaken to investigate the effectiveness of PROMPT in the management of motor speech disorders.

The Theoretical Basis of PROMPT Approach: Dynamic Systems Theory (DST).

"Behaviour and development are emergent properties of system-wide interactions that can create something new from the many interacting components in the system" (Spencer, Perone and Buss, 2011, p. 2).

The alignment of the PROMPT approach with dynamic systems theory (DST) is evident when compared against the core tenets. In this section, four tenets of DST are presented, followed by an interpretation of how these principles are applied within the PROMPT approach.

An open system.

Within the construct of DST, a system is defined as a set of components or domains (collective variables) that are inter-related to function as a unit (Thelen & Smith, 2006). The inter-relationships among the components of the system operate within a state of constant change open to external and internal influences. This means there is a non-linear correspondence between the parts and the whole; and development may differentially vary within each of the systems. The goal of DST is to understand the interconnected relationships within and between the system (Juarrero, 1999).

Self-organisation.

Self-organisation refers to the process by which new behaviours emerge from the complex interactions of the subcomponents within an open system (Warren, 2006). This occurs in the absence of pre-determined hard-wiring, through the repeated interaction between the subcomponents in a system. Whilst it is theoretically possible for a system to generate a number of self-organising behavioural patterns, individuals generally use a subset of preferred movement patterns.

Development is considered to occur in the direction of increasing hierarchical structure, with order maintained through the presence of specific boundary conditions (Newell, Liu, & Mayer-Kress, 2001; Newman & Newman, 2007; Thelen & Smith, 2006). For example, the literature reports that the development of early speech is characterised by progression through an increasingly complex continuum. One end of the continuum is comprised of early pre-speech vocalisations and babbling with progression to single word usage that consists of a complex inventory of vowels, consonants and consonant clusters at the other end. Specific boundary conditions include physiological constraints and potential catalysts. Early physiological constraints include the coupling of the jaw and lip whilst catalysts include the intrinsic desire to communicate (Bleile, 2004; McLeod, van Doorn, & Reed, 2001; Nip, Green, & Marx, 2011; A. Smith & Zelaznik, 2004).

Emergence/Transitions.

New behavioural patterns are considered to emerge when previously unconnected processes or domains become coordinated and interconnected. Preferred behaviours emerge through feedback among many lower order system elements and result in a differentially more complex hierarchy (Newman & Newman, 2007, p. 278). For example, Iverson and Thelen (1999) report a dynamic progression of speech development that is influenced through co-activation of connections with the motor system, such that the onset of babbling is temporally related to changes in patterns of rhythmic hand activity. Specifically, Iverson and Thelen (1999) cite evidence that indicate gains in language development between 9 and 13 months of age are positively associated with the use of gesture.

A preferred or stable movement pattern is referred to as an attractor state. Moving from a preferred stable movement pattern requires perturbation to the system. The more stable an attractor state, the greater a perturbation needs to be to move the state of the system to another attractor state. The emergence of a new behaviour is termed a “phase-shift”. When the current preferred behaviour pattern is destabilised, a new behaviour pattern emerges (Kelso, 2003; Lewis, 2011; Muchisky, Gershkoff-Stowe, Cole, & Thelen, 1996; Spencer & Perone, 2008; Thelen & Smith, 2006).

These patterns of change are realised within the function of time as measured on two scales: real-time and developmental time. Real-time behaviour is the spontaneous assembly of behaviour on a short time scale towards an attractor. Developmental time represents attractor states that self-organise over a longer developmental time frame of months and years.

Parameters and constraints.

A system is organised and structured bi-directionally through order and control parameters, respectively (Kelso, 2003). An order parameter is a single intrinsic entity/variable that describes the organisation of the subsystems within a system (Porter & Hogue, 1998; Van Lieshout, 2004). Control parameters are external (boundary conditions) that act to constrain the order parameter and are responsible for bringing about change/re-organisation to the state of the system. For example, inter-limb and phonation studies indicate that the relative phase of movement is an order parameter and an example of a control parameter is the velocity of movement.

Influences that guide emerging behaviours are considered constraints. Three types are identified by Newell (Newell, 1991b, 2003; Newell, Broderick, & Slifkin, 2003; Newell et al., 2001; Newell & Valvano, 1998) and include:

1. Individual constraints: these refer to the unique structural and functional characteristics of an individual (e.g., physical, cognitive and social);
2. Task constraints: these refer to the goal of a specific task and can be grouped on a number of levels including functional (e.g., activities of daily living), movement attributes (e.g., continuous or discrete movements) and movement stability (e.g., nature of nature of the task being performed); and
3. Environmental constraints: these refer to physical factors (such as lighting conditions and terrain) as well as socio-cultural influences.

It is important to note, as stated by Davids, Savelsbergh and Miyahara (2010), that constraints should not be viewed negatively but as a means to “alleviate the co-ordination problem in dynamical movement systems by structuring the available state space and reducing the number of configurations available ” (p. 174).

Variability.

Variability is considered an adaptive feature of motor output and not as noise or error that needs to be eradicated during development (Fetters, 2010; Newell, Deutsch, Sosnoff, & Mayer-Kress, 2006; Piek, 2002; Stergiou, Harbourne, & Cavanaugh, 2006; Vereijken, 2010). Specifically, a system that is stable at a particular point in time will show limited variability, whilst a system that is undergoing modification will show increased variability. The literature suggests there is an optimal level of variability that is reflective of a healthy adaptive system.

The concept of maladaptive variability is in contrast to adaptive variability and has the potential to limit skill acquisition. For example, childhood apraxia of speech, despite lack of consensus on specific diagnostic features, is identified in part by excessive variability in speech sound production that contributes to impaired speech/language development (Morgan & Vogel, 2008).

The literature indicates increased variability is reflective of instability and a reduced ability to maintain and transfer newly learned skill; whilst reduced variability is reflective of rigidity and low responsiveness to perturbations (Fetters, 2010; Sanger & Kukke, 2007). Both levels of variability have the potential to limit skill acquisition and have been reported in the literature in children with CP (Hadders-Algra, 2001, 2008, 2010; Hong et al., 2011). Thus, a goal of intervention is to facilitate an optimal level of movement variability (Stergiou et al., 2006).

Application of Dynamic Systems Theory to PROMPT.

The alignment of the PROMPT approach with DST is evident when compared against the core tenets of DST:

Open System.

The philosophy and conceptual framework of PROMPT (as illustrated in Figure 2.2) acknowledges the influence of the interdependent relationships between the cognitive-linguistic, social-emotional and physical-sensory domains and the environment, on communication.

A PROMPT trained clinician completes a domain analysis, using a variety of standardised and non-standardised assessment tools to determine the interaction between each of the domains within the system of communication, and subsequently selects the entry point of intervention. The focus of intervention is on strengthening the weakest domain and re-structuring the subsystems, with the ultimate goal of achieving integration between and within all of the subsystems for functional communication.

Emergence.

Speech motor development is viewed as consisting of co-dependent subsystems, with skill acquisition subject to the bidirectional interaction between existing and developing systems. Thus, motor learning is characterised by an alteration to the movement synergies unique to each individual (Doyon & Benali, 2005; Kostrubiec, Tallet, & Zanone, 2006). The PROMPT clinician is trained to assess the co-ordination between the subsystems and work to promote coordination through the establishment of efficient functional higher order synergies.

Parameters and Constraints:

Clinicians need to adopt a problem solving approach to identify constraints (individual, environmental, task) that can be used to optimise learning (Fetters, 2010). Intervention techniques are used to facilitate or act as a control parameter in bringing about change toward a higher level of functioning.

Tactile-kinaesthetic prompts are used to restructure the degrees of freedom available in a speech system to facilitate controlled flexible movements (as bound by conditions of time and space) for accurate speech production.

Variability:

The PROMPT approach acknowledges that maladaptive variability is a hallmark of impairment. As stated by Hayden (2002): “some attractor states may continue to persist and thereby result in a motor system that is out of balance” (p. 26). The tactile-kinaesthetic input is therefore used to facilitate appropriate boundary conditions for the development of efficient and flexible motor speech patterns.

Neural Plasticity

> *"By understanding the basic principles of neural plasticity that govern learning in both the intact and damaged brain, identification of the critical behavioural and neurobiological signals that drive recovery can begin" (Kleim & Jones, 2008, p. S225).*

PROMPT intervention aims to establish new motor patterns to improve speech intelligibility. The premise for this is based on evidence that indicates the brain is plastic and capable of learning new motor skills through the establishment of new motor patterns.

The literature reports that synaptic plasticity is one of the most important mechanisms in the developing brain (Abel & Lattal, 2001; Garvey et al., 2007; Johnston et al., 2009; Landi, Baguear, & Della-Maggiore, 2011). Plasticity is defined as the ability of the brain to organise or re-organise itself in response to different tasks, environments and stimuli. It involves changes in synaptic connections between individual neurons, increases in neuronal assemblies, increased myelination of axons and/or changes in the size/shape of a neuron (Kolb & Whishaw, 1996; Monfils, Plautz, & Kleim, 2005; Pascual-Leone, Amedi, Fregni, & Merabet, 2005). As stated by Pascual-Leone et al. (2005), neural plasticity should be considered an intrinsic property of the nervous system that is an "obligatory consequence of each sensory input, motor act, association, reward signal, action plan, or awareness" (p. 379).

Neuro-imaging studies provide evidence that support the contribution of adaptive plasticity during sensorimotor learning. Specifically, functional brain imaging technology has been used to identify the differential contribution of neural networks during the different phases of sensorimotor learning (acquisition and consolidation) that have been identified in behavioural studies (Abel & Lattal, 2001; Boudreau, Farina, & Falla, 2010; Costa, Cohen, & Nicholelis, 2004; Doyon, 2008; Doyon & Benali, 2005; Sanes, 2003; Seidler & Noll, 2008; Ungerleider, Doyon, & Karni, 2002). For example, Seidler and colleagues (Seidler & Noll, 2008; Seidler, Noll, & Chintalapati, 2006) provide detailed neural imaging data that indicate the brain structures active during early learning involve both the corticostriatal and corticocerebellar systems. Changes in activation are observed in the transfer phase that includes decreased activation and a reduction in brain regions recruited. Doyon and Benali (2005) report the corticostriatal system maintains a role in the long-term maintenance of motor sequence tasks, whilst the corticocerebellar system maintains a role in long-term motor adaptation.

The influence of training on adaptive plasticity has been demonstrated in animals and humans that have undergone treadmill training subsequent to spinal cord injury (De Leon, Hodgson, Roy, & Edgerton, 1999; Frood, 2011; Timoszyk et al., 2002). Two phases are associated with spinal cord injury: the initial phase associated with the mechanical impact and a second phase associated with neurotoxicity. It has been proposed, with some evidence to support the notion, that the treadmill training promotes new connections with the spinal cord by creating an environment that prevents cell death associated with the secondary phase of spinal cord injury (De Leon et al., 1999; Frood, 2011).

Whilst the focus of this section of the thesis is on adaptive plasticity, it is equally important to note that there is also evidence of maladaptive plasticity, as seen in cerebral palsy.

Evidence of re-organisational plasticity in children with CP.

Neurobiological mechanisms that contribute to maladaptive re-organisational plasticity include overproduction of neurons in early development, programmed cell death of excessive neurons, overproduction and elimination of immature synapses in early development and strengthening of synaptic connections later in life (Johnston et al., 2009; Wittenberg, 2009).

The literature indicates that children with CP are most likely to show maintenance of axonal projections that would normally be pruned (Eyre, 2007; J. H. Martin, 2005; J. H. Martin, Friel, Salimi, & Chakrabarty, 2007). An example of this is evident in the corticospinal pathways of children with CP. Transcranial magnetic stimulation (TMS) studies show individuals who have suffered unilateral damage to the motor cortex (such as spastic hemiplegia) can show different patterns of motor projections. These include an increase in the number of fast conduction ipsilateral and contralateral corticospinal axons from the intact motor cortex. This is in contrast to typical development where projections are contralateral (Holmstrom et al., 2010). There is evidence to suggest that the increased ipsilateral projections occur as a result of reduced activity in the infarcted hemisphere leading to increased withdrawal of the surviving contralateral corticospinal projections and displacement from the more active ipsilateral projections (Cowry, 2007; Eyre, 2007; Eyre et al., 2007).

New imaging techniques show that children with CP also display injury to the sensory tracts. Specifically, it has been identified that in comparison to typically developing children there is a reduction in the sensory fibres connecting to the sensory cortex (Hoon et al., 2009; Sanger & Kukke, 2007; Yoshida et al., 2010).

Despite the substantial neural re-organisation evident in children with CP, there is emerging evidence to suggest that intervention can promote functional neural adaptive plasticity in children with CP (Trivedi et al. 2008; Yoshida et al., 2010). Trivedi et al. (2008) report evidence of changes in the corticospinal tracts of children with CP, using diffusion tensor imaging. Eight children with spastic CP participated in an intervention protocol that included botulinum injections and administration of a 6-month intensive standardized physiotherapy regime. At the 6 month follow-up data indicated all participants had made a functional change to mobility, as measured using the Gross Motor Function Classification System (GMFCS). These changes were accompanied by increased functional connectivity in the corticospinal tract as indicated by increased fractional anisotropy in the posterior limb of the internal capsule. The significance of these data is strengthened by the use of 6 control participants who recorded no significant change to the corticospinal tracts between the baseline and follow-up phases.

The study by Trivedi et al. (2008) suggests adaptive plastic changes are possible in children with CP and indicates the potential to enhance therapeutic outcomes.

In summary, whilst no therapeutic approach can repair brain damage, knowledge of the mechanisms that facilitate adaptive changes in the developing brain; and how the brain can be re-organised following disruption/lesions presents clinicians with neuroscientific principles upon which to base intervention protocols for the purposes of maximizing learning.

Motor Learning

> *Learning requires the establishment of new stable patterns of dynamics that can be brought together over a sufficient time scale to realise the demands of either a new task to be learned, or the continued improvement in the performance of a given task" (Newell, 2003, p. 2).*

Presented in this section of the thesis is a behavioural interpretation of the phases of motor learning and training structure framed within the theory of DST.

Phases of Learning.

Skill acquisition.

Skill acquisition is defined as the emergence of a behaviour that is adaptable to a range of varying performance contexts (Araújo & Davids, 2011; Temprado, Zanone, Monno, & Laurent, 2001).

Training a new skill entails the evaluation of both the existing preferred movement pattern behaviours as well as the degree of cooperation/competition that exists with the new "to-be- learned" skill. Initial early acquisition of a motor skill entails modification of pre-existing capacities (Hollenstein, 2007; Kelso, 2003; Kelso & Zanone, 2002; Y.-T. Liu, Mayer-Kress, & Newell, 2010; Newell, 2003; Temprado et al., 2001). It is expected that when a task requirement cooperates with pre-existing coordination tendencies, the behaviour will be stabilised. In contrast, when the "to-be-learned" behaviour competes with pre-existing behaviours it is expected the whole behavioural repertoire will undergo recalibration, including previously stable behaviours.

Evidence of recalibration subsequent to learning a new skill has been reported in typical development. For example, Chen, Metcalfe, Jeka and Clark (2007) report disruption in the sitting posture of infants subsequent to accommodating the newly emerging behaviour of independent walking; and Corbetta and Bojczyk (2002) report a return to two-handed reaching during the transition to walking.

A popular experimental methodology to assess the influence of pre-existing behaviours on newly acquired behaviours during skills training is that of in-phase and anti-phase coordination patterns. This is illustrated in the work of Serrien (2009) who explored the competition between new (2:1 finger-tapping task) and existing (1:1 in/anti-phase finger task) dynamics in a bimanual finger-tapping task, using two experimental conditions with an ABA design.

The use of finger motion tasks is an established experimental methodology for assessing functional coordination (Kelso, 1984; Repp, 2005). The 2:1 finger-tapping task requires participants tap one finger at twice the rate of another finger at a rate paced to a metronome. The dominant finger taps at the faster tempo, whilst the non-dominant finger taps at a slower tempo. The participant is required to hold the slow finger stationary at a peak upward position whilst the faster finger completes the second tap. The 1:1 ratio in-phase task requires a participant to make bimanual finger flexion movements in synchrony with a metronome. The 1:1 finger anti-phase task requires participants synchronise one finger in extension and the other in flexion to the beat of the metronome.

The results of the finger tapping task demonstrated interference from the preferred (in-phase) movement pattern when the two training tasks were interwoven. Specifically, the pre-existing dynamic appeared to dominate the newly acquired movement pattern. The results therefore support claims in the literature that the effectiveness of generalisation will depend on the previous learning history of an individual (Krakauer, 2006).

The ability to enhance motor learning through the provision of sensory information has also been observed through the use of modified phase coordination tasks. For example, Atchy-Dalam, Peper, Zanone and Beek (2005) had two groups of participants learn a relative phasing task of 30° performed using the left and right elbows. One group of participants had an inertial load imposed on the left forearm to induce the phase shift. Group two performed the phasing task in the absence of the inertial load. Both groups of participants performed the required in-phase task initially to the beat of the metronome for 40 seconds and then continued the task in the absence of the metronome for 30 seconds. The data indicate whilst there was no difference in the level of performance obtained there was a significant difference in the practice conditions. That is, the group with the inertial load applied learnt the task faster and with less error than the group without the additional sensory feedback. The results therefore offer support to the premise that the mapping of motor output with sensory consequences facilitates learning.

Consolidation.

From a DST perspective, the “empirical signature” of skill consolidation is both improvement in accuracy and stability; and the phase where susceptibility to interference/competition decreases (Abel & Lattal, 2001; Doyon, 2008; Kelso & Zanone, 2002). Improvement in accuracy represents a shift towards goal attainment, whilst consolidation is proposed to be represented within the stability of the behaviour. As stated by Kostrubiec, Tallet and Zanone (2006) “The interplay between the creation/stabilisation of a new pattern and the transient shift of an existing one enables the memory to cope with incoming perturbations” (p. 243).

Emerging literature suggests with increasing age susceptibility to interference strengthens. Specifically, pre-pubescent children show a stronger ability to co-consolidate successive experience-dependent tasks than post-pubescent children or adults (Bronnikov & Kravtsov, 2006; Dorfberger, Adi-Japha, & Karni, 2007).

An example of age-related changes in susceptibility is found in the study of Dorfberger, Adi-Japha and Karni (2007). They explored the influence of interference in children using a finger-to-thumb opposition task that required participants to tap a sequence on the non-dominant hand. Comparisons of performance across three age-groups (9, 12 and 17 year-old-children) were reported across two experimental conditions. In the first experimental conditions, participants performed a finger sequence task that was repeated across three training sessions. In the second experimental condition, the same task from experiment one was repeated. A second training session followed two hours later where a second finger sequence was introduced and trained. The results show the two youngest age groups (9 years and 12 years) did not experience interference and continued to record improved performance scores, whilst the 17-year-olds recorded significant interference with the introduction of the second sequence.

This “divergence” in motor learning between adults and children suggests the need for caution in the application of motor learning principles predominantly based on adult data to children who are still acquiring motor skills.

An additional concept for consideration is that of continued skill acquisition during non-training periods. This is referred to as “off-line” learning and has been reported in the non-intervention period, subsequent to intervention in children with CP (Bar-Haim et al., 2010; Dorfberger et al., 2007; Trahan & Malouin, 2002). Bar-

Haim et al. (2010) conducted a randomised-control trial study comparing motor coaching (MC) to neurodevelopmental (NDT) intervention. Whilst no significant difference was observed between the two approaches during the training phases, a significant difference at 6 month follow-up was recorded. Particularly noteworthy, is the finding that the MC group continued to record improved motor skills whilst the NDT group recorded a slight decline.

Though the study by Bar-Haim et al. (2010) demonstrated off-line learning in children with CP, it is not clear which components of the MC approach promoted continued improvement. For example, it is unclear whether the different activities per se (e.g., the NDT group appeared to receive treatment only in the clinic whereas the MC group changed environments) or the principles of motor learning (e.g., type of feedback) resulted in improved retention.

Whilst literature is not currently available to define the aspects of intervention protocols that facilitate off-line learning, the data none-the-less suggest the potential benefit of scheduling “rest periods” to accommodate off-line learning.

Generalisation.

Consistent with skill acquisition and consolidation, generalisation of skills is influenced by previous training and by the context/training schedule (Krakauer, 2006; Serrien, 2009). Generalisation is defined by the transference of skills learnt in one context to another.

The literature also refers to a related concept of “savings”, which is the ability to relearn a skill more accurately than during the initial learning. For example, when a participant in an intervention program misses a number of sessions due to vacation, upon recommencement of intervention the re-introduced skill/concept is learnt more rapidly than during the initial training (Seidler & Noll, 2008).

Behavioural data suggests increased generalisation should be expected when training movements are close together and involve similar patterns of muscle activation. In contrast, when training involves overcoming a preferred intrinsic pattern some interference in generalisation may be evident (Balas, Roitenberg, Giladi, & Karni, 2007; Kelso & Zanone, 2002; Mattar & Ostry, 2007).

Two different models of savings are referred to in the literature. The first model is a two-state computational model of adaptation (M. A. Smith, Ghazisadeh,

& Shadmehr, 2006). This two-state model contains an initial process that shows a strong adaptive response by the end of initial training but which does not retain information well. The second faster adaptive process shows little adaptation by the end of initial training but has a strong retention of information.

The second model, based on the work of Huang, Haith, Mazzoni and Krakauer (2011) suggests the process of faster relearning is not a consequence of adaptation but rather a result of additional processes related to use-dependent plasticity and reinforcement. They propose a model of relearning that focuses on the retention of motor memories due to reinforcement as a consequence of successful target attainment.

From a DST perspective, it would appear plausible that both models make a contribution to the understanding of motor-skill acquisition. The first model appears to focus on underlying neural changes in the individual whilst the second model focuses on environmental factors. Both of these components are significant to the DST model.

Phases of learning in children with CP.

Whilst the literature reporting on the phases of motor learning in children with CP is sparse, there are data that suggest two different patterns of motor learning (S. B. Barnes & Whinnery, 2002; Brien & Sveistrup, 2011; Shumway-Cook, Hutchinson, Kartin, Price, & Woollacott, 2003). The first pattern is defined by an initial rapid and immediate change followed by incremental improvement and the second pattern is one of small and gradual change that continued throughout the intervention phase.

These two patterns of learning have been observed in studies using different intervention protocols. For example, Shumway-Cook et al. (2003) conducted a single subject research design study, using massed practice in a clinical setting, to evaluate the effect of balance training on postural stability in 6 children (4 males, 2 females) with CP. The authors report the children with spastic hemiplegia recorded the pattern of immediate change, whilst the children with diplegia recorded the second more gradual pattern. At 30-day-post-intervention follow-up all participants, with the exception of one participant (lost to follow-up) recorded data that showed skill maintenance.

Further support for the same two patterns is found in the study by Barnes and Whinnery (2002), though the results are inconclusive. They implemented a single subject research design study, distributed practice in an educational setting, to evaluate improvement in functional stepping in children with physical disability. This included 2 participants with a diagnosis of spastic quadriparesis, and one each with hemiplegia and hypotonia, respectively. Visual inspection of the "walking with adult support" data shows three participants recorded a learning profile that was consistent with a slow and gradual pattern of acquisition. The authors report continued gains in the maintenance phase. However, the maintenance data is reported 2-years post-intervention making it difficult to attribute the gains to the intervention in the absence of control variables.

Training Structure

"Learning is a process that increases the coordination between perception and action in a way that is consistent with the task and environmental constraints"

(Shumway-Cook & Woollacott, 2012, p. 31).

Though the evidence base is lacking, the motor-speech literature strongly recommends principles of motor learning be applied to intervention protocols for the purposes of maximising treatment efficacy (Maas et al., 2008; Schmidt & Lee, 2005; Strand, Stoekel, & Baas, 2006). Support for applying principles of motor learning in speech intervention protocols is found in the literature that has identified a possible underlying common brain mechanism between speech/language and sequential movement (Iverson and Thelen, 1999).

Key principles of motor learning that can be applied to intervention protocols have been identified and detailed in a number of sources (D. A. Rosenbaum, 2010; Shumway-Cook & Woollacott, 2012; Zwicker & Harris, 2009). Typically the motor-speech field has drawn on data obtained from experiments that have focused on simple tasks that do not reflect the complexity of speech. Further, the time frames under investigation are shorter than those typically applied to speech interventions protocols. Whilst McCauley and Strand (1999) reported the motor learning literature represents "the best available information pending increased research on motor learning for speech in children" (p.193), more recent literature suggests the findings from studies that have used simple tasks do not generalize to complex skill learning (Wulf & Shea, 2002).

Despite the presence of contrasting theoretical positions and tasks used to evaluate motor learning, the need to give consideration to specific elements when developing training schedules appears unequivocal. These include practice conditions (amount, distribution, variability and temporal organisation of practice; task complexity, skill level of the learner and motivation), and sources of information (Guadagnoli & Lee, 2004; Krakauer, 2006; Maas et al., 2008; McCauley & Strand, 1999; Newell, 1991b; Schmidt & Lee, 2005).

Practice conditions.

Examination of the literature regarding the effectiveness of practice conditions in children reveals conflicting results. The use of random, distributed practice schedules versus blocked trial order is recommended as the most effective practice schedule for achieving long term therapy gain (Krakauer, 2006; Y.-T. Liu et al., 2010; Maas et al., 2008; Savion-Lemieux & Penhume, 2010; Tsutsui, Lee, & Hodges, 1998; Zwicker & Harris, 2009). However, some studies report children benefit from random practice; and other studies report blocked practice is more effective (Barreiros, Figueiredo, & Godinho, 2007; Zwicker & Harris, 2009).

An explanation for the conflicting results is that of task complexity and experience of the learner (Balas et al., 2007; Wulf & Shea, 2002). For example, Pinto-Zipp and Gentile (2010) evaluated the benefit of blocked versus random practice using complex whole-body movement tasks (i.e., frisbee throw and rope ball toss) in two groups of participants. Group one consisted of twelve children aged 8-to-10-years and group two consisted of 12 adults. The authors reported high-task variability was a feature in the initial practice and suggest the participants needed to develop some proficiency in the task before benefiting from the random schedule. Their data indicate both participant groups benefited from the blocked practice not only during acquisition but also during the retention and transfer tasks. Thus, it would appear decision making regarding practice conditions is related to task complexity and skill level of the individual.

The findings reported above provide an explanation for the earlier findings reported by Barreiros et al. (2007) that younger children (less experienced) aged between 8 and 9-years, may benefit from blocked practice; and older children (more experienced) aged between 10-12 years may benefit from random practice.

It has been stated that an accepted paediatric clinical practice for speech/language pathologists is to use blocked practice followed with random practice (McCauley & Strand, 1999). Blocked practice is used during the early stages of training practice and then subsequently replaced with random practice to achieve skill generalisation when novelty and task difficulty is reduced. Support to this clinical approach is offered in the study by Pinto-Zipp and Gentile (2010).

Lee and Wishart (2005) suggest the protocols of random and blocked practice represent the poles of the “contextual interferences” continuum and propose that a schedule comprised of small blocks followed by random presentation may facilitate learning in complex tasks. This perspective is particularly relevant to children with CP, where the literature reports a greater number of trials and longer learning time is needed to facilitate functional outcomes (Garvey et al., 2007).

In summary, the literature indicates a prescribed formula of blocked versus random practice needs to be replaced with decision making on the basis of the needs of the individual, the task demands and environmental constraints.

Information.

“The challenge for the therapist, then, is in selecting the physical or informational constraint that induces an efficient and effective search strategy for task-relevant qualitative and quantitative change and functional output in the movement dynamics” (Newell & Valvano, 1998, p. 51).

Newell and Valvano (1998) suggest a clinician can facilitate a learner to optimise their search for the ideal movement strategy by:

1. Assisting the learner to understand the goal of the task and movements to be learned.

2. Providing feedback in the form of knowledge of performance and knowledge of results,

3. Augmenting the search by the learner for the optimum strategy.

The following subsection focuses specifically on the use of tactile-kinaesthetic input as a means of facilitating a learner to optimise their search for the ideal functional movement strategy. The literature highlights the importance of sensory augmentation in particular for children with CP to achieve functional motor output (Hadders-Algra, 2000).

The role of active tactile-kinaesthetic information.

The function of augmentative feedback is to facilitate the search for a task relevant strategy and minimize the practice of inefficient or ineffective strategies. Newell and Valvano (1998) state augmentative information is the provision of information that is not normally available to an individual.

The role of somatosensory input in speech production.

Speech production entails fine movements that are dependent on peripheral input to control, correct, adjust and stabilise oral facial movements. The literature identifies orofacial afferents are not only essential for motor control, they play a critical role in motor learning (Sessle et al., 2005).

There is evidence to suggest that sensory input can modulate motor cortex excitability and therefore has a role to play in facilitating “learning-dependent” plasticity (Monfils, Plautz and Kleim, 2005; Stefan 2000). Specifically, perturbation studies have been used to explore the potential role of the somatosensory system to affect change in the coordination of movement synergies (Ito & Ostry, 2010; Kelso, Tuller, Vatikiotis-Bateson, & Fowler, 1984; Ménard, Perrier, Aubin, Savariaux, & Thibeault, 2008).

These studies have shown articulator coupling patterns will reorganise or compensate as a response to modification/disruptions in articulator movements (such as insertion of a plastic tube in the mouth or a bite block between the teeth), to maintain perceptual integrity and acoustic output. For example, Kelso et al. (1984) report three experiments designed to examine the effects on articulatory cooperation between the jaw, lips and tongue, when a constant force load was applied to the jaw in both opening and closing gestures. They reported that whilst no perceived distortion to the speech signal was observed (acoustic analysis was not provided), kinematic and EMG analysis demonstrated compensatory changes. For example, when an unexpected force was applied to the jaw during production of the word bab /bæb/, compensation was observed through increased activity in the upper and lower lip. Similarly, during production of the word /bæz/ increased tongue activity (but not lip) was observed. They reasoned the lower-lip perturbations, particularly evident when the load was applied in jaw closing, occurred as a result of passive mechanical compensations; whilst a more active neuromuscular response in “locally linked articulators”, was indicated by increased EMG activity in the jaw opening experiments.

Perturbation studies also suggest the potential to improve speech intelligibility through modifying speech movement patterns. Mefferd and Green (2010) explored the strength of the relationship between tongue kinematics and acoustic changes in the vowel /ia/ by manipulating speaking rate and loudness in 10 typical adult speakers during the production of a sentence. They found changes in tongue displacement were closely correlated with changes in acoustic vowel distance, and suggested the potential for speech intelligibility to be improved through maximisation of articulatory specification.

The role of mechanoreceptors.

The literature supports the functional role mechanoreceptors play in providing detailed information pertaining to movement position and control during speech (Estep, 2009; Estep & Barlow, 2007; Francis, Ciocca, & Yu, 2003; Howell, Anderson, Bartrip, & Bailey, 2009; McClean & Tasko, 2003).

The perioral region, in particular the upper lip, corners of the mouth and tongue, is richly innervated and endowed with mechanoreceptors. Research shows the presence of fast (type I) and slowly adapting (type I and II) afferents in the skin of the face and vermillion borders of the lips (Trulsson & Johansson, 2002). Fast adapting type I afferents are activated by discrete stimuli in a small well defined area, maintain burst responses at the beginning and end of sustained skin indentations; and are found mostly in the tip of the tongue. The slowly adapting afferents also have small well defined receptive fields. Slowly adapting type I afferents are reported to be superficially located and “respond to self-generated movements and external loads” (Estep & Barlow, 2007). Type II slowly adapting afferents are located more deeply in the skin and sensitive to lateral skin stretch (Macefield, 2005).

The research also indicates four types of mechano-sensory information are available to the jaw (Türker, 2002). These include 1. golgi tendon organs that provide information about muscle contraction; 2. muscle spindles that provide detailed information about muscle length and rate of change (Finan & Smith, 2005; Murray & Klineberg, 1984); 3. cutaneous receptors (slowly adapting type I and II) in the hairy skin overlying the temporomandibular joint that provides information about condylar movement (Bukowska, Essick, & Trulsson, 2010; Trulsson & Johansson, 2002; Türker, Johnsen, Sowman, & Trulsson, 2006); and 4. slowly adapting periodontal mechanoreceptors (Gilman, 2002).

The literature suggests the type, placement and context in which the stimulation is provided is essential in facilitating sensory-motor reorganisation (Estep, 2009; Gick, Ikegami, & Derrick, 2010; Wilston, Reed, & Braida, 2010). For example, Estep and Barlow (2007) report data that demonstrates changes to the inter-lip angle subsequent to the delivery of tactile stimulation to the upper lip during production of the word "ah-**w**ah". Further they report observing differential changes dependent on the timing of the mechanical inputs during the speech task. Their data reinforces the responsiveness of the orofacial system to external mechano-sensory stimulation during active speech.

Ito and Ostry (2010) completed a series of experiments that demonstrated lip movements could be changed in response to mechanical perturbation. One experiment evaluated the adaption of the upper lip to a facial skin stretch perturbation task during the production of the short phrase "see wood". A mechanical stretch was applied laterally to the oral angle, with change in horizontal displacement of the upper lip used as the measure of change and compared to a control group. The data show that the displacement of the upper lip systematically increased with training; and this was maintained when the load was removed. In contrast, the control group showed no change thus indicating the skin perturbation task modified the motor speech output. Further the authors report that an analysis of the first and second formant frequencies did not reveal any consistent patterns of change. The authors suggest this may be due to other articulatory organs compensating to maintain the acoustic output, or the small change in vocal tract length over the course of the training period.

Though not specifically highlighted in the PROMPT model, it is important to note that the location and placement of the surface prompts for facial placements 1-5 (as illustrated in Figure 2.4) are consistent with the location of fast and slowly adapting mechanoreceptive fields of the infraorbital and inferior alveolar nerves (Trulsson & Essick, 2010; Trulsson & Johansson, 2002).

In summary, there is emerging evidence that supports the role of enhancing somatosensory input to facilitate motor learning.

Implications for children with CP.

As previously stated, children with CP present with a reduction in the fibres connecting to the sensory cortex, which is expected to impact speech (Hoon et al., 2009; Sanger & Kukke, 2007; Yoshida et al., 2010). Within the framework of DST, an imbalance between the motor and sensory systems would be expected to have a significant impact on the development of motor speech control.

Behavioural studies indicate sensory augmentation has a role in enhancing motor learning in general (Stein, 1999; Atchy-Dalama et al, 2005) and learning when stimuli are difficult to perceive (Stein, Wallace, & Stanford, 1999).

These results support the need for research to evaluate intervention approaches, grounded in current empirical data and interpreted within an ecological framework, aimed at addressing this sensory-motor imbalance.

Evidence to Support PROMPT

In this section, the research base to support PROMPT is evaluated on the basis of level of evidence, using the NHMRC (National Health and Medical Research Council) definitions and hierarchy (NHMRC, 2009); and quality using the Single Case Experimental Design (SCED) scale (Tate et al., 2008).

Level of evidence.

A number of studies reported in the literature purport to demonstrate the effectiveness of PROMPT in the management of motor speech disorders in both adults and children (Bose, Square, Schlosser, & Lieshout, 2001; Dodd & Bradford, 2000; Freed, Marshall, & Frazier, 1997; Grigos, Hayden, & Eigen, 2010; Hayden & Square, 1994; Houghton, 2003; Marx, 2008; Rogers et al., 2006; Square, Chumpelik (Hayden), Morningstar, & Adams, 1986). In this thesis, only the 4 published studies that have investigated the effectiveness of PROMPT intervention in children are reviewed.

A review of the four studies by this author, indicate the best level of evidence, as shown in Table 2.1, is designated at level III-2 of the NHMRC levels of evidence (2009).

Table 2.1

Levels of Evidence and Study Design for Published Paediatric Studies Evaluating PROMPT

Reference	**Study Design**	**Protocol**	**Level of Evidence**
Dodd & Bradford (2000)	Comparative concurrent cohort	SSRD (ABACADA) with random allocation	III-2
Rogers et al. (2006)	Comparative concurrent cohort	SSRD (ABA) with random allocation	III-2
Marx (2008)	Case series	Pre-test post-test using an outcome measure	IV
Grigos, Hayden & Eigen[1] (2010)	Interrupted time series with case control	Trends in outcomes compared over multiple time points	III-2

Note: SSRD = single subject research design

Quality of evidence

In this section, three of the above mentioned studies in Table 2.1 are examined in order of publication, using the SCED scale (Tate et al., 2008). This scale contains an 11-item present/absent scale where 1 point is awarded for each item that meets criteria. Item 1 is not included in the score, thus a score of 10 represents a study with a high level of methodological quality.

The SCED scale was developed specifically to enable researchers and clinicians analyse the strengths and weaknesses in single subject research design. The guidelines for SSRD developed by Logan et al. (2008) were used to further supplement interpretation of the SCED scale. A summary of the SCED scale for each of the studies, is summarised in Table 2.2. The study by Marx has been excluded from further analysis as it does not meet more than 2/10 scored items on the SCED scale.

---

[1] It is acknowledged that the study by Grigos et al. (2010) was conducted subsequent to the data being collected for this thesis and therefore was not available to inform this thesis in the development or data collection phase. Grigos et al. (2010) have referenced the poster presented at the 63rd AACPDM annual meeting (2009).

Table 2.2.

Methodological Quality of the PROMPT Studies as Assessed using the SCED Scale

SCED scale Items	Dodd & Bradford (2000)	Rogers et al. (2006)	Grigos, Hayden & Eigen (2010)
1*. Clinical history specified	Y	Y	Y
2. Target behaviours operationally defined	Y	Y	Y
3. Design 1: 3 phases (eg.ABA)	Y	Y	Y
4. Design 2: Sufficient baseline sampling (visual or tabular)	N	Y	Y
5. Design 3: Sufficient treatment phase sampling	Y	Y	Y
6. Design 4. Raw data points reported	N	Y	Y
7. Observed bias	N	Y	Y
8. Independence of assessors	N	Y	Y
9. Statistical analysis	N	N	Y
10. Replication	Y	Y	N
11. Generalisation	N	N	N
Total Items Met (2-11)	4/10	8/10	810

Note. Y = criteria met, N = unable to specify as information not provided.
* = this item is not scored.

1. A comparison of three therapy methods for children with different types of developmental phonological disorders.

Dodd and Bradford (2000) compared the effectiveness of PROMPT to two other treatment approaches, using a single subject with alternating treatment design in three children with phonological impairment. Three intervention approaches (PROMPT, phonological contrast and core vocabulary) were administered to each of the children, with the order of intervention randomised.

Evaluation of this study, using the SCED scale indicated that at least 5/10 items were not met, with serious potential threats to validity, including:

- Variability in behaviour. Sampling of the baseline and follow-up measures are not consistent with the continuous measures collected during the intervention phases.

The lack of consistency of the pre-intervention and follow-up data with the continuous measures used during the intervention phases makes it difficult to determine the specific change in the level, trend and stability of the intervention targets. The authors state the 25 Word Test for Inconsistency was administered at the beginning and end of each phase; and data on the treated and untreated targets were collected every second session during the treatment phases. Further only the raw data of the intervention phase is provided.

- Observer bias. Two potential sources of observer bias include failure to report fidelity to all three intervention approaches and the independence of the assessor from the intervention. Further, whilst the authors report point-to-point reliability for the pre-assessment tools, no reliability measures are reported for the intervention targets. In addition, administration of the PROMPT approach requires a clinician complete a systems analysis observation in order to determine the intervention priorities. This assessment information is not included in the battery of assessment tools, thus making it difficult to determine the appropriateness of the intervention goals for this approach. It should also be noted that the authors state in their hypotheses that they predict the PROMPT intervention will be ineffective. When these factors are considered collectively, a bias against the approach is suggested.
- Verification of treatment efficacy. No statistical analysis or effect size data is provided.

These internal threats to validity indicate the authors' interpretations of the results need to be considered cautiously. The authors conclude that the PROMPT approach was "of minimal use to any of the children" (p.208). However, it could be argued the authors failed to control for intervention bias. The authors state they did not expect PROMPT to be effective because the underlying deficit was not commensurate with the mechanics of the treatment approach. If the authors believed this intervention approach inappropriate to the impairment under investigation, it raises the question as to why the PROMPT treatment approach was selected for investigation.

Although the authors conclude the PROMPT approach did not effect substantial gain to the intervention targets, they do report all children made positive changes to speech production accuracy and intelligibility. This suggests the effectiveness of the PROMPT approach with a population for which the approach was developed, warrants attention.

2. Teaching young nonverbal children with autism useful speech: A pilot study of the Denver Model and PROMPT Interventions.

Rogers, Hayden, Hepburn, Charlife-Smith, Hall and Hayes (2006) report on the effectiveness of two intervention approaches (PROMPT and the Denver Model) in young children with autism, using a single subject ABA design. Five children each were randomly assigned to one of the treatment conditions. The results indicate both treatment approaches were equally effective for 4 of the 5 participants each, with no one treatment approach superior to the other.

Evaluation of this study, using the SCED scale indicated 2/10 potential threats to validity:

- Failure to report statistics, and
- The lack of generalisation of these findings on the basis of small sample size.

A small sample size is a frequent challenge to the validity of a treatment study. The heterogeneous nature of the population under investigation further contributes to difficulties with recruiting participants that meet selection criteria.

Despite the above, the strength of this study is supported by the finding that 9/11 of the SCED scale items were met. The use of a randomised concurrent multiple baseline with a minimum of three participants and clearly defined results suggests this study meets the requirements for the highest level of evidence for SSRD (Logan et al., 2008).

The positive results obtained for 4 of the 5 participants in this pilot study provide evidence to suggest further research of this approach is warranted.

3. Perceptual and articulatory changes in speech production following PROMPT treatment

Grigos, Hayden and Eigen (2010) report on the effectiveness of PROMPT intervention, in a single participant with a severe motor speech disorder using a subject ABA research design. An age-matched peer served as a case control. The authors report positive changes to the speech production accuracy and motor speech movement patterns subsequent to the PROMPT intervention.

Evaluation of this study, using the SCED scale indicated 2/10 potential threats to validity:

- Verification of treatment fidelity. The authors report an independent PROMPT certified clinician administered the intervention. However, fidelity to the approach during this intervention study is not reported.
- Limited generalisation. As an n-of-1 trial, generalisation to other subjects, therapists or settings is limited.

Despite the preceeding, the strength of this study is supported by the use of precise objective measures involving a stimulus set that was not part of the intervention protocol. The recommendation for further research is consistent with both the level of evidence and findings of the study.

Recommendation

It has been reported in the literature that the evidence-base to support PROMPT is equivocal, with a level of evidence consistent with at best "limited testimonial support" (Bowen, 2009, p. xviii). However, this appraisal of the peer reviewed literature shows a level of evidence that is commensurate with many intervention approaches reported to be of value in managing speech sound disorders in children (Williams, McLeod & McCauley, 2010).

The evaluation of the three studies reported in this thesis, combined with the theoretical basis that underpins the approach, suggests there is sufficient support to warrant the further investigation of this approach in the management of motor speech disorders in children with CP.

CHAPTER 3 RATIONALE AND RESEARCH AIMS FOR THE PRESENT THESIS

The literature identifies that although CP remains one of the most prevalent childhood disabilities, the evidence base to support or refute speech intervention approaches, framed within present day theoretical models and relevant empirical evidence, is limited.

The primary goal of this thesis is to make a contribution to the current limited evidence base available to clinicians in the management of motor-speech disorders associated with CP. The lack of sufficient data available to clinicians is a barrier not only in the decision making process regarding the evaluation and selection of an appropriate intervention protocol for clients but also in the allocation of therapy and training budgets.

The treatment approach (PROMPT) selected for investigation in this thesis is aligned with DST and is supported by recent knowledge gleaned from empirical studies pertaining to neural plasticity and principles of motor learning.

Outcome measures used to evaluate the PROMPT approach have been selected to address the domains of part one (function and disability) of the ICF framework. Specifically, changes to the domain of structure and function were evaluated using outcome measures that include *both* perceptual and kinematic measurements.

The use of both perceptual and kinematic measures, within a clinical setting for the purposes of evaluating an intervention approach, is considered unique. The combination of both types of measures enables an evaluation of the functional status of the motor-speech movement patterns and their associated perceptual output in children with a moderate-to-severe motor speech disorder; and the impact of changes to these parameters on speech intelligibility. Whilst the use of perceptual measures is well established and indeed has been identified as the benchmark for assessment (Murdoch, 2011), kinematic measurements have typically been confined to the research laboratory. However, the advances in the portability of motion analysis technology have made kinematic measures more readily accessible to the clinical setting.

In addition to the domain of structure and function of the ICF, two further measures were selected to evaluate changes to the domains of activity and participation. One measure includes a standardised assessment of speech intelligibility. The second measure of activity/participation was based on the COPM (Law et al., 2005). The use of this tool, as framed within the domains of both the ICF and communication provides the opportunity to reflect changes in activity and participation as interpreted within the construct of DST. Both the standardised speech intelligibility measure and the COPM have been identified as robust and sensitive to change in children with CP.

Children with moderate-to-severe speech impairment were identified for inclusion in this study as the literature identifies this group of children as being most at-risk for educational limitations and participation restrictions (Balkom & Verhoeven, 2010). Speech production has been identified as one of the most important early predictors of reading success (Nadeau & Tessier, 2009; Peeters et al., 2009). It has been further identified that the lack of speech interferes with the ability to use silent reading rehearsal therefore limiting a child's ability to play with the sound structure of language for reading success (Ehrich, 2006).

Improvement in a child's ability to use speech that is understood by familiar and unfamiliar listeners therefore presents the opportunity to improve a child's success in interacting with peers and enhance educational opportunities.

Outcome Measures

"There has been a consensual acceptance amongst many childhood disability researchers that maximizing children's effective 'participation' is the overarching goal in providing services...." (Morris, 2009, p. 92).

The major goal of speech therapy for children with severe speech impairments is to improve intelligibility (Hodson, Scherz, & Strattman, 2002; R.D Kent, Miolo, & Bloedel, 1994; Klein & Flint, 2006; Pennington, Goldbart, & Marshall, 2005).

The acceptance of the ICF framework has seen acknowledgement of the need for outcome measures to reflect not only changes in impairment but also to reflect the impact of the intervention on the client's level of activity and participation. The literature reports that parents and children want to see changes across all domains –

body function/structure activity and participation (Vargus-Adams and Martins, 2010).

The outcome measures used in this study (as illustrated in Table 3.1) acknowledge the ICF framework by including perceptual, physiological and social measures, as illustrated in Figure 3.1

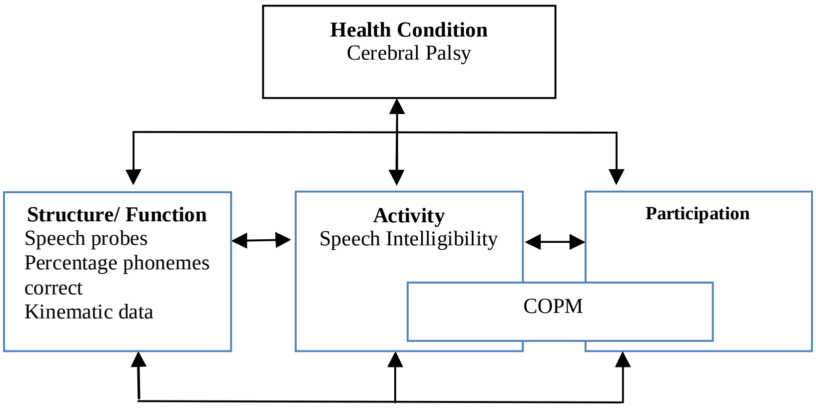


Figure 3.1. Outcomes measure assessments as classified within the components of the ICF (WHO, 2002).

This study investigated (a) perceptual changes in perceived accuracy of speech production, (b) the use of kinematic measures to track changes in speech movement patterns (motion analysis), and (c) changes in activity and participation (Speech Intelligibility Measure and Canadian Occupational Performance Measure), subsequent to intervention. These measures are now discussed as framed within part 1 of the ICF.

Table 3.1

Dependent Measures and Methods of Analysis for the Measures used in this Thesis

	Dependent Variable	Assessment Tool	Analysis	
			Measures	Statistics
1.	Speech Production Accuracy • MSMPs • PA	Weekly Speech Probes	Visual Inspection, Mean Percent Correct	Two-standard deviation band (2SD), Split-middle with binomial test, Effect Size (modified Cohen's d)
2.	Phonetic Accuracy	Arizona-3	Percent Phonemes Correct	Repeated measures ANOVA, Effect size (Cohen's d)
3.	Motor Speech Control	VMPAC	Percent Scores	-
4	Kinematic Measures	3D motion analysis	Distance Velocity Duration	Mann-Whitney U Friedman's ANOVA Wilcoxon-signed rank test
5.	Activity and Participation in daily routines	COPM	Ten-point rating scale	Friedman's ANOVA Wilcoxon-signed rank test
6.	Speech Intelligibility	CSIM	Percent Words Correct	Confidence Intervals, Effect Size (Cohen's d)

Note. MSMPs = motor-speech-movement-parameters, PA = perceptual accuracy, CSIM = Children's Speech Intelligibility Measure, Arizona = Arizona Articulation Proficiency Scale (3rd Edition), VMPAC = Verbal Motor Production Assessment for Children, COPM = Canadian Occupational Performance Measure.

Structure and Function

> *"Fixing itself may not be appropriate when pursued as an end in itself, but can be judiciously employed as a means to helping children reach their functional goals and live well" (Gibson et al., 2009, p. 1451).*

Most measures aimed at examining speech production focus only on the use of perceptual measures (that is, how an individual's speech sounds to a familiar or unfamiliar listener), at the "Body Function" domain of the ICF (McLeod & Bleile, 2004). These measures include improvement in production of speech probes specific to the intervention focus, performance on formal test scores and improved accuracy of articulation through such measures as percentage consonants correct and phonetic transcription (Wambaugh, Duffy, McNeil, Robin, & Rogers, 2006).

However, given dysarthria affects multiple speech subsystems, the use of perceptual measurements alone is not sufficient. This has been highlighted in studies that have evaluated the reliability and accuracy amongst health professionals in classifying the type of dysarthria (Cheng et al., 2007; R.D Kent, Weismer, Kent, Vorperian, & Duffy, 1999; Murdoch, 2011).

Advances in technology now provide clinicians access to tools that were previously inaccessible (e.g., three dimensional motion analysis). Murdoch (2011) states “instrumental assessment can enhance the abilities of the clinician in all stages of clinical management, including the documentation of treatment efficacy”. The use of motion analysis to examine subclinical motor speech signs has been reported in adult dysarthria, dysarthria associated with traumatic brain injury, childhood apraxia of speech and stuttering (Cahill, Murdoch, & Theodorus, 2005; Peters, Hulstijn, & Van Leishout, 2000; Roy, Leeper, Blomgren, & Cameron, 2001; Theodorus, Murdoch, & Horton, 1999). No study of this nature has been undertaken to evaluate changes in motor-speech-patterns in children with CP, subsequent to intervention.

Kinematic analysis.

Motion analysis is a concept used to describe the compilation and analysis of movement data of any kind in two dimensions (2D) or three dimensions (3D). The data may be obtained from various sources including video cameras, VCR, magnetic or mechanical devices, and is captured either ‘on-line’ or ‘off-line’. The use of video systems based on video sequences utilise off line systems where the movement is recorded and later evaluated with the aid of image processing (Castro, Medina-Carnicer, & Galisteo, 2006).

The use of motion analysis in the health sciences is becoming increasingly popular due to the availability of more readily accessible commercial software packages (Green & Wang, 2003; Katz, Bharadwaj, & Stettler, 2006; Maner, Smith, & Grayson, 2000; Ostry, Gribble, & Gracco, 1996; Shiller, Ostry, & Laboissiere, 2001).

Vicon Motus (previously Peak Motus Measurement System) is an example of a 3D motion analysis system. Two or more cameras are used to capture movement in a calibrated space, from which specific 3D points may be identified. The software package allows measurement of distance, angle and rate of change of selected reference points and segments. Motion analysis has been applied to the fields of physiotherapy in gait analysis, orthopaedics, podiatry and sports rehabilitation. More recently it has been applied to the study of speech movement (Green & Wilson, 2006; Grigos & Patel, 2007; Kleinow & Smith, 2006; Lindstrom, 2002).

An independent assessment of Vicon Motus has indicated the system to be accurate and reliable for the precise and objective spatial temporal assessment of facial expression, with a test-retest reliability coefficient of .73 to .99 (Lindstrom, 2002).

Activity and Participation

> *"There has been a consensual acceptance amongst many childhood disability researchers that maximizing children's effective 'participation' is the overarching goal in providing services...." (Morris, 2009, p. 92).*

Two outcome measures were selected to evaluate changes in activity and participation. The first measure focused specifically on changes to speech intelligibility and the second measure focused on global changes to activity and participation within each participant's daily routine.

Speech Intelligibility.

A number of assessment options are available to determine changes in speech intelligibility (Gordon-Brannan & Hodson, 2000; Hodge, 2010; Hustad, 2006; R.D Kent et al., 1994; Yorkston & Beukelman, 1978). For the purposes of this thesis, a formalised assessment, that utilises a closed set task format scored by an unfamiliar listener, was selected.

The Children's Speech Intelligibility Measure (Wilcox and Morris, 1999) was selected as it has been shown to have an established validity and sensitivity in detecting changes to speech intelligibility in children with CP (Pennington et al., 2006). Further, recent evidence suggests the use of forced-choice format reduces variability in listener judgments of speech intelligibility when assessing the speech of speakers with moderate to severe speech impairment (McHenry, 2011).

Changes to Activity and Participation within the daily routine.

The Canadian Occupational Performance Measure (COPM) is an individualised measure of changes in self-perception of occupational performance and satisfaction over the course of a therapeutic intervention. It contains three sections: 1. self-care (activities of daily living), 2. productivity (education and work) and; 3. leisure (play, leisure and social participation) (McColl, Law, Baptiste & Pollock, 2005). The three sections of the COPM reflect the nine domains of the ICF Activity and Participation Domains (WHO, 2001). The COPM is designed for use with clients of all ages and utilises a semi-structured interview format that takes approximately 15-30 minutes to administer. Thus, both the parents and the clients are involved in the process of setting the intervention goals and priorities. Additionally, the COPM is not only a measure of performance but also satisfaction.

The COPM has been widely used in paediatric rehabilitation (De Rezze, Wright, Curran, Campbell, & Macarthur, 2008). Further, Cusick, Lannin and Lowe (2007) report modifying the COPM for use with children with speech impairment associated with CP, without compromise to the robustness of the measure.

Research Study Overview

A single subject multiple-baseline-across-participants research design, as illustrated in Figure 3.2, was used to evaluate the effectiveness of the PROMPT intervention. The study consisted of four phases, consistent with an ABCA research design, as described below:

Phase A1: The baseline data collection phase consists of a 5- to 8-week period during which time participants receive their standard therapy services. All participants will remain in baseline until stable baseline measurements are determined through the application of statistical process control (Portney & Watkins, 2009).

Phase B: PROMPT intervention aimed at one level of the PROMPT motor speech hierarchy (MSH).

Phase C. PROMPT intervention aimed at one level higher on the MSH.

These two phases each consist of 10x once weekly individual intervention blocks, 45 minutes in length. Therapy sessions occurred at the same time of day on the same day of the week.

Phase A2: Follow-up data collection. This consists of two data collection sessions. The first involves the collection of the kinematic and speech intelligibility data and the second involves the collection of the speech probe data. During this study phase, all participants returned to their regular therapy services, consistent with the baseline phases.

The use of a SSRD, with two inter-hierarchical phases of intervention provides the opportunity to evaluate the time course of motor learning in terms of skill acquisition, consolidation, savings and interference to achieve accurate speech production. Experimental control was maintained through the establishment of a stable baseline for all participants prior to the commencement of intervention; and the repeated measurements of both targeted and control behaviours, *throughout* the study phases. This involved the weekly administration of speech probes for each baseline session (A1), at the end of each treatment session (phases B and C) and at 12-weeks post-intervention (phase A2). The speech probes consist of three groups of twenty words. Group one contains trained and untrained words based on intervention priority one, group two contains trained and untrained words based on intervention priority two and group three contains control words based on the untrained intervention priority three.

The study phases are as follows:

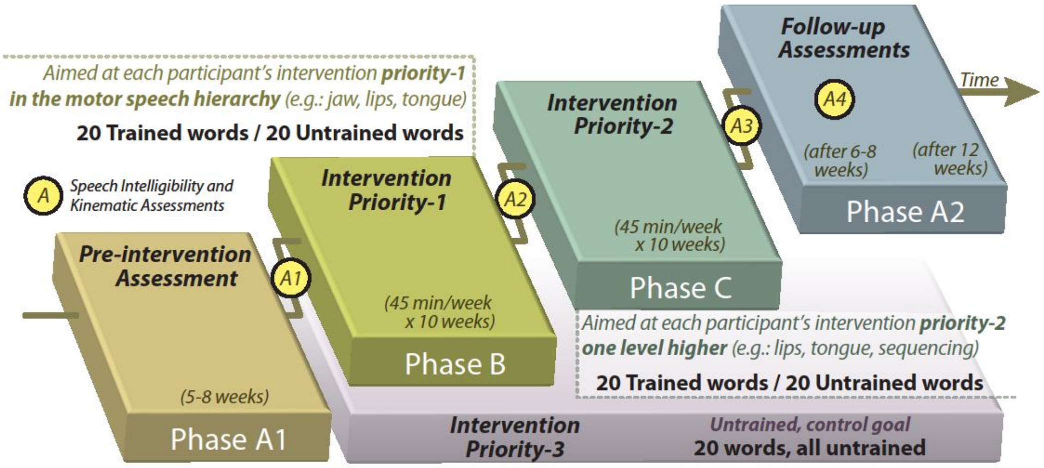


Figure 3.2. Phases of the Study

Three main research questions were posed:

1. Is PROMPT effective in making changes to speech production accuracy in children with CP with moderate-to-severe speech impairment? The following two specific questions were posed:

    1.1 Will speech production accuracy improve subsequent to intervention?

    1.2 Will phonetic accuracy increase?

2. Will children with moderate-to-severe speech impairments associated with CP show changes in distance, velocity and duration measures of the jaw and lips subsequent to PROMPT intervention?

3. Will children with CP show changes in the Activity and Participation domains of the ICF subsequent to intervention? The following two specific questions were posed:

    3.1 Will unfamiliar listeners identify improvements in speech intelligibility subsequent to intervention?

    3.2 Will children with CP be perceived as showing improved participation in tasks and actions of daily life with family members and friends subsequent to the PROMPT intervention?

Single Subject Research Design

> *"…I hope people will resist the siren call of the RCT simply because it is there – and use the best designs for the 'big' questions we need to answer"(P. Rosenbaum, 2010, p. 111).*

The design chosen for this thesis was a single subject research design (SSRD) with concurrent multiple-baseline-across-participants. The role and validity of the SSRD in healthcare disciplines is indicated through the recent development of criteria and 14-point scoring system upon which to evaluate the quality of SSRD studies by the Treatment Outcomes Committee of the AACPDM (Logan, Hickman, Harris, & Heriza, 2008).

Single subject experimental designs have long been recognized as useful for examining effects of language and literacy interventions, (Neuman & McCormick, 1995) and, more broadly, have yielded useful insights in the disability, psychological and special education fields, as illustrated by the Journal of Applied Behaviour Analysis (JABA), which is devoted to single subject designs.

The use of SSRD in children with CP has several advantages over other study designs. It avoids grouping together diverse children with diverse diagnoses and speech impairments, allowing each participant's responses to be considered individually. It permits the investigation of outcome measures, in particular the exploration and refinement of movement analysis to describe differences in articulation. And the use of repeated assessments allows some investigation of the effects of treatment parameters, particularly the length of intervention required to produce effects.

Single subject research designs involve the systematic application of interventions at pre-planned stages and the consistent, repeated measurement of relevant outcomes that are expected to change with the intervention phases (Portney & Watkins, 2009). Each individual constitutes a separate study, even though similar interventions on several children may be running at the same time. These studies differ from case studies, relying on quantitative (not qualitative) data and in being experimental, not merely observational (Portney & Watkins, 2009).

The foundations of a SSRD include:

1. Repeated measurement of a dependent variable. This involves collecting data prior to commencing intervention (baseline) at regular time intervals, and continuing to collect the same data during the intervention phase. Figure 4.1 illustrates the occasions of assessment for each of the dependent variables evaluated in this thesis.

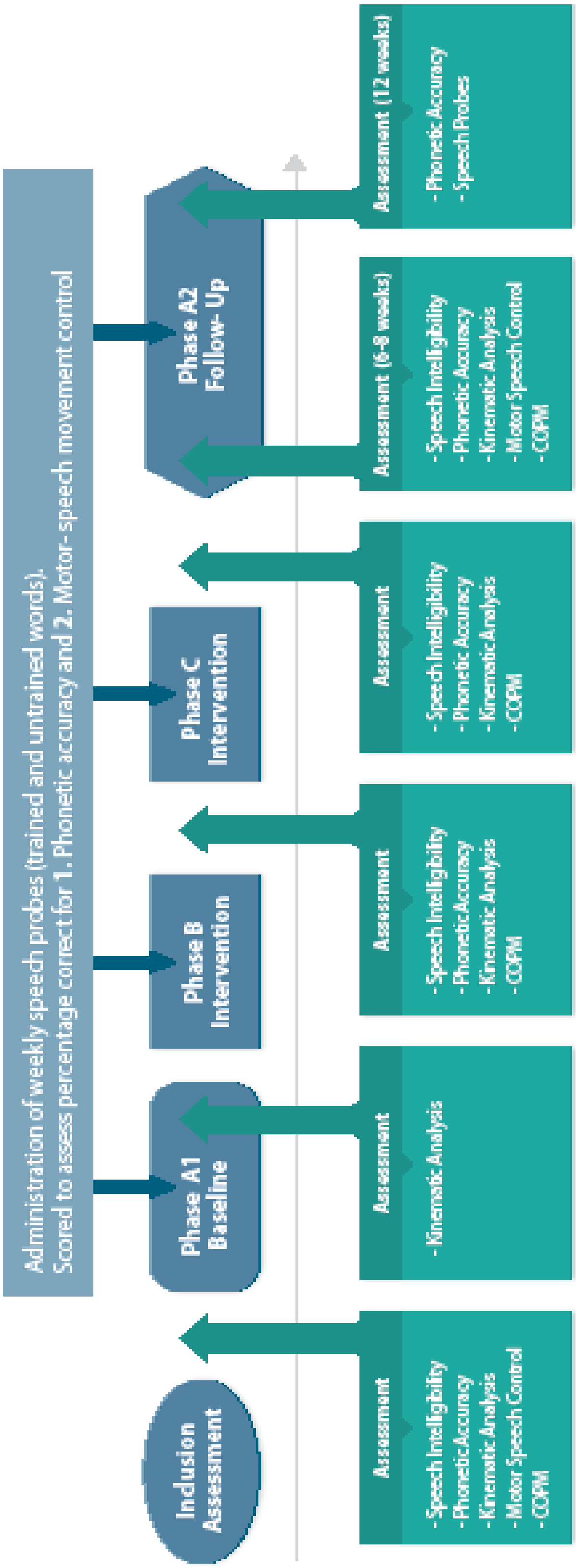


Figure 3.3. Occasions of assessment administration.

2. Establishment of a stable baseline; and
3. Graphing the data.

Visual inspection is the typical method used to interpret the significance of the data. Visual inspection involves judgement of changes in level, slope and variability. Advocates for visual inspection argue it is a reliable and conservative analysis tool.

Recently however, much debate has centred on the need to use statistical procedures to support visual inspection. The criticism has been directed at the lack of formal decision rules upon which to interpret the data and a lack of inter-rater reliability (Fisher, 2003).

The use of statistical analyses has the positive advantage of: (a) reducing uncertainty when evaluating treatment effects in the presence of unstable baselines, (b) producing consistent results, and (c) being suitable to use with serially dependent data (Fisher, Kelley, & Lomas, 2003; Hojem & Ottenbacher, 1988; Nourbakhsh & Ottenbacher, 1994). Statistical procedures commonly cited in the literature include the two-band standard deviation (2SD band) analysis and trend-lines such as the split-middle (SM) method of trend estimation with binomial test (Portney & Watkins, 2009).

Hypotheses

Speech production will improve across the phases of the study, as demonstrated by:

1.1. Speech production accuracy.

Phase B:

i. Improvement in the motor-speech movement patterns will be observed on the speech probes targeted in the first intervention priority. This may cause destabilisation between the pre-existing coordination synergies and result in initially reduced perceptual accuracy.

ii. Due to the biomechanical linkages between the jaw and lips, some destabilisation of the speech probes at intervention priority two may be observed. However, the change in performance will not be significant.

iii. No change to the motor-speech-movement patterns or perceptual accuracy will be observed in the control goal.

Phase C

i. Improvement in performance level and stability, of both the motor-speech movement patterns and perceptual accuracy will be observed on the speech probes targeted during the first intervention priority.

ii. Improvement in the motor-speech movement patterns will be observed on the speech probes targeted in the second intervention priority.

iii. No change to the motor-speech-movement patterns or perceptual accuracy will be observed in the control goal.

Phase A2

i. Off-line learning will continue to occur during the non-intervention phase if a stable shift in the targeted coordination dynamics has occurred.

ii. Improved speech intelligibility will be recorded across the study phases.

1.2. Phonetic accuracy.

Improvement in phonetic accuracy will be cumulative across the study phases, as evidenced by progressively increasing percentage phonemes correct scores.

2. Distance, duration and velocity measures.

Changes in the measures of distance, velocity and duration as targeted across the study phases will be observed as follows:

i. Participants will record the greatest magnitude of change to the kinematic measures that reflect the intervention priority being trained in the first intervention phase. For example, most participants will commence intervention at the mandibular level of control as measured on the PROMPT MSH. Thus, it is expected the measures of jaw control (e.g., Jaw Lateral Distance from Midline, jaw path distance travelled and jaw opening distance) will show the greatest magnitude of change, with a trend direction towards typically developing peers.

ii. Due to the biomechanical linkages between the jaw and lips, changes to the second intervention priority will also observed during the training of the first intervention priority (phase B) but that during the training of the second intervention priority (phase C), a greater treatment effect will be observed. That is, participants that received intervention focused on labial-facial control will show changes to the labial-facial measures (e.g., lip rounding) during the second intervention phase.

iii. The training of new motor-speech movement patterns will result in destabilisation of an existing pattern of motor-speech movement patterns. As a result, with the initiation of a new motor-speech movement pattern, an initial "worsening" of the targeted behaviour may be apparent until speech subsystem re-organisation is achieved. Continued skill acquisition during the follow-up non-intervention period is expected with stabilisation of the newly acquired motor-speech-movement patterns.

iv. A limited treatment effect is expected to occur on the movement patterns that are not targeted during intervention (for example, the production of words that require lingual control and which are not targeted in intervention, may show limited improvement due to improved mandibular and labial-facial control).

3. Activity and participation.

3.1. Speech intelligibility.

Improvement in speech intelligibility will be cumulative across the study phases, as evidenced by progressively increasing intelligibility scores recorded on the standardised measure of speech intelligibility.

3.2 Changes to activity and participation within the daily routine.

Changes to activity and participation within the daily routine will occur if the communication domains have sufficiently re-organised to achieve integration between the physical-sensory, social-emotional and cognitive-linguistic domains. Thus, it is not anticipated a change in activity and participation will be recorded before phase C.

CHAPTER 4 QUESTION ONE.

IS PROMPT EFFECTIVE IN MAKING CHANGES TO SPEECH PRODUCTION ACCURACY IN CHILDREN WITH CP WITH MODERATE-TO-SEVERE SPEECH IMPAIRMENT?

Introduction

Speech production is a goal oriented process that results from movement of the jaw, lips, tongue, velum, vocal folds, and respiratory system. The transition from early vocalisations to intelligible speech requires mastery and coordination, achieved through precise timing and accurate positioning of multiple sub speech systems (Ballard, Granier, & Robin, 2000; Barlow, 1999; Caruso & Strand, 1999; Green et al., 2000; Tasko & McClean, 2004). In addition, the motor speech processes are influenced by not only the differential development of cognitive and linguistic skills but also sensory motor, tactile, auditory/visual stimulation and perceptual saliency (Barlow, 1999; Connor & Abbs, 1998; Green et al., 2000; A. Smith, 1992; Trulsson & Johansson, 2002).

The literature is increasingly reporting data that highlight the significant role somatosensory input plays in motor speech control and learning (Estep, 2009; Estep & Barlow, 2007; Ito & Ostry, 2010; Sessle et al., 2005). In particular, researchers have shown that the speech production system is responsive to the provision of enhanced kinaesthetic information to cutaneous afferents (Estep, 2009; Gick et al., 2010; Wilston et al., 2010). For example, researchers have demonstrated that the modifications to the speech system through the application of external perturbation, such as through the stretching of the facial skin at the lateral angle of the mouth, changes speech production (Estep & Barlow, 2009). Further, studies have also shown that articulator coupling patterns will reorganise or compensate as a response to modifications/disruptions in articulator movements. These findings are further enriched by behavioural studies that indicate sensory augmentation can play a role in enhancing motor learning in general, particularly when stimuli are difficult to perceive (Atchy-Dalama et al., 2005; Stein, Wallace, & Stanford, 1999).

Motor speech impairments associated with CP may impact an individual’s ability to produce speech efficiently and accurately, due to impairments in timing and coordination across the speech subsystems (Hustad et al., 2010; E. L. Lin et al., 2007; Soloman & Charron, 1998; Workinger, 2005). Impairments to the motor speech movement patterns of children with CP reported in the literature include excessive mandibular displacement, with lip and tongue blade movements highly dependent on the mandible in children with athetoid CP (Kent & Netsell, 1978). Ortega et al. (2008) reported significantly decreased mouth opening and increased lateral deviation in children with spastic CP. Further, the kinematic study by Hong et al. (2007) reported a significant difference in the temporal coupling between the lower lip and jaw movements in children with CP, as compared to the age matched peers. It has been hypothesised that a poor relationship between the motor command and perceptual consequences of the speech movement may be one of the possible explanations for this impaired motor control (Kent & Netsell, 1978; Neilson & O'Dwyer, 1981).

Recent brain imaging studies show that children with CP indeed present with injury to the sensory system that includes a reduction in fibres connecting to the sensory cortex (Hoon et al., 2009). These findings support the hypothesis that impaired motor speech control in children with CP could be associated with the selection of inefficient or ineffective movement strategies due insufficient information regarding control, adjustment and stabilisation through peripheral (sensory) input.

Research findings indicate the enhancement of somatosensory input during speech can not only affect change in the coordination of movement synergies but also influence learning that can be maintained across time. These findings suggest potential therapeutic value in enhancing tactile-kinaesthetic input to children with CP (Mefferd & Green, 2010).

Although the use of tactile-kinaesthetic input to facilitate speech production in children with motor speech impairment has an established history in the literature (Crickmay, 1966; Dworkin, 1991; Pannbacker, 1988; Square, 1999; Stinchfield & Young, 1938) the scientific evidence base supporting the role of somatosensory enhancement in clinical practice for the management of motor speech impairment in children is limited.

Evidence based practice is an approach for clinical practice that requires the "…conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence-based-medicine means integrating individual clinical expertise with the best available external evidence from systematic research" (Sackett et al., 1996, p. 71).

The current research climate advocates that research focused on the evaluation of treatment outcomes be conducted in phases. Specifically, it is recommended that novel treatment approaches first be evaluated using a single subject research design with a small number of participants in order to evaluate the treatment effect (Beeson & Robey, 2006; Robey & Schultz, 1998).

Three intervention approaches, reported recently in the peer-reviewed literature to employ tactile kinaesthetic input, have utilised early phase single subject research designs to evaluate treatment effectiveness: the Touch-Cue-Method (Bashir, Grahamjones, & Bostwick, 1984; Gordon-Brannan & Weiss, 2007), Dynamic Temporal and Tactile Cueing (Strand et al, 2006), and PROMPT (Chumpelik, 1984).

The Touch-Cue-Method method utilises a hierarchical sequence of 8 touch cues (b, d, g, s, f, n, ʃ, l) that are provided to the face and neck, simultaneously with auditory and visual cues. The approach is comprised of three stages that include producing sounds in isolation and progress to multiword sequences. Martikainen and Korpilahti (2011) evaluated the effectiveness of the Touch-Cue-Method and a non-tactile method (Melodic Intonation Therapy) in a 4 year-old girl with childhood apraxia of speech. The study design consisted of an A1BA2CA3 design with the Touch-Cue-Method administered subsequent to the non-tactile method. Outcome measures included percentage vowels and consonants correct using narrow phonetic transcription; and phonological mean length of utterance.

Visual inspection of one of the dependent variables (percentage of vowels correct) showed an accelerating trend in the baseline phase that continued throughout the study phases. Further, the percentage-consonants-correct data showed an increasing trend direction at the commencement of phase A2 (rest phase after administration of the non-tactile approach) that continued until the end of the study phases. The continued improvement in the non-intervention phase, before commencement of the Touch-Cue-Method limits the interpretation of the effectiveness of the touch-cue-method as it is not possible to reliably assign the improvement to the intervention approach specifically.

Dynamic Temporal and Tactile Cueing is a treatment approach, developed by Strand (Strand et al., 2006), that is based on integral stimulation (Gordon-Brannan &

Weiss, 2007; Strand & Skinder, 1999). The method utilises a hierarchically organised sequence of stimuli, with an emphasis on “the shaping of movement gestures for speech production” (2006, p. 298). Strand et al. (2006) report a clinician utilises the tactile input to facilitate accurate jaw and lip positions for the speech target. In the early treatment stages, where maximal support is required the child is assisted to maintain the movement position in order to “maximise the proprioceptive processing” (p. 298). Gestural cues are faded as the child’s accuracy and independence increase.

Dynamic Temporal and Tactile Cueing has been evaluated most recently in two studies (Baas, Strand, Elmer, & Barbaresi, 2008; Strand et al., 2006) that utilised multiple-baseline-across-behaviours designs. In both of these studies, the authors report positive treatment outcomes that they attribute to multiple aspects of the intervention approach, including treatment frequency, stimulus targets and principles of motor learning embedded in the therapy routine.

Rogers et al. (2006) evaluated the use of PROMPT in facilitating the development of functional speech in five children with autism, using a single subject ABA research design. The authors of this study show that of the 5 children who participated in the PROMPT intervention, 4 children recorded positive increases in functional speech as recorded by an increase in the number of functional words and phrases spoken across the study phases.

Whilst the authors of all of the above studies report tactile input is used to shape the correct articulation posture, the frequency and administration of the tactile-kinaesthetic input is not specified. Further, the outcome measures are not designed to record how these cues facilitated changes to correct the articulation postures under investigation. The absence of outcome measures focused on evaluating the tactile-kinaesthetic input in the above studies, therefore limits the ability to assess the specific benefits of enhanced sensory-motor input.

Despite this, the positive speech outcomes for the speech and communication skills of the participants in these studies suggest further investigation of intervention approaches focused on providing enhanced tactile-kinaesthetic input for the purposes of improving speech intelligibility *during speech* merits attention. In addition, the use of outcome measures that documents changes to the speech movement patterns across the study phases is also required.

The literature suggests the type, placement and context in which the stimulation is provided is essential in facilitating sensory-motor reorganisation (Estep, 2009; Gick et al., 2010; Wilston et al., 2010). The PROMPT intervention approach has been developed specifically to facilitate articulatory control for improved speech production; and has been identified as treatment approach that has direct relevance for children with motor speech disorders (Murdoch & Horton, 1998, page 401). The approach utilises specific types of prompts to target 1. joint receptors and muscle spindles for postural stabilisation and 2. cutaneous afferents to stimulate specific motor speech postures. A PROMPT trained clinician uses specific tactile-kinaesthetic input *during active speech* directed to specific orofacial regions that are richly innervated with slowly adapting, cutaneous mechanoreceptors that are responsive to external low level inputs during motor activity (Andreatta & Barlow, 2009; Feng, Gracco, & Max, 2011; Trulsson & Johansson, 2002).

The purpose of this chapter is to make a contribution to the evidence base by investigating perceptual changes to speech production in six children with CP subsequent to PROMPT intervention.

The research question addressed in this chapter is as follows:

Is PROMPT effective in making changes to speech production accuracy in children with CP with moderate-to-severe speech impairment? The following two specific questions were posed:

1.1 Will speech production accuracy improve subsequent to intervention?

1.2 Will phonetic accuracy increase?

Method

Participants

Inclusion criteria.

The inclusion criteria for this study were:

1. Diagnosis of cerebral palsy.
2. Age range 3 – 14 years.
3. Stable head control – independent or supported.

4. Developmental quotient greater than 70 as measured on the Leiter-Brief International Performance Scale R Brief (Leiter-R) (Roid & Miller, 1997) a nonverbal cognitive assessment.

5. Spontaneous use of at least 15 words verbally.

6. Standard score at or below 1.5 standard deviations on the Arizona Proficiency Scale – 3rd Revision (Arizona-3) (Fudala 2001).

Exclusion criteria for this study were:

1. Past treatment using the PROMPT approach,

2. Receptive language impairment greater than two standard deviations below the mean on the CELF-P (Wiig, Secord, & Semel, 1992) or CELF 4 (Semel, Wiig, & Secord, 1995), and

3. A hearing loss greater than 25dB as measured through pure tone audiometric screening.

Recruitment.

Participants were recruited through The Centre for Cerebral Palsy (TCCP). TCCP is a not-for-profit organisation that provides supports and services to people with cerebral palsy and their families, living in Western Australia. Services include access to physiotherapy, speech pathology, occupational therapy, respite, health promotion, employment, as well as access to specialized technology/equipment.

All speech pathologists at TCCP (eight in total), working with children between 3 and 14 years, attended an information session outlining the purpose of the study and the inclusion criteria for participants. After this session, the speech pathologists were given parent information sheets to pass on to the families of any children whom they considered would be likely to meet the inclusion criteria.

Ten families were identified as potential candidates and invited to participate. Eight of these families expressed an interest. One participant was excluded because the child had previously received treatment using the PROMPT approach. The remaining 7 children were tested to determine eligibility to participate in the study on the basis of the selection criteria. Six children met the criteria. The family of the 7th child were informed that their child did not meet selection criteria. They were offered therapy consistent with the study protocol but were excluded from the analysis phase of the data collected in this study.

Ethics approval was initially obtained from LaTrobe University Human Research Ethics Committee (application 06-137) and The Ethics Committee of Princess Margaret Hospital (1298/EP). Subsequent to the transfer of candidacy to Curtin University, ethics approval was further obtained from the Curtin University Human Research Ethics Committee (HR102/2007).

All procedures and protocols were observed with no complaints or withdrawals. All participants completed all phases of the study. Participant five (P5) missed one therapy session in block two and one appointment in the follow-up phase due to the family temporarily leaving the country.

Participant description.

Table 4.1 summarizes the characteristics of the six participants (3 girls and 3 boys) that met selection criteria. Ages ranged from 3 years to 11 years, 9 months at study commencement. All participants had cerebral palsy and were native speakers of English. All participants were assigned a participant number and pseudonym. Throughout the thesis, the participants will be referred to by their assigned participant number.

Table 4.1

Participant Characteristics

Characteristic	P1	P2	P3	P4	P5	P6
Age	11;9	8;5	5;4	5;2	3;0	3;6
Sex	F	F	F	M	M	M
Type of CP	Dyskinetic	RH	Quad	LH	RH	LH
GMFCS	3	3	2	2	2	1
Vision	NAD	Corrected	NAD	NAD	NAD	Reduced in left eye
Hearing	NAD	NAD	NAD	NAD	NAD	NAD
Epilepsy	NAD	Controlled	NAD	NAD	NAD	Controlled
IQ Estimate [a]	79	70	85	73	95	121
Attention and Memory [a]	93	90	73	81	-	100
Receptive language [b]	-1SD	+1SD	-1SD	-2SD	-1SD	+1SD
Intelligibility [c]	54%	54%	36%	20%	34%	30%
Arizona-3	-2SD	-2SD	-1.5SD	-1.5SD	-1.5SD	-1.5SD
Total Score	67.5	79	69	68.5	60.5	54.4
PPC	2.5%	12.6%	8%	13.5%	6.5%	5.6%
VMPAC[d]						
Global Motor	25%	65%	50%	60%	60%	70%
Focal Oromotor	37%	53%	26%	57%	29%	43%
Sequencing	91%	65%	83%	24%	0%	34%
Connected Speech/Language	58%	78%	58%	51%	35%	46%
Speech Characteristics	14%	57%	14%	57%	28%	57%

Note. CP = cerebral palsy, RH = spastic right hemiparesis, LH = spastic left hemiparesis, Quad = spastic quadriparesis, NAD = no abnormality detected, GMFCS = Gross Motor Function Classification System, Arizona-3 = Standard deviation and total score obtained on The Arizona Proficiency Scale, Third Revision (Fudala, 2000), PPC = percentage phonemes correct.

[a] Based on the Leiter-R International Performance Scale (Roid and Miller, 1997).[b] Obtained on the Clinical Evaluation of Language Fundamentals - Preschool (Wiig, Secord and Semel, 1992) or Clinical Evaluation of Language Fundamentals - 4 (Semel, Wiig and Secord, 2003).

[c] Obtained on the Children’s Speech Intelligibility Measure (Wilcox and Morris, 1999).

[d] Verbal Motor Production Assessment for Children (Hayden and Square, 1999).

Measures

Selection criteria.

The following standardised measures were used for the assessment of cognition, speech and language:

1. The Leiter International Performance Scale-Revised (Leiter-R) (Roid & Miller, 1997).

The Leiter-R is a standardised test designed to assess nonverbal cognitive functioning in children and adolescents, aged between 2 and 20 years. The test contains two groupings of subtests: ten subtests of nonverbal ability associated with visualisation, reasoning and spatial ability (VR), and two subtests of attention and memory (AM). An estimate of global intellectual ability can be obtained through administration of the full Leiter-R or the Brief IQ Screener.

The Brief IQ Screener consists of 4 subtests that assess figure ground, form completion, repeating patterns and sequential order. Three types of responses are elicited from the child by the examiner and include placing response cards into slots on an easel frame, arranging shapes and pointing. The examiner gives all instructions non-verbally. Administration time is approximately 25 minutes.

Raw scores are converted to normalised scaled scores. The Brief IQ score is calculated from the sum of the subtests normalised scaled scores and converted to a normalised standard score.

The authors report reliability coefficients of .88, .90 and .89 across three main age ranges (2-5, 6-10, 11-20 years). In addition, Tsatsanis et al. (2003) reported a correlation of 97% between the Leiter R Brief and the Leiter-R Full Scale.

The Leiter-R was developed for administration with children with severe speech impairment and has been established in the literature as one of the most widely used cognitive tests in children with CP (Brossard-Racine et al., 2012; Majnemer et al., 2008).

2. The Receptive Language Subtests of the Clinical Evaluation of Language Fundamentals Preschool (CELF-P), (Wiig et al., 1992) or the Clinical Evaluation of Language Fundamentals 4 (CELF-4), (Semel et al., 1995).

Both these tests are norm-referenced and measure language ability.

The CELF-P is designed to assess the expressive and receptive language skills of children aged between 3 and 6 years. It contains six subtests: three subtests (linguistic concepts, basic concepts and sentence completion) provide a receptive language score and three subtests (recalling sentences in context, formulating labels and word structure) provide an expressive language score.

The CELF- 4 contains 19 subtests designed to measure four aspects of language (phonology/syntax, semantics, pragmatics and phonological awareness) in children aged between 5 and 21 years of age. A receptive language index is derived from three subtests for 8 year-olds and two sub-tests for 9-12 year-olds.

Only the receptive language subtests were administered. Participants are required to respond to questions by pointing to pictures. One subtest of the CELF-4 (score form 5-8 year olds) requires single word responses. Testing can be stopped between the subtests to give the participant a break if required.

Both tests convert raw scores to yield standardised scores with percentile ranks, confidence intervals, standard deviations and age equivalents.

The authors report test-retest reliability coefficients for the composite scores to be between .81- .96, and .87 - .95 on the CELF-P and CELF-4, respectively.

3. The Arizona Proficiency Scale, Third Revision (Arizona-3) (Fudala, 2001).

The Arizona-3 is a standardised test of articulation for children aged 18 months to 18 years. The test gathers data on an individual’s articulation proficiency, articulation competence and global speech intelligibility based on a total of 67 consonants, vowels and diphthongs, in single words.

Children are asked to look at and label simple picture cards. Test administration time is approximately 15 minutes. A total score is calculated and converted to yield a standardised score, severity rating and intelligibility rating.

Fudala (2000) reports a strong test-retest reliability of .97. High correlations with other articulation tests were also reported including the Goldman-Fristoe Test of Articulation (.89) and the Photo Articulation Test (.84).

4. A questionnaire was designed and administered to parents to determine the child’s history of speech therapy (Appendix A).

Measures for the selection of intervention priorities for the intervention phases.

1. The PROMPT Motor Speech Hierarchy (MSH) and System Analysis Observation (SAO) (Hayden, 2003).

The MSH is used to evaluate the level of control within an individual's motor speech system and identify intervention priorities within the speech subsystem. The PROMPT trained clinician is required to complete the MSH and then select three intervention priorities.

The MSH is completed using the PROMPT Systems Analysis Observation (SAO). The PROMPT SAO is an informal yes/no checklist that scores the structural, function and integration of an individual's motor speech system (see Appendix B). The checklist consists of seven stages that reflect the seven stages of the MSH. A yes/no response is scored against each of the items for each of the seven stages. The negative responses are tallied for each stage and transferred to the MSH.

In addition to the SAO, formal assessment tools can be used to complete the MSH analysis. For the purposes of this study, data obtained from The Arizona Proficiency Scale, Third Revision (Arizona-3) (Fudala, 2001) and the Verbal Motor Production Assessment of Children (VMPAC) (Hayden & Square, 1999) were used to supplement the SAO. These two tests were also used as outcome measures and are described below.

Outcome measures.

Informal and formal assessment tools were used to gather data on three dependent variables used to evaluate the effectiveness of PROMPT therapy (see Table 4.2).

Table 4.2

Assessment Tools used to Evaluate the Dependent Variables

Dependent Variable	Assessment Tool
Speech Production Accuracy	Weekly Speech Probes
Phonetic Accuracy	Arizona-3
Motor Speech Control	VMPAC

Weekly Speech Probes.

Speech probes were administered at each baseline session, at the end of each treatment session and at 12-weeks post phase A2 (follow-up). The speech probes consisted of three groups of twenty words, as illustrated in Table 3.3. Group one contained trained and untrained words based on intervention priority one, group two contained trained and untrained words based on intervention priority two and group three contained control words based on the untrained intervention priority three.

Table 4.3

Word Pool for Speech Probes

	Group 1	Group 2	Group 3
Words	IP1 (e.g. mandibular)	IP2 (e.g. labial-facial)	IP3 (e.g. lingual)
Trained	20 words	20 words	
Untrained Control	20 words	20 words	20 words

Note. IP = Intervention Priority

The word pools were individualised to each participant and designed to facilitate the establishment of new motor-speech movement patterns. They contained (a) low frequency words (b) high frequency words that provided opportunities for mass and distributed practice during daily routines and play/school activities, and (c) words that were age-appropriate.

The speech probes were scored for both perceptual accuracy and accuracy of the motor-speech movement-parameter goal established for each participant.

Phonetic Accuracy.

A measure of phonetic accuracy was obtained using the stimulus words from the Arizona-3 (Fudala, 2001). The stimulus words were transcribed off-line using narrow phonetic transcription and a percentage phonemes correct (PPC) score was calculated. The PPC metric is an extension of the percentage consonants correct (PCC) reported by Shriberg and Kwiatowski (1982 as cited by Shriberg, Lewis, McSweeny, & Wilson, 1997). The PPC score is calculated by dividing the number of correct phonemes by the total number of phonemes and multiplying by 100. Substitutions, distortions and deletions are scored as incorrect. This differs from the PCC score where only the consonants are included in the calculation.

Shriberg et al. (1997) reported this to be an appropriate measure to use when calculating a total index of phonemes, as opposed to only consonants. They present reliability information based on a speech sample of 33 children and adults. The pooled data indicated a relatively small error of measurement (0.9) and a correlation coefficient of .96.

Motor Speech Control.

The Verbal Motor Production Assessment for Children (VMPAC) (Hayden and Square, 1999).is a standardised test designed to assess global motor control (muscle symmetry, range and tone of movement in the face), focal oromotor control, sequencing control, connected speech and language control and speech characteristics in children aged three to 12 years. Test administration time is approximately 30 minutes.

Raw scores are converted to mean percent correct scores for each area. The data are then transferred to a standardised age-based profile graph for comparison to the corresponding age group (3, 4, 5, 6 and 7-12 years).

Hayden and Square (1999) reported test-retest reliability coefficients ranging between .56 and .90 across the five subtest areas. The areas of focal oromotor control and sequencing scored the highest correlations of .90 and .88, respectively. The lowest correlations were recorded on the two subtests with the smallest number of test items – global motor control and speech characteristics.

Table 4.4

Summary of the Assessment Measures and Occasions of Testing

Measures	Selection Tests	Pre-Baseline	Baseline	Intervention Phases B & C	End Phase B	End Phase C	Follow Up
Selection criteria measures							
Leiter – R (Brief)	✓						
CELF-P OR CELF-4	✓						
Parent Questionnaire	✓						
Hearing Screening	✓						
Intervention Priority Measures							
PROMPT MSH and SAO		✓					
Outcome Measures							
Speech intelligibility (CSIM)		✓			✓	✓	✓
Speech Production Accuracy (Speech Probes)			✓	✓			✓
Phonetic Accuracy (Arizona-3)		✓			✓	✓	✓
Kinematic Measures (motion analysis)		✓			✓	✓	✓
Motor Speech Control (VMPAC)		✓					✓
Satisfaction and Performance (COPM)		✓			✓	✓	✓

Note. Arizona-3 = The Arizona Proficiency Scale, Third Revision (Fudala, 2000), Leiter-R = Leiter-R International Performance Scale (Roid and Miller, 1997), CELF-P = Clinical Evaluation of Language Fundamentals - Preschool (Wiig, Secord and Semel, 1992), CELF-4 = Clinical Evaluation of Language Fundamentals - 4 (Semel, Wiig and Secord, 2003), CSIM = Children's Speech Intelligibility Measure (Wilcox and Morris, 1999) COPM = Canadian Occupational Performance Measure- 4th Edition (Law et al., 2005).

Baseline data collection.

Baseline data were collected over a 5- to 8-week period, as illustrated in

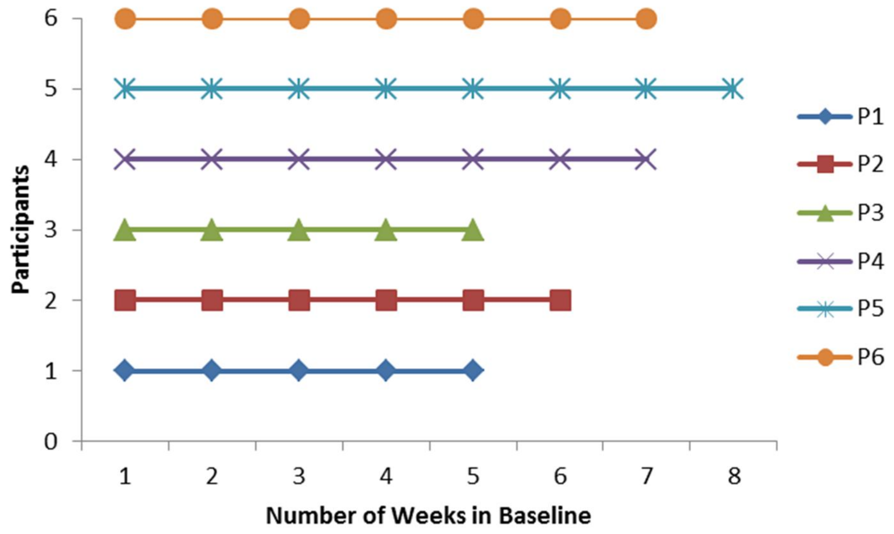


Figure *4.1*. Upon completion of a 5-week baseline-data-collection period and evidence of stable baselines (as assessed through statistical process control), participants 1 and 3 commenced intervention. Participant 2 continued in baseline for another week staying in baseline for six weeks before commencing intervention. Participant four and six continued in baseline for a further week and commenced intervention after seven weeks of baseline data collection. Participant five commenced the study one week later and completed eight weeks in baseline.

Portney & Watkins (2009) report the use of the staggered stable baselines strengthens experimental control. Once stable baselines were established, participants were randomly allocated to commence intervention, while other participants remain in baseline. This process continued on a staggered basis until all participants commenced intervention. If changes in behaviour are observed to occur only when the intervention is applied, the independence of the baselines is demonstrated and the change in behaviour can more reliably be attributed to the intervention effect.

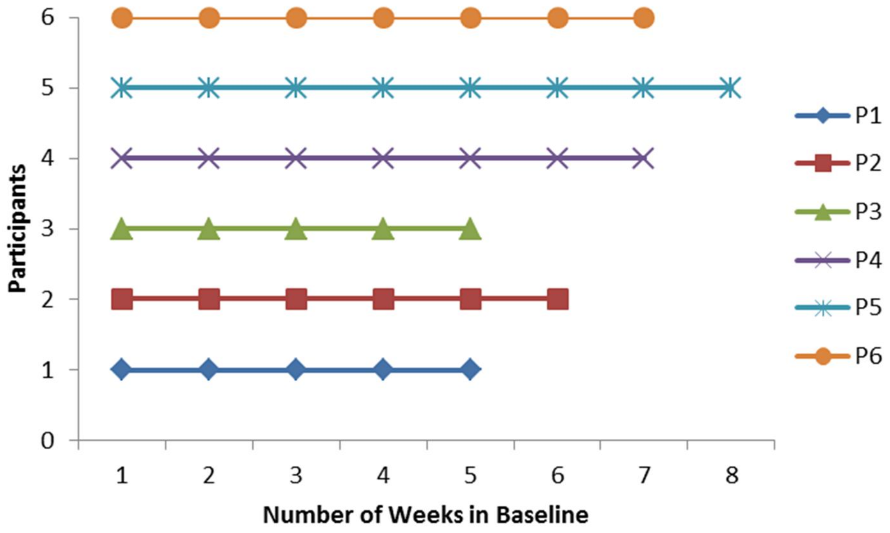


Figure 4.1. Timeline for baseline periods of each participant

All sessions were conducted in a treatment room at TCCP. This room contained a chair, a height-adjustable cut-out-table, and video camera. Each participant sat in a chair selected to maximize postural stability. This chair remained constant throughout testing. The participant sat in the chair behind the cut-out-table. All sessions were video recorded with the camera positioned in the frontal view and zoomed to capture the participant's face. A wireless Bluetooth microphone (Sony ECM-HW 1R) was attached to the collar of the participant's shirt to enhance audio recording for future scoring, with the exception of P5 and P6 where the microphone was placed on the table. The investigator sat in front of the participant to the left of the video camera.

A speech probe wordlist and book was generated for each participant. Each word was represented on one card. The four younger participants (P3, P4, P5, and P6) had pictures on their cards; the two older participants (P1 and P2) had printed words.

At each testing session, 6 cards from each of the 5 trained and untrained 20-word pools were randomly selected, to give a total of 30 words to be used on that day (see Figure 4.2). These cards were then shuffled and administered to the children in random order. At the end of the session, the cards were returned to the word pools. At the next session, 6 words were selected randomly again, without any consideration of which words had been chosen in any previous sessions. Colour coding the backs of the cards facilitated the process of returning the cards to their original word pools.

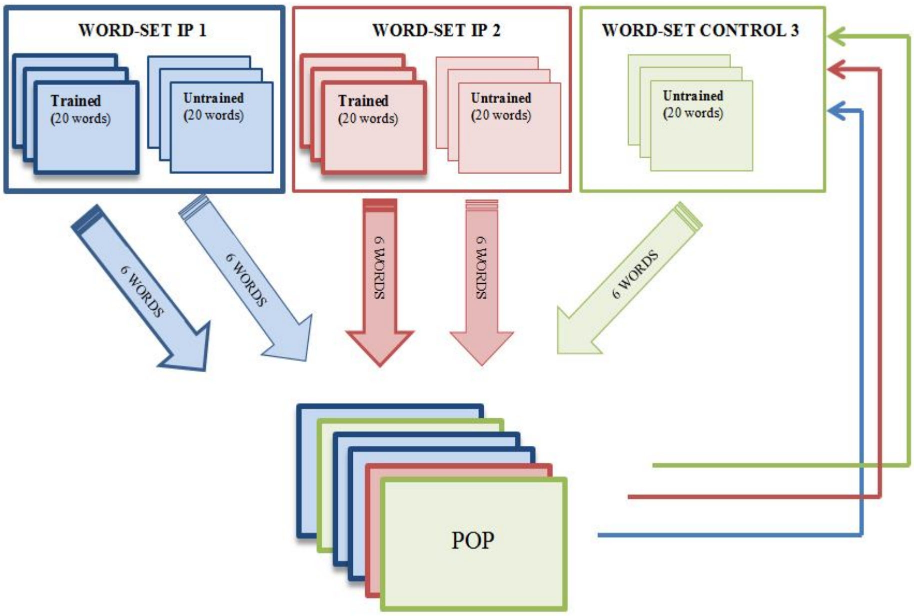


Figure 4.2. Illustration of word-pool selection process

Elicitation of the speech probes occurred as follows.

P5 and P6: The speech probes were represented on individual picture cards. The investigator held up a picture card and briefly described it (e.g., Mum is pushing the boy on the *swing*). The participant was asked to “say [word]” (e.g., Say swing). Six words were elicited. The participant was then given a time-limited toy of interest to play with (e.g., puzzle). When the activity was completed, another six words were elicited. This format continued until all 30 words had been recorded.

The first production of the word was accepted regardless of the accuracy of the production, except when a participant yawned, hiccupped or moved out of camera view. The participant was then asked to repeat the word.

Feedback was not given regarding the accuracy of the word. Positive reinforcement regarding on-task attendance and participation was provided.

P3 and P4: The speech probes were represented on individual picture cards. The chief investigator held up the card and gave a brief description. The participant was then asked to "say [word]", e.g., "The boy is drinking from a cup. Say cup".

Upon elicitation of all 30 words, the participant chose a game/toy to play with the chief investigator, as reward.

P1 and P2: The speech probes were printed on individual cards. The participant read the word from the card held up by the investigator. The cards were held to one side and behind the camera so the participant's face remained visible to the camera. A word card was held in view and the participant was asked to read the word aloud. If a word was misread, the investigator used sentence completion to elicit the correct response. For example, "When the lawn grows too long, you need to (mow) the lawn." The word card was then shuffled through the pack and re-presented a second time.

Intervention programme

As described in the literature review, PROMPT is a motor-speech intervention approach founded upon the theoretical construct of dynamic systems theory. That is, the PROMPT approach acknowledges the dynamic inter-relationship between the physical-sensory, cognitive-linguistic and social-emotional domains of the individual, as well as the external influences of the environment, in motor speech production. Therefore, for long-term change to occur, intervention needs to involve all domains, with a focus on strengthening the weakest domain (Hayden, 2008).

The PROMPT approach incorporates a technique that utilises dynamic tactile-kinaesthetic-proprioceptive input to facilitate speech production.

There are currently four levels of PROMPT training:

1. Introduction to Technique
2. Bridging PROMPT technique to Intervention
3. PROMPT Certification, and
4. PROMPT Instructor.

The minimum requirement for administration of the PROMPT intervention approach is completion of the three-day workshop 'Introduction to Technique'. All participants of this workshop are instructed in and provided with a manual that details the theoretical model and framework underpinning PROMPT; administration of the assessment protocol (SAO, and MSH) and setting of intervention priorities within the PROMPT framework; different types and levels of PROMPTs and, intervention principles.

The intervention protocol was designed to adhere to the theoretical framework and principles of PROMPT as detailed in the Introduction to Technique manual (2003).

Intervention protocol.

Three intervention priorities were selected and treatment objectives written for the first two. The third intervention priority served as a control goal, thus no treatment objectives were developed for this priority. Participants 2, 3, 5 and 6 targeted mandibular control in phase B and labial-facial control in phase C. Participant 1 targeted labial-facial control in phase B and lingual control in phase C. Participant 4 targeted mandibular and labial-facial control simultaneously in phase B and lingual control in phase C. Each participant's intervention priorities across the intervention phases are illustrated in Table 4.5

Table 4.5

Participant Intervention Priorities

Participant	Intervention Priority One: Phase B	Intervention Priority Two: Phase C	Intervention Priority Three: Control
1	Reduce jaw open distance in words containing high vowels. Lip to lip contact during bilabial productions.	Anterior elevation of the tongue within the mouth and independent of the jaw (tongue movements external and laterally rotated).	Sequenced movements (e.g., CCVC).
2	Facilitate jaw grading and distance between low vowels. Decrease anterior thrust of jaw (evident with increased jaw open distance).	Decrease jaw open distance on high vowels. Facilitate appropriate neutral, rounded and retracted lip movements.	Anterior tongue movements independent of jaw.
3	Reduce path distance travelled on low vowels. Promote controlled open-to-closed jaw actions (ballistic action pushing lower lip superior to upper lip and excessive retraction used to stabilise jaw).	Independent lip movements - rounded movements for rounded vowels. Lip-to-lip contact during bilabial contact.	Anterior tongue movements independent of jaw.
4	Facilitate jaw grading in words containing low and high vowel positions. Facilitate rounding and retraction.	Anterior tongue control independent of jaw.	Sequenced movements.
5	Increase jaw grading between the jaw height positions. Maintain midline stability on low vowels.	Facilitate appropriate neutral and rounded lip movements (excessive retraction).	Anterior tongue movements independent of jaw.
6	Increase jaw open distance on low vowels with return to closure on CVC words.	Facilitate appropriate neutral and rounded lip movements (excessive retraction).	Anterior tongue movements independent of jaw.

Note: C = consonant, V= vowel.

Video footage of each participant completing the Arizona-3, and the chief investigator's observations of each participant's motor speech movement patterns, was sent to Ms Deborah Hayden (Director and Founder of the PROMPT Institute) for confirmation of both the intervention priorities, and the vocabulary.

Upon selection of the intervention goals, the chief investigator consulted with the treating speech pathologist to set the intervention protocol. Each participant received two intervention blocks, each 10 weeks in duration. Table 4.6 illustrates the number of sessions each participant attended across the study phases.

Table 4.6

Number of Sessions Attended by each Participant across the Study Phases

Participants	Phase A1	Phase B	Phase C	Phase A2
P1	5	10	10	2
P2	6	9	10	2
P3	5	8	10	2
P4	7	10	10	2
P5	8	10	9	1
P6	7	7	10	2

Therapy sessions occurred once weekly and lasted 45 minutes. Twenty target words were selected for training in each treatment block. Ten target words were trained in weeks one to five, and the other 10 target words were trained in weeks six to ten. At the end of the first treatment block, each participant progressed to the second treatment block regardless of performance in the first treatment block.

The intervention protocols were developed in consultation with the PROMPT therapist and individually tailored to reflect the individual interests and age of each participant.

Structure of intervention.

The treatment protocol was consistent across all intervention sessions and formulated to reflect the nine core elements of PROMPT (Hayden, 2003). For all participants, the weakest domain was the physical-sensory domain. Thus, this was the main focus of intervention. However, the cognitive-linguistic and social-emotional domains were also supported through the selected activities as described below.

The PROMPT technique has four types of prompts:

Parameter Prompts - provide maximum postural stability and support to either the jaw or facial muscles.

Syllable Prompts - support both the actions of the jaw and facial muscles, with emphasis on the vowel shape.

Complex Prompts - provide as much information as possible about the components of a single motor phoneme unit (e.g., tongue tension and mouth shape).

Surface Prompts - provide the most critical but least information necessary to produce a motor phoneme sequence through a co-articulated movement sequence (Hayden, 2003).

The types of prompts administered were dependent on the needs of the individual participant.

The structure of the intervention sessions was as follows:

Motor-phoneme "warm up" 1 (5 minutes).

The participant was asked to say individual sounds/words. The sounds/words were selected on the basis of the target vocabulary. The therapist demonstrated to the participant the sound/word using a surface prompt. The therapist then asked the participant to say the sound/word and provided support using a surface, parameter, complex or syllable prompt for *each* production. The type of prompt used by the therapist was dependent on the level of support required by the participant. For example if the participant was asked to produce /ah/ and opened the jaw too wide, the participant would be asked to use a smaller mouth and be supported with a parameter prompt. The participant was asked to say the word/sound to a maximum of five correct productions, continuing to give the appropriate level of tactile support. Specific verbal feedback was given throughout the warm-up drills.

The "warm up" period consisted of a schedule of massed practice to help the participant learn the speech movement pattern. All participants were encouraged to start in a neutral posture (i.e., lips softly closed together without excessive retraction). Knowledge of performance feedback was provided after each trial. Upon completion of the warm-up, the therapist moved to the first activity where the sounds/words were embedded into a game.

Activity 1 (15 minutes).

The five target words were embedded into a game that centred on a daily routine relevant to the participant (such as getting dressed, making breakfast etc). The participant was given the opportunity to use each target word no less than 15 times. The level and amount of tactile-kinaesthetic input (prompting) was individually tailored to the needs of the participant based on the following sequence: The target word was first modelled to the participant using a surface prompt, to elicit the targeted response. The level and type of prompting subsequently given to support the participant to produce the word varied dependent on the intervention priority. For example, when targeting the intervention of mandibular control a participant may be given a parameter prompt during their production of the target word. When the target word was produced accurately (both perceptually and motorically), the tactile-input was reduced. During the 15 minute activity words from the trained word-set pool were practiced in a distributed manner. Knowledge of performance and results were randomly given.

Motor-phoneme "warm up drill" 2 (5 minutes).

The procedure followed was identical to the first motor phoneme warm-up using sounds/words specific to Activity 2.

Activity 2 (15 minutes).

The five target words were embedded into a social routine relevant to the participant (such as playing an age appropriate game). The procedure followed was identical to the first activity. The participant used each target word no less than 15 times. Verbal praise and reinforcement was given throughout the therapy session. Token reinforcements such as stickers were also used. The session concluded with a discussion regarding home practice for the week (5 minutes).

Therapists.

Four independent PROMPT-trained therapists administered the treatment protocols in this study (Table 4.7). The therapists administered the intervention protocol and were not involved in the data collection or analysis.

Inclusion criteria for therapist participation in the study included (a) completion of the Introduction to Technique workshop, (b) completion of the case study detailed in the Introduction to Technique manual within 3 months of the workshop, (c) regular use of the technique for at least 9 months, (d) attendance at a PROMPT mentoring day held by Deborah Hayden in October 2006, (e) a fidelity rating to the PROMPT approach of no less than 80% as assessed by an independent senior PROMPT Instructor, and (f) an expression of interest to participate in the study.

Three therapists were trained to level 2 (Bridging PROMPT technique to intervention) and one therapist was trained to level 1 (Introduction to technique). Three therapists administered treatment to one participant each. The fourth therapist administered treatment to three participants. The author of this thesis did not administer any therapy sessions.

Table 4.7

Therapist Assigned to each Participant, and Level of Training

Participant	Therapist	Level of Training
P1	1	Introduction to technique
P2	1	Introduction to technique
P3	1	Introduction to technique
P4	2	Bridging
P5	3	Bridging
P6	4	Bridging

Intervention speech probes.

The speech probes were administered at the end of each treatment session by the chief investigator. The investigator randomly selected and presented 30 words – six words from each word group set, similarly to or exactly as described previously during the baseline phase. The only difference was that a picture description was not always provided. As the participants became familiar with the words, they started to say the word as soon as they saw the card. If they said the correct word, their first response was accepted. If the word was wrong, the participant was given a picture description and asked to “say [word]”.

Procedure

Table 4.2 illustrates the occasions of testing throughout the phases of the study. All participants attended an initial appointment during which standardized assessments of cognition, hearing, speech and language were administered. This testing was completed to determine eligibility for inclusion in the study and was approximately 2 hours in duration.

Upon determination of eligibility, two subsequent appointments were attended to collect data for determining each participant’s intervention priorities and administration of the initial outcome measures. Upon completion of these appointments, baseline data collection commenced.

The chief investigator administered the hearing screening, and speech and language assessments. A graduate psychology student, under the supervision of the Clinical Psychologist employed by TCCP, administered the cognitive assessment.

All testing was completed in the same treatment room at TCCP. Periodic breaks were given, as necessary, to prevent fatigue. All assessment sessions were video-recorded.

Upon completion of the testing, participants moved to the baseline phase and subsequently into the intervention protocol.

Reliability and Fidelity

All scoring of outcome measures and intervention fidelity was completed by independent and blinded researchers, as detailed below.

PROMPT intervention.

The PROMPT Institute provided an independent senior PROMPT Instructor to evaluate each therapist's fidelity to the treatment approach, using the PROMPT fidelity protocol (Rogers et al., 2006). Prior to commencing the study, each therapist's fidelity to the PROMPT approach was evaluated, with all therapists obtaining a minimum of 80% fidelity.

All intervention sessions were video recorded throughout the study. Two further fidelity measures, per participant, per intervention phase were taken to generate a total of four fidelity ratings per participant. Therefore therapists 2 through 4 underwent four fidelity ratings each; therapist 1 underwent 15 fidelity ratings. The intervention sessions were randomly selected by an independent research assistant using a random number selection. The sessions were transferred by the research assistant to DVD, after removing all information identifying the therapist. The DVDs were sent to the PROMPT Instructor who was blinded to the phases of the study and the intervention session.

Fidelity measures throughout intervention block one (phase B) ranged between 77.7% and 93.7%. All therapists achieved the desired 80% fidelity during intervention block two (phase C) with scores ranging between 80.2% and 97%.

Data Preparation and Generation

Preparation of the data for analysis for each of the outcome measures is described below.

An independent PROMPT trained speech-language pathologist (referred to as the transcriber), blinded to the phases of the study and the participants, completed the scoring of the data for speech production accuracy and phonetic accuracy.

Speech production accuracy: Scoring of speech probes.

All treatment sessions were de-identified and randomised, with the transcriber blinded to the intervention sessions.

A scoring protocol was provided to the transcriber that identified the motor-speech and perceptual goals for each participant. Each word was scored for accuracy of the targeted motor speech movement pattern (MSMP) and perceptual accuracy (PA). A binary coding system was used to code each parameter, where 0 = inaccurate and 1 = accurate. A score of 1 was assigned as follows:

MSMP: the targeted motor speech movement pattern of that intervention priority for the individual participant was appropriately executed. Words that contained more than one movement goal (e.g. push = lip-to-lip contact for /p/ and rounding /sh) were assigned a fraction (e.g., /p/ = ½, /sh/ = ½ point) to enable a maximum score of one point for each parameter.

PA: production of the target word was perceptually correct, as identified using narrow phonetic transcription.

Twenty percent of the data were randomly selected by the research assistant and given to the transcriber for rescoring. The absolute difference between the first and second occasion of scoring was calculated and converted to a percentage agreement. An intra-rater agreement of 94% and 93% for accuracy of speech production and motor-speech-movement-parameters respectively, was achieved.

Fifty percent of the data was selected for determination of inter-rater reliability. The same research assistant de-identified the treatment sessions for both the chief investigator and transcriber to score. Points of difference were identified and reviewed for consensus. When consensus could not be obtained (5%) the transcriber consulted with the independent PROMPT Instructor for transcription confirmation.

The absolute difference between the scoring of the transcriber and chief investigator was calculated and converted to a percentage agreement. An inter-rater agreement of 87% and 91% for accuracy of speech production and motor-speech-movement-parameters respectively, was achieved. These agreement values are within the range deemed “acceptable” for research needs (Shriberg et al., 2010) and consistent with inter-rater agreement values reported in the literature (E. Barnes et al., 2009; Bose et al., 2001; Davis, Jacks, & Marquardt, 2005; Paatsch, Blamey, Sarant, & Bow, 2006).

Phonetic accuracy: Narrow phonetic transcription.

Training process.

The speech of individuals with dysarthria is reported to include prosodic, resonance, and disordered articulation errors. The standard International Phonetic Association (IPA) symbols, as used in broad phonetic transcription, do not provide the necessary symbols to code these features. Therefore, the extIPA (Ball, 2005) diacritics that code sliding articulation, tongue position (e.g., retracted, bladed), dental production of bilabials, labial spreading and nasalisation were used to transcribe the speech characteristics of the participants in this study.

The literature documents the potential for reduced transcriber reliability with the use of narrow phonetic transcription due to increased transcription complexity (Ball, Müller, Klopfenstein, & Rutter, 2009). To strengthen reliability and prevent transcriber drift, Shriberg et al. (1997) suggest the use of consensus transcription and re-calibration.

In this study, the following procedures were undertaken to promote consistency in narrow phonetic transcription:

Pre-training.

The transcriber and chief investigator jointly transcribed a speech sample of a child (non-participant) with moderate-to-severe speech disorder, with speech characteristics similar to the speech of the children anticipated to participate in the study. The key error patterns sampled were discussed and key diacritics of the extIPA used to represent these errors were identified.

Consensus.

The transcriber and chief investigator independently transcribed a speech sample of a child (non-participant) with a moderate- to-severe speech disorder using narrow phonetic transcription. All points of difference or disagreement were discussed and transcription consensus reached. Upon obtaining 90% inter-rater agreement, the transcriber commenced independent transcription of the speech samples of the participants.

Calibration.

The transcriber and chief investigator independently, blinded to the testing occasion, re-transcribed the data of one participant. The research assistant randomly selected and de-identified the data. The absolute difference between the first and second occasion of transcription was calculated and converted to a percentage difference. Inter-rater reliability was 92% agreement.

Data Analysis

Speech production accuracy.

Both visual inspection and statistical tests were used to analyse the speech probe data. Visual inspection requires the examination of graphed data, with the target behaviour plotted on the Y-axis and time plotted on the X-axis. The MSMP and PA scores for each intervention priority were graphed with the trained word-sets plotted separately to the untrained.

The determination of intervention effects in single subject research design requires a judgement about changes in the performance pattern both within and between the design phases using visual inspection and statistical analysis (Portney & Watkins, 2009).

Within-phase characteristics.

Within phase characteristics were judged according to stability (consistency of response over time) and trend (performance direction described as accelerating, decelerating, variable or stable based on a line of best fit).

Portney and Watkins (2009) report on the application of statistical process control (SPC) to evaluate whether baseline data is within the limits of expected “common cause” stability/variability. This involves the calculation of a moving-mean-range (X-mR) and the plotting of a 3 standard deviation band to depict the upper confidence limit (UCL) and lower confidence limit (LCL). The data are determined to be stable if the data points fall within the confidence limits.

The establishment of a stable baseline is essential for determining intervention effectiveness. In this study, the baseline was determined to be stable when 1. all data points fell inside the UCL and LCL as determined by SPC and 2. there was an absence of trend direction or a decelerating slope was observed.

Between-phase characteristics.

Assessment of the between-phase characteristics requires a judgement for each dependent variable about change in (a) level (magnitude of performance), (b) slope (steepness of the trend direction), (c) trend (performance direction typically described as accelerating, decelerating, variable or stable based on a line of best fit), and (d) variability between each phase and the following one.

In addition to visual inspection, statistical methods were used to evaluate changes in the data trend and level. The three statistical measures used in this study included the two standard deviation band (2SD band) analysis (change in level), the conservative dual criterion split-middle method of trend estimation with binomial test (change in trend and slope) and effect size (Fisher et al., 2003; Nourbakhsh & Ottenbacher, 1994; Portney & Watkins, 2009; Satake, Jagaroo, & Maxwell, 2008):

1. 2SD band: Typically a significant change in level in the 2SD band method is considered to have occurred when two consecutive points occur outside the UCL and LCL (Orme & Cox, 2001; Portney & Watkins, 2009). The literature reports two consecutive data points above the 2SD band are considered to be consistent with a p-value <0.05. However, this method is based on the assumption of normal distribution and that observations are independent. Campbell and Herzinger (2010) report the presence of serial dependency that frequently occurs in SSRD, can render the p-value to 0.1. Given there were insufficient data points to calculate the degree of serial dependency in the datasets of this study, a more stringent criterion of 3 consecutive data points between two and three standard deviations was used (Orme & Cox, 2001).

2. Split-middle method of trend estimation with binomial test: The conservative dual-criterion (CDC) method as detailed by Fisher et al. (2003) was implemented. This method involves raising the positions of the mean and split-middle lines by a further 0.25 standard deviations. This method has been shown to be superior to other methods (i.e., split-middle method, general linear model and dual criterion method) in controlling type I errors when the data are autocorrelated (Fisher et al., 2003). In addition, the use of this method has been reported in single subject research designs in the speech pathology field (Wambaugh & Ferguson, 2007).

3. Effect size: Solanas, Manolov and Onghena (2010) investigated the optimum effect size measurement for single subject data containing short data series (i.e., less than 10 data points per study phase). Their analyses indicated formulas based on the standardised mean difference (e.g., d-index) were the least susceptible to autocorrelation and still sensitive to intervention effects. Therefore, this study applied a modified Cohen's d using the pooled standard deviation as recommended by Dunst, Hamby and Trivette (2004) for single subject research design.

Phonetic accuracy.

Percentage Phonemes Correct (PPC) scores were calculated using the wordlist from the Arizona 3 (third revision) (Fudala, 2000). The PPC score was calculated by scoring correct responses on the consonants and vowel/diphthong phonemes. Distortions, deletions and substitutions were scored as incorrect.

The percentage of phonemes correct was then entered into SPSS and repeated measures ANOVA was performed. In addition the Cohen's d was also calculated to determine the effect sizes across the study phases.

Motor-speech control.

The Verbal Motor Production Assessment for Children (VMPAC) (Hayden and Square, 1999) assesses five areas of motor speech control: global motor control, focal oromotor control, sequencing, connected speech and language control, and speech characteristics. Each area is scored to yield a percentage correct score. Initial (pre phase A1) and post intervention (phaseA2) data are reported for each subtest along with a percentage improvement score for each participant.

Results

Speech Production Accuracy (Speech Probes)

In this section the data for dependent variable one (speech production accuracy), are presented for each participant as individual case studies, followed by a group summary.

Speech production accuracy was assessed through the administration of weekly speech probes. The speech probes were administered and scored for accuracy on two parameters: 1. motor-speech-movement-parameters (MSMPs) and

2. perceptual accuracy (PA). The data were analysed with adherence to visual inspection protocol and statistical analyses.

The data for each individual participant are presented as follows: 1. visual inspection, 2. statistical analyses and 3. overall summary.

Participant 1

Visual inspection.

Listed in Table 4.8 are the intervention priorities and number of sessions attended by P1 across the phases of the intervention study.

Table 4.8

P1's Intervention Priorities and Number of Sessions Attended

Phase	Description	Intervention Priority	Sessions
A1	Baseline		5/5
B	Intervention Priority One	Labial-Facial	10/10
C	Intervention Priority Two	Lingual	10/10
A2	Follow-up		2/2

The data, provided in Table 4.9 and described in detail below, indicate a positive treatment effect. P1 demonstrated increased accuracy on the MSMPs and PA of intervention priority one (labial-facial control) during intervention block one and intervention priority two (lingual control) during intervention block two. Generalisation to the untrained speech probes was evidenced on both intervention priorities. No change in the MSMP speech probes of the control goal was observed.

Table 4.9

Mean Percent Correct Performance on the Speech Probes across the Study Phases for P1

	IP 1 Labial-Facial				IP2 Lingual				IP 3 Sequencing	
	Trained		Untrained		Trained		Untrained		Control	
Phase	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1	7%	27%	10%	10%	3%	23%	7%	27%	0%	6%
B	40%	55%	49%	48%	8%	35%	11%	27%	0%	8%
C	75%	72%	77%	73%	35%	60%	28%	58%	0%	10%
A2	50%	83%	67%	67%	42%	50%	33%	50%	0%	16%

Note. IP = Intervention Priority, MSMP = motor-speech-movement-parameters, PA = perceptual accuracy.

Intervention priority one (Labial-facial control): Trained speech probes.

Figure 4.2 illustrates P1’s performance on both parameters, across the four phases of the study, during production of the trained speech probes for intervention priority one.

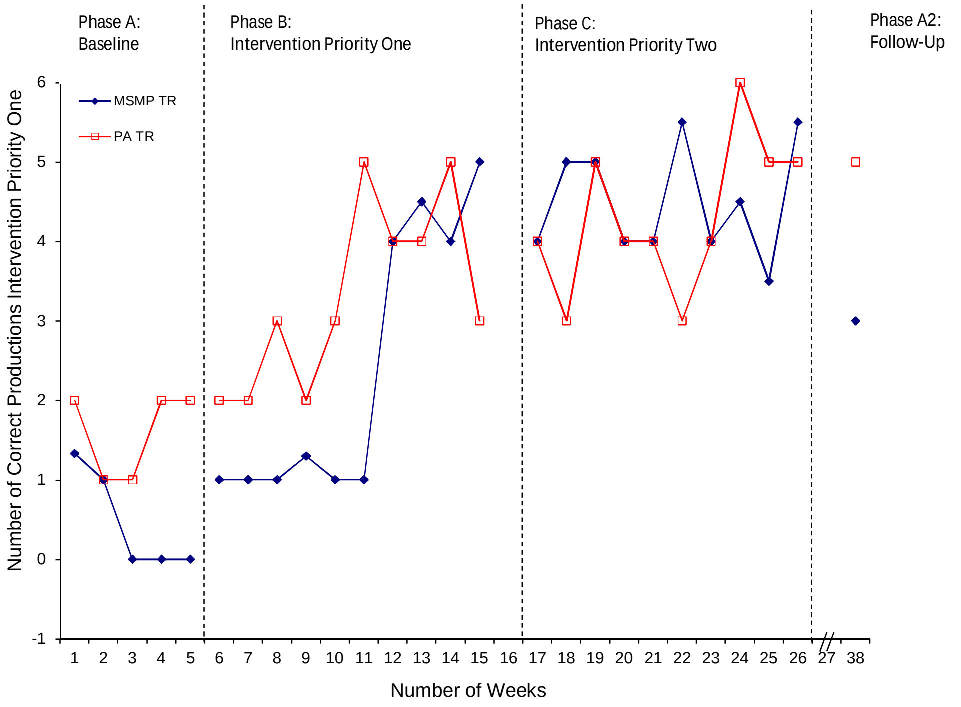


Figure 4.3. P1’s performance on the motor-speech movement patterns (MSMP) and perceptual accuracy (PA) on the trained word-sets for intervention priority one.

Phase A: Both parameters met stability criteria as determined using statistical process control (SPC).

Phase B: A steadily increasing trend and performance level was recorded on both parameters. This trend and absence of overlapping data in the final four intervention sessions indicate a positive treatment effect for intervention priority one: labial-facial control.

Phase C: Both parameters show a flattening in the angle of the slope, although the trend direction continued to increase. These data indicate maintenance of the performance gains in the MSMPs and PA achieved in phase B.

Phase A2: A mean performance increase of 43% and 56% was recorded between phase A1 and A2 on the MSPMs and PA, respectively. Despite a slight decline in performance between phase C and A2 in MSMP, maintenance of a positive treatment effect is indicated.

Intervention priority one (Labial-facial control): Untrained speech probes. Figure 4.4 illustrates P1’s performance on both parameters across the four phases of the study, during production on the untrained speech probes for intervention priority one.

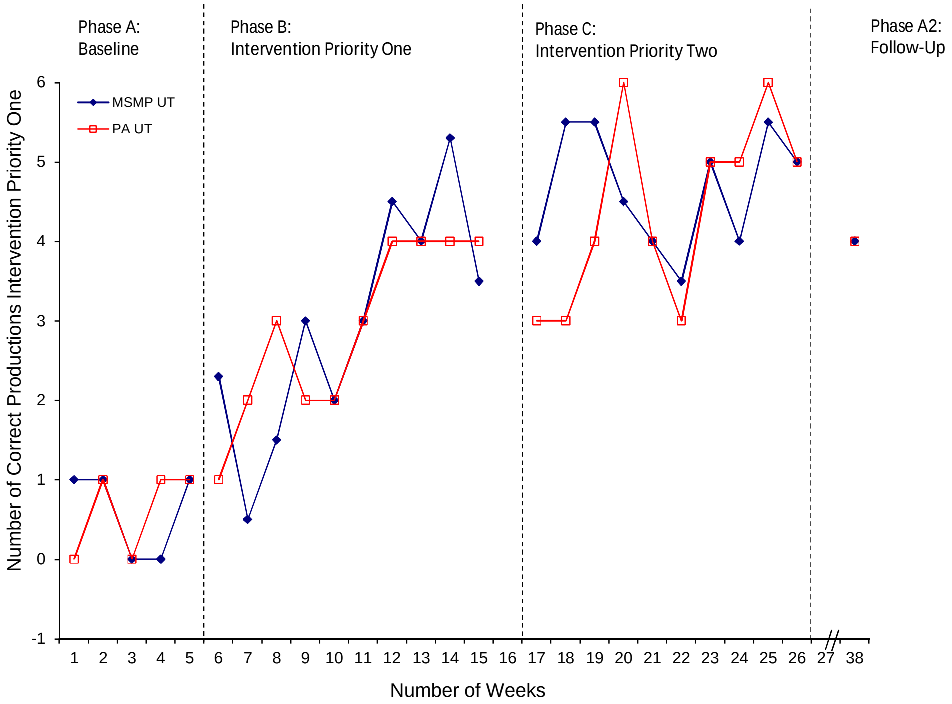


Figure 4.4. P1's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority one.

Phase A1: Both parameters met stability criteria.

Phase B: Consistent with the trained speech probes, an overall increasing trend direction and performance level on the MSMPs and PA respectively, was recorded. This trend and minimal data overlap between phase A1 and B indicates skill generalisation to intervention priority one: labial-facial control.

Phase C: Figure 4.4 shows a flattening in the angle of the slope on both parameters with less variability. The maintenance of performance level and consistency in the performance scores between the two parameters indicates maintenance of the skills obtained in phase B.

Phase A2: Skill maintenance at 12 weeks post-intervention was indicated with an accuracy of 67% recorded on both the MSMPs and PA.

Intervention priority two (Lingual control): Trained speech probes.

Figure 4.5 illustrates P1's performance on both parameters, across the four phases of the study, during production of the trained speech probes for intervention priority two.

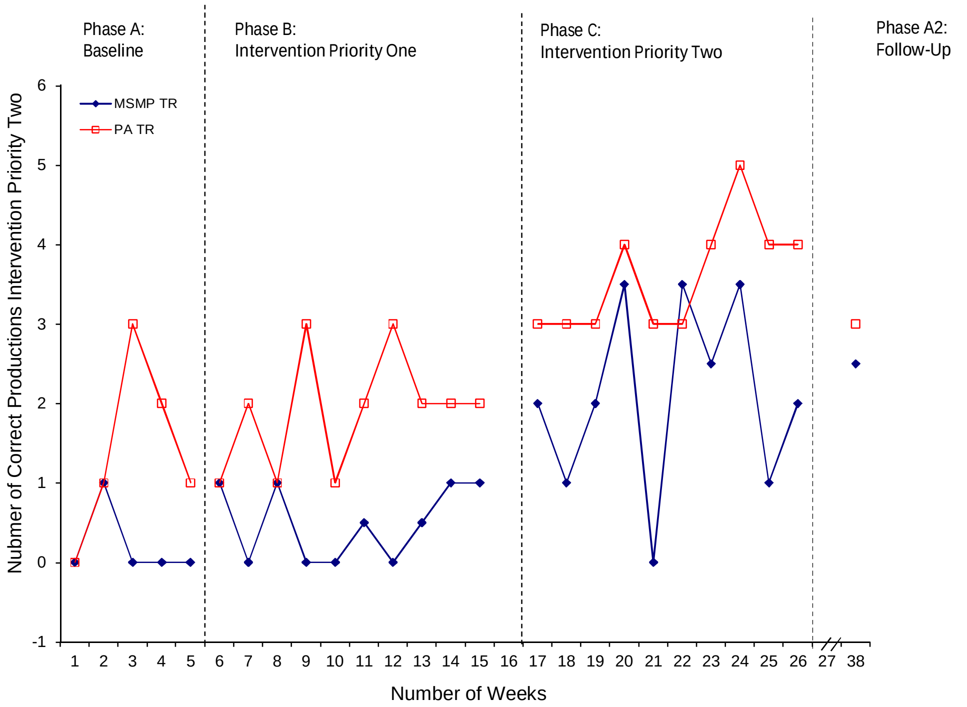


Figure 4.5. P1's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the trained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria.

Phase B: A mean performance increase of 5% and 12% on the MSMPs and PA respectively, was recorded on the second intervention priority (lingual control) during training of the first intervention priority (labial-facial control). However, 100% overlapping of data suggests the absence of a significant treatment effect.

Phase C: An increase in the steepness of the trend direction and mean performance increase of 27% and 25% on the MSMPs and PA respectively, was recorded on both parameters. These results and the high percentage of non-overlapping indicate a positive treatment effect for intervention priority two: lingual control when treatment for the second intervention priority was introduced.

Phase A2: At 12 weeks post-intervention a mean performance increase of 39% and 27% on the MSMPs and PA respectively, between phases A1-A2 was recorded. This indicates a positive treatment effect, with evidence of skills maintenance.

Intervention priority two (Lingual control): Untrained speech probes.

Figure 4.6 illustrates P1's performance on both parameters, across the four phases of the study, during production of the untrained speech probes for intervention priority two.

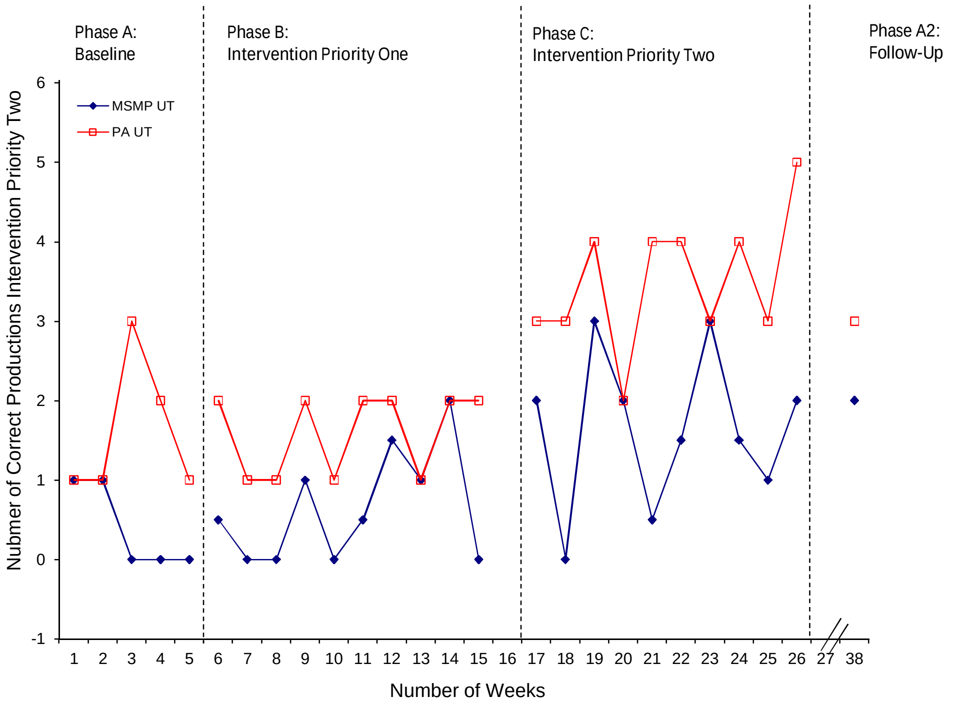


Figure 4.6. P1's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria.

Phase B: Consistent with the trained speech probes, both parameters on the untrained speech probes continued to meet the criteria of a stable trend direction. No real change in the second intervention priority (lingual control) during training of the first intervention priority (labial-facial control) is indicated by the mean performance increase of 4% and 0% in the MSMPs and PA, respectively.

Phase C: An increase in the steepness of the trend direction and slight increase in performance level for both parameters indicates some generalisation to the untrained speech probes when intervention targeted the second intervention priority (lingual control) during the second intervention block. However, the high percentage of overlapping data suggests the generalisation effect to the untrained speech probes is small.

Phase A2: At 12 weeks post-intervention a mean performance increase of 26% and 23% was recorded on the MSMPs and PA, respectively between phases A1-A2. The data therefore suggests the presence of a small treatment effect.

Intervention priority three (Sequencing control): Control speech probes.

Figure 4.7 illustrates P1's performance on both parameters, across the four phases of the study, for the control speech probes.

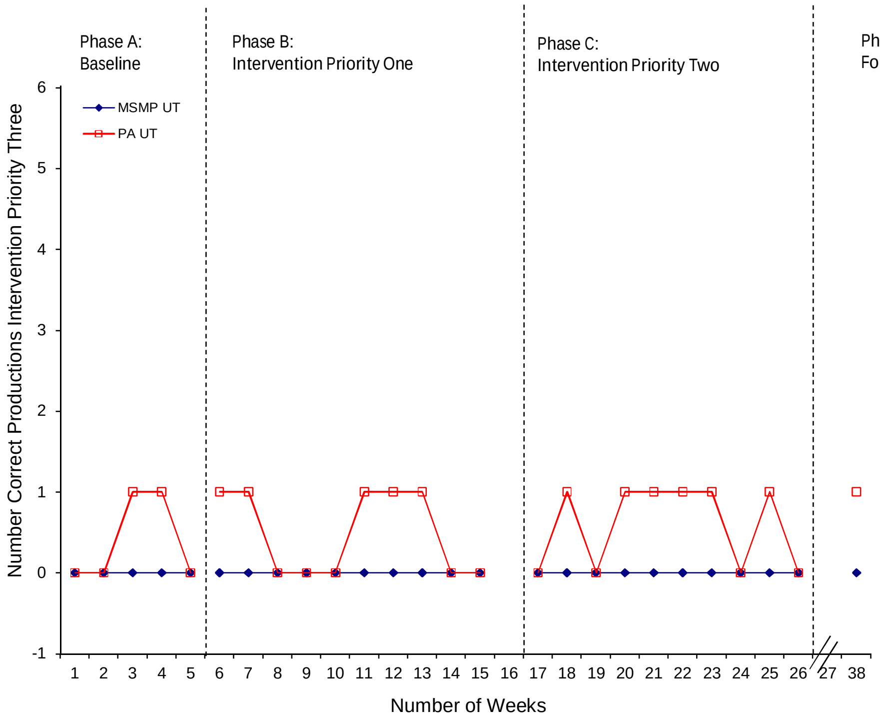


Figure 4.7. P1's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the control speech probes for the untrained intervention priority three.

Phase A1: Mean performance scores of 0% on both parameters indicate a stable baseline.

Phase B: The presence of 100% overlapping data, with no change in performance level or trend direction, indicates no treatment effect occurred.

Phase C: The presence of 100% overlapping data, with no change in performance level or trend direction, indicates no treatment effect occurred.

Phase A2: The presence of 100% overlapping data, with no change in performance level or trend direction, indicates no treatment effect occurred in the control goal (intervention priority three: sequencing control).

Statistical data.

Change in level.

The results in Table 4.10 indicate P1 achieved a significant change in performance level on the trained and untrained speech probes for both parameters. The largest increase in performance level was observed on intervention priority one (labial-facial control) during phase B (intervention block one) and intervention priority two (lingual control) during phase C (intervention block two). The data are further supported by the large effect size data obtained using a modified Cohen's d, as illustrated in Table 4.11. No increase in performance was observed on the speech probes of the control goal throughout the phases of the study.

Table 4.10

Summary of the Two-Standard Deviation Band Analysis on the Speech Probes across the Study Phases for P1

	IP 1 Labial-Facial				IP 2 Lingual				IP 3 Seq	
Phase	TR		UT		TR		UT		Control	
	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A1→ B	*S	*S	*S	*S	I	I	I	I	I	I
NAL	4	7	7	9	0	0	1	0	0	1
CNAL	4	6	7	9	0	0	0	0	0	0
A1→C	*S	*S	*S	*S	*S	*S	*S	*S	I	I
NAL	10	10	7	10	7	5	7	5	0	2
CNAL	10	10	7	10	3	4	3	2	0	0
B→C	I	I	I	*S	*S	*S	I	*S	I	I
NAL	2	1	0	3	7	5	2	9	0	2
CNAL	0	10	0	2	3	4	0	6	0	0
A1→A2	*S	*S	*S	*S	*S	*S	*S	*S	I	I

Note. *S = significant, I = insignificant, IP = Intervention Priority, MSMP = motor-speech-movement parameter, Seq = sequencing, PA = perceptual accuracy, NAL = number above the two standard deviation band and CNAL = consecutive number above the two standard deviation band.

Table 4.11

Effect Size Data on the Speech Probes across the Phases of the Study for P1

	PHASE B					PHASE C				
	IP 1 LF		IP 2 Ling		IP 3 Seq	IP 1 LF		IP 2 Ling		IP 3 Seq
	TR	UT	TR	UT	C	TR	UT	TR	UT	C
MSMP	1.5	2.2	0.7	0.2	U/C	1.6	1.5	1.8	1.2	U/C
PA	1.9	2.6	0.5	0.0	0.2	1.2	1.3	2.4	2.7	0.2

Note: IP = Intervention Priority, TR = trained, UT = untrained, C = control, LF = labial-facial, Ling = lingual, Seq = sequencing, U/C = unable to calculate due to data consisting of zero scores.

Change in trend and slope.

The data in Table 4.12 demonstrate a significant change in the trend and slope in the MSMPs and PA, of the trained and untrained speech probes during the training of the targeted intervention priority, was achieved. That is, a significant change in trend and slope was observed on intervention priority one during phase B (intervention block one) and intervention priority two during phase C (intervention block two). No significant change in trend and slope was observed on the control goal throughout the phases of the study.

Table 4.12

Summary of the Split-middle and Binomial Test on the Speech Probes across the Study Phases for P1

Phase	IP 1 Labial-Facial				IP 2 Lingual				IP3 Seq	
	TR		UT		TR		UT		C	
	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A1→B	*S	*S	*S	*S	I	I	I	I	I	I
A1→C	*S	*S	*S	*S	*S	*S	*S	*S	I	I
B→C	I	I	I	I	*S	*S	I	I	I	I

Note. IP = intervention priority, TR = trained, UT = untrained, C = control, *S = significant, I = Insignificant, MSMP = motor-speech-movement-parameters, PA = perceptual accuracy.

Overall summary of P1’s speech production accuracy (Speech probes).

The above results indicate P1’s intervention program was successful in effecting positive changes in the MSMPs and PA in both intervention priorities, with transfer of the learned behaviours to the untrained speech probes. The greatest change in performance, as shown using visual inspection and supported by the statistical analysis, was observed to have occurred on intervention priority one during phase B (intervention block one) and priority two during phase C (intervention block two).

No changes were observed in the control goal (sequencing control) across the phases of the study.

Participant 2

Visual inspection.

Table 4.13 lists the number of sessions attended by P2 across the phases of the intervention study. One session was missed in phase B due to a family holiday.

Table 4.13

P2's Intervention Priorities and Number of Sessions Attended

Phase	Description	Intervention Priority	Sessions
A1	Baseline		6/6
B	Intervention Priority One	Mandibular	9/10
C	Intervention Priority Two	Labial-Facial	10/10
A2	Follow-up		2/2

The data, provided in Table 4.14 and described in detail below, indicates a positive treatment effect. P2 demonstrated an increase in accuracy on the MSMPs and PA of intervention priority one (mandibular control) during intervention block one and intervention priority two (labial-facial control) during intervention block two. Generalisation to the untrained speech probes was evidenced on both intervention priorities. No change in the MSMPS of the control goal was observed.

Table 4.14

Mean Percent Correct Performance on the Speech Probes across the Study Phases for P2

	IP 1 Mandibular				IP2 Labial-Facial				IP 3 Lingual	
	Trained		Untrained		Trained		Untrained		Control	
Phase	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1	8%	47%	14%	55%	5%	42%	3%	31%	0%	5%
B	65%	81%	59%	72%	24%	63%	23%	61%	5%	18%
C	82%	90%	81%	88%	66%	75%	63%	88%	8%	15%
A2	66%	83%	75%	83%	75%	83%	83%	100%	33%	33%

Note. IP = Intervention Priority, TR = trained, UT = untrained, MSMP = motor-speech-movement-parameter, PA = perceptual accuracy, Mand = Mandibular, LF = Labial-Facial, Ling = Lingual.

Intervention priority one (Mandibular control): Trained speech probes.

Figure 4.8 illustrates P2’s performance on both parameters, across the four phases of the study, during production of the trained speech probes for intervention priority one.

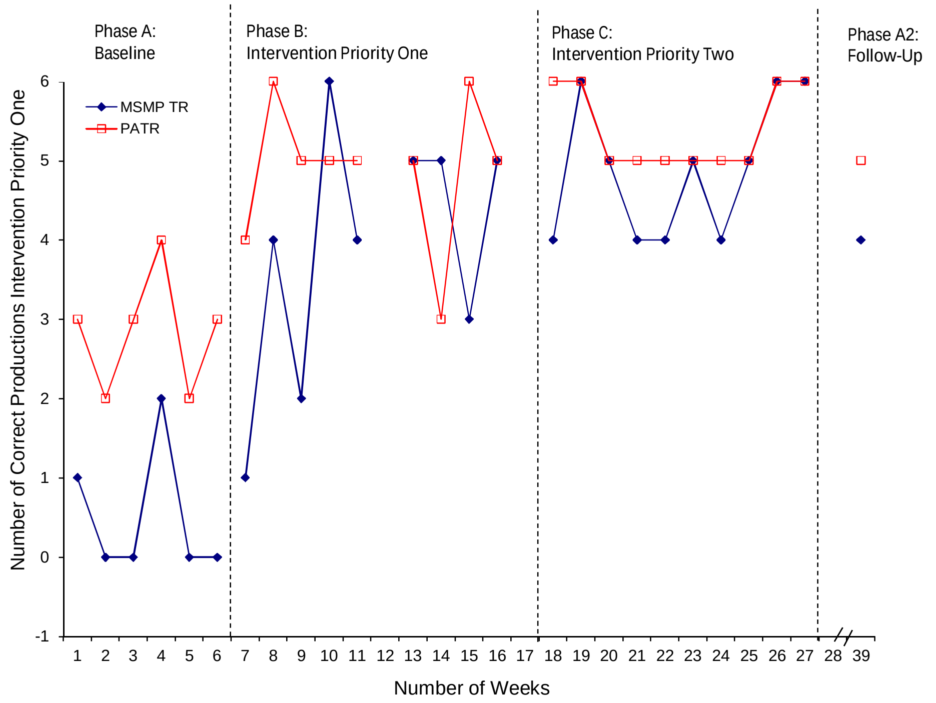


Figure 4.8. P2's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the trained speech probes for intervention priority one.

Phase A1: Both parameters met stability criteria.

Phase B: The increasing trend and limited data overlap between phase A1 and B indicates a positive treatment effect for intervention priority one: mandibular control.

Phase C: The flattening of the slope and stabilized trend direction suggests maintenance of the skills achieved in Phase B. The mean performance scores of 82% and 90% obtained on the MSMPs and PA respectively, demonstrates the consistency in performance scores between the two parameters.

Phase A2: At 12 weeks post-intervention a mean performance decrease of 16% and 7% was recorded between phases C and A2. The results indicate a positive treatment effect was maintained despite a relatively small decrease in performance between phases C and A2.

Intervention priority one (Mandibular control): Untrained speech probes.

Figure 4.9 illustrates P2's performance on both parameters across the four phases of the study, during production of the untrained speech probes for intervention for priority one.

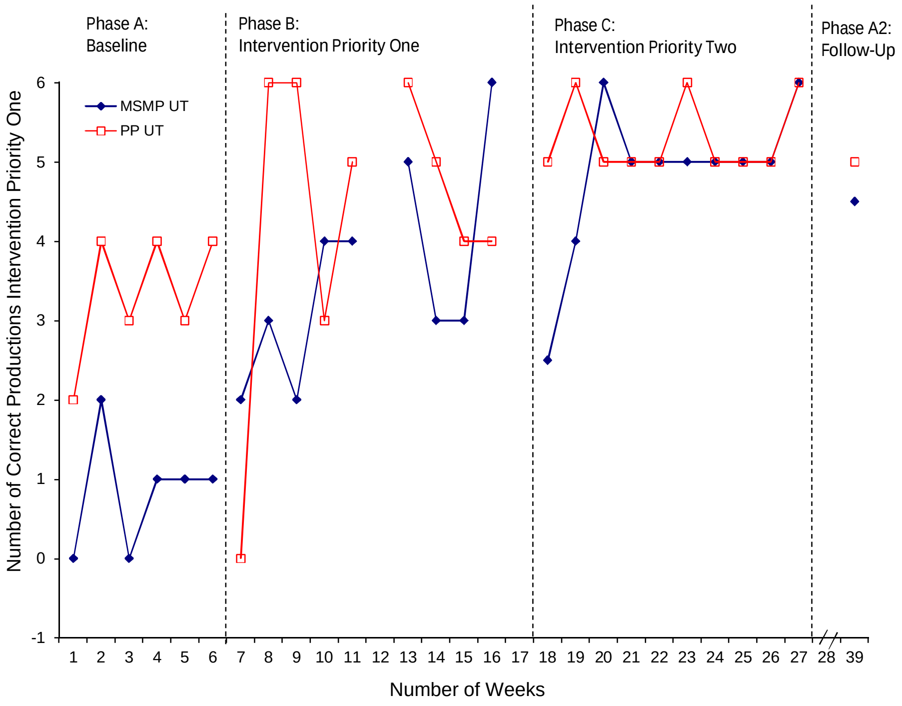


Figure 4.9. P2's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority one.

Phase A1: Both parameters met stability criteria.

Phase B: The overall increasing trend direction and limited data overlap between phase A1 and B indicates generalisation of intervention priority one: mandibular control to the untrained word-set.

Phase C: The stable trend and consistency in the performance scores between the two parameters suggests skill maintenance and stabilization during the training of intervention priority two: labial-facial control.

Phase A2: A mean performance decrease of 6% and 5% in the MSMPs and PA respectively, was recorded between phases C and A2. Despite this small decrease in performance, the results indicate a positive treatment effect with a mean performance increase of 61% and 28% recorded on the MSMPs and PA, respectively between phases A1 andA2.

Intervention priority two (Labial-facial control): Trained speech probes.

Figure 4.10 illustrates P2’s performance on both parameters across the four phases of the study, during production of the trained speech probes for intervention for priority two.

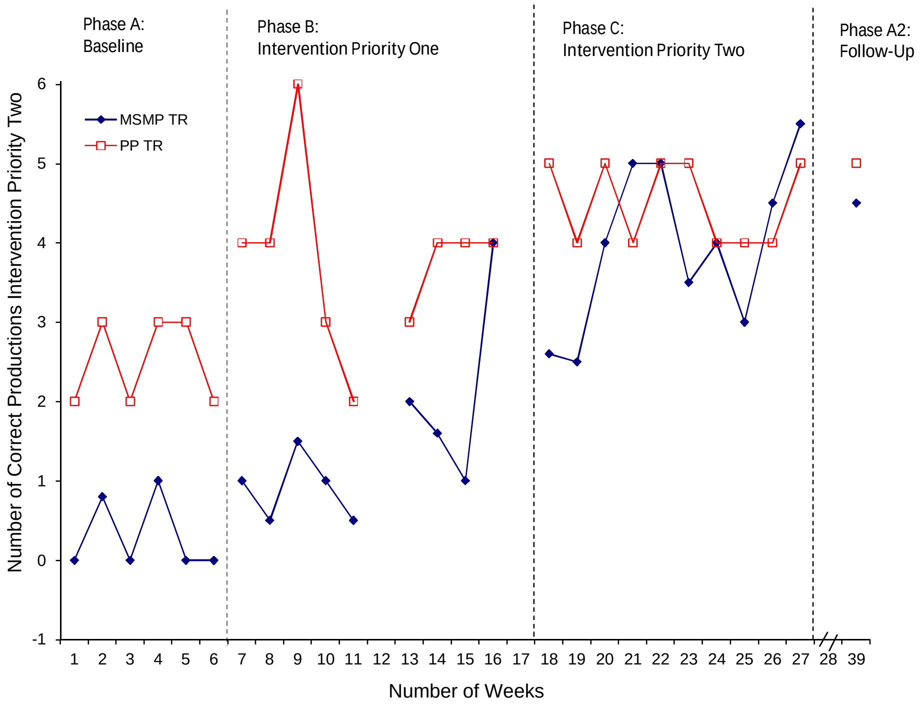


Figure 4.10. P2's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the trained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria. A mean performance score of 5% and 42% in the MSMPs and PA respectively, indicates a substantial mean performance difference between the two parameters of 37%.

Phase B: The commencement of an increasing trend towards the end of phase B suggests the presence of a treatment effect on the labial-facial parameters whilst intervention targeted the mandibular parameters (intervention priority one).

Phase C: A 42% increase in the mean performance accuracy of the MSMPs was recorded when intervention directly targeted the labial-facial movement parameters in this phase. The performance gap recorded between the MSMPs and PA at baseline decreased to a performance difference of 8%. The data indicate the presence of a large treatment effect.

Phase A2: The data between phases C and A2 show no loss in performance thus indicating skill maintenance.

At 12 weeks post-intervention, a mean performance increase of 70% and 41% was recorded between phases A1 and A2 on the MSMPs and PA, respectively. These data suggest the intervention was effective.

Intervention priority two (Labial facial control): Untrained speech probes.

Figure 4.11 illustrates P2’s performance on both parameters across the four phases of the study, during production of the untrained speech probes for intervention priority two.

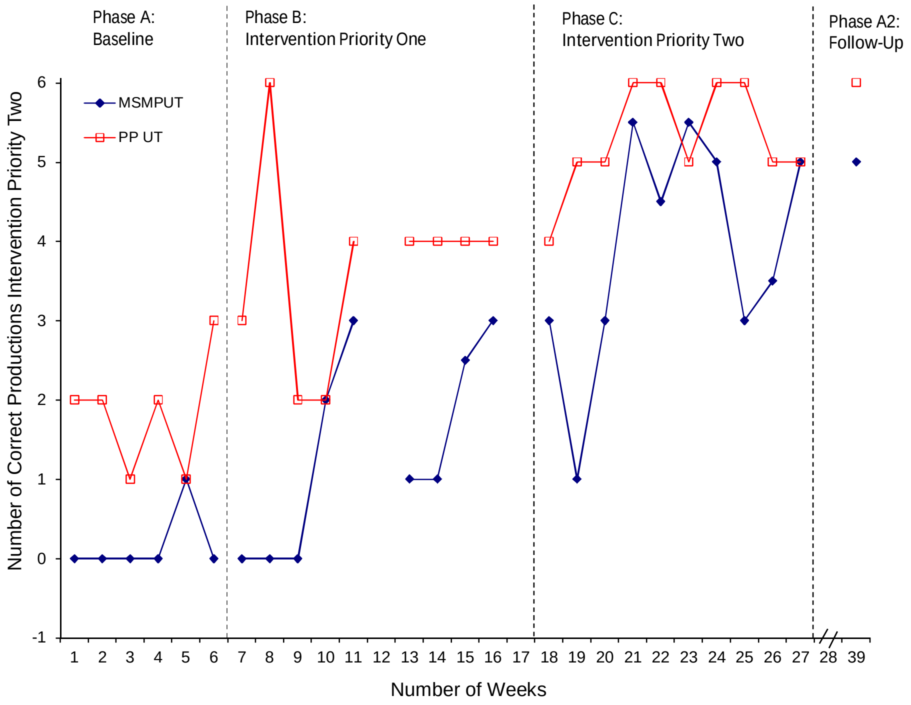


Figure 4.11. P2's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria.

Phase B: The commencement of an increasing trend and performance level towards the end of phase B suggests a positive treatment effect on the labial-facial parameters whilst intervention targeted the mandibular parameters (intervention priority one). A mean performance increase of 20% and 30% was recorded in the MSMPs and PA, respectively. This is consistent with the results obtained on the trained speech probes.

Phase C: The steeply increasing trend direction and high percentage of non-overlapping data in both parameters between phases B and C, indicate a positive treatment effect when intervention targeted the labial-facial parameters.

Phase A2: Between phases C and A2 continued improvement was recorded, with a mean performance improvement of 9% and 8% on the MSMPs and PA, respectively.

At 12 weeks post-intervention a mean performance increase of 80% and 69% was recorded on the MSMPs and PA, respectively between phases A1 and A2. These data suggest a positive treatment effect.

Intervention priority three (Lingual control): Control speech probes.

Figure 4.12 illustrates P2’s performance on both parameters, across the four phases of the study, during production of the untrained speech probes for intervention priority three.

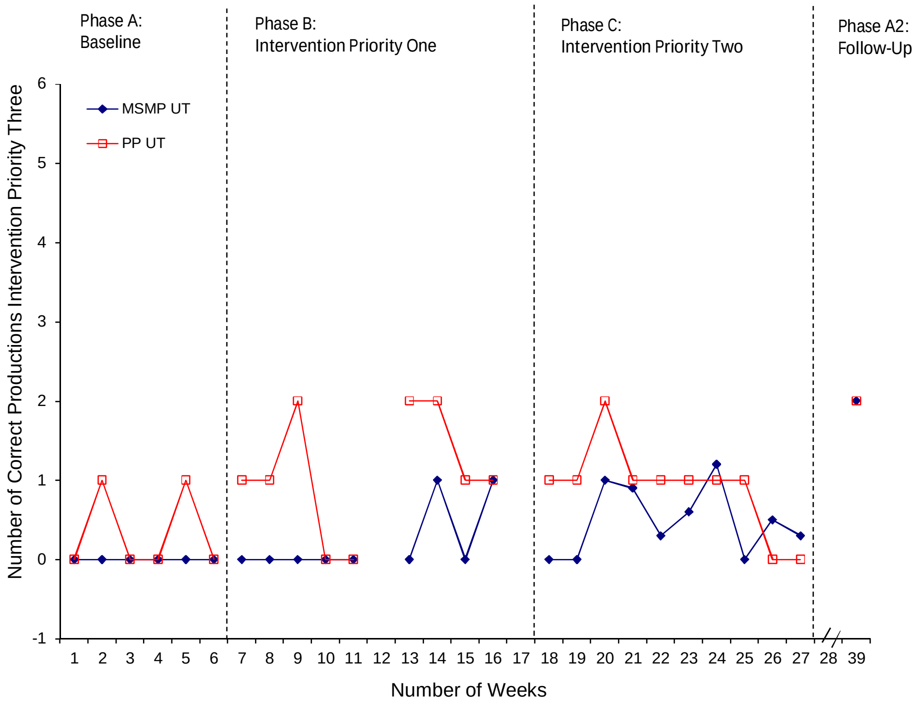


Figure 4.12. P2's performance on the motor-speech-movement parameters (MSMP) and perceptual accuracy (PA) on the control speech probes for the untrained intervention priority three.

Phase A1: Both parameters met stability criteria.

Phase B: A slight increase in performance level was observed on both parameters after session five between phase A1 and B. However, the number of overlapping data points with phase A1 suggest the treatment effect is not significant.

Phase C: No increase in performance level was observed on the parameters between phase B and C. However, an increase in performance on the untrained MSMP was observed between phase A1 and C.

Phase A2: An improvement in performance was recorded post-intervention with both the MSMP and PA both showing an accuracy of 33%, an increase of 33% and 28% respectively, compared to phase A1.

Statistical data.

Change in level.

The results in Table 4.15 demonstrate that P2 achieved a significant change in performance level on the trained and untrained speech probes for both parameters. The largest increase in performance level was observed on intervention priority one (mandibular control) during phase B (intervention block one) and intervention priority two (labial-facial control) during phase C (intervention block two). The data are further supported by the large effect size data obtained using a modified Cohen's d, as illustrated in Table 4.16. A significant increase in performance was observed on the MSMP control goal during the last half of phase C (intervention block two). No significant change in the control goal was observed on the PA control goal. This lack of substantial change to the control goal is supported by the small effect sizes obtained on the MSMP and PA, (0.3 and 0.57) respectively.

Table 4.15

Summary of the Two-Standard Deviation Band Analysis on the Speech Probes across the Study Phases for P2

Phase	IP 1 Mandibular				IP 2 Labial-Facial				IP 3 Lingual	
	TR		UT		TR		UT		Control	
	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1→B	*S	*S	*S	I	I	*S	I	*S	I	I
NAL	8	7	7	5	4	6	4	6	3	3
CNAL	7	4	4	2	2	3	2	4	2	2
A1→C	*S	*S	*S	*S	*S	*S	*S	*S	*S	I
NAL	10	10	10	10	10	10	9	10	7	1
CNAL	10	10	10	10	10	10	8	10	5	0
B→C	C	I	I	C	*S	I	*S	C	I	I
NAL	C	0	2	C	6	0	5	C	0	0
CNAL	C	0	0	C	3	0	4	C	0	0
A→A2	*S	*S	*S	*S	*S	*S	*S	*S	I	I

Note. *S = significant, I = insignificant, IP = Intervention Priority, MSMP = motor-speech-movement parameter, PA = perceptual accuracy, NAL = number above the two standard deviation band and CNAL = consecutive number above the two standard deviation band.

Table 4.16

Effect Size Data on the Speech Probes across the Phases of the Study for P2

	PHASE B					PHASE C				
	IP 1 Mand		IP 2 LF		IP 3 Ling	IP 1 Mand		IP 2 LF		IP 3 Ling
	TR	UT	TR	UT	C	TR	UT	TR	UT	C
MSMP	3.0	2.5	1.4	1.5	0.9	0.8	1.4	2.3	1.8	0.3
PA	2.4	0.7	1.5	1.8	1.2	0.7	0.7	0.5	0.7	0.6

Note. IP = Intervention Priority, TR = trained, UT = untrained, MSMP = motor-speech-movement-parameter, PA = perceptual accuracy, Mand = Mandibular, LF = Labial-Facial, Ling = Lingual.

Change in trend and slope.

The data in Table 4.17 indicate P2 achieved a significant change in performance trend and slope occurred on the untrained and trained speech probes, during the training of the targeted intervention priority. A significant change in trend and slope was observed on intervention priority one during phase B (intervention block one) and intervention priority two during phase C (intervention block two). No significant change in trend and slope was observed on the control goal throughout the phases of the study.

Table 4.17

Summary of the Split-middle and Binomial Test on the Speech Probes across the Study Phases for P2

Phase	IP 1 Mandibular				IP 2 Labial-Facial				IP3 Lingual	
	TR		UT		TR		UT		C	
	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A1→B	*S	*S	*S	I	*S	I	I	I	I	I
A1→C	*S	*S	*S	*S	*S	*S	*S	*S	I	I
B→C	I	I	I	I	I	I	I	*S	I	I

Note. IP = intervention priority, TR = trained, UT = untrained, C = control, *S = significant, I = Insignificant, MSMP = motor-speech-movement-parameters, PA = perceptual accuracy.

Overall summary of P2's speech production accuracy (Speech probes).

The above results indicate P2's intervention program was successful in effecting positive changes in the MSMPs and PA in both intervention priorities, with transfer of the learned behaviours to the untrained speech probes.

The untrained intervention priority three goal that acted as a control goal showed movement in the second half of intervention block one that continued into intervention block two. However, the overlapping data between the phases indicates no real change in performance between the phases. A change in performance was observed at follow-up.

Participant 3

Visual inspection.

Table 4.18 lists the number of sessions attended by P3 across the phases of the intervention study. Two sessions were not attended in the first intervention priority (phase B) due to family holidays.

Table 4.18

P3's Intervention Priorities and Number of Sessions Attended

Phase	Description	Intervention Priority	Sessions
A1	Baseline		5/5
B	Intervention Priority One	Mandibular	8/10
C	Intervention Priority Two	Labial-Facial	10/10
A2	Follow-up		2/2

The data provided in Table 4.19 and described in detail below, indicates a positive treatment effect. P3 demonstrated an increased accuracy in the MSMPs and PA of intervention priority one (labial-facial control) during intervention block one and intervention priority two (lingual control) during intervention block two. Generalisation to the untrained speech probes was evidenced on both intervention priorities. No change in the speech probes of the control goal was observed.

Table 4.19

Mean Percent Correct Performance on the Speech Probes across the Study Phases for P3

	IP 1 Mandibular				IP2 Labial-Facial				IP 3 Lingual	
	Trained		Untrained		Trained		Untrained		Control	
Phase	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1	13%	37%	23%	40%	7%	23%	3%	10%	3%	10%
B	58%	77%	56%	83%	14%	48%	14%	31%	1%	10%
C	68%	86%	60%	92%	59%	63%	51%	53%	0%	13%
A2	83%	67%	67%	50%	50%	50%	55%	33%	0%	17%

Note. IP = Intervention Priority, TR = trained, UT = untrained, MSMP = motor-speech-movement-parameter, PA = perceptual accuracy, Mand = Mandibular, LF = Labial-Facial, Ling = Lingual.

Intervention priority one (Mandibular control): Trained speech probes.

Figure 4.13 illustrates P3's performance on both parameters, across the four phases of the study, during production of the trained speech probes for intervention priority one.

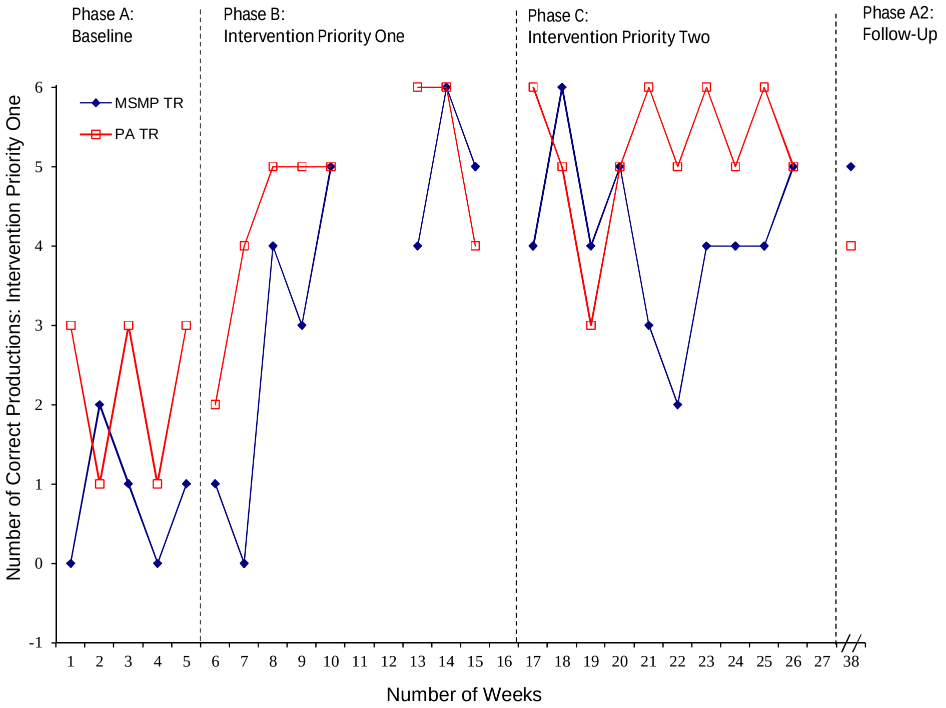


Figure 4.13. P3's performance on the motor-speech movement patterns (MSMP) and perceptual accuracy (PA) on the trained word-sets for intervention priority one.

Phase A1: Both parameters met stability criteria.

Phase B: An increasing trend direction and minimal data overlap are observed on both parameters of MSMP and PA compared to phase A1. A performance increase of 45% and 40% on the MSMPs and PA respectively, indicates a positive treatment effect for intervention priority one: mandibular control.

Phase C: The flattening in the angle of the slope and data overlap with Phase B suggests skill maintenance. A mean performance increase of 10% and 9% in the MSMPs and PA respectively, was recorded.

Phase A2: The final score obtained at the end of phase C was maintained at12 weeks post-intervention on the MSMPs. Whilst a slight decrease in performance was recorded in PA 12 weeks post-intervention, a percentage increase of 30% indicates the treatment effect was maintained.

Intervention priority one (Mandibular control): Untrained speech probes. Figure 4.14 illustrates P3’s performance on both parameters across the four phases of the study, during production on the untrained speech probes for intervention priority one.

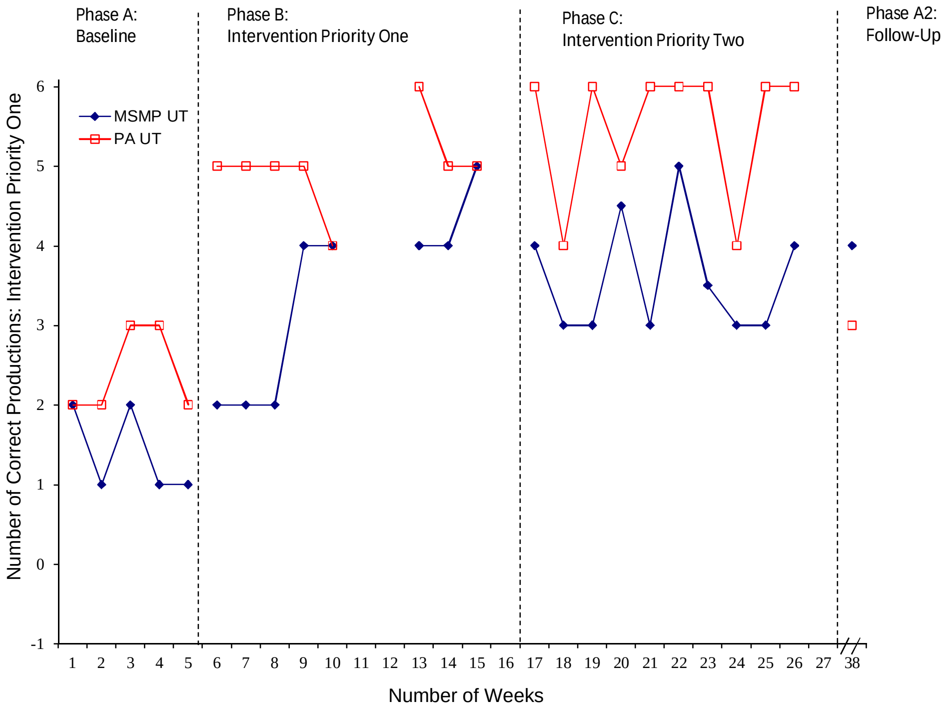


Figure 4.14. P3’s performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority one.

Phase A1: Both parameters met stability criteria.

Phase B: The overall increasing trend direction and absence of data overlap between phase A1 and B indicates skill generalisation on intervention priority one: mandibular control.

Phase C: The flattening in the angle of the slope and overlapping data between Phases B-C on both parameters suggest skill maintenance. The data illustrates consistency with that obtained on the trained speech probes.

Phase A2: The final score obtained on the MSMPs at the end of phase C, were maintained at12 weeks post-intervention. This indicates skill maintenance that is consistent with the trained speech probes. A decrease in PA between phases C-A2 and a mean percentage increase of 10% between phases A1-A2 suggest the treatment effect was not maintained for PA.

Intervention priority two (Labial-facial control): Trained speech probes.

Figure 4.15 illustrates P3's performance on both parameters across the four phases of the study, during production of the trained speech probes for intervention priority two.

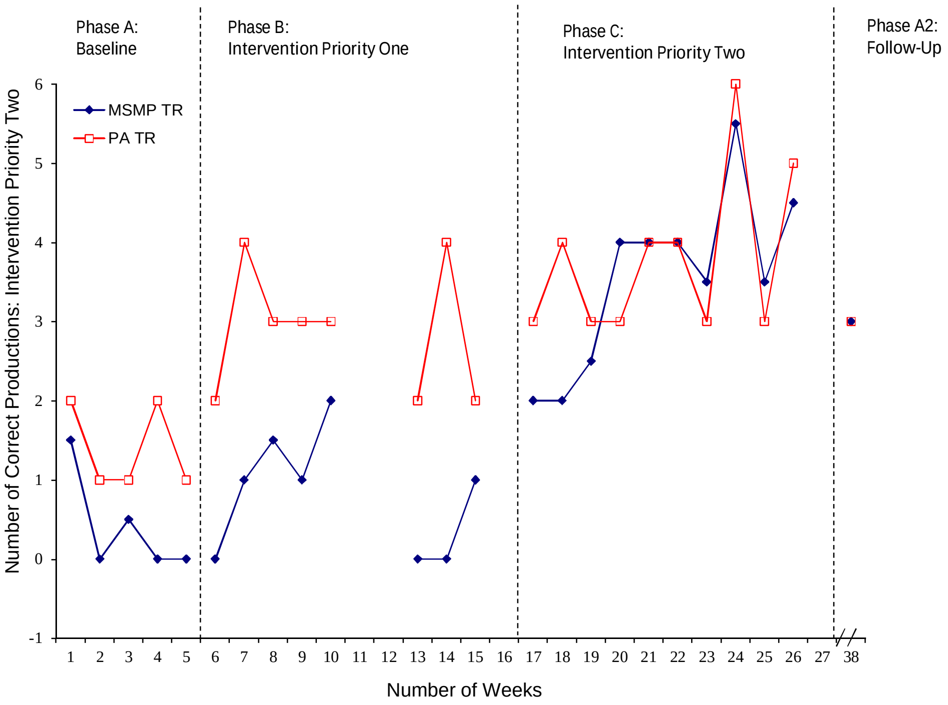


Figure 4.15. P3's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the trained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria.

Phase B: An increasing trend direction and absence of overlapping data points in the PA data, suggests the training of the first intervention priority (mandibular control) had a significant effect on the PA of the second intervention priority (labial-facial control) during phase B. No real change was recorded in the MSMPs.

Phase C: The change to a steadily increasing trend and absence of overlapping data points indicate a positive treatment effect on the MSMPS during the training of intervention priority two: labial-facial control. A mean performance increase of 15% between phases B-C was recorded in PA. Synchrony in the accuracy of the MSMPs and PA is observed in the final six sessions of this phase.

Phase A2: At 12 weeks post-intervention a mean percentage score of 50% was recorded on both parameters. These results indicate a mean performance increase between phases A1-A2 of 43% and 27% in the MSMPs and PA, respectively. These results suggest a positive treatment effect.

Intervention priority two (Labial facial): Untrained speech probes.

Figure 4.16 illustrates P3’s performance on the parameters across the four phases of the study, during production of the untrained speech probes for intervention priority two.

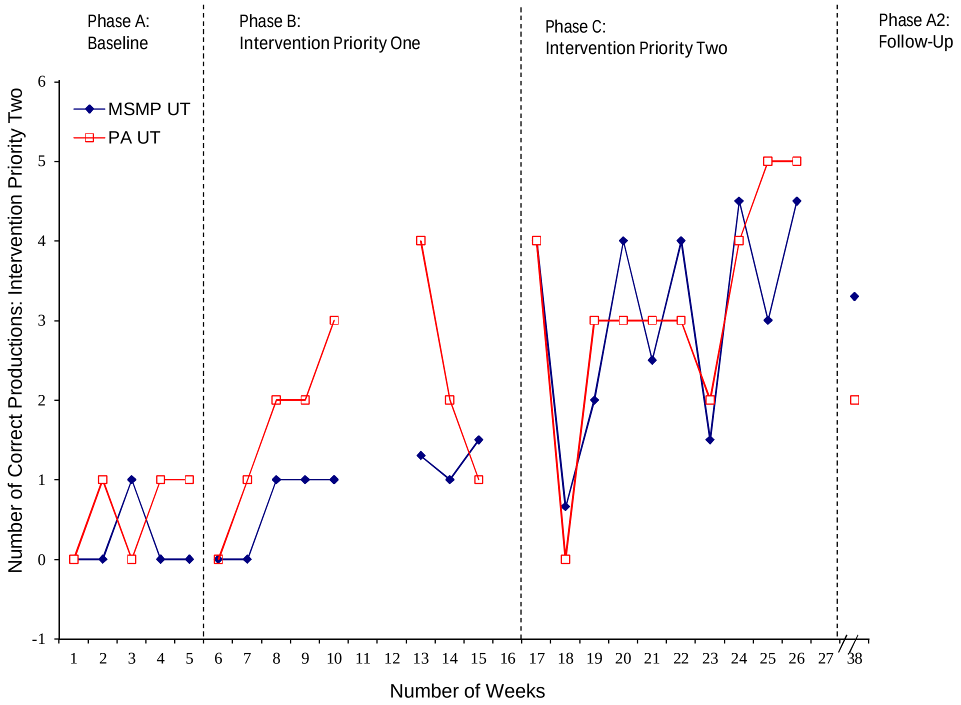


Figure 4.16. P3's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria.

Phase B: Consistent with the trained speech probes, the PA of the untrained speech probes showed an initially increasing trend direction. However, this trend was not maintained for the last three sessions. These data suggest the training of the first intervention priority in phase B (mandibular control) destabilized the second intervention priority (labial facial control) and did not result in sustained performance gain.

Phase C: The change to an overall increasing trend direction and mean performance increase of 37% and 22% on the MSMPs and PA respectively indicates generalisation to the untrained speech probes when intervention targeted the labial-facial parameters.

Phase A2: A mean performance increase of 52% and 23% was recorded on the MSMPs and PA, respectively between phases A1 and A2 (12-weeks post-intervention). The PA recorded a decrease in performance between phase C and A2, indicating the treatment effects were less stable on the untrained speech probes.

Intervention priority three (Lingual control): Control speech probes.

Figure 4.17 illustrates P3’s performance on both parameters, across the four phases of the study, of the control speech probes.

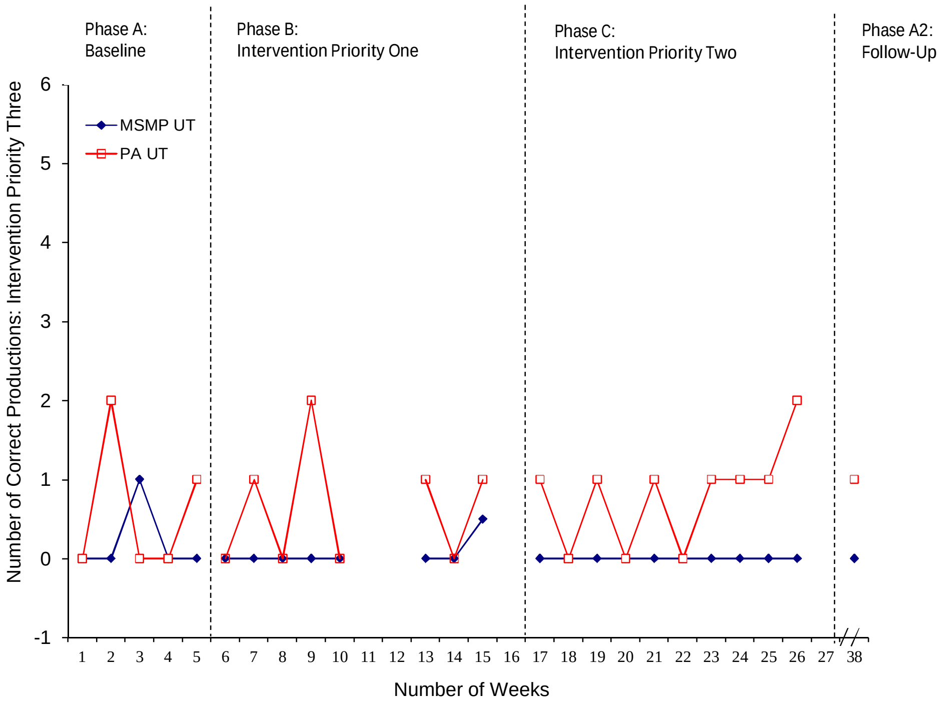


Figure 4.17. P3's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the control speech probes for the untrained intervention priority three.

Phase A1: Both parameters met stable baseline criteria.

Phase B: The complete overlapping of data and absence of an increasing trend direction suggest no change in the MSMPs and PA between phase A1 and B. This indicates no treatment effect occurred.

Phase C: The absence of trend direction and performance increase on the control priority continued between phases B-C for both parameters. These results indicate an absence of a treatment effect.

Phase A2: No change in the performance level was recorded on the MSMPs. The final score recorded in PA was consistent with phase A1 data. These results indicate no treatment effect occurred on the control goal (intervention priority three: lingual control).

Statistical data.

Change in level.

The results in Table 4.20 demonstrate that P3 achieved a significant change in performance level on the trained and untrained speech probes for both parameters. The largest increase in performance level in the MSMPs was observed on intervention priority one (mandibular control) during phase B (intervention block one) and intervention priority two (labial-facial control) during phase C (intervention block two). The greatest increase in performance level in PA occurred during phase B for both intervention priorities. The data are further supported by the large effect size data obtained using modified Cohen's d, illustrated in Table 4.21. No significant change in performance was observed on the control goal throughout the phases of the study.

Table 4.20

Summary of the Two-Standard Deviation Band Analysis on the Speech Probes across the Study Phases for P3

	IP 1 Mandibular				IP 2 Labial-Facial				IP 3 Lingual	
Phase	TR		UT		TR		UT		Control	
	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1→ B	*S	*S	*S	*S	I	*S	I	*S	I	I
NAL	6	5	5	6	0	5	2	5	1	0
CNAL	6	3	3	3	0	4	0	3	0	0
A1→C	*S	I	*S	I	*S	*S	*S	*S	I	I
NAL	9	6	10	6	8	9	9	9	0	0
CNAL	6	2	10	3	8	9	8	8	0	0
B→C	I	I	I	I	*S	I	*S	I	I	I
NAL	0	-	0	-	8	1	7	2	0	0
CNAL	0	-	0	-	8	1	3	2	0	0
A1→A2	*S	*S	*S	*S	*S	*S	*S	*S	I	I

Note. MSMP = motor-speech-movement-parameter, PA = perceptual accuracy, TR = trained, UT = untrained.
*S = significant, I = insignificant, MSMP, "-" = unable to calculate due to ceiling effect.

Table 4.21

Effect Size Data on the Speech Probes across the Phases of the Study for P3

	PHASE B					PHASE C				
	IP 1 Mand		IP 2 LF		IP 3 Ling	IP 1 Mand		IP 2 LF		IP 3 Ling
	TR	UT	TR	UT	C	TR	UT	TR	UT	C
MSMP	1.7	2.1	0.6	1.3	-0.4	0.4	0.5	2.9	2.1	-0.5
PA	0.5	0.7	1.0	1.0	0.0	1.0	0.6	1.1	1.1	-1.2

Note. IP = Intervention Priority, Mand = mandibular, LF = labial-facial, Ling = lingual, TR = trained, UT = untrained, U/C = unable to calculate due to data consisting of zero scores.

Change in trend and slope.

The results in Table 4.22 demonstrate a significant change in trend level and slope were obtained on the MSMPs for intervention priority one during phase B (intervention block one) and intervention priority two during phase C (intervention block two) for both the trained and untrained speech probes. A significant change in PA was recorded in phases B and C for the trained speech probes of intervention priority one and two; and phase B for the intervention priority one untrained speech probes. No change was recorded in the speech probes of the control goal.

Table 4.22

Summary of the Split-middle and Binomial Test on the Speech Probes across the Study Phases for P3

Phase	IP 1 Mandibular				IP 2 Labial-Facial				IP3 Lingual	
	TR		UT		TR		UT		C	
	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1→B	*S	*S	*S	*S	I	*S	I	I	I	I
A1→C	*S	*S	*S	*S	*S	*S	*S	*S	I	I
B→C	I	I	I	I	*S	I	*S	I	I	I

Note. MSMP = motor-speech-movement-parameter, PA = perceptual accuracy, TR = trained, UT = untrained.
*S = significant, I = insignificant.

Overall summary of P3’s speech production accuracy (Speech probes).

The above results indicate P3’s intervention program was successful in effecting positive changes in the MSMPs and PA in both intervention priorities, with transfer of the learned behaviours to the untrained speech probes. The greatest change in MSMP performance, as shown using visual inspection and supported by the statistical analyses, was observed to have occurred during intervention priority one during phase B (intervention block one) and priority two during phase C (intervention block two) when intervention targeted these priorities. The greatest change in PA for both intervention priorities was recorded to occur during phase B.

No changes were observed in the control goal (intervention priority three: lingual control) across the phases of the study.

Participant 4

Visual inspection.

Table 4.23 lists the intervention priorities and number of sessions attended by P4 across the phases of the intervention study.

Table 4.23

P4’s Intervention Priorities and Number of Sessions Attended

Phase	Description	Intervention Priority	Sessions
A1	Baseline		7/7
B	Intervention Priority One	Labial-Facial	10/10
C	Intervention Priority Two	Lingual	10/10
A2	Follow-up		2/2

The data provided in Table 4.24 and described in detail below indicates a positive treatment effect was observed on the first intervention priority only. Specifically, the trained and untrained MSMPs of intervention priority one (labial-facial control) during the training of this priority recorded a positive treatment effect. A treatment effect was not seen in the PA of intervention priority one (labial-facial control) until phase C (intervention block two).

The MSMPs of intervention priority two (lingual control) demonstrated only a slight increase in performance across the phases of the study. The performance pattern of this priority was both unstable and variable with a limited treatment effect observed on the trained speech probes only. No change in performance was observed in the MSMPs of the control goal (intervention priority three). A slight increase in mean performance PA accuracy was observed however, the percentage of overlapping data suggests this change was not significant.

Table 4.24

Mean Percent Correct Performance on the Speech Probes across the Study Phases for P4

	IP 1 Labial-Facial				IP 2 Lingual				IP 3 Sequencing	
	Trained		Untrained		Trained		Untrained		Control	
Phase	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A1	6%	7%	11%	10%	0%	0%	0%	7%	0%	0%
B	43%	25%	44%	38%	9%	15%	11%	15%	0%	3%
C	56%	43%	63%	57%	11%	35%	6%	23%	0%	7%
A2	58%	50%	50%	50%	25%	50%	42%	33%	0%	16%

Note. IP = Intervention Priority, MSMP = motor-speech-movement-parameters, PA = perceptual accuracy, TR = trained, UT = untrained

Intervention priority one (Labial-facial control): Trained speech probes.

Figure 4.18 illustrates P4’s performance on both parameters, across the four phases of the study, during production of the trained speech probes for intervention priority one.

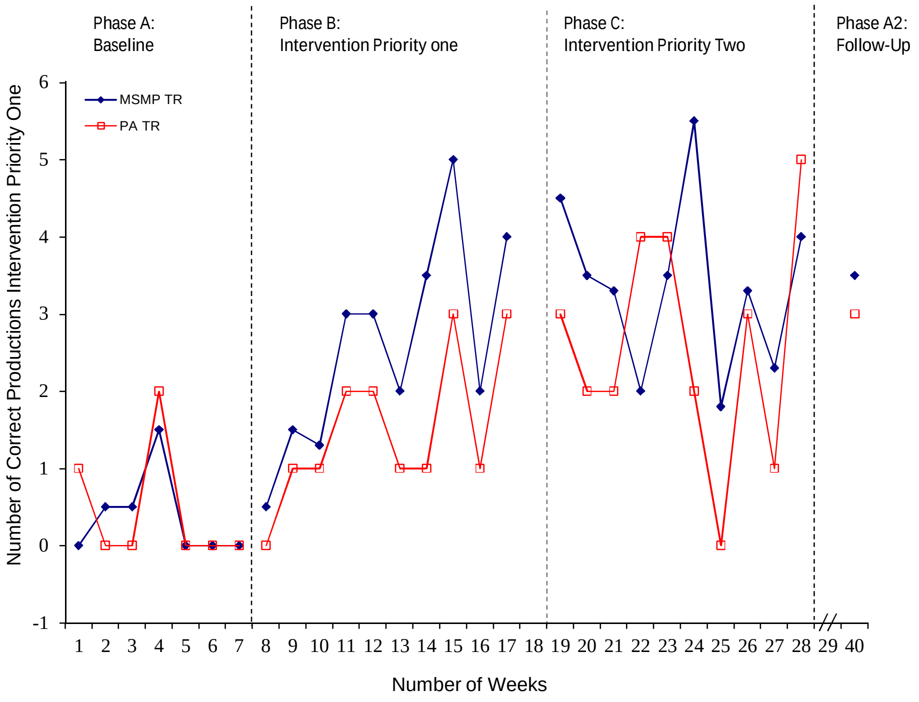


Figure 4.18. P4's performance on the motor-speech movement patterns (MSMP) and perceptual accuracy (PA) on the trained word-sets for intervention priority one.

Phase A1: Both parameters met stability criteria.

Phase B: A steadily increasing trend and mean performance increase of 37% and 18% on the MSMPs and PA respectively, was recorded. These results indicate a positive treatment effect for intervention priority one: labial-facial control.

Phase C: Both parameters show a flattening in the angle of the slope with a mean performance increase of 13% and 18% on the MSMPs and PA, respectively. The presence of overlapping data with phase B and continued variability in performance on both parameters suggest continued acquisition of intervention priority one (labial-facial control) during the training of the second intervention priority (lingual control).

Phase A2: A positive treatment effect is suggested by a mean performance increase between phases A1and A2 of 52% and 43% in the MSMPs and PA, respectively. Skill maintenance between phases C and A2 is also indicated based on a mean performance decrease of only 2% in MSMPs and increase of 7% in PA.

Intervention priority one (Labial-facial control): Untrained speech probes.

Figure 4.19 illustrates P4’s performance, on both parameters across the four phases of the study, during production on the untrained speech probes for intervention priority one.

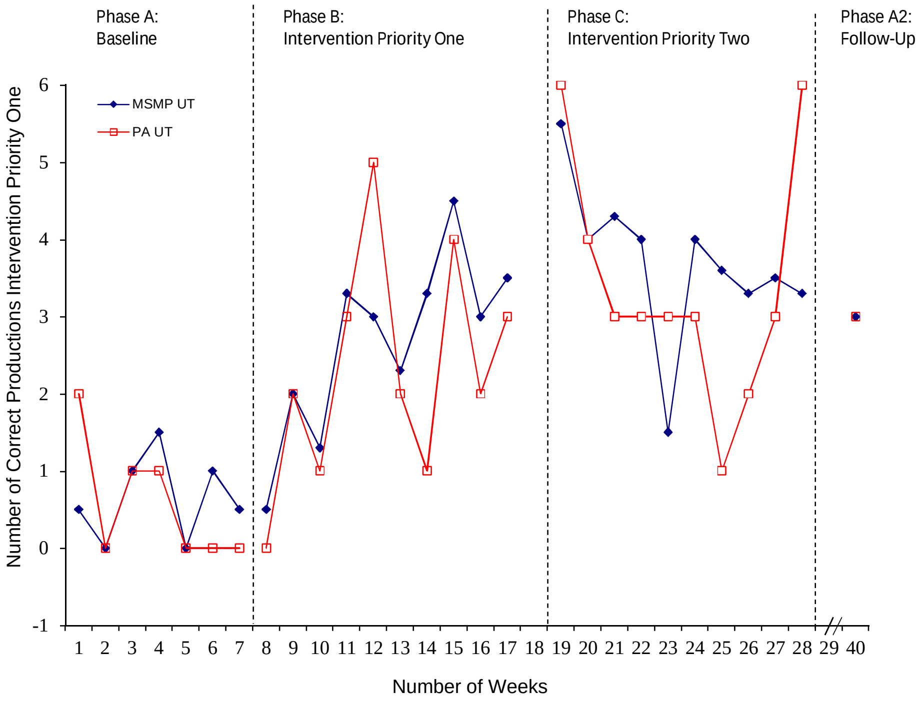


Figure 4.19. P4's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority one.

Phase A1: Both parameters met stability criteria.

Phase B: The overall increasing trend direction and limited overlapping data between phases A1 and B indicate generalisation to the untrained speech probes for intervention priority one: labial-facial control.

Phase C: Both parameters show a flattening in the angle of the slope and a mean performance increase of 19% on both parameters. Consistent with the trained speech probe data, the presence of overlapping data with phase B as well as continued variability in performance, suggest continued acquisition of intervention priority one (labial-facial control) during the training of the second intervention priority (lingual control).

Phase A2: A positive treatment effect is suggested by a mean performance increase between phases A1-A2 of 39% and 40% in the MSMPs and PA, respectively. Skill maintenance between phases C-A2 is also indicated despite a performance decrease of 13% and 7% on the MSMPs and PA, respectively.

Intervention priority two (Lingual control): Trained speech probes.

Figure 4.20 illustrates P4’s performance on both parameters, across the four phases of the study, during production of the trained speech probes for intervention priority two.

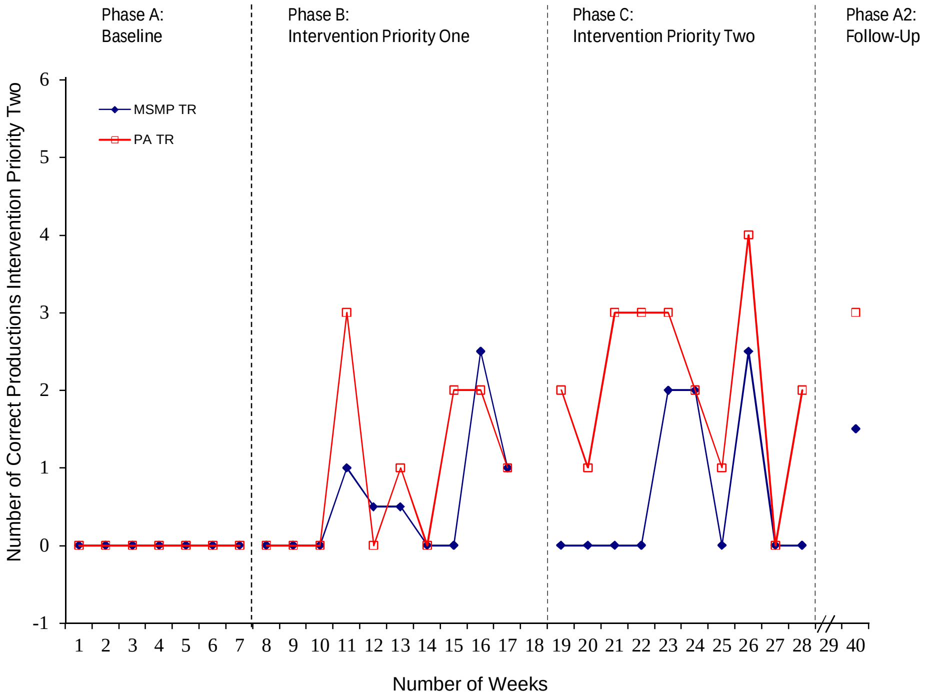


Figure 4.20. P4's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the trained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria, with zero baseline scores on the MSMPs and PA, respectively.

Phase B: An increasing trend direction for both parameters with a mean performance increase of 9% and 15% on the MSMPs and PA respectively, was recorded. Fifty percent of the data are non-overlapping with phase A1. This indicates the training of intervention priority one (labial-facial control) affected the performance of intervention priority two (lingual control).

Phase C: A mean performance increase of 2% and 20% on the MSMPs and PA respectively, was recorded between phases B-C. Variability in performance and 90% data over-lap with phase B suggests ongoing destabilization of intervention priority two (lingual control) during the training of this priority.

Phase A2: A positive treatment effect is suggested by a mean performance increase between phases A1-A2 of 25% and 50% in the MSMPs and PA, respectively. Continued learning between phases C-A2 is also indicated with a performance increase of 14% and 15% on the MSMPs and PA, respectively.

Intervention priority two (Lingual control): Untrained speech probes.

Performance on the parameters across the four phases of the study, during production of the untrained speech probes for intervention priority two is presented in Figure 4.21.

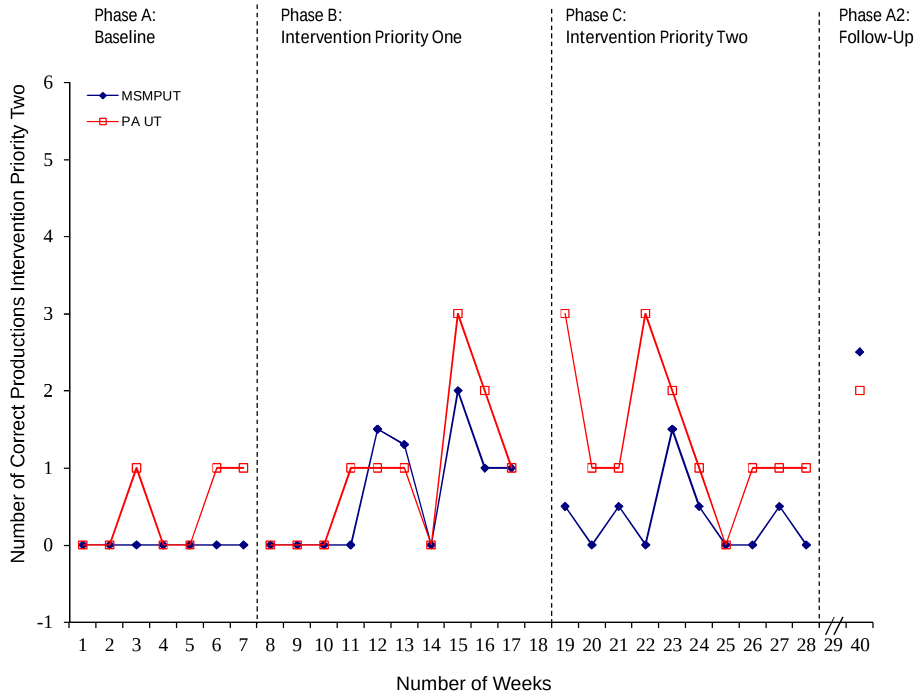


Figure 4.21. P4's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria.

Phase B: Consistent with the trained speech probes, the untrained speech probes displayed an overall increasing trend direction between phase A1 and B. A mean performance increase of 11% and 8% was observed on the MSMPs and PA, respectively. These data indicate the training of intervention priority one (labial-facial control) affected the performance of intervention priority two (lingual control).

Phase C: A mean performance decrease of 5% on MPMPs, an increase of 8% on PA and 100% overlapping of data with phase B suggest no presence of a treatment effect on intervention priority two, during the training of this intervention priority.

PhaseA2: At 12 weeks post-intervention a mean performance increase of 42% and 26% on the MSMPs and PA, respectively was recorded between phases A1 and A2. These results show a performance increase between phase C and A2; and suggest continued learning during the follow-up period.

Intervention priority three (Sequencing control): Control speech probes.

Figure 4.22 illustrates P4's performance on both parameters of the untrained intervention priority three speech probes, across the four phases of the study.

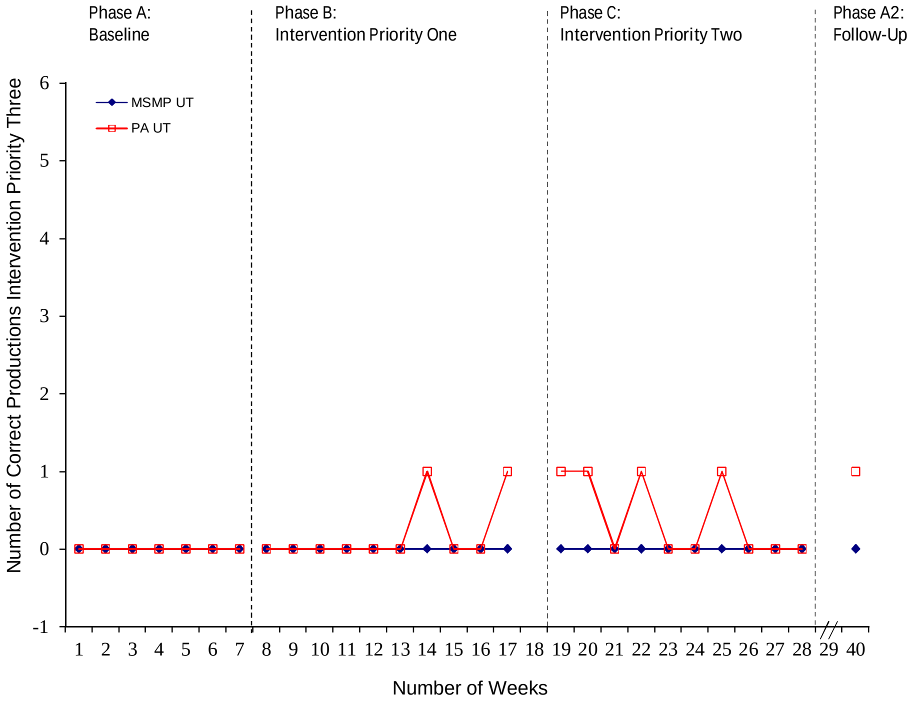


Figure 4.22. P4's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the control speech probes for the untrained intervention priority three.

Phase A1: Both parameters met stability criteria with scores of 0%.

Phase B: Scores of 0% were maintained on the MSMPs and near-zero for PA. This indicates no significant treatment effect occurred in the MSMPs and PA between phase A1 and B.

Phase C: No change was recorded in trend direction or performance level on the MSMPs and PA between phase B and C. The results indicate no treatment effect occurred.

Phase A2: No change in the performance score was recorded on the MSMPs. A 16% increase was recorded in the PA between phase A1 and A2. Eighty percent of the data are overlapping between phase A1 and B; and 90% of the data are overlapping between phases B and C. These results indicate no treatment effect occurred on the MSMPS of the control goal (intervention priority three: sequencing control).

Statistical data.

Change in level.

The data in Table 4.25 indicates P4 achieved a significant change in performance level of the MSMPs for both intervention priorities during phase B: both trained and untrained word-sets for intervention priority one (labial-facial control) and the trained word-set intervention priority two (lingual control). In addition, a significant change in PA for the trained word-set of intervention priority two was also recorded.

During phase C, a significant change in PA of the trained and untrained word-sets of intervention priority one (labial facial control) was recorded. No change in performance was observed on the control goal throughout the phases of the study or the PA of the untrained speech probes for intervention priority two.

The data are further supported by the effect size data obtained using a modified Cohen’s d, as illustrated in Table 4.26.

Table 4.25

Summary of the Two-Standard Deviation Band Analysis on the Speech Probes across the Study Phases for P4

Phase	IP 1 Labial-Facial				IP 2 Lingual				IP 3 Seq	
	TR		UT		TR		UT		Control	
	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1→B	*S	I	*S	I	*S	*S	I	I	I	I
NAL	7	4	8	4	5	5	3	2	0	0
CNAL	7	0	7	2	3	3	2	2	0	0
A1→C	*S	*S	*S	*S	I	*S	I	I	I	I
NAL	9	8	10	8	3	9	5	3	0	5
CNAL	6	4	10	6	2	7	0	2	0	2
B→C	I	I	I	I	I	I	I	I	I	I
NAL	1	3	2	2	1	1	0	2	0	0
CNAL	0	2	0	0	0	0	0	0	0	0
A1→A2	*S	*S	*S	*S	*S	*S	*S	*S	I	I

Note. IP = Intervention Priority, Seq = sequencing, MSMP = motor-speech-movement-parameter, PA = perceptual accuracy.
*S = Signficant, I = Insignificant.

Table 4.26

Effect Size Data on the Speech Probes across the Phases of the Study for P4

	PHASE B					PHASE C				
	IP 1 LF		IP 2 Ling		IP 3 Seq	IP 1 LF		IP 2 Ling		IP 3 Seq
	TR	UT	TR	UT	C	TR	UT	TR	UT	C
MSMP	1.9	2.3	1.0	0.9	U/C	1.1	0.9	1.1	0.5	U/C
PA	1.2	1.4	1.2	0.6	0.7	0.9	0.7	1.0	0.5	0.4

Note. IP = Intervention Priority, LF = labial-facial, Ling = Lingual, Seq = Sequencing, TR = trained, UT = untrained, U/C = unable to calculate due to data consisting of zero scores.

Change in trend and slope.

The data in Table 4.27 illustrates a significant change in trend and slope was recorded in the data for the trained and untrained speech probes of intervention priority one (labial-facial control). This occurred in both phase B (intervention block one). No significant change was recorded in the trained speech probes of intervention priority two (lingual control) in any phase. However, a significant change in the untrained speech probes of intervention priority two (lingual control) was recorded between phase A1 and phase C.

No significant change in the control goal was recorded throughout the phases of the study.

Table 4.27

Summary of the Split-middle and Binomial Test on the Speech Probes across the Study Phases for P4

Phase	IP 1 Labial-Facial				IP 2 Lingual				IP3 Seq	
	TR		UT		TR		UT		C	
	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A1→B	*S	*S	*S	*S	I	I	I	I	I	I
A1→C	*S	*S	*S	*S	I	*S	I	*S	I	I
B→C	I	I	I	I	I	I	I	I	I	I

Note. Seq = Sequencing, MSMP = motor-speech-movement-parameters, PA = perceptual accuracy. *S = significant, I = Insignificant

Overall summary of P4's speech production accuracy (Speech probes).

The above results indicate P4's intervention program was successful in effecting positive changes in the MSMPs and PA in intervention priority one, with transfer of the learned behaviours to the untrained speech probes. The data shows the MSMPs recorded a significant change during phase B (intervention block one) whilst the improvement in PA (with the exception of the trained word-set of intervention priority two) was recorded in phase C (intervention block two).

Minimal change was observed to occur on intervention priority two (lingual control) thus indicating the absence of a treatment effect. No changes were observed in the control goal (intervention priority three: lingual control) across the phases of the study.

Participant 5

Visual inspection.

Table 4.28 lists the number of sessions attended by P5 across the phases of the intervention study. One session was missed in each of phases C and A2 due to a family holiday.

Table 4.28

P5's Intervention Priorities and Number of Sessions Attended

Phase	Description	Intervention Priority	Sessions
A1	Baseline		8/8
B	Intervention Priority One	Mandibular	10/10
C	Intervention Priority Two	Labial-Facial	910
A2	Follow-up		1/2

The data provided in Table 4.29 and described in detail below, indicate a positive treatment effect. P5 demonstrated an increase in accuracy on the MSMPs and PA of intervention priority one (mandibular control) during intervention block one and intervention priority two (labial-facial control) during intervention block two. Generalisation to the untrained speech probes was evidenced on both intervention priorities. The control goal started to show unstable performance changes during the latter half of intervention block two.

Table 4.29

Mean Percent Correct Performance on the Speech Probes across the Study Phases for P5

	IP 1 Mandibular				IP2 Labial-Facial				IP 3 Lingual	
	Trained		Untrained		Trained		Untrained		Control	
Phase	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1	11%	29%	7%	21%	5%	12%	3%	8%	2%	6%
B	38%	42%	42%	45%	36%	32%	33%	35%	2%	15%
C	41%	63%	50%	56%	69%	50%	57%	32%	3%	19%
A2	-	-	-	-	-	-	-	-	-	-

Note. MSMP = motor-speech-movement parameter, PA = perceptual accuracy, TR = trained, UT = untrained

Intervention priority one (Mandibular control): Trained speech probes.

Figure 4.23 illustrates P5's performance on both parameters, across the four phases of the study, during production of the trained speech probes for intervention priority one.

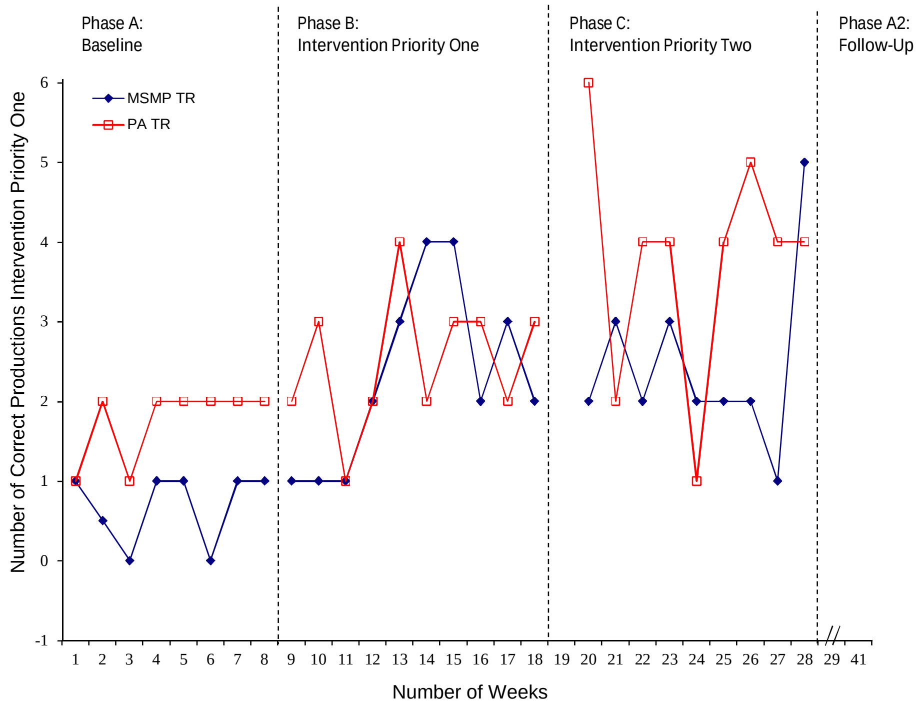


Figure 4.23. P5's performance on the motor-speech movement patterns (MSMP) and perceptual accuracy (PA) on the trained word-sets for intervention priority one.

Phase A1: Both parameters met stability criteria. An 18% performance difference between the MSMPs and PA was recorded, with PA recording greater accuracy.

Phase B: The increasing trend direction and 27% and 13% increase in mean performance level observed in the MSMPs and PA respectively, suggests a positive treatment effect on intervention priority one: mandibular control.

Phase C: A flattening in the slope with a mean performance increase of only 3% was recorded in the accuracy of the MSMPs. An increasing trend and increased variability was recorded in the PA. A mean performance score of 63% indicate PA exceeded the accuracy of the MSMPs by 22% in this phase.

Intervention priority one (Mandibular control): Untrained speech probes.

Figure 4.24 illustrates P5's performance on both parameters across the four phases of the study, during production of the untrained speech probes for intervention priority one.

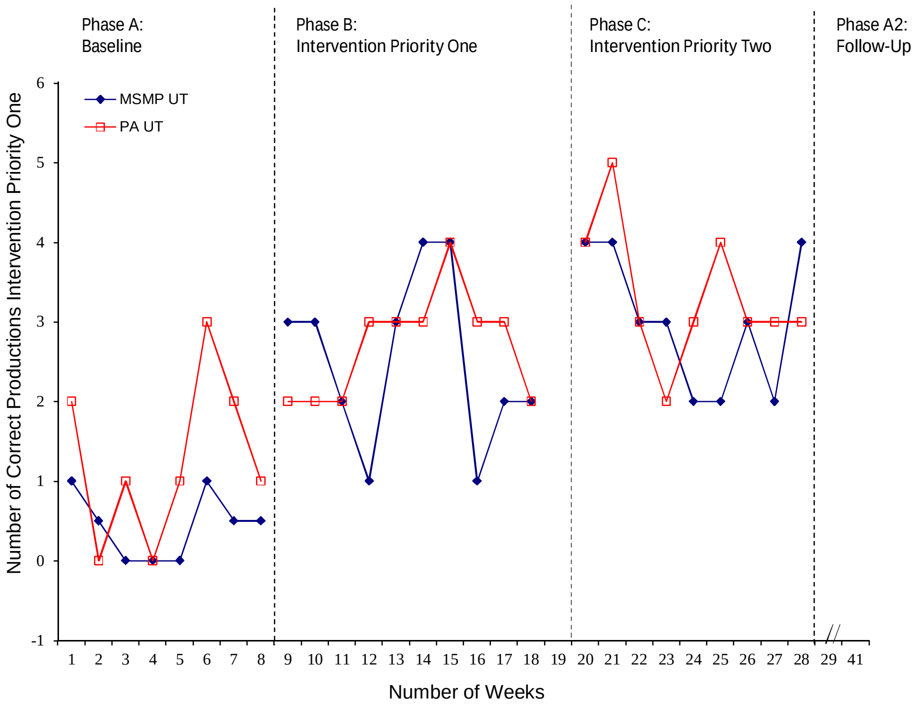


Figure 4.24. P5's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority one.

Phase A1: The application of statistical process control to the untrained PA baseline data indicate session six recorded a data point outside common cause variation (i.e., exceeded the UCL of the 3sd band). A further two baseline sessions indicated the presence of a downward trend. The MSMPs met stability criteria.

Consistent with the trained speech probes, PA recorded greater accuracy than the MSMPs, with a performance difference of 14%.

Phase B: The data indicate generalisation to the MSMPS of the untrained speech probes of intervention priority one: mandibular control. The MSMPs recorded a variable pattern of performance (increasing and decreasing trends) with mean percentage increase of 35%.

The increasing trend direction and mean percentage increase of 24% in PA suggests generalisation to the untrained word-set.

Phase C: The trend directions of both parameters remain consistent with phase B. A small mean performance increase of 8% and 11% on the MSMPs and PA respectively, indicate skill maintenance between phase B and C.

Intervention priority two (Labial-facial control): Trained speech probes.

Figure 4.25 illustrates P5’s performance on both parameters across the four phases of the study, during production of the trained speech probes for intervention priority two.

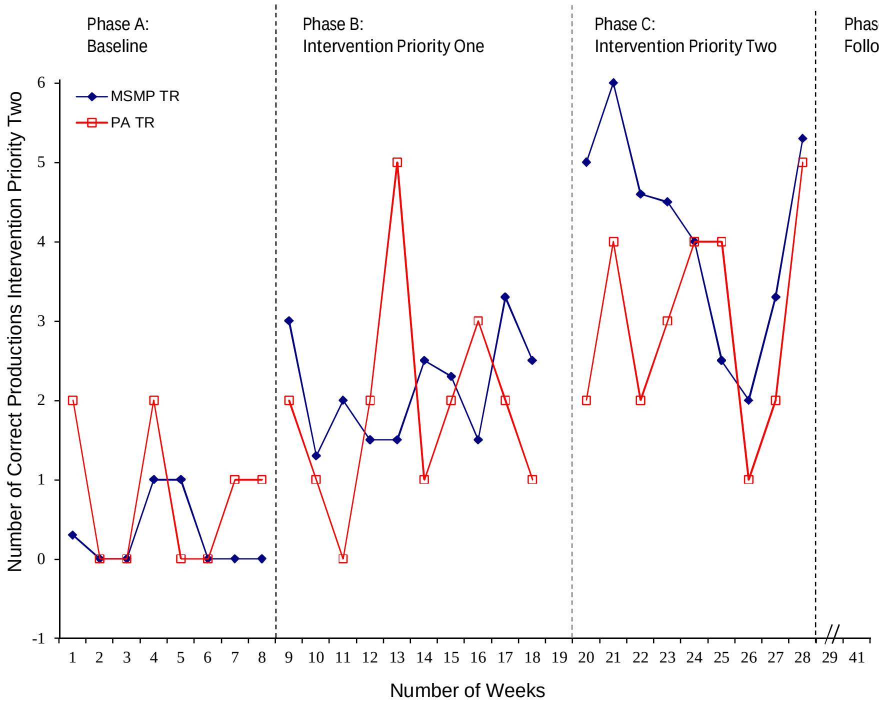


Figure 4.25. P5's performance on the motor-speech-movement parameters (MSMP) and perceptual accuracy (PA) on the trained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria.

Phase B: The increasing trend direction and performance level (no overlapping data compared to phase A1) of the MSMPs indicate a positive treatment effect on labial-facial control (intervention priority two) whilst intervention targeted mandibular control (intervention priority one). A 20% increase in performance level and overall increasing trend direction is observed in the PA. The increase in variability, and considerable overlapping data with phase A1, indicates intervention priority one destabilized PA.

Phase C: Both parameters record an increase in performance level between phases B-C. The decrease in trend and performance observed in session 26 coincides with the introduction of the ten additional trained words for this phase (see methods p. 21). A rapid return to an increasing trend is observed in the final sessions. The high percentage of non-overlapping data between phase A1 and phase C on the MSMPs and PA suggests a positive treatment effect on intervention priority two: labial facial control.

Intervention priority two (Labial facial control): Untrained speech probes.

Figure 4.26 illustrates P5's performance on both parameters across the four phases of the study, during production of the untrained speech probes for intervention priority two.

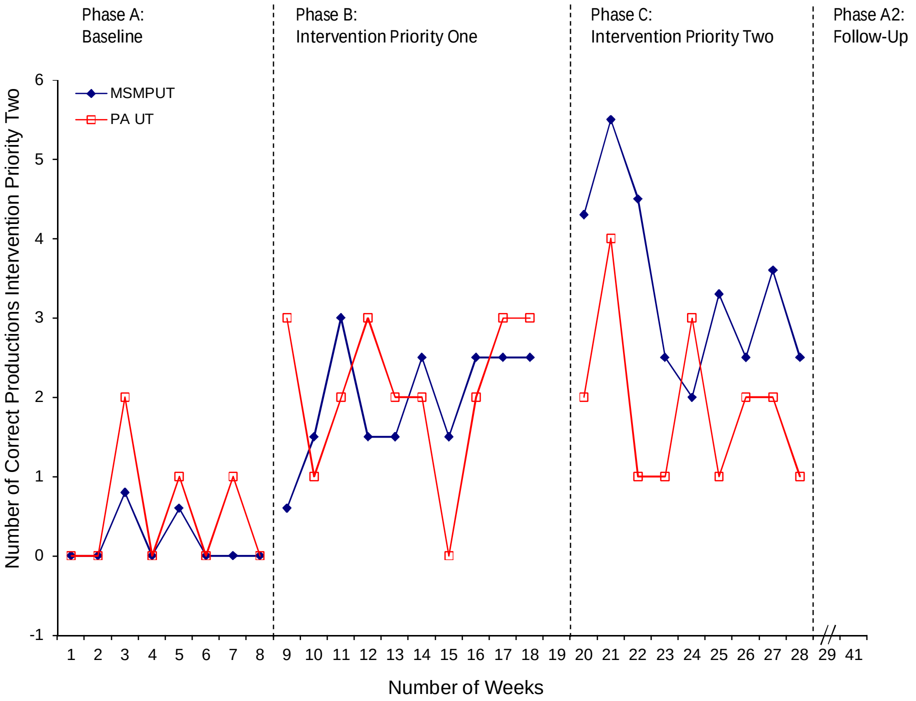


Figure 4.26. P5's performance on the motor-speech movement parameters (MSMP) and perceptual accuracy (PA) on the untrained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria.

Phase B: Both parameters show an increasing trend direction and similar pattern of performance. A mean performance increase of 30% on the MSMPs untrained speech probes suggests the presence of a treatment effect during the training of the first intervention priority (mandibular control). The PA speech probes show a high percentage of non-overlapping data (80%) and therefore indicate the presence of a treatment effect on the second intervention priority during the training of the first intervention priority (mandibular control).

Phase C: Both parameters show a variable trend directions and performance in this phase. A mean increase of 24% was recorded on the MSMPs, whilst a decrease of 3% was recorded in PA. These data suggest a generalisation effect on the training on the MSMPS of intervention priority two: labial facial control.

Intervention priority three (Lingual control): Control speech probes.

Figure 4.27 illustrates P5’s performance on both parameters of the untrained intervention priority three speech probes, across the four phases of the study.

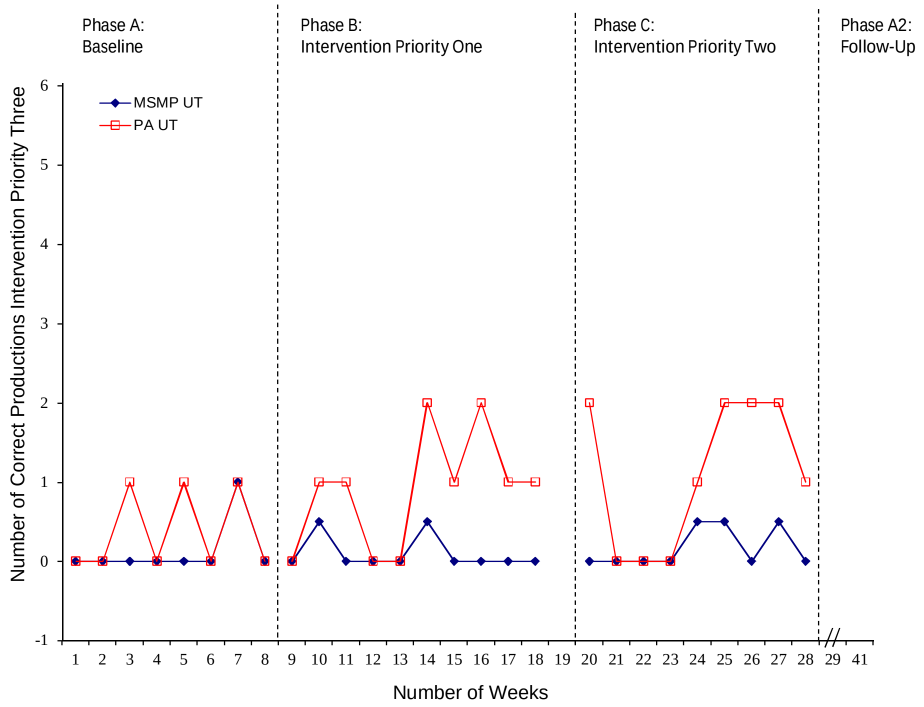


Figure 4.27. P5's performance on the motor-speech-movement parameters (MSMP) and perceptual accuracy (PA) on the control speech probes for the untrained intervention priority three.

Phase A1: Both parameters met stability criteria.

Phase B: A slightly increasing trend direction occurred on both parameters between phase A1 and B. The high percentage of overlapping data points suggest no change in performance occurred on the control speech probes.

Phase C: No increase in performance level was observed on both parameters between phase B and C. However, an increase in PA was observed in the second half of phase C. The percentage of non-overlapping data points between phase A1 and C (67%) indicates the presence of a positive treatment effect.

Statistical data.

Change in level.

The data in Table 4.24 indicate a positive treatment effect on the trained and untrained speech probes of the MSMPs for intervention priority one and two. The largest increase in performance level was observed on intervention priority one (mandibular control) during phase B (intervention block one) and intervention priority two (labial-facial control) during phase C. The effect size data in Table 4.31 indicate the greatest magnitude of change occurred in phase B for both intervention priorities. No increase in performance was observed on the MSMP control goal throughout the phases of the study.

A significant change in performance level was recorded in the PA of the trained speech probes of intervention priority one (mandibular control) and two (labial-facial control) in phase C. The untrained PA speech probes recorded a baseline data point that exceeded the expectations of common cause variation. Exclusion of this data point from the analysis suggests a significant change was recorded across both phases B and C. A significant increase in the PA of the control goal was also recorded in phase C.

Table 4.30

Summary of the Two-Standard Deviation Band Analysis on the Speech Probes across the Study Phases for P5

	IP 1 Mandibular				IP 2 Labial-Facial				IP 3 Lingual	
Phase	TR		UT		TR		UT		Control	
	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A→ B	*S	I	*S	‡S	*S	I	*S	I	I	I
NAL	9	5	8	6	10	2	9	4	0	1
CNAL	7	2	3	6	10	0	9	2	0	0
A→C	*S	*S	*S	*S	*S	*S	*S	I	I	*S
NAL	8	6	9	8	10	5	9	2	0	4
CNAL	7	4	9	8	10	3	9	0	0	3
B→C	I	I	I	I	*S	I	*S	I	I	I
NAL	1	1	0	1	6	1	4	0	0	0
CNAL	0	0	0	0	5	0	3	0	0	0
	-	-	-	-	-	-	-	-	-	-

Note. IP = Intervention Priority, TR = trained, UT = untrained, NAL = number of data points above the 2SD band; CNAL = consecutive number of data points above the 2SD band, - = no data, ‡ = baseline datapoint six removed from the analysis.

Table 4.31

Effect Size Data on the Speech Probes across the Phases of the Study for P5

	PHASE B					PHASE C				
	IP 1 Mand		IP 2 LF		IP 3 Ling	IP 1 Mand		IP 2 LF		IP 3 Ling
	TR	UT	TR	UT	C	TR	UT	TR	UT	C
MSMP	1.8	2.5	3.2	3.1	-0.1	0.1	0.5	1.9	1.5	0.3
PA	1.1	1.7	1.0	1.8	0.8	1.1	0.8	0.8	-0.2	0.3

Note. IP = Intervention Priority; TR = trained; UT = untrained, IP = intervention priority, Mand = Mandibular, LF = labial-facial, Ling = Lingual.

Change in trend and slope.

The data in Table 4.32 indicate a significant change in performance trend and slope occurred on the untrained and trained speech probes on the MSMPs, during training of the targeted intervention priority. That is, a significant change in trend and slope was observed on intervention priority one during phase B (intervention block one) and intervention priority two during phase C (intervention block two).

A significant change in performance trend and slope occurred on the PA of the trained and untrained speech probes of the second intervention priority during

Phase B and maintained in phase C. A statistically significant increase in trend was not recorded between phases B-C.

No significant change in trend and slope was observed in the control goal throughout the phases of the study.

Table 4.32

Summary of the Split-middle and Binomial Test on the Speech Probes across the Study Phases for P5

Phase	IP 1 Mandibular				IP 2 Labial-Facial				IP3 Lingual	
	TR		UT		TR		UT		C	
	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A→B	*S	I	*S	I	*S	*S	*S	*S	I	I
A→C	*S	*S	*S	*S	*S	*S	*S	*S	I	I
B→C	I	I	I	I	I	I	I	I	I	I

Note. IP = intervention priority, TR = trained, UT = untrained, C = control.
*S = significant, I = Insignificant, MSMP = motor-speech-movement-parameters, PA = perceptual accuracy.

Overall summary of P5’s speech production accuracy (Speech probes.)

The above results indicate P5’s intervention program was successful in effecting positive changes in the MSMPs in both intervention priorities, with transfer of the learned behaviours to the untrained speech probes. Changes in PA were not significant until phase C.

Participant 6

Visual inspection.

Table 4.27 lists the number of sessions attended by P6 across the phases of the intervention study. Three sessions were not attended in phase B (intervention block one) due to family holidays.

Table 4.33

P6's Intervention Priorities and Number of Sessions Attended

Phase	Description	Intervention Priority	Sessions
A1	Baseline		7/7
B	Intervention Priority One	Mandibular	7/10
C	Intervention Priority Two	Labial-Facial	10/10
A2	Follow-up		2/2

The data provided in Table 4.28 and described in detail below indicate a positive treatment effect. P6 demonstrated an increased accuracy in the MSMPs and PA in intervention priority one (mandibular control) during intervention block one, with transfer of the learned behaviours to the untrained speech probes. Significant changes were also observed in the MSMPs of intervention priority two. However, the PA of intervention priority two was not observed to change significantly until phase A2 (follow-up).

No changes were observed in the control goal (intervention priority three: lingual control) across the phases of the study.

Table 4.34

Mean Percent Correct Performance on the Speech Probes across the Study Phases for P6

	IP 1 Mandibular				IP2 Labial-Facial				IP 3 Lingual	
	Trained		Untrained		Trained		Untrained		Control	
Phase	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA	MSMP	PA
A1	12%	29%	8%	21%	13%	19%	13%	19%	0%	2%
B	55%	62%	57%	55%	34%	45%	34%	45%	0%	5%
C	74%	67%	66%	60%	68%	43%	72%	52%	0%	7%
A2	67%	100%	50%	67%	67%	50%	67%	50%	0%	50%

Note. IP = intervention priority, TR = trained, UT = untrained, C = control.
*S = significant, I = Insignificant, MSMP = motor-speech-movement-parameters, PA = perceptual accuracy.

Intervention priority one (Mandibular control): Trained speech probes.

Figure 4.28 illustrates P6's performance on both parameters, across the four phases of the study, during production of the trained speech probes for intervention priority one.

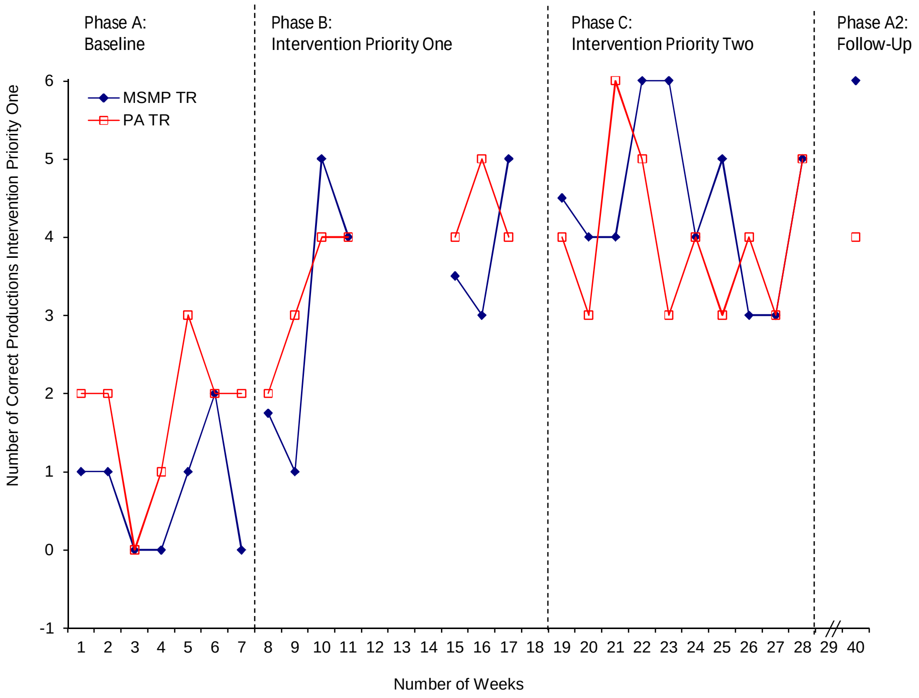


Figure 4.28. P6's performance on the motor-speech movement patterns (MSMP) and perceptual accuracy (PA) on the trained word-sets for intervention priority one.

Phase A1: Both parameters met stability criteria.

Phase B: An overall increasing trend direction between phase A1 and B is observed, with a mean performance increase of 43% and 33% on the MSMPs and PA recorded, respectively. These results indicate a positive treatment effect for intervention priority one: mandibular control.

Phase C: Both parameters show a slightly decreasing trend direction with a 19% and 5% increase in performance level in the MSMPs and PA, respectively between phase B and C. These results demonstrate skill maintenance on the first intervention priority (mandibular control) during training of the second intervention priority (labial-facial control).

Phase A2: A positive treatment effect is indicated by a mean performance increase between phases A1-A2 of 55% and 71% in the MSMPs and PA, respectively. Skill maintenance between phases C-A2 is indicated in the MSMPs despite a mean performance decrease of 7%. Continued improvement in PA was recorded during the 12-week post-intervention period with a 33% increase in performance recorded.

Intervention priority one (Mandibular control): Untrained speech probes.

Figure 4.29 illustrates P6's performance on both parameters across the four phases of the study, during production of the untrained speech probes for intervention priority one.

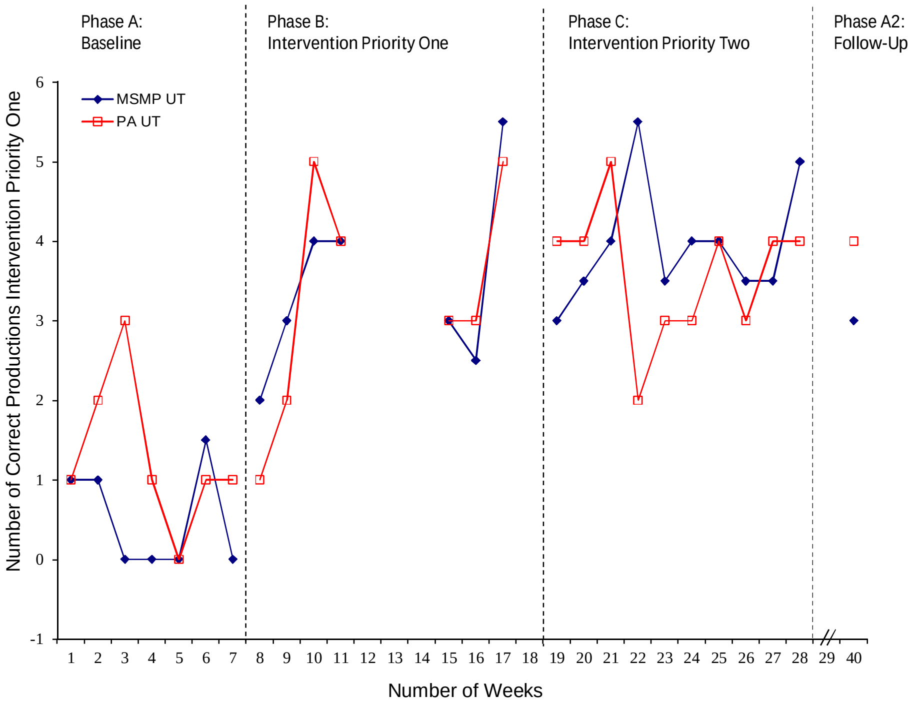


Figure 4.29. P6's performance on the motor-speech movement parameters (MSMPs) and perceptual accuracy (PA) on the untrained speech probes for intervention priority one.

Phase A1: Both parameters met stability criteria with a decreasing trend direction on PA. Greater PA was recorded with a 13% performance difference between the two parameters.

Phase B: An increasing trend direction and mean performance increase of 49% and 34% on the MSMPs and PA respectively, indicates skill generalisation to the untrained speech probes on intervention priority one: mandibular control.

Phase C: Reveals a flattening in the angle of the slope for both parameters. The MSMPs maintained an increasing trend direction, whilst the PA recorded a slightly decreasing but generally stable trend direction. The data demonstrate consistency with the trained speech probes and suggest skill stabilisation.

Phase A2: A positive treatment effect is indicated by a mean performance increase between phases A1-A2 of 42% and 46% in the MSMPs and PA, respectively. Skill maintenance between phases C-A2 is indicated in the MSMPs despite a mean performance decrease of 16%. Continued improvement in PA was recorded during the 12-week post-intervention period with a 7% increase in performance recorded.

Intervention priority two (Labial-facial control): Trained speech probes.

Figure 4.30 illustrates P6’s performance on both parameters across the four phases of the study, during production of the trained speech probes for intervention priority two.

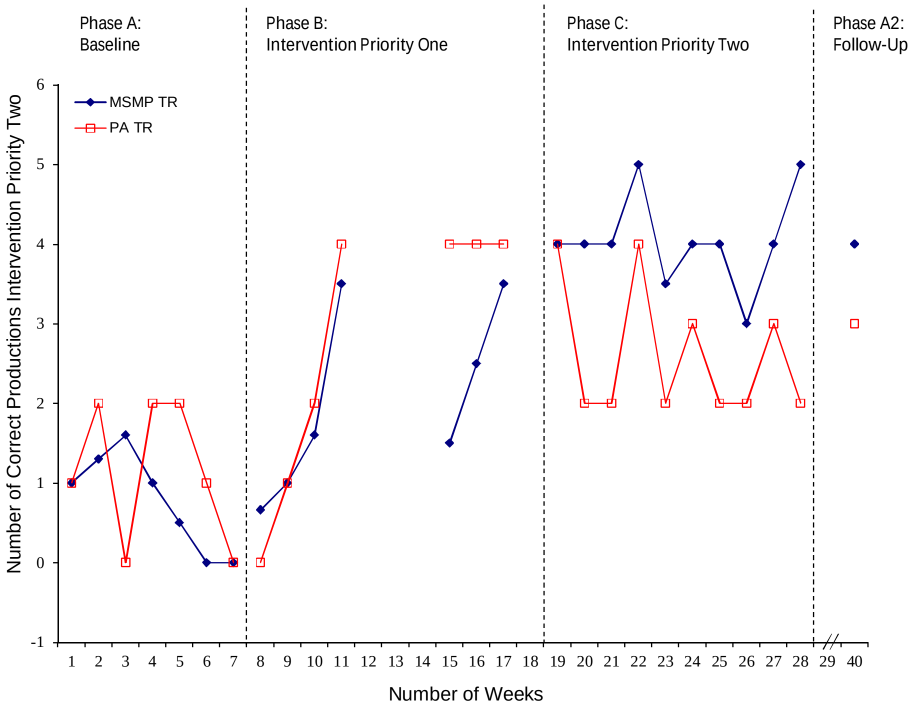


Figure 4.30. P6's performance on the motor-speech movement parameters (MSMPs) and perceptual accuracy (PA) on the trained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria with a decreasing trend direction.

Phase B: A change to an increasing trend direction for both parameters with a mean performance increase of 21% and 26% on the MSMPs and PA. The data indicate a positive treatment effect on both parameters of intervention priority two (labial-facial control) whilst intervention targeted intervention priority one (mandibular control).

Phase C: A flattening in the angle of the slope and reduced variability in the MSMP data was recorded between phase B and C. A mean performance increase of 34% and 80% non-overlapping data indicates a positive treatment effect on the MSMPs of intervention priority two (labial-facial control) when intervention targeted this priority. A flattening in the angle of the slope and change in trend direction in PA, between phase B and C, is also recorded. A 2% mean decrease in performance level and complete overlapping of data indicate no real change in performance between phase B and C. These results suggest maintenance of the skills obtained in phase B.

Phase A2: A positive treatment effect is indicated by a mean performance increase between phases A1-A2 of 54% and 31% in the MSMPs and PA, respectively. Skill maintenance between phases C-A2 is indicated in the MSMPs despite a mean performance decrease of 1%. Continued improvement in PA was recorded during the 12-week post-intervention period with a 7% increase in performance recorded.

Intervention priority two (Labial facial control): Untrained speech probes.

Figure 4.31 illustrates P6’s performance on both parameters across the four phases of the study, during production of the untrained speech probes for intervention priority two.

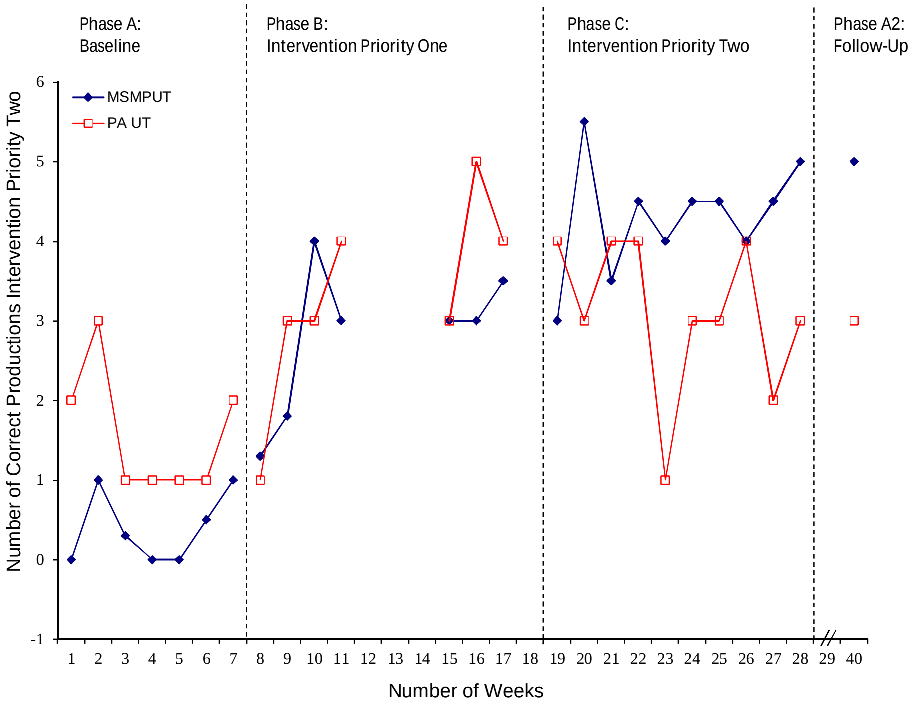


Figure 4.31. P6's performance on the motor-speech movement parameters (MSMPs) and perceptual accuracy (PA) on the untrained speech probes for intervention priority two.

Phase A1: Both parameters met stability criteria. PA exceeds MSMPs by 6% which is consistent with the data of the trained speech probes.

Phase B: An increasing trend direction for both parameters with a mean performance increase of 21% and 26% on the MSMPs and PA respectively, is indicated. The data indicate a positive treatment effect with generalisation to both parameters of the untrained speech probes for intervention priority two (labial-facial control) whilst intervention targeted intervention priority one (mandibular control).

Phase C: The increasing trend direction on the MSMPs continued in phase C with reduced slope in the angle. A mean performance increase of 38% a positive treatment effect occurred on the MSMPs when intervention targeted the labial-facial parameters. A 7% increase in PA accuracy was recorded suggesting stabilisation of the PA.

Phase A2: A positive treatment effect is indicated by a mean performance increase between phases A1-A2 of 54% and 31% in the MSMPs and PA, respectively. Skill maintenance between phases C-A2 is indicated in MSMPs and PA despite a mean performance decrease of 5% and 2% respectively.

Intervention priority three (Lingual control): Control speech probes.

Figure 4.32 illustrates P6's performance on both parameters of the untrained intervention priority three speech probes, across the four phases of the study.

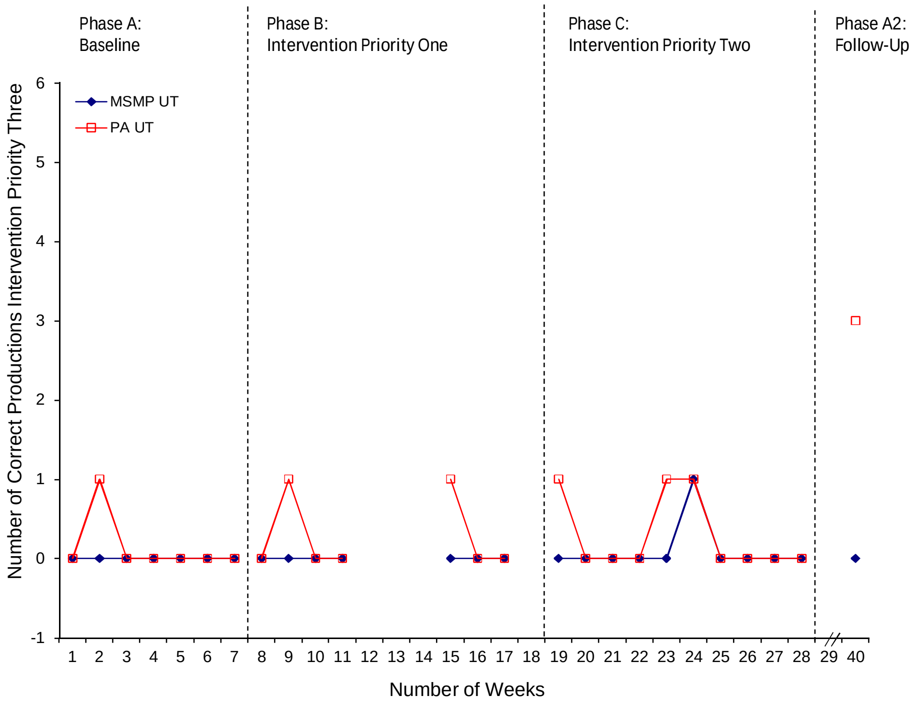


Figure 4.32. P6's performance on the motor-speech movement parameters (MSMPs) and perceptual accuracy (PA) on the control speech probes for the untrained intervention priority three.

Phase A1: Both parameters met stability criteria.

Phase B: No real change in performance was recorded on the MSMPs and PA of the control speech probes during this phase.

Phase C: No real change in performance was recorded on the MSMPs and PA of the control speech probes during this phase.

Phase A2: A positive treatment effect is indicated in PA during the 12-week post-intervention period with a mean performance increase between phases C-A2 of 43%. No treatment effect was recorded in the MSMPs.

Statistical data.

Change in level.

The data in Table 4.35 indicate P6 achieved a significant change in performance level on the trained and untrained speech probes for both parameters of intervention priority one (mandibular control). This occurred during phase B (intervention block one) when intervention targeted this priority. A significant change in performance level was also recorded in the MSMPs of intervention priority two (labial-facial control) during phase C (intervention block two). The change in the PA of intervention priority two did not reach significance until phase A2 (follow-up). No change in performance was observed on the control goal throughout the phases of the study. The data are further supported by the effect size data obtained using a modified Cohen's d, as illustrated in Table 4.36. A large effect size is seen in both parameters on the trained and untrained speech probes of intervention priority one during phase B. A large effect size is also seen on the MSMPs of intervention priority two during phase C.

Table 4.35

Summary of the Two-Standard Deviation Band Analysis on the Speech Probes across the Study Phases for P6

	IP 1 Mandibular				IP 2 Labial-Facial				IP 3 Lingual	
Phase	TR		UT		TR		UT		Control	
	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A1→B	*S	*S	*S	*S	I	*S	*S	I	I	I
NAL	5	5	7	6	3	4	6	4	1	2
CNAL	3	3	4	3	2	3	3	2	0	0
A1→C	*S	*S	*S	*S	*S	I	*S	I	I	I
NAL	10	6	10	9	10	4	10	4	0	4
CNAL	10	2	10	6	10	0	10	0	0	2
B→C	I	I	I	I	I	I	I	I	I	I
NAL	0	1	0	1	2	0	2	0	0	0
CNAL	0	0	0	0	0	0	0	0	0	0
A1→A2	*S	*S	*S	*S	*S	*S	*S	*S	I	I

Note. IP = Intervention Priority, MSMP = motor-speech-movement-parameter, PA = perceptual accuracy, TR = trained, UT = untrained.
*S = *Signficant, I = Insignificant

Table 4.36

Effect Size Data on the Speech Probes across the Phases of the Study for P6

	PHASE B					PHASE C				
	IP 1 Mand		IP 2 LF		IP 3 Ling	IP 1 Mand		IP 2 LF		IP 3 Ling
	TR	UT	TR	UT	C	TR	UT	TR	UT	C
MSMP	2.2	3.1	1.4	3.3	0.5	0.9	0.5	2.0	1.7	-0.5
PA	2.1	1.8	1.2	1.6	0.3	0.2	0.1	0.1	-0.3	0.2

Note. IP = Intervention Priority, TR = trained, UT = untrained, MSMP = motor-speech-movement-parameter, PA = perceptual accuracy, Mand = Mandibular, LF = Labial-Facial, Ling = Lingual.

Change in trend and slope.

The data in Table 4.31 indicate a significant change in trend and slope was achieved on the trained and untrained speech probes for both parameters of intervention priority one (mandibular control). This occurred during phase B (intervention block one) when intervention targeted this priority. A significant change in trend and slope was also recorded in the MSMPs of intervention priority two (labial-facial control) during phase C (intervention block two). The change in the PA of intervention priority two was significant on the trained speech probes in phase C; and the untrained speech probes in phase B and C. No change in slope and trend was observed on the control goal throughout the phases of the study.

Table 4.37

Summary of the Split-middle and Binomial Test on the Speech Probes across the Study Phases for P6

Phase	IP 1 Mandibular				IP 2 Labial-Facial				IP3 Lingual	
	TR		UT		TR		UT		C	
	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA	MS MP	PA
A→B	*S	*S	*S	*S	I	*S	*S	*S	I	I
A→C	*S	*S	*S	*S	*S	*S	*S	*S	I	I
B→C	I	I	I	I	*S	I	I	I	I	I

Note. IP = Intervention Priority, MSMP = motor-speech-movement-parameter, PA = perceptual accuracy, TR = trained, UT = untrained, C = control
*S = *Signficant, I = Insignificant

Overall summary of P6's speech production accuracy (Speech probes).

The above results indicate P6's intervention program was successful in effecting positive changes in the MSMPs and PA in intervention priority one, with transfer of the learned behaviours to the untrained speech probes. Significant changes were also observed in the MSMPs of intervention priority two. However, the PA of intervention priority two was not observed to change significantly until phase A2 (follow-up).

No changes were observed in the control goal (intervention priority three: lingual control) across the phases of the study.

Summary Overview All Participants

The speech probe data is summarised in Figures G1 to G6 (Appendix G) for each of the participants across the study phases: baseline, two intervention phases and follow-up. Data for the MSMPs and PA for each intervention priority are presented in separate graphs, ordered from top to bottom with the first intervention priority presented at the top, second intervention priority in the middle and the third control at the bottom.

First the data pertaining to the MSMPs will be reported, followed by the data pertaining to PA.

The data indicate, although different patterns of improvement are observed, a positive treatment effect is evident for all participants.

Motor speech movement patterns.

Intervention priority one.

Visual inspection of the data show participants demonstrated low and stable baselines across all behaviours prior to the initiation of intervention. The average of the mean performance scores for intervention priority one was 10% with a range of 6% to 13% across the participants.

With the initiation of the PROMPT intervention, the average of the mean performance scores for the trained intervention priority one in phase B (block one) was 50%, with a range from 38% to 65% across the participants.

The gains in the MSMPs that were recorded in the first intervention phase (phase B) were maintained in the second intervention phase (phase C). The average of the mean performance scores in phase C was 65%, with a range of 41% to 82% across the participants.

These data suggest a positive treatment effect on intervention priority one.

Intervention priority two.

Visual inspection of the data show participants demonstrated low and stable baselines across all behaviours prior to the initiation of intervention. The average of the mean performance scores for intervention priority two was 6% with a range of 0% to 13% across the participants.

With the initiation of the training of intervention priority one in phase B (block one), the average of the mean performance scores for the trained intervention priority two increased to 21%, with a range from 8% to 36% across the participants.

With the initiation of the training of intervention priority two in phase C (block two), the average of the mean performance scores further increased to 51%, with a range from 11% to 69% across the participants.

These data suggest a positive treatment effect on intervention priority two.

Control goal.

Visual inspection of the data show participants demonstrated low and stable baselines across all behaviours prior to the initiation of intervention. The average of the mean performance scores for the control goal was 1% with a range of 0% to 3% across the participants.

No significant changes were recorded in the control goal during the phases of the study.

Perceptual accuracy.

Intervention priority one.

Visual inspection of the data shows all participants demonstrated low and stable baselines across all behaviours prior to the initiation of intervention.

Visual inspection of the data show PA exceeded performance in the MSMPs for all participants. Low and stable baselines were recorded, with an average of the mean performance scores of 29%, with a range from 7% to 47% across the participants.

With the initiation of the PROMPT intervention, the average of the mean performance scores for the trained intervention priority one in phase B (block one) increased to 57%, with a range from 25% to 81% across the participants.

The gains recorded in the first intervention phase increased in the second intervention phase (phase C). The average of the mean performance scores was 71%, with a range of 43% to 90% across the participants.

These data suggest a positive treatment effect on intervention priority one.

Intervention priority two.

Visual inspection of the data show participants demonstrated low and stable baselines across all behaviours prior to the initiation of intervention. The average of the mean performance scores for the trained intervention priority two was 20%, with a range of 0% to 42%. Five of six participants recorded a range of 0% to 23%.

With the initiation of the training of intervention priority one in phase B (block one), the average of the mean performance scores for intervention priority two increased to 40%, with a range from 15% to 63% across the participants.

With the initiation of the training of intervention priority two in phase C (block two), the average of the mean performance scores slightly increased to 54%, with a range from 35% to75% across the participants.

These data suggest the greatest magnitude of change in PA occurred in phase B (block one) for intervention priority two.

Control goal.

Visual inspection of the data show participants demonstrated low and stable baselines across all behaviours prior to the initiation of intervention. The average of the mean performance scores for the control goal was 5% with a range of 0% to 10% across the participants.

With the initiation of the training of intervention priority one in phase B (block one), the average of the mean performance scores for the control goal increased slightly to 10%, with a range of 3% to 18% across the participants.

With the initiation of the training of intervention priority two in phase C (block two), the average of the mean performance scores slightly increased to 12%, with a range of 5% to19% across the participants.

These data suggest a slight shift in the PA of the control goal.

Phonetic Accuracy

In this section the data for dependent variable two (phonetic accuracy) is presented first as individual data across the study phases as illustrated in Figure 4.33. This is followed by the statistical analyses of the group data, using a repeated measures ANOVA.

The data for phonetic accuracy was obtained using the wordlist of the Arizona-3 (3rd edition) (Fudala, 2000). The test was administered prior to baseline data collection (pre- Phase A), at the end of intervention blocks one and two (end of Phase B and C), and on two occasions at follow-up (phase A2): 6-8 weeks post-intervention (subsequent to the motion analysis) and again at 12 weeks intervention (subsequent to speech probe data collection).

Each word on the Arizona-3 word-list was transcribed using narrow phonetic transcription. Percentage phonemes correct (PPC) (Shriberg and Kwiatkowski, 1982) scores were calculated by awarding a point for each consonant and vowel spoken correctly. The number of correct phonemes was tallied and divided by the total number of consonants and vowels of the word-list.

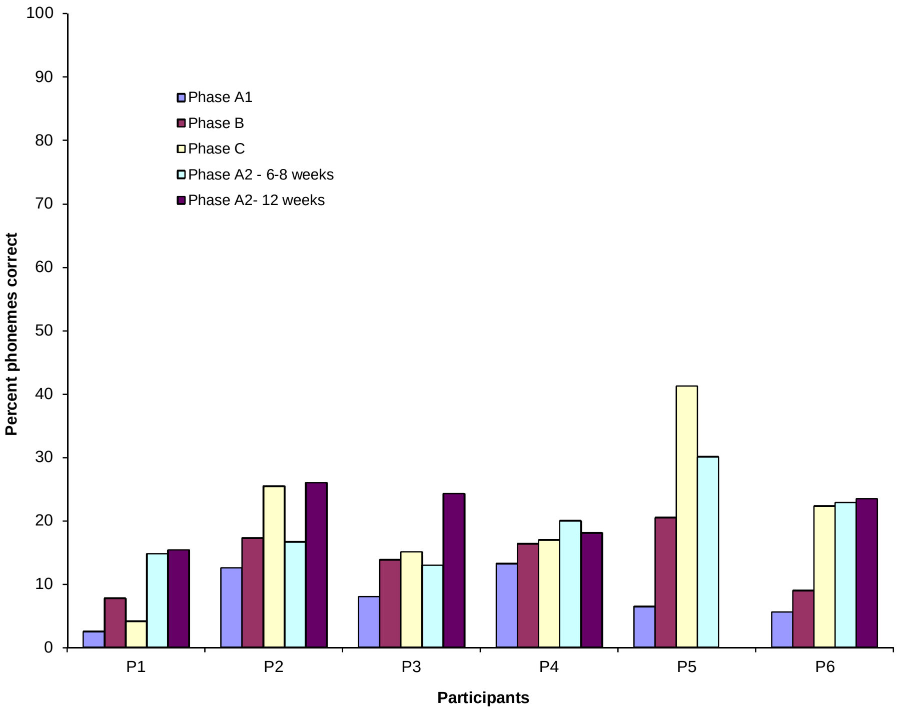


Figure 4.33. Percentage phonemes correct (PPC) for each participant across the phases of the study.

The data illustrated in Figure 4.33 show all participants recorded an increase in percentage phonemes correct across the study phases A1-B. This increase continued for five participants (with the exception of P1) between phases B-C. At 6-8-weeks post-intervention three participants continued to record improvements in phonetic accuracy and all participants maintained scores that exceeded pre-intervention scores. At 12-weeks post-intervention all participants recorded scores that were at least commensurate with the scores obtained at the end of phase C (with the exception of P5, due to missing data).

The data from each of the participants were entered into SPSS (version 17) and a repeated-measures ANOVA ($p \leq .05$) performed. Mauchley's test was non-significant thus indicating the assumption of sphericity was not violated $\chi 2(5)=6.46$, $p>.05$.

The results in Table 4.32 show a statistically significant increase in percentage phonemes correct was obtained $F(3,18) = 5.55$, $p <.05$. Post-hoc comparisons reveal the increases were significant across each of the phases with the exception of between the phases B-C.

The magnitude of the treatment effect was evaluated using the Cohen's d effect size, calculated across each of the study phases. The data indicate a cumulative treatment effect across the study phases, with phases A1-A2 recording the largest effect size.

Table 4.38

Summary of the Repeated Measures ANOVA, Estimated Percentage Increase in Performance and Effect Size Data for the Percentage Phonemes Correct across the Study Phases

Phase	*p*	df	F	Estimated % increase	Effect size
A1-B	0.007	1,6	16.109	74%	0.98
A1-C	0.026	1,6	8.676	127%	1.33
A1-A2	0.017	1,6	10.647	103%	1.74
B-C	0.187	1,6	5.466	28%	0.50

Motor-Speech Control

In this section the data for dependent variable four (motor-speech control) is presented as individual data.

The Verbal Motor Production Assessment for Children (VMPAC) (Hayden & Square, 1999) assesses five areas of motor speech control: 1. Global Motor Control, 2. Focal Control, 3.Sequencing, 4. Connected Speech and Language Control, and 5. Speech Characteristics. Each area is scored to yield a percentage correct score.

The test was administered on two occasions: prior to the commencement of the baseline data collection (pre phase A1) and again at 6-8-weeks follow-up (phase A2).

Figure 4.34 summarises the pre (prior to phase A1) and post-intervention (Phase A2) performance scores obtained by each of the participants on each subtest of motor-speech-control. Each motor-speech-control score is represented on the Y axis to a maximum possible score of 500% (i.e., 5 x 100%).

Whilst the profiles of improvement are different for each participant, three areas recorded the most change overall: speech characteristics, sequencing and focal oromotor control. Minimal change was observed in the area of connected speech and language control, with one participant each recording a positive (participant five) and negative (participant four) change.

No change was expected in the area of global motor as this area assesses tone, reflexes and vegetative functions. P5 and P6 demonstrated a 5% improvement in this area. Review of the raw data indicated this improvement occurred as a result of improved control in sequential swallowing during drinking. The two youngest participants demonstrated the most improvement – P5 improved in all five areas, whilst P6 improved in four. P4 demonstrated the least change, recording improvement in the area of sequencing control only.

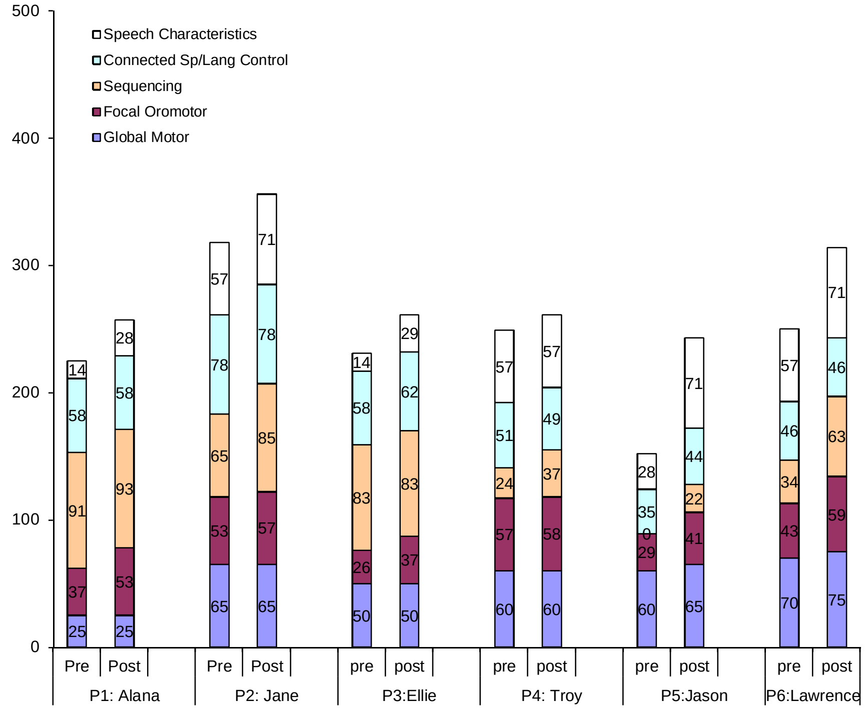


Figure 4.34. Performance scores for each participant in each motor-speech-control area of the verbal motor assessment for children.

Summary Overview of the Perceptual Measures

The results indicate there was a significant change to the perceptual measures subsequent to the PROMPT intervention for all participants. Specifically, the data indicate:

1. A statistically significant increase in performance level for 6/6 participants on the MSMPs of IP1 between phases A1-B; and 4/6 between phases B-C during the training of IP2. The data further show that five participants (P5 has no follow-up speech probe data) achieved a statistically significant increase at 12-weeks post-intervention as compared to phase A1.

2. Four participants achieved a statistically significant increase in performance level in PA on IP1 and IP2 between phases A1-B. Whilst only one participant recorded a statistically significant increase in PA between phases B-C, five participants achieved a statistically significant increase in IP2 between phases A1-C. The data further show all participants achieved a statistically significant increase in PA on both intervention priorities at 12-weeks post-intervention.

3. All participants recorded data that indicated improved phonetic accuracy across the study phases, as indicated by a statistically significant increase in the percentage phonemes correct scores $F(3,18) = 5.55$, $p<.05$.

The magnitude of the treatment effect was evaluated using the Cohen's d effect size, calculated across each of the study phases. The data indicate a cumulative treatment effect for all perceptual outcome measures across the study phases, with phases A1-B and A1-A2 recording the largest effect size.

Discussion

In this section the effectiveness of PROMPT in facilitating changes to the perceptual measurements of speech production and phonetic accuracy of children with CP, are discussed. It was hypothesised that therapy aimed at maximising motor speech control would improve the speech production accuracy in children with moderate-to-severe speech impairment.

Speech Production Accuracy

The findings of this study show all participants recorded substantial change in speech production accuracy. Speech production was assessed for both perceptual accuracy (PA) and attainment of the targeted motor-speech movement pattern (MSMP) using weekly speech probes. All participants recorded changes on the trained and untrained speech probes for the intervention priorities targeted during both intervention phases of the study. There was no significant change to the control word-sets thus providing evidence that the changes in perceptual accuracy and motor speech movement patterns were due to the therapy and not as a result of maturation or chance.

The use of a SSRD, with two inter-hierarchical phases of intervention, has provided the opportunity to evaluate the time course of motor learning in terms of skill acquisition, consolidation, savings and interference to achieve accurate speech production (Doyon, 2008; Kostrubiec et al., 2006; Landi et al., 2011; Luft & Buitrago, 2005; Savion-Lemieux & Penhume, 2010; Schmidt & Lee, 2005; Shumway-Cook & Woollacott, 2012; Zanone & Kelso, 1997). Specifically, the initial relatively short-term skill acquisition of the first intervention priority in intervention block one was compared to the ongoing skill acquisition/consolidation of that same skill, during a second intervention phase that targeted a second intervention priority. The subsequent introduction of a second intervention priority during the second intervention phase presented the opportunity to make observations regarding anterograde interference. Anterograde interference is the effect of therapy on the first intervention priority during the training of the second intervention priority. The weekly speech probes collected at the end of each treatment session in this study allow for evaluation of variability/stability in performance between treatment sessions across the study phases.

Intervention priority one.

Phase B: Change in rate and performance level.

The results, obtained on the first intervention priority in the first intervention phase (phase B) show all participants with the exception of P1, recorded relatively rapid short-term gains. This was indicated by the steeply accelerating trend in the celeration line (SM binomial) of the data for five participants (P2-P6). The results for one participant (P1) suggest delayed skill acquisition with limited change from baseline data until week eight, where a rapid gain followed by gradual skill acquisition was observed. All participants recorded a significant change in performance level of the MSMPs as demonstrated using the 2SD band method, whilst 4 of the 6 participants (not P4 and P5) also recorded a significant change in performance in PA.

The results of this study are similar to the two patterns of motor learning reported in intervention studies aimed at developing complex motor control skills in children with cerebral palsy (Logan et al., 2008; Love, 1992; Newell, 2003). The first pattern, defined by an initial rapid and immediate change followed by incremental improvement, was observed in P2 through P6. The second pattern, defined by small and gradual change that continues throughout the intervention phase, was observed in P1 who differed from the other participants in terms of diagnosis, age and intervention priorities targeted.

The data for one of the participants (P6) supported the notion of prior experience laying down a memory that allowed for faster subsequent re-learning or what the literature refers to as “savings”(Landi et al., 2011; Seidler & Noll, 2008; M. A. Smith et al., 2006). The observation of the phenomenon of savings in this study arose as a consequence of this participant missing three successive intervention sessions due to a family vacation. Upon resumption of therapy, this participant recorded results that exceeded the performance level of the initial four sessions recorded prior to going on vacation. Barnes and Whinnery (2002) also report similar data on one participant who showed progress beyond results obtained during initial training, upon resumption of training after a break in intervention.

Two different theoretical perspectives are offered in this thesis for the interpretation of savings. Smith et al. (2006) suggest the rapid short-term acquisition phase and ability for retention can be attributed to a rapid two-state model of adaptation. This two-state model of adaptation consists of an initial process that shows a strong adaptive response by the end of initial training but does not retain information well. The second, faster adaptive process shows little adaptation by the end of initial training but has a strong retention of information. With initial learning of a task it is hypothesised that both of these processes are operating at zero. When re-learning a task, the internal model is not at zero because the second adaptive response has retained some memory and is therefore already biased to learning.

The second model, based on the work of Huang, Haith, Mazzoni and Krakauer (2011) suggests the process of faster relearning is not a consequence of adaptation but rather a result of additional processes related to use-dependent plasticity and reinforcement. They propose a model of relearning that focuses on the retention of motor memories due to reinforcement as a consequence of successful target attainment.

Despite the lack of a consistent interpretation regarding the underlying processes, the observation of savings in the data set was unexpected given the literature reports children with CP are less successful in learning sequences and take longer to learn tasks (Gagliardi, Tavano, Turconi, Pozzoli, & Borgatti, 2011). Indeed, Garvey (2007) suggests off-line learning is probably absent in children with CP. However, the data recorded by P6 suggests it is possible for children with CP to not only achieve relatively rapid adaptation to the new motor task after four weeks of intervention but also show evidence of faster re-learning upon resumption of therapy.

There is a paucity of, as well as diversity in the design of, experimental speech treatment studies investigating the efficacy of intervention for children with CP. This makes it difficult to benchmark the *rate* of change observed in the dependent variables of this study against other experimental studies aimed specifically at speech production. For example, whilst Marchant, McCauliffe and Huckabee (2008) conducted an ABACA design aimed at improving the speech intelligibility of a single participant with spastic quadriparesis CP, the study differed in intensity and therapy type. In addition, the absence of longitudinal graphs (only means and standard deviations were reported) makes it difficult to visually inspect the data to compare the rate of change. Wu and Jeng (2004) also report on the effects of a motor based intervention in a single subject with CP, aged 11 years. However, whilst they provide graphs of the intervention phase no data are shown or reported for the baseline phase, thus making it difficult to interpret the effects of intervention and rate of change.

One motor-speech SSRD intervention study, conducted by Strand, Stoekel and Baas (2006), despite targeting a different clinical population (childhood apraxia of speech), is relevant to this thesis for two reasons. Firstly, the motor speech treatment approach under investigation applied tactile-kinaesthetic input (dynamic temporal and tactile cueing). Although this technique differs from PROMPT it does emphasise the "shaping of movement gestures for speech production" (p. 298), that is, the use of tactile input to guide articulatory movements. Secondly, one of the four participants of the study presented with a concomitant diagnosis of dysarthria (in the absence of a diagnosis of CP). Though the data reported on the participant of interest to this study are limited to eight words, visual inspection of the illustrated graphs by this author, seems to also suggest two patterns of learning that appear related to word complexity. That is, the words "no", "pooh", "dad", "hi" and "what" are single syllable words that could arguably be produced predominately through one plane of movement (mandibular or labial-facial). Performance on these words suggest an initial decrease subsequent to the initiation of intervention, followed by a rapid phase of acquisition that slowed to incremental gain on the words "dad" and "hi". In contrast the word "honey" and the phrase "I do" indicate a slower more gradual process of acquisition. Strand et al. (2006) report targeting improved mandibular and labial facial control for the production of CV configurations in this participant. Given this, it is conceivable that these two stimuli required a higher level of articulatory co-ordination and represented a higher level of complexity, requiring integration of planes of movement (mandibular, labial-facial or lingual). This interpretation of the data reported in the study by Strand et al. (2006) is consistent with the findings reported in this thesis.

Possible explanations for the different patterns of learning in children with CP could be linked to severity, diagnosis, age of the individual or any non-linear combination of these. Shumway-Cook et al. (2003) suggested the two patterns of motor learning observed in their study were associated with the level of disability. In their study the two participants rated level I on the GMFCS (the least severe) with spastic hemiplegia showed rapid change, whilst three participants rated at level II with diplegia showed gradual improvement. Similarly in this thesis, the participant to record the most gradual change was rated level III on the GMFCS, had the severest global motor score on the VMPAC, a diagnosis of athetosis and in addition was the oldest participant. It is also possible that the pattern of learning is influenced by age. For example, one of the younger participants in this thesis recorded a rapid profile of change. In contrast to the data reported by Shumway-Cook (2003), P3 had a diagnosis of spastic quadriparesis and was rated level II on the GMFCS. P3 also had the second lowest global motor score on the VMPAC. These data indicate a complicated and non-linear relationship to the process of skill acquisition in individuals with neurologic impairment. Future research in this area could further elucidate these results.

Phase C: Consolidation.

The hypothesis that training the second intervention priority in phase C would not interfere with consolidation of the earlier trained behavior (intervention priority one) in phase B was supported. During phase C, when intervention priority two was targeted, the overall pattern observed in the data for intervention priority one was consistent with a phase of consolidation. This was indicated by a decrease in the steepness of the slope, small incremental gains in performance level and increased stability in the data.

The results obtained in phase C are discussed within the context of resource allocation as well as the role of tactile-kinaesthetic input. In this study, resource allocation is considered in terms of both cognitive attention required for the task and strength of coupling between the existing and "to-be-learned" behavior (Temprado et al., 2001).

Learning a sequenced task (as is required in speech) involves consolidation of both explicit and implicit components of the task, with these two components operating on different time scales (Ghilardi, Moisello, Silvestri, Ghez, & Krakauer, 2009). The literature suggests children with CP are less successful than TD peers in learning sequences due to increased cognitive demands that contributed to impaired implicit and explicit memory skills (Ghilardi et al., 2009).

Empirical evidence to support the hypothesis that training one intervention priority at a time has the benefit of decreasing the cognitive load can be found in coordination studies. For example, the work of Serrien (2009) provides evidence that attending to two tasks during the rapid acquisition phase can create competition between the existing skill and the new to be-developed skill. She explored the competition between new (2:1 finger-tapping task) and existing (1:1 in/anti-phase finger task) dynamics in a bimanual finger-tapping task, using two experimental conditions with an ABA design.

The results of the study by Serrien (2009) show that whilst both groups recorded significantly improved performance in the training task, the participants that had their training schedules interrupted with another task (that consisted of an already acquired behaviour) were less accurate. The interpretation of this finding was that competition occurred as a result of attending to two tasks.

It is noted that the tasks used in the study described above do not require the same degree of complexity as is required for speech. Speech is a highly complex task that involves precise, rapid and complex goal-oriented behaviours with many potential degrees of freedom of movement, with interleaving between different articulators (Saltman and Munhall, 1989). Further, the work of speech scientists have demonstrated that motor performance is affected not only by cognitive processes but also by the complexity of the language demands (Maner, Smith, & Grayson, 2000; Nip, Green, & Marx, 2009; Nip et al., 2011).

Despite the lesser complexity of these experimental tasks compared to speech, the findings do provide support for the interpretation that training the second intervention priority separately, as opposed to interweaving the two intervention priorities in the same phase, promoted stabilization due to minimization of competing resource allocation.

Further, empirical data indicates the greater the coupling (intrinsic biomechanical properties, cognitive demands and task constraints) between the existing (intervention priority one) and new behaviour (intervention priority two), the greater the resistance to interference (Temprado et al., 2001). The speech science literature supports the notion of a lower order jaw/lip and higher order lip aperture synergy (Smith & Zelaznik, 2004). It is possible that the interarticulator coupling and use of tactile-kinaesthetic input to control the degrees of freedom of movement, promoted consolidation.

It is proposed that the tactile-kinaesthetic input provided in this study served to stabilise the first intervention priority (as shown by the small incremental gain and decrease in variability) whilst destabilising the second intervention priority, to facilitate a phase shift toward a transition of change. Kelso, Fink, DeLaplain, &

Carson (2001) state “coupling specific aspects of an individual movement to specific sensory information from the environment serves to stabilise coordination globally” (p. 1210). They report haptic information serves to stabilise movement patterns in one training condition, whilst destabilising in another condition. The data from this study are consistent with this statement.

Further research aimed at evaluating single versus concurrent acquisition would further our knowledge pertaining to competing attention in skill acquisition in children with CP. It is well recognised that the type of training schedule affects motor learning (Lee, Wulf, & Schmidt, 1992; Maas et al., 2008; Schmidt & Lee, 2005; W. F. W. Wu et al., 2011). Whilst the literature also provides evidence to support concurrent skills training, there are limited data available that examines schedules of motor skill learning in children with CP. Recently, Wambaugh and Mauszycki (2010) reported evidence of over-generalisation in a participant with acquired apraxia of speech, subsequent to dual skills training. They postulated impaired sensory motor integration may have attributed to over-generalisation observed in the participant in their study. Given children with CP present with impaired sensory motor integration, this needs to be further examined when considering intervention protocols.

Intervention priority two.

Phase B: Change in rate and performance level.

Visual inspection of the speech probe data during phase B indicates that the training of intervention priority one affected the performance of intervention priority two during this phase. Two participants (P4 and P5) recorded a significant change in performance level to the MSMPs of IP2, whilst four participants recorded a significant change in PA (P2, P3, P4 and P6). Further, the data shows increased variability in comparison with the baseline phase.

Evidence also exists that suggests increased generalisation should be expected when training movements that are close together and involve similar patterns of muscle activation (Mattar & Ostry, 2007). The results observed in this study support these findings for the four participants who were directly targeted for mandibular control (intervention priority one). Empirical data indicates the jaw is the primary articulator, with early lip movements tied to mandibular control in early motor development (Green et al., 2000; Green et al., 2002; Walsh et al., 2006).

Perturbation studies have also demonstrated that perturbation of the jaw will cause compensatory changes to the lips. It was therefore hypothesised that improving and refining control of the mandible would result in changes at the labial-facial level of control.

Additional support for the interpretation that movements that involve similar patterns show better generalisation is also found in the data recorded for P1. This participant commenced training at the labial-facial level of control (IP1). The second intervention priority targeted lingual control. Her data show that whilst there was an increase in the variability of IP2 during the training of IP1, there was no change in performance level or trend direction. As explained by Mattar & Ostry (2007), it may be that the patterns of muscle activation were too dissimilar and thus generalisation was less.

Phase C: Interference.

The changes observed in intervention priority two in phase C are interpreted with reference to behavioural studies that have explored the effect of anterograde interference on motor learning (Abel & Lattal, 2001; Doyon, 2008; Kelso & Zanone, 2002; Krakauer, Mazzoni, Ghazisadeh, Ravindran, & Shadmehr, 2006; Sing & Smith, 2010). Anterograde interference refers to the process by which learning a novel task (task B) is influenced by the previously learned behaviours (task A). Of particular interest to this thesis are the data reported by Sing and Smith (2010) that suggest the learning of a subsequent task may proceed more slowly than the previously trained task. Visual inspection of the data during the training of the second intervention priority (phase C), show the maximum performance level achieved was 67% for MSMPS and 75% for PA on the trained word set. Whilst the change in performance level was statistically significant for 5 participants, the level of performance and rate of learning on IP2 was less than IP1 for all participants in this study. These results are therefore consistent with findings reported in the literature.

Two possible explanations for interference include the level of skill mastery and the effect of task similarity. Sing and Smith (2010) found that duration of training, and not necessarily the level of mastery, had a significant impact on the degree of interference. They state “the amount of anterograde interference depends systematically on the strength of a particular component of the initial adaptation rather than on the total amount of adaptation that is achieved” (p. 2). Specifically, the group of participants in their study that had more training trials (230-trial group) had more interference than the group that received less training (13-trial group), even though this group had recorded a lower level of mastery.

The data from this thesis challenge the application of high level skill mastery as a criterion for continuing or terminating intervention. Typically the success of an intervention program is based on performance mastery, with a mastery criterion typically of approximately 80% - 90% applied before proceeding to the next intervention phase (Katz & McNeil, 2010; Marchant et al., 2008; Powell, Elbert, Miccio, Strike-Roussos, & Brasseur, 1998; Williams, 2000). This thesis differed in that an a priori decision was made to continue intervention regardless of performance gain (Gierut, 1998). None of the participants recorded performance mastery of the MSMPs above 66% in IP1. However, all participants with the exception of P4 made progress on IP2. In addition, there was minimal interference on IP1. It is therefore interpreted that a mastery of 80% accuracy is not a requirement for moving to a second intervention priority. In fact, it could be argued that setting a criterion of mastery too high could interfere with the mastery of a second higher-order skill. These results support the statement of Rvachew, Rafaat and Martin (1999) that “it is unnecessary and inefficient to treat an individual target sound continuously *until mastery is achieved* [emphasis added]” (p. 33).

A second explanation for the observation of minimal interference is based on evidence that suggests learning both requires and results in the modification of pre-existing behaviours (Kelso & Zanone, 2002). Thus, the learning of a new task may be expected to either cooperate or compete with existing behaviours. A “to-be-learned behaviour” that cooperates with a previously learned behaviour is expected to increase the rate of learning as a result of a reduction of competition between task requirements.

The data from this thesis indicate that the training of intervention priority one was a cooperative priority to intervention priority two, for the participants who commenced training at the mandibular level of control. Continued improvement to intervention priority two was recorded in five participants, between baseline and the second intervention priority.

An example of how training of a second intervention priority competes with previously learned behaviour is evident in the data from P4. The clinician was required to support mandibular stability for P4 whilst targeting labial-facial control.

This participant recorded data that showed rapid but variable skill acquisition in the first intervention priority, with a mean performance increase of 44% and 18% on the MSMPs and PA, respectively. During the training of the second intervention priority, the first intervention priority maintained a variable pattern of performance, with a slight decrease in the trend direction. No real change was observed in the performance accuracy of the second intervention priority in this phase. Thus the data from this participant supports the notion that training of the first intervention priority was successful because the muscles of activation were similar, however the second intervention priority (lingual control) introduced patterns of activation that were too dissimilar and contributed to resource competition.

Further, the results suggest that changes to the higher order synergy of lip aperture required greater refinement and therefore lagged the MSMP changes. Whilst significant changes in the MSMPs were recorded between phases B-C, changes in PA reached statistical significance between phases A-C for five participants but only one participant recorded a statistically significant change between phases B-C.

Interpretation of the results of this study, as considered within the theoretical perspective framework of dynamic systems theory (and coordination dynamics) suggest the learning of intervention priority two, (for five participants) was sympathetic to the skills acquired in intervention priority one, and therefore promoted learning of the second intervention priority. For one participant, the second intervention priority introduced competition. This perspective supports the results that were obtained not only on the speech production measures discussed here, but also the kinematic measures discussed in further detail in the subsequent section.

The results obtained in this study indicate the need for additional research to further develop our understanding of our ability to predict the influence of interference on motor learning. The role for further research aimed at not only examining the rate and level of performance change, but also potential to influence performance mastery by manipulating time frames within treatment designs requires further investigation.

Phonetic Accuracy

> *"Articulatory imprecision has been reported as the greatest contributor to 'intelligibility'" (Morgan et al., 2007, p. 1183).*

Changes in phonetic accuracy across the phases of this study were evaluated based on a calculation of percentage phonemes correct (PPC). This measure was selected based on the literature that indicates word speech intelligibility can be maximized through improving the phonetic repertoire of speakers (Shriberg & Kwiatkowski, 1982). The PPC measure provides a global assessment of change in the phonetic repertoire of the participants of this study, as opposed to specific changes recorded on the speech probe measures.

All participants in this study recorded improved accuracy in the percentage of phonemes correctly produced subsequent to the PROMPT Intervention. Pre-assessment data for all participants showed significant articulatory impairment with a mean percentage improvement of 10% between phases A1 (baseline) and A2 (follow-up).

The results of this study support the recommendations of early researchers (Dworkin, 1991; Hixon & Hardy, 1964; Murdoch & Horton, 1998) that intervention for children with motor speech disorders associated with CP would benefit from the establishment of appropriate motor speech movement patterns.

The results will be discussed first by considering the role of articulatory complexity in the speech error patterns of individuals with CP; followed by consideration for the implementation of a hierarchical subsystems approach to intervention.

Articulatory complexity.

It is asserted in this thesis that the improved phonetic accuracy recorded in the participants of this study was due to a focus on targeting articulatory complexity at an appropriate level within the motor-speech hierarchy. Support for this hypothesis is grounded in the literature pertaining to the developmental hierarchy of motor speech control and patterns of articulatory imprecision reported in speakers with cerebral palsy.

Kinematic data, obtained by speech scientists (Green et al., 2000; Green et al., 2002) provide empirical evidence that suggests phoneme acquisition follows the hierarchical progression of motor-speech control. For instance, as discussed in the literature review, the mandible has been identified as the earliest developing articulator, pivotal to the development and integration of more complex movements of the lips and tongue (Cheng et al., 2007; Grigos et al., 2005; Riely & Smith, 2003; A. Smith, 1992; A. Smith & Zelaznik, 2004; Terband et al., 2010). Early developmental data indicate bilabial compression is initially achieved through the mechanical action of the jaw. With development, differentiation between the lips and jaw increases with bilabial activity achieved through more refined individual upper and lower lip action.

Examination of the work of early researchers investigating the articulatory precision of speakers with cerebral palsy suggests a pattern of articulatory imprecision related to the physiological complexity (integration of jaw, lip and tongue control) of articulation (Byrne, 1959; Clarke & Hoops, 1980; Clement & Twitchell, 1959; Hixon & Hardy, 1964; Ingram & Barn, 1961; Love, 1992; Milloy & Morgan-Barry, 1990; Platt et al., 1980; Workinger, 2005; Workinger & Kent, 1991). For example, in a study conducted by Irwin (1972), as cited by Love (1992), production of labial phonemes and nasals were reportedly the easiest, whilst dentals, glottals, fricatives and glides were the most difficult. These findings support those reported by Byrne (1959) who also stated the acquisition of the bilabial stops (p, b) and nasals (m, n) in speakers with CP are the easiest to produce. Interestingly, Clements and Twitchell (1959) report speakers with CP demonstrate difficulty with lip compression for bilabials. Although these two statements appear to be in conflict, if considered from a physiological perspective they are compatible. That is, it is possible the bilabials were being produced through the mechanical motion of the jaw. With increased control and refinement, bilabials are produced with active engagement of the lips. The inability to actively engage the lips suggests the use of a lower level movement strategy to produce these sounds. The dominant use of the mandible to achieve lip closure, would limit further integration of movement patterns requiring increased articulatory complexity.

Recent literature has provided data that show speakers with low speech intelligibility will substitute complex sounds with sounds that required lower complexity (H. Kim et al., 2010). Kim et al. (2010) directly researched the role of articulatory complexity and speech intelligibility, and revealed a positive relationship between speech intelligibility and percentage consonants correct, as well as a positive correlation between articulatory complexity and error types. That is, sounds that required a higher level of motoric complexity recorded the most error. Specifically, fricatives, affricates and liquids recording the lowest level of accuracy, whilst nasals and glides were most correct.

Interpretation of the above data suggests that an intervention approach that systematically assesses articulatory complexity within a framework of hierarchical motor-speech control; and utilises that same framework to systematically effect change to the coordinative constraints operating within an individual motor-speech system will be effective in improving speech intelligibility in children with disordered motor-speech control. Thus the data reported above and presented in this research study lend support to a hierarchical subsystems approach to intervention that addresses the motor complexity of the phonetic repertoire; and explain the improved articulatory precision observed in the participants of this study.

The PROMPT approach recognises the relationship between articulatory complexity and the biological/functional constraints impacting on the motor speech control of each individual. Within the PROMPT system the acquisition of bilabial and nasal phonemes would initially be targeted at level III (mandibular control) of the motor speech hierarchy. At this level, bilabial closure would be expected to be achieved through the mechanical motion of the jaw. Phonemes targeted at this level are considered to have less articulatory complexity than sounds requiring independent lip motion (such as f) that are coded at level IV. The more difficult anterior tongue tip sounds are considered to require integration of the jaw, lips and tongue and therefore coded at level V of the MSH. Thus, a child presenting with a motor-speech pattern characterised by ballistic movements driven by the motion of the jaw will be expected to produce particular phonemes with accuracy and misarticulate others that require more complex control and differentiation.

Perceptual accuracy.

Changes to the perceptual signal may be due to changes in any combination of the biomechanical linkages between the mandibular, labial, lingual, laryngeal and pharyngeal muscles. For example, fricatives are regarded as the most complex group of sounds requiring a high level precision within the vocal tract (Honda & Takemoto, 2010; Iskarous, Shadle, & Proctor, 2011).

The complexity of articulation is illustrated in a study by Honda, Takano and Takemoto (2010). They report data that highlight the complex interaction between the jaw, lips and tongue during the production of vowels. For example, production of /i/ requires a high jaw position, labial-facial retraction, and lingual tension that are typically created through co-contraction of the anterior and posterior bundles of the genioglossus muscle. Honda et al. (2010) report when the elevation of the tongue dorsum is achieved through excessive force applied by the posterior bundles of the genioglossus, the anterior bundles of the genioglossus will act to counteract the force. This action will also result in a compensatory decrease in jaw open distance. Honda et al. (2010) report these muscle activation patterns are not represented in the format frequency data on the same timescale. Thus, a complex relationship between vocal tract dynamics, articulatory movements and how this is reflected in the perceptual signal is indicated.

The perceptual data from the speech probes indicates change to the motor-speech movement patterns preceded the perceptual changes. The results support a non-linear articulation-perceptual relationship consistent with dynamic systems theory which predicts a dynamic progression in the coupling of motor control and speech output; such that large changes to the movements of articulators may only create small change in the perceptual signal.

Several possible reasons for delay in the perceptual changes are considered. Firstly, the perceptual shift may not have been perceivable. Support for this hypothesis is found in the work of Zhou et al. (2008). They examined the acoustic difference between tongue shape of the bunched and retroflex /r/. They reported whilst their adult listeners did not perceive the differences between the two sounds, differences in the lingual pattern were observed in the distance between formant 4 and formant 5. Thus, it is possible that had acoustic analysis also been undertaken, a shift that was not yet perceivable perceptually may have been identified.

Secondly, there may have been insufficient change to the vocal tract. Ito and Ostry (2010) recorded data that indicated no change in F1 and F2 in adult participants subsequent to changes in lip position stimulated by perturbation. They suggested the absence of acoustic change may have been due to small overall changes in the vocal tract length or the possibility that other articulators compensated to maintain the acoustic output. Singh and Singh (2008) provide data that suggests only 50% of children aged between 7-8 years of age display the adult features of formant transitions and place of articulation. Green and Nip (2010) also report acoustic and/or perceptual measures may not be sensitive to changes in articulatory control in young children. Thus, it may be that in order for change to be perceivable for the participants in this study, more than one subsystem (e.g., two phases of intervention) would be required to produce change. Examination of the results of P1 and P5 lend some support to this interpretation. They both record data that show congruency between the MSMPs and PA is achieved in the second phase of intervention for the trained word-sets on intervention priority one and two.

Finally, it is also possible that the intervention acted to destabilise the relationship between the existing maladaptive movement pattern and incumbent perceptual output. In this case the incongruency between the movement pattern and speech output is reflective of the motor learning process. Iverson and Thelen (1999), propose four dynamic transition periods (initial linkages, emerging control, flexible coupling and synchronous coupling) in early speech development. During the establishment of the initial linkages, the motor and speech systems are only loosely coupled. With increasing control (flexible coupling), Iverson and Thelen (1999) report the timing relationship between motor system and speech mutually influence one another and “ultimately settle on a ‘compromise’ frequency at which they entrain to produce a coordinated behaviour” (p. 33). Thus, the asymmetry between the two systems (speech output and movement) observed in the data of this thesis, could be reflective of reorganisation of the motor-speech movement system. As a result during the initial acquisition phase of an intervention protocol clinicians should expect to observe a period of asynchrony in speech/motor control. With increasing control and the establishment of a new preferred state, synchronous motor speech movement patterns and perceptual output is expected.

Some support for the interpretation of this is found in the data of the participants in this thesis who displayed incongruent MSMPs and PA scores pre-intervention. For example P5 recorded baseline data that showed PA exceeded MSMP accuracy. Subsequent to the first intervention phase the converse was recorded. That is, the MSMP data exceeded the PA. In the second intervention phase congruency between the two measures was recorded.

Further research, noteworthy of consideration, but outside the scope of this study, is that of a child’s own perception of their production and the role this may have in fine-tuning perceptual output. Shiller, Gracco and Rvachew (2010) report "children may be less able to detect perceptual variability related to their own productions, and hence show less perceptual fine-tuning to accommodate such changes" (p.7). Thus it may be possible that changes in articulation control and coordination may not be apparent in early speech output. More recent research by Ito and Ostry (2012) provide some evidence that suggests "sound and proprioception are integrated in the neural processing of speech" (p. 445). That is, facial somatosensory input plays a role in altering speech sound perception. Thus, it is also possible that children with CP may take longer to achieve perceptual changes due to poor integration between the sensory, motor and auditory inputs.

Conclusion

The hypothesis that the participants of this study would demonstrate improved speech production and phonetic accuracy, subsequent to participation in the PROMPT intervention, is supported. Specifically, the results provide evidence to suggest the implementation of a hierarchical subsystems approach aimed at developing efficient functional movement synergies (e.g., jaw/lower lip synergies) through the establishment of appropriate movement boundaries, resulted in improved motor-speech control.

The use of a SSRD, with two inter-hierarchical phases of intervention, also demonstrated a cumulative treatment effect. This finding is consistent with the literature that reports improved generalisation when training movement patterns with similar patterns of muscle activation (Mattar & Ostry, 2007).

The finding of differential changes to the motor-speech movement patterns of each of the participants, over the phases of the study support the need for additional objective measures (e.g., kinematic data) to further enhance the interpretation of perceptual data. This is supported by the literature that identifies many different movements patterns can be used to produce a similar perceptual outcome (Green & Nip, 2010; Honda & Takemoto, 2010; Ito & Ostry, 2010). Whilst the data from the perceptual measures of this study identifies changes to the motor-speech movement patterns occurred, further evaluation using objective kinematic measures is warranted in order to gain a more complete understanding of the relationship between the perceptual and kinematic changes.

CHAPTER 5 QUESTION TWO

WILL CHILDREN WITH MODERATE-TO-SEVERE SPEECH IMPAIRMENTS ASSOCIATED WITH CP SHOW CHANGES IN DISTANCE, VELOCITY AND DURATION MEASURES OF THE JAW AND LIPS SUBSEQUENT TO PROMPT INTERVENTION?

Introduction

Changes in articulatory movements associated with dysarthria lead to aberrant speech acoustics and a perceptually recognizable disorder (Yunusova, Weismer, Westbury & Lindstrom, 2008, p. 596).

The most common speech disorder associated with CP is that of dysarthria (Hodge & Wellman, 1999; Ingram & Barn, 1961; Love, 1992; Workinger, 2005; Workinger & Kent, 1991). Pennington, Miller and Robson (2009) describe dysarthria as:

> an articulatory disturbance which arises when neuromuscular impairment affects the tone, power and coordination of any or all of the muscles used for speech …. leading to loss or inaccuracy of articulatory movements. When this happens listeners perceive the distortion or omission of sounds and syllables and the alterations to voice quality characteristic of dysarthria (p. 10).

Although the above definition identifies articulatory disturbance as a contributing source of impaired speech intelligibility; and intervention is frequently aimed at establishing different movement patterns (Pennington et al., 2009), the use of perceptual outcome measures appear to be the established benchmark for evaluating the effectiveness of a motor speech intervention approach (R.D Kent & Kent, 2000; Murdoch, 2011; Murdoch & Horton, 1998).

The validity of using these measures in the absence of instrumental analysis, for both the diagnosis and treatment planning of motor speech disorders, has been a topic of debate in the literature (Chenery, 1998; Cheng et al., 2007; Kearns & Simmons, 1988; Ozsancak et al., 2006) Typically, motor speech disorders affect multiple speech subsystems that include respiration, phonation, articulation and resonance (R.D Kent & Kent, 2000; Love, 1992; Netsell, 2001, Love, 1992 #315). Therefore the assessment of speech impairment, including identification of phonetic and phonological processes, needs to be considered within the context of the movement proficiencies of the individual articulators (Netsell, 2001). Determination of the possible contribution of any or all of these subsystems to speech impairment has contributed to a lack of reliability and validity in identifying speech impairments on the basis of perceptual analysis alone.

Given this limitation, the need to supplement perceptual analysis with instrumental analysis (e.g., acoustics) in the assessment and diagnosis of the types of motor speech disorders is recognised (Kearns & Simmons, 1988; R.D Kent & Kim, 2003; R.D Kent et al., 1999; Y. Kim et al., 2011; Murdoch, 2011). The literature indicates the use of acoustic analysis as an outcome measure is typically associated with intervention studies focused on the manipulation of rate, prosody and loudness (Yorkston et al., 2008; Pennington et al., 2009, Patel, 2002). Examples of acoustic measures include spectrographic analysis to identify changes to intensity, duration and fundamental frequency (Patel & Campellone, 2009; Thompson-Ward & Theodoros, 1998; Wenke, Cornwell, & Theodoros, 2010).

A limitation of using perceptual and acoustic analysis as an outcome measure in the evaluation of interventions aimed at making changes to speech movement patterns includes the inability of these measures to inform a clinician as to the contribution of each of the individual motor-speech subsystems to overall speech intelligibility (Gracco, 1992; Yunusova, Weismer, Westbury, & Lindstrom, 2008).

In the absence of such measures, researchers have hypothesised as to the potential benefit of changes to specific movement patterns for speech intelligibility. For example, Wenke, Cornwell and Theodoros (2010), based on the analysis of acoustic data, proposed that increasing law and lip displacement may be a strategy to increase the vowel space area and thus improve speech intelligibility.

The challenge of proposing modifications to speech movement patterns based on acoustic analysis is that many different movement patterns may produce the same perceptual or acoustic end-product (Yorkston, Beukelman and Traynor (1988). For example, the literature identifies changes to the perceptual signal may be due to changes in any combination of the biomechanical linkages between the mandibular, labial, lingual, laryngeal and pharyngeal muscles (Honda & Takemoto, 2010; Iskarous et al., 2011). Therefore, "…inferences regarding movements that are based solely on acoustic or perceptual measures must be viewed with caution" (Yorkston, Beukelman & Traynor, 1988 (p.352).

The inability of a clinician to objectively assess and evaluate therapeutic changes to motor-speech movement patterns highlight the need for clinical access to physiological measures that would support this process (Murdoch, 2011; Theodorus et al., 1999; Weismer, 2006).

Advances in technology now provide clinicians access to tools that were previously inaccessible (e.g., three dimensional motion analysis). Murdoch (2011) states "instrumental assessment can enhance the abilities of the clinician in all stages of clinical management, including the documentation of treatment efficacy". The use of motion analysis to examine subclinical motor speech signs has been reported in adult dysarthria, dysarthria associated with traumatic brain injury, childhood apraxia of speech and stuttering (Cahill et al., 2005; Peters et al., 2000; Roy et al., 2001; Theodorus et al., 1999).

The positive results obtained on the perceptual measures for all participants in the PROMPT intervention study support the use of tactile-kinaesthetic input, applied systematically and actively during speech, contributed to modifying the speech-movement patterns of the participants and led to improved speech production and phonetic accuracy.

The differential changes in speech production accuracy and the motor-speech movement patterns recorded across the phases of the PROMPT study, as reported in chapter 4, support the use of a more objective physiological level of analysis to facilitate the objective evaluation and interpretation of the changes in motor speech movement patterns and associated improvements in speech production accuracy for each of the participants observed in this study.

In this chapter, the use of 3D motion analysis to analyse changes to the kinematic measures of distance, velocity and duration of jaw and lip movements is investigated.

The following question was addressed:

Will children with moderate-to-severe speech impairments associated with CP show changes in distance, velocity and duration measures of the jaw and lips subsequent to PROMPT intervention?

Method

Participants

All 6 participants described in chapter 3 participated in the collection of data for the kinematic measures. In addition, to facilitate interpretation of the kinematic data obtained on the 6 participants across the phases of the PROMPT intervention, 12 typically-developing (TD) peers were recruited to serve as a reference group.

Cohort of typically developing (TD) peers.

Recruitment.

A convenience sample of 12 TD peers served as a reference group. The TD peers were known either to the speech pathologists administering the PROMPT intervention, research assistant or principal investigator. Ethics approval was successfully obtained from Curtin University Human Research Ethics Committee. Families were approached by the principal investigator and provided with information on the purpose of the study, and the procedure for collecting the motion analysis data. The parents were asked to discuss the study with their children and obtain consent to participate. Informed consent was obtained from both the parents and the TD children. All procedures and protocols were followed and no complaints received.

Description.

All TD peers scored within age-appropriate limits on oral motor and speech tests [The Arizona Proficiency Scale (3) (Fudala, 2001) and The Verbal Motor Production Assessment for Children (VMPAC, Hayden and Square, 1999)]. Parent report indicated there was no history of language impairment. All TD peers passed a pure-tone hearing screening, using the staircase method at 20dB at frequencies of 1000, 2000, 4000 and 8000Hz. In addition, English was the first and primary language of all participants.

With the exception of P2 and P4, three TD peers were also age and sex matched to each participant with CP (see Table 5.1).

Table 5.1

Age-and-Sex Matching of Participants with CP to TD Peers

Participants with CP		TD peers			
Reference	Age	No. of TD peers	Reference	Sex	Age (M, SD)
P1	11;9	3	TD 11, 12, 13	F	11 (11;7, 0.26)
P2	8;5	2	TD 21, 22	F	8 (8;2, 0.15)
P3	5;4	3	TD 31, 32, 33	F	5 (5;2, 0.21)
P4	5;2	1	TD 41	M	5;1
P5	3;0	3	TD 51, 52, 53	M	3 (3;4, 0.26)
P6	3;6	3	TD 51, 52, 53	M	3 (3;4, 0.26)

Procedure

Each child was seated on a wooden ladder-back chair positioned in front of three tripod-mounted video cameras. A research assistant, trained in marker placement and the motion analysis video data acquisition procedure, but independent to the study, prepared the participants and administered the motion analysis trials. The chief investigator was present during all motion analysis trials, with the exception of TD 52. As a result of technical failures, a second data collection was required and conducted by the research assistant.

The research assistant described the task to the child, explaining they would be shown a picture card representing a word and then asked to repeat the word (e.g. “man”). To ensure compliance and task understanding, all children completed a pilot run of the motion analysis procedure. During the pilot run, the children were trained in the protocol and given specific feedback that included remaining seated on the chair, keeping feet flat on the floor and waiting for the research assistant to tell them to say the word. All children demonstrated understanding of the task requirements and proceeded to data collection.

Each child was recorded on video as they repeated each word that was presented in random order. Perceptual accuracy and visibility of markers during production of the words were monitored on-line. When it was identified that performance deviated from the task requirement, feedback was given and the child was asked to repeat the word. A maximum of 8 trials were elicited in order to obtain 5 error-free trials of each word (i.e., 5 x11 words for analysis). A pause of approximately 3 seconds was used after the target was produced by the participant and before presenting the next word. Data collection time varied across each child, dependent on the child's need to take breaks between trials. No data collection occasion exceeded one hour.

Set-up.

Each child sat in a ladder-back chair with feet firmly on the ground. A cut-out-table was positioned in front of the participant to allow propping through the elbow to provide postural stability through the trunk.

Three video cameras (Sony HDRHC3E PAL HDV 1080i) were used to capture the speech movement patterns. Camera one was positioned directly in front of the participant. Cameras two and three were positioned 30 degrees to either side of camera one, which was placed 1.3 meters from the centre of the chair. Each camera was mounted on a Sony remote control tripod (VCT-D68ORM). The bubble level of the tripod was used to ensure the camera was level. Masking tape was placed on the floor for the duration of the study to maintain camera and chair placement. Accuracy of camera placement was confirmed with a plumb line.

The video cameras were linked to an OTIC television (OTM 515). The cameras were white balanced, manually focused and zoomed until the calibration cube image filled the television monitor.

Two Rove halogen floor lamps (35/50W) were placed horizontally on the floor to the left and right of the participant's face. The lamps were covered with photographic paper to diffuse the light. A white block-out fabric backdrop was positioned behind the participant. All overhead fluorescent lights were turned on during recording. The window treatments were drawn throughout all trials to keep lighting as consistent as possible.

Two fluorescent markers were placed on the left and right side of the chair, in line with the participant's ears to identify postural changes during the recording. No head posture restraints were used during testing.

Microphone placement was dependent on participant tolerance and compliance. Placement options included fixed to the participant's shirt/lapel, placed on the table in front of the participant at elbow height or attached posteriorly to a rung of the ladder-back chair at mouth height.

Measures

Five repetitions of 11 untrained stimulus words were used to elicit the kinematic measures of distance, velocity and duration.

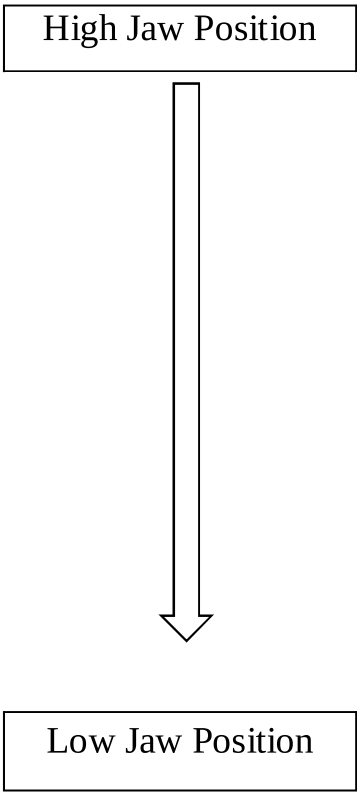
Distance.

Three distance measures of the jaw were calculated:

1. Jaw path distance travelled (JPD) - Sum of the 3D Euclidian distance of the middle jaw marker across each time sample (Yunusova et al., 2010).
2. Jaw open distance (JOD) - The 3D Euclidian distance between the middle forehead marker and middle jaw marker subtracted from the corresponding distance at rest (Green et al., 2000).
3. Jaw Lateral Distance from Midline (JLDM) - Average lateral displacement from midline distance of the middle lower lip + jaw marker (LL) from rest (Moore, 2004).

Mean maximum movement measures were obtained for JOD, whilst the JPD and JLDM measures were based on the average value obtained across the repetitions.

In addition, a measure of jaw grading (JG) was derived from the JOD measures at each jaw height position (JHP) for participants 5 and 6. Figure 5.1 illustrates the JHP's for the stimulus words used in this study, as based on the Standard Australian English vowel map presented by Cox (2006, 2008). Jaw grading was defined as a participant's ability to yield significantly different JODs for each JHP. This measure is therefore derived from the JOD measures during statistical analysis.



JHP	Words
1	Push Two Six Beep
2	Off Shop Spot
3	Up
4	Mine Man Hat

Figure 5.1. The jaw height positions of the stimulus word-set.

Two distance measures of the lips were extracted and calculated:

1. Lip Rounding/Retraction (LRR): Distance between the left and right corners of the lips in the horizontal plane boundary (Caldognetto, Cosi, Drioli, Tisato, & Cavicchio, 2004). As this measure is subtracted from rest, a positive value indicates retraction and a negative value indicates rounding.

2. Inter-lip distance during bilabial contact (BLC), obtained on the 4 stimulus words containing the bilabial (m, p, b) in word initial position, and consists of two components:

a. Minimum inter-lip distance during bilabial contact: calculated as the 2D Euclidian distance between the upper lip (located at midline on the vermillion border of the upper lip) and the lower lip (located at midline on the vermillion border of the lower lip).

b. Position of the upper lip (UL) and lower lip (LL) at the point of minimum bilabial contact calculated in the vertical position.

Each distance measure was normalised to a mean rest position for each participant, on each testing occasion. This cancelled out the effect of changes in the resting face shape and possible small variations in marker placement across the phases of the study (Faraway, 2004).

Velocity and duration.

Peak jaw/lower lip opening velocity (J/L Vel) and average word duration (WD) measures were calculated on the LL marker, thus representing the combined action of the jaw and lower lip (Goffman & Smith, 1999).

Table E1 in Appendix E fully describes the calculations used to derive each of the kinematic measures.

Stimulus Words

The stimulus words, used to elicit the data were selected to:

1. Reflect the levels of the PROMPT motor speech hierarchy (MSH) targeted during PROMPT intervention (mandibular, labial-facial, lingual). These words were untrained words and not used in the speech probe word-pool. As the motion capture system (Peak Motus 9.1) used in this study does not capture lingual movements, only the jaw and lip movements of the stimulus words have been analysed.

The stimulus words were grouped as follows, and illustrated in

Figure *5.2*:

i. Word-set one (Mandibular Control): mine, man, hat, up.

This word-set contains low vowels that are consistent with PROMPT jaw height positions three and four.

ii. Word-set two (Labial-facial Control): push, beep, two, shop, off[2].

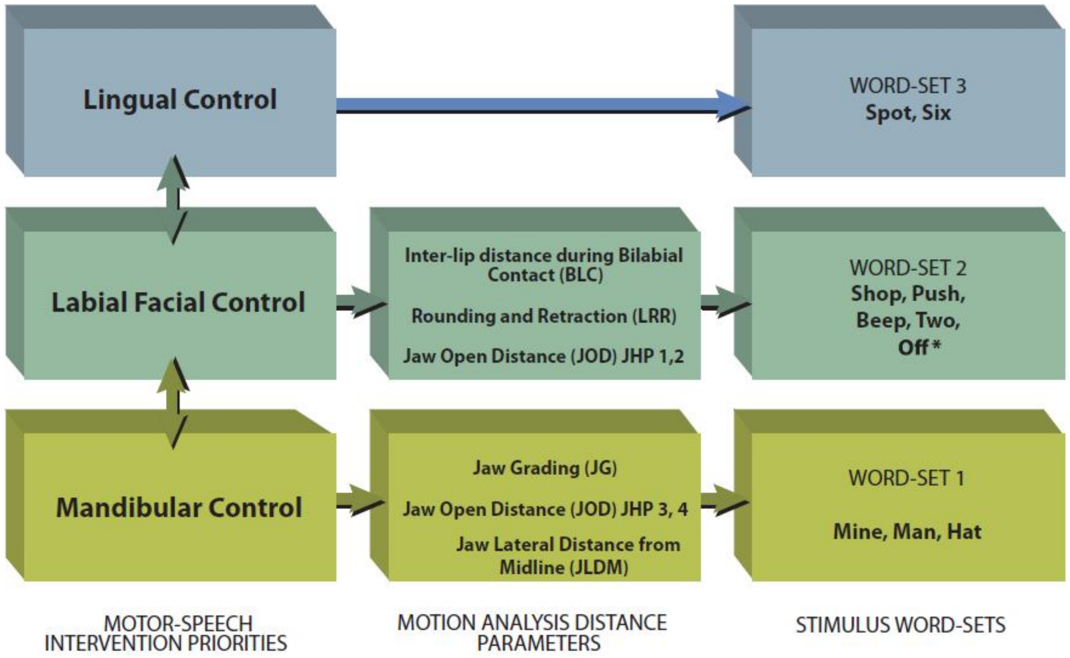
This word-set contains high vowels are consistent with PROMPT jaw height positions one and two.

iii. Word-set three (Lingual Control): six, spot.

The kinematic stimulus words were untrained and designed to reflect changes in jaw and lip movements independent to the weekly outcome measures collected within the study phases.

---

[2] In a young child the jaw height position will be lower and produced within the mandibular plane. In a mature system the jaw height position will be higher and produced in the labial-facial plane



Off* = in a young child jaw height position will be lower and produced within the mandibular plane. In a mature system jaw height position will be higher and produced in the labial-facial plane.

Figure 5.2. Word stimulus sets for the motion analysis as categorised across three levels of the motor-speech hierarchy.

2. Contain vowels that spanned the articulatory space. Vowels were selected on the basis of jaw height (low, half-low, half-high, high) and lip shape (rounded/retracted/neutral). A total of seven monophthongal vowels, one diphthong and 4 syllable shapes were represented (see Table 5.2).

Table 5.2

Stimulus Words used to Elicit the Kinematic Data as Framed within the Motor Speech Hierarchy Planes of Movement (MSH)

Stimuli			MSH plane of movement	
			Mandibular (Vertical)	Labial-Facial (Horizontal)
Word	Syllable structure	M/D	Jaw Height Position	Lip Position
Man	CVC	æ	4	Neutral
Hat	CVC	æ	4	Neutral
Mine	CVC	ai	4→ 1	Neutral
Up	VC	ʌ	3	Neutral
Off*	VC	ɒ	2	Neutral
◆Shop	CVC	ɒ	2	Rounded
◆Spot	CCVC	ɒ	2	Neutral
◆Six	CVCC	ɪ	1.5	Retracted
(Beep)	CVC	i	1	Retracted
Push	CVC	ʊ	1	Rounded
Two	CV	u	1	Rounded

Note. M = monophthongal vowel, D = diphthong
* = this word in a young child may be produced more in the vertical plane, that is with a lower jaw height position, = ◆ these words would also be classified within the anterior-posterior plane of movement on the MSH, however, 3D motion analysis is not able to analyse lingual movement

Due to the severity of the speech impairment in the participants, the stimulus words were not embedded in carrier phrases. Each word was randomly presented, by the research assistant, 5 times in isolation for the participants to repeat.

Instrumentation.

Jaw and lip measurements were tracked in three dimensions (3D) at a sampling rate of 50 frames/sec using Vicon Motus (9. 1). Data were captured in standard PAL DV format (720 x 576 pixels) using three Sony HDR-HC3E PAL HDV 1080i video cameras mounted on Sony remote control tripods (VCT-D68ORM). The speech acoustic signal, recorded at 44 kHz, was simultaneously recorded using a wireless Bluetooth microphone (Sony ECM-HW 1R) connected to the central video camera.

The position of each marker on the participant’s face was calibrated to a 24cm x 24 cm reference cube. This cube was comprised of 8 spherical markers suspended from a frame by nylon line. The frame was suspended directly above the seat of the ladder-back chair in the space to be occupied by the participant’s head, prior to the participant sitting in the chair. A spirit level was used to ensure the calibration cube was level. The video cameras were positioned and the camera lenses zoomed so that the cube filled the field. The calibration cube was filmed before each testing period for each participant.

Facial marker placement.

The markers of interest, for the measurements reported in this thesis (see Figure 5.3), include:

1. A reference array of markers used to create the three dimensional (3D) head-based coordinate system, independent of head rotation and translation.

This contained four forehead calibration markers and one nose marker. The x, y and z axis represented the horizontal, vertical and orthogonal axes, respectively.

2. Markers used to define the movements under investigation.

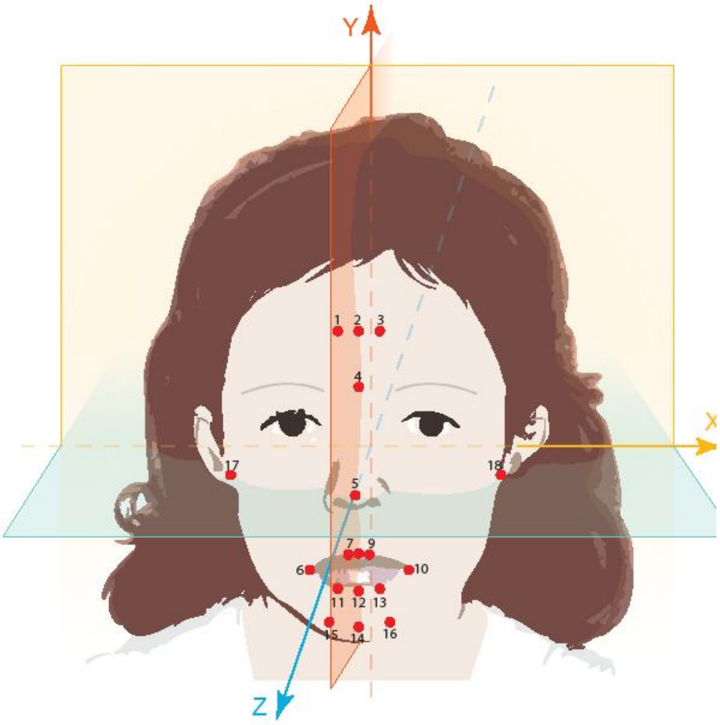


Figure 5.3. Facial marker placement.

One jaw marker placed at the base of the mental protuberance of the chin. Eight lip markers placed as follows: a. Right and left corners of mouth, b. Right and left upper points of Cupid’s bow, c. Midpoint located on the lower lip (LL) vermillion, and d. A virtual marker located on the upper lip (UL) vermillion. The LL marker represented the combined motion of the lower lip and jaw.

Table F1 in Appendix F fully describes the marker position and anatomical location utilised in this study.

Vicon Motus is designed to track movements automatically by detecting a contrast between a circular or spherical marker and the surrounding pixels. A light source adjacent to the each camera and retro-reflective markers positioned on the moving person are usually used to create this contrast (bright white against a darker surround). During piloting for this study, the facial movements during speech production placed the participants at potential risk of swallowing some of the spherical retro-reflective markers. Therefore, in this study, black liquid eyeliner and white zinc lipstick were used to create flat circular markers against a contrasting background (black markers against a lighter surround).

Three templates, created from thick acetate paper, were used to ensure consistent placement of the markers. Template one contained markers 1 to 4 and template two contained markers 14 to 16. These markers were 3.6mm in diameter. Markers 6 to 13 were drawn using a third template that provided a marker that was approximately 2.5mms in diameter. Due to the small mouth size of the younger participants, placement of marker 8 was abandoned and a virtual marker calculated.

Two markers consisting of black spherical beads of approximately 2.5 mm diameter were positioned on the left and right mandibular condyle. The participant was instructed to say ‘ah’ when the assistant palpated for the mandibular condyle. The beads were adhered to the mandibular condyle using double sided hypo-allergenic tape. These markers were not used due to post-processing difficulties.

All participants were enthusiastic about having their “face painted” with the white zinc lipstick and black liquid eyeliner that was used to create the facial markers. No children experienced any allergic reaction to the marker application or wipes used to clean the face.

Data Processing

A four-step post-processing procedure was undertaken to prepare the speech and movement data for analysis, as shown in Figure 5.4.

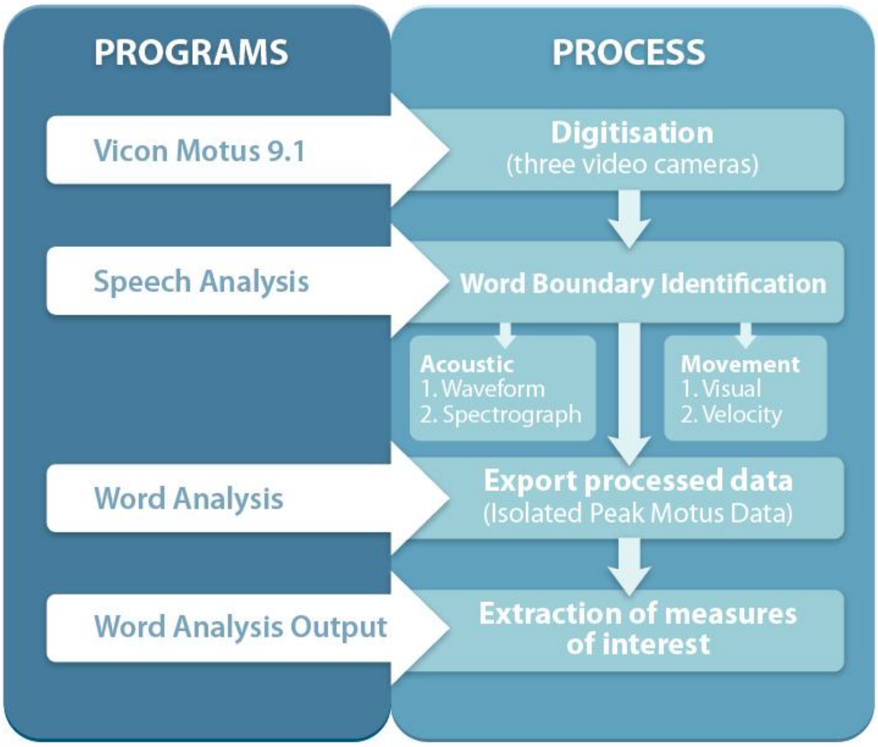


Figure 5.4. Post processing of PEAK Motus data.

Digitisation.

The 50Hz video was captured from the video cameras onto a computer via an IEEE1394 lead, imported into the PEAK Motus software and automatically digitised. Poorly performing markers were identified during the automatic digitisation process and subsequently, manually digitised. The digitised data from the 3 camera views was then processed to produce three-dimensional (3D) scaled coordinates and exported as an ASCII comma delimited dataset.

Three custom programs, written using LabVIEW 8.6.1 (National Instruments Corporation, Austin, TX, USA), were used to extract the data.

Word boundary analysis.

The PEAK Motus video footage, containing the speech acoustic and kinematic data, was exported into a custom written program (Speech Analysis), created using LabVIEW 8.2.1 (National Instruments Corporation), for word boundary identification.

Perceptual analysis.

Stimulus words were analysed for perceptual and movement errors by the chief investigator. A correct/incorrect scoring criterion was utilised for the TD peers. Productions were excluded if they contained articulatory errors, with the exception of the word “push” by the 3-year-old TD peers. This word was produced as “pus” with facial rounding. This production was accepted because the error was attributed to inadequate tongue tension that did not affect the movement patterns investigated in this study.

Word productions of the stimulus words from the participants with CP were transcribed using broad phonetic transcription. Articulatory errors were excluded only if they deviated substantially from their ‘typical’ productions.

All transcription was completed by the principal investigator.

Acoustic word boundary analysis.

The video footage was exported into the custom written speech analysis program. The acoustic word-onset and -offset was initially identified visually and aurally using the plotted waveform displayed in the speech analysis program. The audio track (.wav files) containing these word boundaries (frame numbers) were then exported for use in a spectrographic analysis program (SFS/WASP (Huckvale, 2007). The wide-band spectrographic display was used to confirm the word boundary through identification of the onset and cessation of acoustic energy associated with each word (Francis et al., 2003; Howell et al., 2009; McClean & Tasko, 2003). All jaw measures, lip rounding/retraction distance, jaw/lip opening velocity and word duration were analysed within the acoustic onset and offset boundaries. Mean maximum movement measures were obtained for JOD, whilst the JPD and JLDM measures were based on the average value obtained across the repetitions.

Movement word boundary analysis.

The general location of a movement-preparation boundary, prior to the acoustic-onset was identified for each word. This was initially identified based on visual inspection of the video footage in the speech analysis program. The precise point of the velocity zero-crossing, closest to the acoustic onset, was subsequently determined automatically within a window that occurred between the movement preparation phase and the acoustic onset. This was done using an algorithm written into a specifically developed word analysis program, created using Labview 8.2.1. The velocity trace was based on the recording of the lower lip + jaw marker. All automatically identified zero-crossings were manually confirmed.

Reliable identification of movement offsets with this single-word-data-set proved problematic. The speech science literature frequently reports the use of carrier phrases such as “buy bobby a puppy” where the words of interest are preceded and followed by a jaw raising or lowering movement, thus creating a change in direction that promotes the identification of a peak or zero-crossing in the velocity trace (Goffman & Smith, 1999; Green et al., 2002; Löfqvist & Gracco, 1997; Walsh et al., 2006). The inability of the participants in this study to produce a carrier phrase required the use of single stimulus word-set only. Visual inspection of the data in this thesis indicated the offset-zero-crossing could not be consistently identified. Given this, the offset was based on the acoustic data.

The acoustic and movement boundary frames were subsequently recorded in an excel spreadsheet and named using a convention that would allow a specifically written program (word analysis) to read the frame numbers that identified the word boundaries.

Word analysis.

The isolated data (that is the data independent of head rotation and translation), containing the word as measured within the onset and offset boundaries, were smoothed and time normalised to 200 points using a cubic spline algorithm (De Boor, 2001), and exported to an Excel spreadsheet. These words were further processed in the specifically developed “word analysis” program, created using Labview 8.2.1 to identify the measures of interest – distance, position, velocity and duration.

Visual inspection of the data was undertaken for all markers of interest to identify any possible post-processing errors.

Word-analysis output.

The measures of interest were automatically extracted using a specifically written program (Speech Word Analysis Output), created using LabVIEW 8.2.1 (National Instruments Corporation).

Data exclusion.

All productions were excluded from analysis if they contained excessive volume, coughing, laughing or excessive movements that resulted in missing markers.

Reliability

Acoustic word boundaries.

Intra-rater reliability of the acoustic word boundaries was evaluated by re-measuring 10% of the participant data.

Intra-rater reliability of the acoustic word boundaries was evaluated by comparing the time frames of the total word duration obtained using the spectrographic analysis. The averaged absolute difference between the original and the repeated measures was 31msecs.

Reliability measures for the kinematic measures of distance, velocity and duration were not undertaken as the data are extracted automatically using custom written programs.

Data Analysis

Non-parametric statistics were selected for the analysis of the motion analysis data. Nonparametric statistics are recommended when sample size is small; data distribution is unequal; the number of trials elicited per participant across testing occasions is unequal and; data violates the assumptions of normality and homogeneity (deVries, 1994; Field, 2009). The statistical analyses undertaken for each of the kinematic measures are summarised in Table 5.4.

Exploratory analysis of the data was also undertaken using parametric tests. However, the results indicated the data for some of the participants violated the assumptions of homogeneity on some of the word stimuli. Log transformations were applied but did not correct the violations in all cases. In addition, the number of repetitions per word per testing occasion varied across the participants. In particular, Participant 1 was able to produce only 3 repetitions per word during phase B.

The data were analysed as summarised in Table 5.1 for each participant across the phases of the study:

1. Pre-Intervention: Assessment of the kinematic measures (distance, duration and velocity) obtained prior to participation in the PROMPT Intervention. These data were collected following administration of the final baseline speech probe measure (Phase A). The Mann-Whitney test was used to determine the significance of the differences between the kinematic measures of each participant and the reference group of TD peers who were age-and-sex-matched to each participant.
2. Post-Intervention: Assessment of changes in the kinematic measures obtained subsequent to participation in each of the two phases (B and C) of PROMPT intervention, and again at follow-up (phase A2). Two non-parametric statistical tests were used. Friedman's ANOVA ($p \leq .05$) was used to test for the presence of a main effect. Bonferroni-corrected pair-wise comparisons using the Wilcoxon signed-rank test ($p \leq .01$) were used to evaluate differences in the values for each of the measures across the study phases.

Two-tailed tests were used on all mandibular measures of velocity and duration. One tailed tests were used on lip rounding/retraction (LRR) and inter-lip distance during bilabial contact (BLC) based on a priori knowledge that these distances were greater than the TD peers; and intervention was aimed at reducing this distance. In addition, for P5 and P6 a linear mixed effect model (LME) was used to analyse the change in jaw grading (JG) across each of the four jaw height positions (see method section). This model does not require the assumptions of homoschedasticity, compound symmetry or sphericity (Field, 2009; Quené & van den Bergh, 2004). In this model, ‘occasion’ was a fixed factor and ‘word effect’ and ‘phase effect’ were treated as random factors.

The magnitude of the treatment effect for all measurements was evaluated using effect size data calculated using the Wilcoxon signed-rank test (Field, 2009) and evaluated using the Cohen`s effect size criteria.

The literature indicates the interpretation of effect size magnitude should be based on prior relevant studies with the same dependent variable rather than rigid benchmarks (Meline &Wang, 2004; Beeson & Robey 2006, Thompson, 2002; Cohen, Manion, Morrison and Morrison, 2007). However, in the absence of published data, the Cohen’s criteria may be “the next best resource for interpretation” (Meline &Wang, 2004, p. 205).

As this is a phase I study, interpretation of the magnitude of the effect sizes is based on the Cohen’s effect-size correlation benchmark for SSRD of 0.1 = small, 0.3= medium and >0.5 = large (Field, 2009). Values in which a large effect size was demonstrated are highlighted using boldface. The means and standard deviations, for each word, are illustrated for each measure for each participant in Appendices H - M.

Descriptive data (means and standard deviations) are provided for each participant on each testing occasion, for each kinematic measure and presented in the appendices (Appendices H to M).

Table 5.3

Statistical Procedures Used to Analyse each Kinematic Measure (Distance, Duration and Velocity) across the Study Phases

Phase	Description	Analysis
A1	Pre-Intervention	Mann-Whitney U Descriptive statistics
End of B and C; A2	Post-Intervention	
	Main Effect	Friedman’s ANOVA
	Pairwise Comparisons	Wilcoxon Signed rank test Effect sizes Descriptive statistics

Table 5.4

Tests used to Analyse Data obtained on the Kinematic Measures across the Study Phases

Kinematic Measures		Analysis		
		Peer Comparison	Main Effect	Comparisons across the study phases
Distance	JOD, JPD, JLDM, LRR, BLC	Mann-Whitney test	Friedman's ANOVA	Wilcoxon signed-rank test Effect Size
	Jaw Grading		Linear Mixed Model	
Duration Velocity		Mann-Whitney test	Friedman's ANOVA	Wilcoxon signed-rank test Effect Size

Results

The results for each participant will be presented for each measure in turn. First, an overview of the intervention priorities addressed during the two intervention phases will be presented. This will be followed by a summary overview of the measures that recorded a significant difference to the TD peers at pre intervention and the significant changes subsequent to participating in the PROMPT intervention. Finally, there will be a detailed analysis for each kinematic measure.

Then detailed analyses for each word on each kinematic measure pre- and post-intervention, are reported as follows:

1. Distance Measures

a. Mandibular Control Measures - The measures of Jaw Path Distance (JPD), Jaw Open Distance (JOD), and Jaw Lateral Distance from Midline (JLDM) are reported for each word.

b. Labial Facial Measures - The distance measure of Lip Rounding/Retraction (LRR) are reported for each word. Minimum inter-lip distance during bilabial contact (BLC) is reported for two words from word-set one (mandibular control) and two words from word-set two (labial-facial control). Word-set three did not contain bilabials and are therefore excluded from the analysis. In addition to the BLC distance, position measures for the UL (upper lip) and lower lip (LL) during BLC are also reported.

2. Jaw/ Lip Opening Velocity (J/L Vel) - Peak opening velocity, calculated on the lower lip (LL) marker, thus representing the combined action of the jaw and lower lip is reported for each word.

3. Word Duration (WD) – The average word duration calculated for each word.

Participant 1

The following motor-speech movement patterns were targeted during the PROMPT Intervention:

Phase B: (Intervention priority one: labial-facial control) – Facilitate jaw grading through jaw height positions (JHPs) 1 and 2, engage lip to lip contact during the production of bilabials, timing and duration.

Phase C: (Intervention priority two: lingual control) – intra-oral contact of alveolar plosives (e.g. /t/) in the mandibular plane. As Peak Motus (9.1) does not record lingual movements, kinematic data collected during this phase reflects changes in mandibular and labial-facial measurements subsequent to intervention that targeted a higher level of motor-speech control.

The words that evidenced significant impairment of the jaw and lip measures for P1 as compared with the typically developing (TD) peers pre-intervention and significant changes post-intervention are presented in Table 5.5. Results are based on five repetitions of each word, with the following exceptions: phase B - 3 trials only per word as a result of fatigue preventing elicitation of 5 trials, and phase A2 - 4 trials of the word ‘spot’ phase A2, with one trial removed due to missing markers.

The distance data (see Appendix I) at pre-intervention show mandibular control measures of word-set two and three, inter-lip distance during bilabial contact (BLC) on 2/4 words and all lip retraction (LRR) values were significantly increased in comparison to TD peers. Duration values differed across all word-sets, whilst velocity measures differed for two words in word-sets two and three.

The post-intervention data show a positive treatment effect. Specifically, the labial-facial distance measures; and the J/L Vel values of word-set three recorded the most significant change (64% of LRR stimulus words and 100% of BLC stimulus words).

Table 5.5

Words that Recorded Significantly Different Pre (Mann-Whitney Test) and Post-Intervention (Friedman's ANOVA) Values on the Kinematic Measures of Distance, Velocity and Duration for P1

	*Mandibular Control						†Labial-Facial Control							
Word Stimuli	JPD		JOD		JLDM		LRR		BLC		J/LVEL		WD	
MSH	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Wordset 1														
Mine	X				X		X	✓	X	✓				
Man					X		X	✓	X	✓			X	✓
Hat							X		-	-			X	
Up				✓			X	✓	-	-			X	
Wordset 2														
Off					X		X	✓	-	-			X	
Shop	X		X	✓	X		X		-	-			X	
Beep	X		X				X	✓		✓			X	
Push	X		X		X		X			✓	X		X	
Two	X		X				X	✓	-	-	X	✓	X	
Wordset 3														
Six	X		X	✓			X	✓	-	-	X	✓	X	
Spot	X		X		X		X		-	-	X	✓	X	
Total	7	0	6	3	6	0	11	10	2	4	4	3	10	1

Note. Pre = pre-intervention comparison with peers, Post = post intervention comparison (phases B, C and D), X = movement pattern significantly different to TD peers, ✓ = significant change recorded, MSH = motor speech hierarchy plane of movement, JPD = jaw path distance, JOD = jaw open distance, JLDM = Jaw lateral distance from midline, LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact, J/L VEL = jaw/lip opening velocity, WD =word duration.
* = p value ≤ .05, two-tailed, †= p value ≤ .05, one-tailed.

Distance measures.

Mandibular control measures.

Pre-intervention.

Analyses of the kinematic data provided in Table 5.6 indicate impaired mandibular control at pre-intervention. Specifically:

JPD and JOD – mean values were significantly increased, relative to the TD peers, at the labial facial (word-set 2) and lingual level of control (word-set 3).

JLDM – all words recorded mean values that exceeded the TD peers, with 8/11 words recording a significant difference.

Table 5.6

Mann-Whitney Test Results of the Pre-Intervention Mandibular Distance Measures Comparing P1 with the TD Peers

		JPD		JOD		JLDM	
JHP	Word	U	**p*	U	**p*	U	**p*
4	Mine	14	**.042**	36	.933	7	**.005**
4	Man	21	.168	18	.098	25	.306
4	Hat	17	.081	37	1	7	**.005**
3	Up	20	.142	31	.612	8	**.008**
2	Off	35	.866	28	.445	6	**.004**
2	Shop	.000	**.000**	1	**.000**	.000	**.000**
2	Spot	6	**.004**	14	**.042**	14	**.042**
1.5	Six	7	**.005**	11	**.019**	18	.098
1	Beep	1	**.000**	.000	**.000**	10	**.015**
1	Push	4	**.002**	6	**.004**	9	**.011**
1	Two	.000	**.000**	.000	**.000**	23	.230

Note. JPD = jaw path distance, JOD = jaw open distance, JLDM = Jaw lateral distance from midline. *= two-tailed test, bold face = $p \leq .05$.

Post intervention.

The results for the three distance measures, obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect sizes are presented in Table 5.7. Means and SDs are presented in Figures H.1, H.2 and H.3.

Table 5.7

Friedman's ANOVA and Wilcoxon- Signed-Rank-Test Data for Each Mandibular Distance Measure for Each Word across the Study Phases for P1

	Friedman's ANOVA		Pairwise comparisons - Wilcoxon Signed-Rank Test														
	(df 3)		A1-B			A1-C			B-C			A1-A2			C-A2		
Word	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
Path Distance (JPD)																	
Mine	1.00	.182	0.00	1.00	0.00	-1.21	0.31	0.38	0.00	1.00	0.00	-1.21	0.31	0.38	-0.13	1.00	0.04
Man	4.20	.300	-1.07	0.50	0.38	-1.75	0.13	**0.55**	-1.60	0.25	**0.57**	-1.75	0.13	**0.55**	-0.67	0.63	0.21
Hat	2.20	.083	-1.07	0.50	0.38	-2.02	0.06	**0.64**	-1.07	0.50	0.38	-0.13	1.00	0.04	-0.94	0.44	0.30
Up	6.60	.075	-0.53	0.75	0.19	-2.02	0.06	**0.64**	-1.60	0.25	**0.57**	-1.21	0.31	0.38	-2.02	0.06	**0.64**
Off	2.60	.524	-0.53	0.75	0.19	-2.02	0.06	**0.64**	-0.53	0.75	0.19	-1.75	0.13	**0.55**	-0.13	1.00	0.04
Shop	5.80	.148	-1.60	0.25	**0.57**	-1.46	0.25	0.46	-1.60	0.25	**0.57**	-1.75	0.13	**0.55**	-1.83	0.13	**0.58**
Spot	5.40	.175	0.00	1.00	0.00	-2.02	0.06	**0.64**	-1.60	0.25	**0.57**	-1.46	0.25	0.46	-1.10	0.38	0.35
Six	3.80	.342	-1.07	0.50	0.38	-2.02	0.06	**0.64**	-0.53	0.75	0.19	-0.40	0.81	0.13	-2.02	0.06	**0.64**
Beep	4.20	.300	0.00	1.00	0.00	-1.48	0.19	0.47	-1.60	0.25	**0.57**	-0.40	0.81	0.13	-1.36	0.22	0.43
Push	1.00	.910	-0.53	0.75	0.17	-0.13	1.00	0.04	-1.07	0.50	0.34	-1.75	0.13	**0.55**	-1.48	0.19	0.47
Two	1.00	.910	-0.53	0.75	0.19	-0.40	0.81	0.13	-1.07	0.50	0.38	-1.21	0.31	0.38	-1.21	0.31	0.38
Jaw Open Distance (JOD)																	
Mine	1.00	.910	0.00	1.00	0.00	-0.40	0.81	0.13	0.00	1.00	0.00	-1.21	0.31	0.38	-1.75	0.13	**0.55**
Man	2.20	.608	-0.53	0.75	0.19	-0.40	0.81	0.13	-0.53	0.75	0.19	-0.13	1.00	0.04	-0.94	0.44	0.30
Hat	2.60	.524	-1.60	0.25	**0.57**	-1.75	0.13	**0.55**	-0.53	0.75	0.19	-0.40	0.81	0.13	-0.13	1.00	0.04
Up	7.00	**.054**	-0.53	0.75	0.19	-0.13	1.00	0.04	-1.60	0.25	**0.57**	-1.48	0.19	0.47	-2.02	0.06	**0.64**
Off	6.60	.075	-1.60	0.25	**0.57**	-0.67	0.63	0.21	-1.60	0.25	**0.57**	-0.13	1.00	0.04	-1.48	0.19	0.47
Shop	8.20	**.017***	-1.60	0.25	**0.57**	-0.73	0.63	0.23	-1.60	0.25	**0.57**	-2.02	0.06	**0.64**	-1.83	0.13	**0.58**
Spot	5.80	.148	-0.53	0.75	0.19	-2.02	0.06	**0.64**	-1.60	0.25	**0.57**	0.00	1.00	0.00	-1.83	0.13	**0.58**
Six	8.20	**.017***	-1.60	0.25	**0.57**	-2.02	0.06	**0.64**	-1.60	0.25	**0.57**	-2.02	0.06	**0.64**	-0.40	0.81	0.13
Beep	1.00	.910	-0.53	0.75	0.19	-1.21	0.31	0.38	0.00	1.00	0.00	-1.75	0.13	**0.55**	-1.99	0.06	**0.63**
Push	3.80	.342	-0.53	0.75	0.17	-0.13	1.00	0.04	-1.60	0.25	**0.51**	-0.94	0.44	0.30	-0.94	0.44	0.30
Two	4.20	.300	-0.53	0.75	0.19	-1.75	0.13	**0.55**	-0.53	0.75	0.19	-2.02	0.06	**0.64**	-0.67	0.63	0.21

Jaw Lateral Distance from Midline (JLDM)																	
Mine	2.60	.524	-1.07	0.50	0.38	-0.94	0.44	0.30	0.00	1.00	0.00	-0.40	0.81	0.13	-0.13	1.00	0.04
Man	0.60	.958	-0.53	0.75	0.19	-1.21	0.31	0.38	-0.53	0.75	0.19	-0.13	1.00	0.04	-0.40	0.81	0.13
Hat	1.80	.727	0.00	0.63	0.00	-1.75	0.06	**0.55**	-1.07	0.25	0.38	-0.13	0.50	0.04	-2.02	**0.03**	**0.64**
Up	1.00	.910	0.00	1.00	0.00	-2.02	0.06	**0.64**	-1.07	0.50	0.38	-1.21	0.31	0.38	-1.21	0.31	0.38
Off	1.80	.727	-0.53	0.75	0.19	-0.67	0.63	0.21	-0.53	0.75	0.19	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Shop	4.20	.300	-1.60	0.25	**0.57**	-1.83	0.13	**0.58**	-1.60	0.25	**0.57**	-0.13	1.00	0.04	-1.46	0.25	0.46
Spot	2.20	.608	-1.07	0.50	0.38	-2.02	0.06	**0.64**	-1.60	0.25	**0.57**	-0.73	0.63	0.23	-1.83	0.13	**0.58**
Six	5.00	.207	-1.07	0.50	0.38	-1.75	0.13	**0.55**	0.00	1.00	0.00	-0.13	1.00	0.04	-0.94	0.44	0.30
Beep	2.20	.608	0.00	0.63	0.00	-0.94	0.22	0.30	-1.60	0.13	**0.57**	-2.02	0.03	**0.64**	-0.40	0.41	0.13
Push	1.80	.727	-0.53	0.75	0.17	-0.40	0.81	0.13	0.00	1.00	0.00	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Two	7.00	**.054**	-0.53	0.75	0.19	-2.02	0.06	**0.64**	-1.60	0.25	**0.57**	-0.13	1.00	0.04	-2.02	0.06	**0.64**

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).
*=*p* ≤ .05, two-tailed test, boldface = large effect size.

Jaw Path Distance (JPD).

Whilst the results of the Friedman's ANOVA and Wilcoxon signed-rank tests indicate no statistically significant change, the effect size data (Table 4.4) and the descriptive data (Figure H.1) indicate clinically significant changes across the study phases.

Decreases in mean values, with a trend towards the TD peers were recorded between phases A-B in 3/5 words of word-set two (beep, push and shop). Phase C (intervention priority: lingual control) was characterized by an increase in mean values that exceeded pre-intervention in 10/11 words and indicates a trend away from the TD peers. However, between phases C-A2, a return to decreasing values was observed in these same 10 words, with 5/10 (up, shop, push, beep, two) words recording values lower than pre-intervention (phase A1).

Jaw Open Distance (JOD).

The results obtained using Friedman's ANOVA indicate the presence of a main effect on three words (up, shop and six).

Whilst the pairwise comparisons between phases A-B were not significant, large effect sizes were recorded on four words (hat, off, shop, six). This indicates a clinically significant effect (intervention priority: labial-facial control) with a trend towards the TD peers. Phase C (intervention priority: lingual control) yielded a return to an increase in mean values on these same words, however they remained below pre-intervention values (Table H.2).

Between phases A1-A2, large effect sizes were recorded in word-sets two and three, with a trend direction towards the TD peers. This indicates a clinically significant change.

Jaw Lateral Distance from Midline (JLDM).

The results obtained using Friedman's ANOVA indicate no presence of a main effect on any word, thus indicating no statistically significant changes.

However, clinically significant changes were indicated. Moderate effect sizes were recorded on four words (shop, spot, six and mine). Mean values (see Table H.3) increased between phases B-C with three words (hat, up, two) recording values above 3mm. Phase A2 (follow-up) showed a return to decreasing values with 5/11 recording values less than pre-intervention (phase A1).

Labial-facial control measures.

Pre-intervention.

Analyses of the kinematic data presented in Table 5.8 indicate impaired labial-facial control at pre-intervention. Specifically:

LRR – All 11 words recorded values that exceeded those of the TD peers.

BLC – A statistically significant difference in inter-lip distance was recorded on both words in word-set one.

Table 5.8

Mann-Whitney Test Results of the Pre-intervention Labial-Facial Distance Measures Comparing P1 with the TD Peers

	LRR			BLC	
Word	U	†*p*		U	†*p*
Mine	4	**.002**	mine	12	**.013**
Man	.000	**.000**	man	19	**.059**
Hat	2	**.001**	push	21	.084
Up	.000	**.000**	beep	35	.433
Off	7	**.005**			
Shop	.000	**.000**			
Spot	.000	**.000**			
Six	8	**.008**			
Beep	.000	**.000**			
Push	13	**.033**			
Two	.000	**.000**			

Note. LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact.
†= one-tailed test, boldface = p ≤.05.

Post intervention.

The results obtained using Friedman’s ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data, for the two distance measures are presented in Table 5.6. In summary, these analyses, (supported by the descriptive data in Tables H.4 and H.5) indicate the presence of a treatment effect on labial-facial measures.

Table 5.9

Friedman's ANOVA and Wilcoxon Signed Rank Data for each Labial-Facial Distance Measure for each Word for P1

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
Lip Rounding/Retraction (LRR)																	
Mine	8.20	.017*	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-2.02	.031	**0.64**
Man	9.00	.002*	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-2.02	.031	**0.64**
Hat	5.80	.148	-1.07	.250	0.38	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-1.21	.156	0.38	-2.02	.031	**0.64**
Up	8.20	.017*	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-1.21	.156	0.38	-2.02	.031	**0.64**
Off	7.00	.054	-1.07	.250	0.38	-2.02	.031	**0.64**	-1.07	.250	0.38	-2.02	.031	**0.64**	-2.02	.031	**0.64**
Shop	5.80	.148	0.00	.625	0.00	-1.83	.063	**0.58**	-1.60	.125	**0.57**	-1.21	.156	0.38	-1.83	.063	**0.58**
Spot	8.20	.017*	-0.53	.375	0.19	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-1.83	.063	**0.58**	-1.83	.063	**0.58**
Six	8.20	.017*	-1.07	.250	0.38	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-2.02	.031	**0.64**
Beep	7.00	.054	-1.07	.250	0.38	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-2.20	.016	**0.70**
Push	4.20	.300	-1.60	.125	**0.51**	-2.02	.031	**0.64**	-1.07	.250	0.34	-1.48	.094	0.47	-1.75	.063	**0.55**
Two	8.20	.017*	-1.07	.250	0.38	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-2.02	.031	**0.64**
Bilabial Inter-lip Distance (BLC)																	
Mine	9.00	.002*	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-0.94	.219	0.30
Man	7.40	.033*	0.00	.625	0.00	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.75	.063	**0.55**
Push	7.40	.033*	0.00	.625	0.00	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-0.67	.313	0.21
Beep	8.20	.017*	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-0.40	.406	0.13
Upper Lip (UL) Position																	
Mine	1.00	.910	-0.53	.375	0.19	-1.75	.063	**0.55**	0.00	.625	0.00	-1.75	.063	**0.55**	-1.21	.156	0.38
Man	3.40	.446	0.00	.625	0.00	-0.13	.500	0.04	0.00	.625	0.00	-2.02	.031	**0.67**	-2.02	.031	**0.67**
Push	2.60	.524	0.00	.625	0.00	-0.67	.313	0.21	-0.53	.375	0.19	-1.48	.094	0.47	-2.02	.031	**0.64**
Beep	6.60	.075	-1.60	.125	**0.57**	-2.02	.031	**0.64**	0.00	.625	0.00	-2.02	.031	**0.64**	-2.02	.031	**0.64**
Lower Lip (LL) Position																	
Mine	9.00	.002*	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.48	.094	0.47
Man	5.80	.148	0.00	.625	0.00	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-0.13	.500	0.04
Push	8.20	.017*	0.00	.625	0.00	-2.02	.031	**0.64**	-1.60	.125	**0.51**	-2.02	.031	**0.64**	-2.02	.031	**0.64**
Beep	7.00	.054	-1.07	.250	0.38	-2.02	.031	**0.64**	-1.60	.125	**0.57**	-2.02	.031	**0.64**	-1.75	.063	**0.55**

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).
* = p ≤.05, one-tailed test, boldface = large effect size.

Lip Rounding/Retraction (LRR).

The results obtained using Friedman's ANOVA indicates a main effect on 6/11 words.

The pair-wise comparisons indicate phase C (intervention priority: lingual control) yielded the most substantial change with effect sizes greater than 0.6 for 10/11 words. This phase was characterised by an increase in mean values and a trend away from TD peers. Phase A2 was characterised by a return to decreased values with a significant difference in 7/11 words, and 3 words (off, spot, two) recording values that were significantly less than pre-intervention (phase A1).

Closer examination of the data revealed a change of where in the word the maximum retraction distance was recorded, subsequent to intervention. Further analysis was undertaken that involved segmenting each word for each trial into the components of non-lingual consonant, lingual consonant and vowel; and determining the point of maximum retraction. Table 5.10 shows the changes in where the maximum retraction across the study phases occurred. At the end of phase A1, 36% of the occasions of maximum retraction occurred on the lingual consonants. Phase C was characterised by a 20% increase on the occasions of maximum retraction occurring on the lingual consonants.

Table 5.10

Timing of Maximum Retraction within Words, across the Study Phases

	Study Phases											
	Phase A1			#Phase B			Phase C			Phase A2		
Word	C-NL	V	C-L	C-NL	V	C-L	C-NL	V	C-L	C-NL	V	C-L
Mine	1	2	2		3				5			5
Man		4	1		2	1			5		3	2
Hat	1	2	2	2		1	2	1	2		2	3
Up	4	1		1	2		3	2		5		
Off	5			3			1	4		2	3	
Shop			5	3					5			5
‡Spot	1	1	3	2		1			5			4
Six		2	3		2	1		1	4		1	4
Beep		5		1	2			5			5	
Push	1		4			3			5			5
Two		5			3			5			5	
TOTAL	13	22	20	12	14	7	6	18	31	7	19	28
%	26	40	36.4	40	42.4	21.2	12	32.7	56.4	14	35.2	51.9

Note. C-NL = non-lingual consonants, V = vowel, C-L = lingual consonants, # phase B = consists of 3 trials, ‡spot = 4 trials in phase A2.

Inter-lip distance during Bilabial Contact (BLC).

The results obtained using Friedman’s ANOVA indicate a significant main treatment effect on the inter-lip distance during bilabial lip contact on all four words, with phase C yielding the most significant change.

Plots of the average vertical positions of the UL and LL markers at the point of bilabial contact, for each of the four words, are shown in Figure 5.1. The LL is plotted on the X-axis and the UL is plotted on the y-axis. A negative value reflects an inferior (downward) position, whilst a positive value reflects a superior (upward) position, from rest.

A change in the interaction between the UL and LL, across the study phases, during bilabial contact is indicated. At the point of minimum bilabial contact the UL was positioned increasingly inferiorly (downwards towards the bottom lip) on the word ‘mine’ and ‘beep’ across all study phases in comparison to pre-intervention. Phase A2 yielded the most significant change with all words recording a more inferior position compared to pre-intervention (phase A1). The LL values recorded a more superior position (upward) from rest across the study phases, with phase C yielding a significant increase. Phase A2 recorded a return to values that were less superior, however, these values remained higher than recorded at pre-intervention.

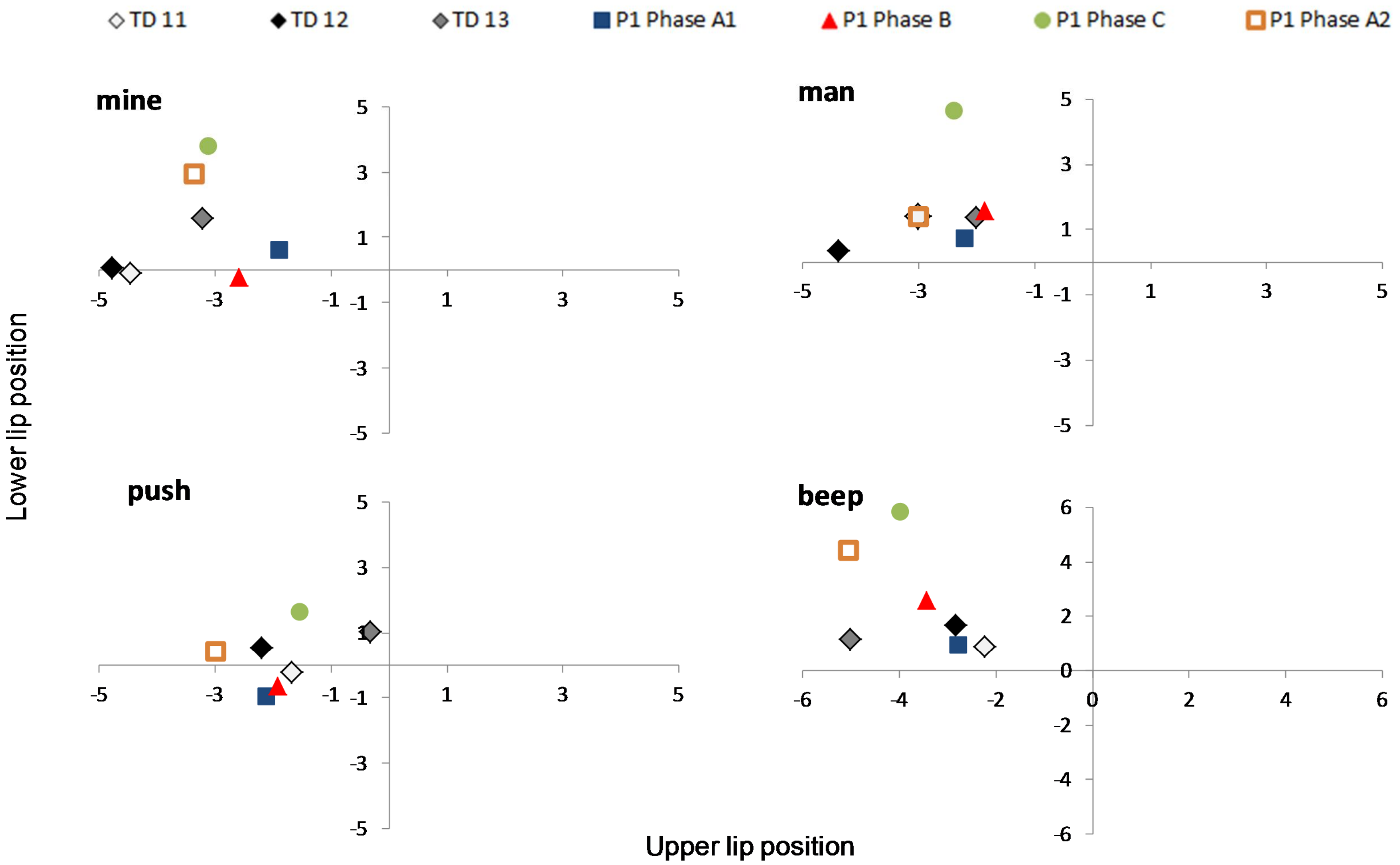


Figure 5.5. Average position of the upper lip (X axis) and lower lip (Y axis), across the study phases, as measured at minimum inter-lip distance at the point of bilabial contact (mms) for P1 and the (TD) peers.

Jaw/Lip Opening Velocity (J/L Vel).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by the P1 and the TD peers are presented in Table 5.11. The results show the peak rate of movement was generally slower than the TD peers in word-set two and three.

Table 5.11

Mann-Whitney test Results and Descriptive Data (Means and Standard Deviations) of the Pre-Intervention Jaw/Lip Opening Velocity Measures Comparing P1 with the TD Peers

			TD peers			P1
	Velocity		TD 11	TD 12	TD13	Phase A
Word	U	*p	M(SD)	M(SD)	M(SD)	M(SD)
Mine	32	.672	145.03(13.77)	81.73(16.00)	87.11(13.15)	94.72(27.44)
Man	28	.445	174.35(13.84)	92.87(18.03)	58.74(25.52)	115.89(12.91)
Hat	17	.081	29.35(20.82)	6.95(2.54)	7.80(13.35)	22.45(5.28)
Up	17	.081	27.95(3.06)	22.89(3.55)	1.96(2.74)	29.01(18.36)
Off	19	.119	9.14(3.46)	20.35(5.69)	5.63(2.36)	6.72(7.34)
Shop	25	.306	88.10(6.21)	42.31(7.53)	36.90(10.30)	66.81(12.43)
Spot	4	**.002**	99.06(14.77)	60.05(6.24)	47.83(9.19)	36.08(5.60)
Six	12	**.025**	29.63(12.78)	13.31(4.35)	15.60(8.02)	34.05(5.19)
Beep	16	.066	88.46(11.23)	26.60(3.31)	9.98(9.14)	81.70(10.04)
Push	12	**.025**	28.19(12.67)	13.43(14.02)	5.07(3.56)	36.10(5.09)
Two	.000	**.000**	6.73(2.87)	10.77(2.40)	5.39(6.15)	30.07(6.70)

Note. TD = typically developing
* = two-tailed tests, boldface = significant ≤ .05

Post intervention.

Results obtained using the Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data on the measures of jaw/lip opening velocity are presented in Table 5.13.

The results indicate a significant main treatment effect on three words (shop, spot and two). Whilst the pairwise comparisons show no evidence of statistically significant changes, moderate to large effect sizes were recorded across each study phase. There were decreased mean peak values in Phase B and increases in Phase C. Phase A2 yielded increased mean values for 9/11 words in comparison to pre-intervention (phase A1).

Word Duration (WD).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by P1 and the TD peers are presented in Table 5.12. The results show significantly longer durations on 10/11 words.

Table 5.12

Mann-Whitney test Results and Descriptive Data (Means and Standard Deviations) of the Pre-Intervention Word Duration Measures Comparing P1 with the TD Peers

			TD peers			P1
	Duration		TD 11	TD12	TD13	Phase A
Word	U	**p*	M(SD)	M(SD)	M(SD)	M(SD)
Mine	19	.113	0.56(0.04)	0.48(0.07)	0.47(0.02)	0.61(0.15)
Man	13	**.030**	0.56(0.04)	0.48(0.04)	0.46(0.04)	0.58(0.08)
Hat	.000	**.000**	0.60(0.06)	0.52(0.03)	0.47(0.05)	0.77(0.08)
Up	13	**.030**	0.43(0.07)	0.34(0.09)	0.36(0.08)	0.59(0.18)
Off	11.5	**.019**	0.40(0.06)	0.46(0.06)	0.47(0.05)	0.52(0.06)
Shop	.000	**.000**	0.57(0.05)	0.50(0.03)	0.52(0.06)	0.98(0.09)
Spot	.000	**.000**	0.79(0.08)	0.68(0.04)	0.69(0.11)	1.27(0.05)
Six	.500	**.000**	0.71(0.07)	0.66(0.04)	0.64(0.07)	0.86(0.07)
Push	5	**.002**	0.41(0.09)	0.40(0.10)	0.34(0.05)	0.66(0.09)
Beep	.5	**.000**	0.64(0.04)	0.54(0.01)	0.56(0.07)	0.76(0.12)
Two	9	**.009**	0.50(0.04)	0.43(0.06)	0.44(0.02)	0.58(0.08)

Note. TD = typically developing
*= two-tailed tests, boldface = significant ≤ .05

Post intervention.

The results obtained on Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data, are presented in Table 5.13.

The results show a main effect on one word (man) only. There was a decrease in WD mean values between phases A-B for 9/11words. A large effect size was recorded on three words (shop, hat and two). There was a return to increased mean values in Phase C for 7/11 words. Phase A2 yielded the greatest change and indicated a trend towards the TD peers, with a return to decreased mean values that were lower than those recorded at pre-intervention. Six of eleven words recorded effect sizes between 0.45 and 0.58 (hat, up, shop, spot, beep, push, two).

Table 5.13

Friedman's ANOVA and Wilcoxon Signed-Rank Data for Velocity and Word Duration Measures for Each Word across the Study Phases for P1

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test															
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
	Jaw/Lip Opening Velocity (J/L Vel)																
Mine	2.60	.525	-1.60	0.25	**0.57**	-0.67	0.63	0.21	-1.07	0.50	0.38	-1.21	0.31	0.38	-2.02	0.06	**0.64**
Man	2.60	.524	-1.07	0.50	0.38	-0.13	1.00	0.04	-1.60	0.25	**0.57**	-0.67	0.63	0.21	-0.67	0.63	0.21
Hat	0.60	.968	-0.53	0.75	0.19	-1.21	0.31	0.38	0.00	1.00	0.00	-1.21	0.31	0.38	-0.13	1.00	0.04
Up	6.60	.075	0.00	1.00	0.00	-2.02	0.06	**0.64**	-1.60	0.25	**0.57**	-1.21	0.31	0.38	-2.02	0.06	**0.64**
Off	0.20	1.000	0.00	1.00	0.00	-0.13	1.00	0.04	-0.53	0.75	0.19	-1.21	0.31	0.38	-1.21	0.31	0.38
Shop	7.00	.054	-1.07	0.50	0.38	-0.73	0.63	0.23	-1.60	0.25	**0.57**	-0.67	0.63	0.21	-0.37	0.88	0.12
Spot	8.20	.017*	-1.60	0.25	**0.57**	-2.02	0.06	**0.64**	-1.60	0.25	**0.57**	-1.83	0.13	**0.61**	-0.37	0.88	0.12
Six	1.00	.910	-1.07	0.50	0.38	-1.75	0.13	**0.55**	-1.07	0.50	0.38	-0.13	1.00	0.04	-1.21	0.31	0.38
Beep	2.20	.608	-0.53	0.75	0.19	-0.67	0.63	0.21	-1.07	0.50	0.38	-0.13	1.00	0.04	-0.13	1.00	0.04
Push	6.60	.075	-1.60	0.25	**0.57**	-1.75	0.13	**0.55**	-1.60	0.25	**0.51**	-2.02	0.06	**0.64**	-0.94	0.44	0.30
Two	7.00	.054	-1.60	0.25	**0.57**	-0.67	0.63	0.21	-1.60	0.25	**0.57**	-0.40	0.81	0.13	-0.13	1.00	0.04
	Word Duration (W/D)																
Mine	4.18	.278	0.00	1.00	0.00	-0.73	0.63	0.23	-1.63	0.25	**0.58**	-0.13	1.00	0.04	-2.06	0.06	**0.65**
Man	7.32	.042*	0.00	1.00	0.00	-2.02	0.06	**0.64**	-1.63	0.25	**0.58**	-1.83	0.13	**0.58**	-1.83	0.13	**0.58**
Hat	3.41	.403	-1.60	0.25	**0.57**	-0.68	0.63	0.21	0.00	1.00	0.00	-1.35	0.25	0.43	-0.68	0.63	0.21
Up	4.20	.300	-0.53	0.75	0.19	-0.40	0.81	0.13	-1.07	0.50	0.38	-1.76	0.13	**0.56**	-2.02	0.06	**0.64**
Off	0.60	.958	0.00	1.00	0.00	-1.08	0.38	0.34	-0.53	0.75	0.19	-0.40	0.81	0.13	0.00	1.00	0.00
Shop	5.00	.207	-1.60	0.25	**0.57**	-0.73	0.63	0.23	-1.07	0.50	0.38	-1.63	0.19	**0.52**	-1.83	0.13	**0.58**
Spot	2.57	.521	0.00	1.00	0.00	-0.14	1.00	0.04	-0.45	1.00	0.16	-1.60	0.25	**0.53**	-0.92	0.50	0.31
Six	3.83	.333	0.00	1.00	0.00	-1.84	0.13	**0.58**	-1.60	0.25	**0.57**	-0.27	0.88	0.09	-1.46	0.25	0.46
Beep	5.90	.115	0.00	1.00	0.00	-0.40	0.81	0.13	-1.60	0.25	**0.57**	-1.83	0.13	**0.58**	-2.03	0.06	**0.64**
Push	0.72	.931	0.00	1.00	0.00	-0.27	0.88	0.09	-0.53	0.75	0.17	-0.37	0.75	0.12	0.00	1.00	0.00
Two	2.79	.483	-1.07	0.50	0.38	0.00	1.00	0.00	-1.07	0.50	0.38	-1.47	0.25	0.47	-1.35	0.25	0.43

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one: labial-facial control), C = phase C (intervention priority two: lingual control), A2 = phase A2 (follow-up).
*= $p \leq .05$, two-tailed, boldface = large effect size.

Overall summary of P1’s kinematic measures.

Subsequent to the PROMPT intervention, the following changes were evident across the study phases:

Phase B – yielded a decrease in mean values across most measures, with a trend towards the TD peers.

Phase C – was characterised by an increase in mean values, with some measures (JLDM, JPD and LRR) exceeding the pre-intervention values, thus indicating a trend away from the TD peers.

Phase A2 – a return in trend direction towards the TD peers was observed, with words in each word-set recording values less than those recorded at pre-intervention.

The above results indicate P1’s intervention program was successful in producing changes to the motor-speech movement patterns under investigation.

Participant 2

The following motor-speech movement patterns were targeted during the PROMPT Intervention:

Phase B: (Intervention priority one: mandibular control) - Facilitate jaw grading and distance between the jaw height positions of low vowels (i.e., JHPs 3 and 4). Reduce anterior thrust of the jaw during production of low vowels.

Phase C: (Intervention priority two: labial-facial) – decrease jaw open distance on high vowels (i.e., JHPs 1 and 2). Facilitate appropriate neutral, rounded and retracted lip movements.

Table 5.14 summarises the words that recorded significant change in the jaw and lip measures for P2 as compared with the TD peers pre-intervention and significant changes post-intervention, for these words. Results are based on five repetitions for all words.

The distance data (see Appendix J) at pre-intervention show decreased JOD on the words containing low vowels, and increased JOD on words containing high vowels in comparison with the TD peers. Lip retraction values also exceeded the TD peers.

The post-intervention data show a positive treatment effect with changes to the measures of JOD in phase B and LRR in phase C reflective of the intervention priorities.

Table 5.14

Words that Recorded Significantly Different Pre (Mann-Whitney Test) and Post-Intervention (Friedman's ANOVA) Values on the Kinematic Measures of Distance, Velocity and Duration for P2

	*Mandibular Control						†Labial-Facial Control							
Word Stimuli	JPD		JOD		JLDM		LRR		BLC		J/LVEL		WD	
MSH	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Wordset 1														
Mine			X				X	✓						
Man	X	✓	X	✓			X	✓	X	✓				✓
Hat	X		X	✓										
Up	X	✓					X	✓		✓	X			
Wordset 2														
Off							X	✓						
Shop					X		X				X	✓	X	
Beep				✓			X		X	✓		✓		✓
Push									X		X	✓		
Two				✓										
Wordset 3														
Six				✓			X						X	✓
Spot	X		X				X							
Total	4	2	4	5	1		8	4	3	3	3	3	2	3

Note. Pre = pre-intervention comparison with peers, Post = post intervention comparison (phases B, C and A2), X = movement pattern significantly different to TD peers, ✓ = significant change recorded, MSH = motor speech hierarchy plane of movement, JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline, LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact, J/L VEL = jaw/lip opening velocity, WD =word duration.
* = *p* value ≤ .05, two-tailed, †= *p* value ≤ .05,one-tailed

Distance measures.

Mandibular control.

Pre-intervention.

Analyses of the kinematic data provided in Table 5.12 indicate impaired mandibular control at pre-intervention. Specifically:

JOD and JPD – were reduced in words containing low vowels (i.e. JHP 4), with two of three words (man, hat, up) showing a statistically significant difference relative to the TD peers. JHP 3 ('up') significantly exceeded the JPD and JOD measures of JHP 4.

Words containing high vowels (i.e. JHP 1) and mid-high vowels (i.e. JHP 2) recorded lower values that the TD peers. However, results obtained on the Mann-Whitney indicate these lower values were not statistically significant. Therefore performance is considered comparable to the TD peers.

JLDM – Words in the mid-jaw range (off, six, beep) recorded values that exceeded the TD peers. However, all values were within the acceptable range reported in the literature (that is within 2 -3 mm).

Table 5.15

Mann-Whitney Test Results of the Pre-Intervention Mandibular Distance Measures Comparing P2 with the TD Peers

		JPD		JOD		JLDM	
JHP	Word	U	**p*	U	**p*	U	**p*
	Mine	17.00	.371	7.00	**.028**	12.00	.129
4	Man	7.00	**.028**	8.00	**.040**	14.00	.206
	Hat	6.00	**.019**	6.00	**.019**	12.00	.129
3	Up	2.00	**.003**	19.00	.513	6.00	**.019**
	Off	16.00	.310	25.00	1.000	15.00	.254
2	Shop	14.00	.206	18.00	.440	12.00	.129
	Spot	20.00	.594	20.00	.594	16.00	.310
1.5	Six	7.00	**.028**	4.00	**.008**	15.00	**.028**
	Beep	10.00	.075	19.00	.513	7.00	**.028**
1	Push	22.00	.761	18.00	.440	24.00	.953
	Two	16.00	.310	11.00	.099	24.00	.953

Note. JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline.
*= two-tailed test, boldface = p ≤.05.

Post intervention.

The results for the three distance measures, obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect sizes are presented in Table 5.13. Means and SDs are presented in Figures I.1, I.2 and I.3.

In summary, the results indicate the presence of a positive treatment effect on the motor-speech-movement patterns targeted across the study phases. Specifically, increases in JPD and JOD in words containing low and mid-low vowels (i.e. JHP 4 and 3) were recorded at the end of phase B (intervention priority one).

Table 5.16

Friedman's ANOVA and Wilcoxon- Signed-Rank-Test Data for Each Mandibular Distance Measure for Each Word across the Study Phases for P2

	Friedman's ANOVA Main Effect (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
Word	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
Path Distance (JPD)																	
Mine	2.52	.521	-0.94	0.44	0.30	-0.40	0.81	0.13	-1.21	0.31	0.38	-0.40	0.81	0.13	-0.67	0.63	0.21
Man	9.24	.017*	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-0.13	1.00	0.04	-2.02	0.06	**0.64**	-1.21	0.31	0.38
Hat	2.28	.561	-0.40	0.81	0.13	-0.67	0.63	0.21	-1.75	0.13	**0.55**	-0.94	0.44	0.30	-1.75	0.13	**0.55**
Up	9.72	.012*	-2.02	0.06	**0.64**	-1.21	0.31	0.38	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**
Off	2.04	.652	-0.94	0.44	0.30	-1.75	0.13	**0.55**	-0.13	1.00	0.04	-1.21	0.31	0.38	-0.40	0.81	0.13
Shop	4.44	.226	-0.67	0.63	0.21	-1.48	0.19	0.47	-1.21	0.31	0.38	-1.48	0.19	0.47	-0.40	0.81	0.13
Spot	2.04	.652	-1.21	0.31	0.38	-0.40	0.81	0.13	-0.13	1.00	0.04	-1.75	0.13	**0.55**	-0.94	0.44	0.30
Six	2.52	.521	-0.13	1.00	0.04	-1.48	0.19	0.47	-1.21	0.31	0.38	-0.40	0.81	0.13	-1.48	0.19	0.47
Beep	6.12	.107	-1.21	0.31	0.38	-0.94	0.44	0.30	-0.67	0.63	0.21	-0.13	1.00	0.04	-1.75	0.13	**0.55**
Push	1.08	.857	-0.67	0.63	0.21	-0.40	0.81	0.13	-0.67	0.63	0.21	-0.13	1.00	0.04	-0.13	1.00	0.04
Two	5.16	.162	-0.13	1.00	0.04	-0.13	1.00	0.04	-0.67	0.63	0.21	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**
Jaw Open Distance (JOD)																	
Mine	1.56	.709	-0.13	1.00	0.04	-1.21	0.31	0.38	-0.94	0.44	0.30	-0.67	0.63	0.21	-0.13	1.00	0.04
Man	8.04	.034*	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-0.13	1.00	0.04	-1.75	0.13	**0.55**	-0.13	1.00	0.04
Hat	8.28	.031*	-1.48	0.19	0.47	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-0.67	0.63	0.21
Up	7.08	.067	-0.13	1.00	0.04	-2.02	0.06	**0.64**	-1.21	0.31	0.38	-0.40	0.81	0.13	-2.02	0.06	**0.64**
Off	4.20	.260	-1.21	0.31	0.38	-1.48	0.19	0.47	-0.13	1.00	0.04	-0.94	0.44	0.30	-0.67	0.63	0.21
Shop	6.84	.075	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-0.94	0.44	0.30
Spot	7.80	.044*	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-1.48	0.19	0.47
Six	6.12	.107	-0.40	0.81	0.13	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-1.48	0.19	0.47	-0.40	0.81	0.13
Beep	5.00	.031*	-1.48	0.19	0.47	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-0.13	1.00	0.04
Push	5.88	.123	-0.13	1.00	0.04	-1.75	0.13	**0.55**	-1.75	0.13	**0.55**	-0.67	0.63	0.21	-0.94	0.44	0.30
Two	10.20	.007*	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-0.94	0.44	0.30

Jaw Lateral Distance from Midline (JLDM)																	
Mine	3.96	.298	-0.40	0.81	0.13	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-0.13	1.00	0.04	-0.94	0.44	0.30
Man	4.92	.210	-1.21	0.31	0.38	-0.67	0.63	0.21	-0.94	0.44	0.30	-0.67	0.63	0.21	-0.67	0.63	0.21
Hat	5.40	.151	-1.75	0.13	**0.55**	-1.75	0.13	**0.55**	-0.40	0.81	0.13	-1.48	0.19	0.47	-0.67	0.63	0.21
Up	0.60	.944	-0.67	0.63	0.21	-0.13	1.00	0.04	-0.40	0.81	0.13	-0.13	1.00	0.04	-0.40	0.81	0.13
Off	2.52	.521	-0.94	0.44	0.30	-0.13	1.00	0.04	-1.21	0.31	0.38	-0.67	0.63	0.21	-1.21	0.31	0.38
Shop	6.36	.093	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-0.13	1.00	0.04
Spot	0.12	1.000	-0.67	0.63	0.21	-0.40	0.81	0.13	-0.40	0.81	0.13	-0.67	0.63	0.21	-0.40	0.81	0.13
Six	2.28	.561	-1.21	0.31	0.38	-0.67	0.63	0.21	-1.21	0.31	0.38	-0.40	0.81	0.13	-0.13	1.00	0.04
Beep	4.20	.260	-2.02	0.06	**0.64**	-0.13	1.00	0.04	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Push	4.92	.210	-0.40	0.81	0.13	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-0.40	0.81	0.13	-0.94	0.44	0.30
Two	3.00	.445	-0.94	0.44	0.30	-0.67	0.63	0.21	-0.13	1.00	0.04	-1.21	0.31	0.38	-2.02	0.06	**0.64**

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).
*=$p \leq .05$, two-tailed test, Bold face = large effect size.

Jaw Path Distance (JPD).

The results obtained using Friedman's ANOVA indicate a positive treatment effect subsequent to intervention. A main effect was recorded on 2/3 words – 'man' at JHP 4 and 'up' at JHP 3.

Pair-wise comparisons indicate treatment phase B yielded the most significant change with evidence of maintenance at follow-up (phases A-A2).

Jaw Open Distance (JOD).

The results obtained using Friedman's ANOVA indicate a positive main effect on the 2 words at JHP 4 that differed significantly from the TD peers at pre-intervention. The pair-wise comparisons indicate the treatment effect occurred in phase A1-B. Increasing values continued in phase C, with evidence of maintenance at follow-up (phase A2).

In addition, a significant increase in JOD was also recorded on the words 'spot' (JHP2) 'beep' and 'two' (JHP1). Pair-wise comparisons indicate these changes were recorded in phase C.

Jaw Lateral Distance from Midline (JLDM).

The results obtained using Friedman's ANOVA did not indicate the presence of a main effect on any word. Thus, JLDM remained comparable with the TD peers.

Labial-facial control.

Pre-intervention.

Analyses of the kinematic data provided in Table 5.17 indicate impaired labial-facial control at pre-intervention. Specifically:

LRR – Eight of 11 words recorded values that exceeded those of the TD peers. Excessive retraction was recorded on all words (except 'hat') at JHPs 4, 3 and 2. The two words containing rounded vowels at JHP 1 ('push' and 'two') were comparable to the TD peers.

BLC – A statistically significant difference in inter-lip distance was recorded on three of the four words containing the bilabial in the word initial position. Positive values were recorded in both the UL and LL position for all words, except 'beep', at pre-intervention. This indicates that, at the point of minimum bilabial lip contact, the UL and LL were positioned superiorly to the rest position.

Table 5.17

Mann-Whitney Test Results of the Pre-Intervention Labial-Facial Distance Measures Comparing P2 with the TD Peers

		LRR			BLC	
JHP	Word	U	†*p*		U	†*p*
	Mine	5.00	**.006**	mine	17.00	.185
4	Man	2.00	**.001**	man	9.00	**.028**
	Hat	14.00	.103	beep	8.00	**.020**
3	Up	10.00	**.038**	push	8.00	**.020**
	Off	5.00	**.006**			
2	Shop	9.00	**.028**			
	Spot	8.00	**.020**			
1.5	Six	5.00	**.006**			
	Beep	11.00	**.050**			
1	Push	22.00	.384			
	Two	15.00	.127			

Note. JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline. †=one- tailed test boldface = $p \leq .05$.

Post intervention.

The results obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data, for the two distance measures are presented in Table 5.18.

In summary, the results (supported by the descriptive data in Tables I.4 and I.5) indicate the presence of a treatment effect on labial-facial movement patterns. Whilst LRR values initially increased during phase B (intervention priority: mandibular control, Phase C (intervention priority: labial-facial control) was characterised by a positive treatment effect with LRR values less than those recorded at pre-intervention. Thus a trend towards the TD peers was observed when intervention targeted this priority. A decrease in inter-lip distance during bilabial contact was recorded in phases B and C.

Table 5.18

Friedman's ANOVA and Wilcoxon Signed Rank Data for each Labial-Facial Distance Measure for each Word for P2

	Friedman's ANOVA		Pairwise comparisons - Wilcoxon Signed-Rank Test														
	Main Effects (df 3)		A1-B			A1-C			B-C			A1-A2			C-A2		
Word	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
						Lip Rounding/Retraction (LRR)											
Mine	8.280	.031*	-1.21	0.16	0.38	-0.94	0.22	0.30	-2.02	**0.03**	**0.64**	-0.41	0.41	0.14	-1.21	0.16	0.40
Man	9.240	.017*	-2.02	0.03	**0.64**	-0.67	0.31	0.21	-2.02	**0.03**	**0.64**	-0.14	0.50	0.05	-0.41	0.41	0.14
Hat	1.080	0.857	-1.48	0.09	0.47	-0.67	0.31	0.21	-0.40	0.41	0.13	-0.94	0.22	0.30	-0.13	0.50	0.49
Up	10.920	.003*	-0.94	0.22	0.30	-2.02	0.03	**0.64**	-2.02	**0.03**	**0.64**	-1.75	0.06	**0.58**	-1.48	0.09	0.04
Off	8.280	.031*	-0.40	0.41	0.13	-1.75	0.06	**0.55**	-2.02	0.03	**0.64**	-1.75	0.06	**0.55**	-0.67	0.31	0.21
Shop	4.000	0.445	-0.40	0.41	0.13	-0.67	0.31	0.21	-1.75	0.06	**0.55**	-0.13	0.50	0.04	-0.67	0.31	0.21
Spot	1.560	0.709	-0.94	0.22	0.30	-0.67	0.31	0.21	-1.21	0.16	0.38	-0.40	0.41	0.13	-0.94	0.22	0.21
Six	2.280	0.561	-0.13	0.50	0.05	-0.67	0.31	0.21	-0.40	0.41	0.14	-1.21	0.16	0.38	-0.94	0.22	0.47
Beep	4.200	0.260	-0.13	0.50	0.04	-1.21	0.16	0.38	-2.02	0.03	**0.64**	-0.40	0.41	0.13	-1.48	0.09	0.30
Push	3.000	0.445	-0.67	0.31	0.21	-1.21	0.16	0.38	-0.13	0.50	0.04	-2.02	0.03	**0.64**	-0.67	0.31	0.30
Two	5.880	0.123	-0.40	0.41	0.13	-0.67	0.31	0.21	-2.02	0.03	**0.64**	-0.40	0.41	0.13	-2.02	0.03	**0.64**
						Bilabial Inter-lip Distance (BLC)											
Mine	4.920	0.210	-1.21	0.16	0.43	-0.94	0.22	0.30	-2.02	**0.03**	**0.72**	-0.67	0.31	0.21	-0.67	0.31	0.21
Man	9.240	.017*	-2.02	0.03	**0.72**	-0.94	0.22	0.30	-1.75	0.06	**0.62**	-0.40	0.41	0.13	-1.48	0.09	0.49
Push	1.080	0.857	-0.94	0.22	0.33	-0.40	0.41	0.13	-0.40	0.41	0.14	-1.75	0.06	**0.55**	-0.40	0.41	0.13
Beep	4.920	0.210	-1.21	0.16	0.43	-1.75	0.06	**0.55**	-0.40	0.41	0.14	-0.94	0.22	0.30	-1.48	0.09	0.47
						Upper Lip (UL) Position											
Mine	3.480	0.372	-0.94	0.22	0.33	-0.94	0.22	0.30	-0.13	0.50	0.05	-1.21	0.16	0.38	-0.40	0.41	0.13
Man	2.040	0.652	-0.94	0.22	0.33	-1.48	0.09	0.47	-0.13	0.50	0.05	-1.48	0.09	0.47	-0.67	0.31	0.21
Push	9.720	.012*	-2.02	0.03	**0.72**	-2.02	0.03	**0.64**	-0.67	0.31	0.24	-2.02	**0.03**	**0.64**	-1.21	0.16	0.38
Beep	6.120	0.107	-1.21	0.16	0.43	-1.75	0.06	**0.55**	-2.02	**0.03**	**0.72**	-1.21	0.16	0.38	-0.13	0.50	0.04
						Lower Lip (LL) Position											
Mine	6.360	0.093	-0.67	0.31	0.24	-1.48	0.09	0.47	-2.02	**0.03**	**0.72**	-1.75	0.06	**0.55**	-0.13	0.50	0.04
Man	9.720	.012*	-1.75	0.06	**0.62**	-0.40	0.41	0.13	-2.02	**0.03**	**0.72**	-2.02	**0.03**	**0.64**	-0.94	0.22	0.30
Push	3.000	0.445	-1.21	0.16	0.38	-0.94	0.22	0.30	-0.40	0.41	0.13	-0.13	0.50	0.04	-0.94	0.22	0.30
Beep	10.668	.005*	-1.48	0.09	**0.52**	-0.40	0.41	0.13	-1.48	0.09	**0.52**	-2.02	**0.03**	**0.64**	-2.02	**0.03**	**0.64**

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up)
* = *p* ≤.05 one-tailed test, boldface = large effect size.

Lip Rounding/Retraction (LRR).

The results obtained using Friedman's ANOVA indicate a main effect on four of the eight words - 'mine' and 'man' (JHP4), 'up' (JHP3) and 'off' (JHP2).

The pair-wise comparisons indicate phase B-C yielded the most significant change. This is associated with an increase in LRR values during phase B (intervention priority: mandibular control). Phase C (intervention priority: labial facial control) was characterized by a return to a decrease in LRR values, with 8 words yielding values lower than recorded at phase A1 (pre-intervention phase A1). Treatment effects were maintained on four words at follow-up (phase A2).

Inter-lip distance during Bilabial Contact (BLC).

Whilst the results obtained using Friedman's ANOVA indicate a significant main treatment effect on the word 'man' only, the pair-wise comparisons indicate three words (mine, man, push) recorded a positive treatment effect during phase C.

Plots of the average vertical positions of the UL and LL markers at the point of bilabial contact, for each of the four words, are shown in Figure 5.2. The LL is plotted on the X-axis and the UL is plotted on the y-axis. A negative value reflects a downward position, whilst a positive value reflects an upward position, from rest.

UL and LL data show the presence of negative values in the UL and LL in all words during phases C and A2. This indicates movement, inferior to rest, in both lips during minimum bilabial lip contact.

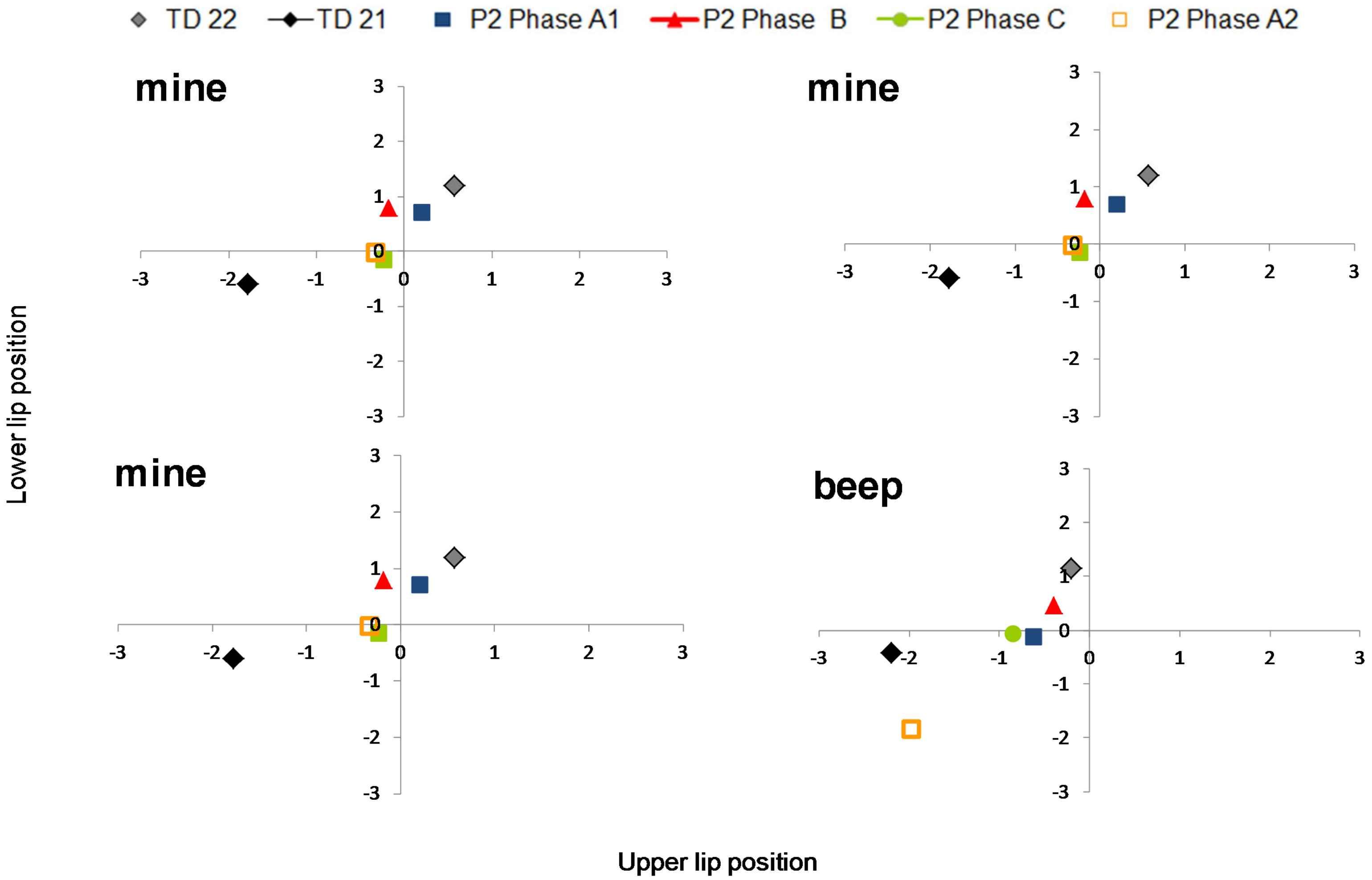


Figure 5.6. Average position of the upper lip (X axis) and lower lip (Y axis), across the study phases, as measured at minimum bilabial inter-lip distance (mms) for P2 and the TD peers.

Jaw/Lip Opening Velocity (J/L Vel).

Pre-intervention.

The Mann-Whitney test results and data (M, SD*)* for each word spoken by the P2 and the TD peers are presented in Table 5.19. The results show decreased values were recorded at JHP 4, whilst the word 'up' at the JHP 3 recorded increased values. This is consistent with the distance results, where JOD values were decreased at JHP 4 and increased at JHP3. Mann-Whitney test results indicate the rate of movement used by P2 was comparable to the TD peers on all but two words (mine and up).

Table 5.19

Mann-Whitney test Results and Descriptive Data (Means and Standard Deviations) of the Pre-Intervention Jaw/Lip Opening Velocity Measures Comparing P2 with the TD Peers

		Velocity		TD 21	TD22	P2 A
JHP	Word	U	*p	mean(SD)	mean(SD)	mean(SD)
4	Mine	2.00	**.003**	138.25(18.10)	120.81(12.44)	87.65(16.74)
4	Man	15.00	.254	115.43(14.89)	105.83(27.28)	94.10(21.59)
4	Hat	22.00	.768	14.18(23.84)	28.17(11.49)	14.44(10.96)
3	Up	0.00	**.001**	16.72(4.85)	14.01(7.80)	57.31(17.15)
2	Off	21.00	.679	11.93(2.73)	4.09(1.69)	9.13(3.67)
2	Shop	9.00	.055	20.44(7.30)	42.25(17.53)	48.65(11.98)
2	Spot	20.00	.594	40.05(7.06)	45.77(12.70)	40.53(7.81)
1.5	Six	10.00	.075	22.55(7.48)	21.57(10.90)	12.58(5.12)
1	Beep	13.00	.165	67.50(17.23)	44.05(24.42)	68.84(11.70)
1	Push	20.00	.594	14.72(3.46)	18.81(8.48)	21.76(14.46)
1	Two	13.00	.165	2.47(3.31)	4.56(4.60)	5.04(2.31)

Note. TD = typically developing
*= two-tailed test, boldface = $p \leq .05$

Post intervention.

The results obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data, for the measure of jaw/lip opening velocity are presented Table 5.21.

In summary, the results indicate the presence of a treatment effect. A main treatment effect was seen on three words (shop, push and beep), however, five words recorded a significant clinical change between pre-intervention and follow-up (phase A1-A2). The descriptive data indicate a trend towards the movement speed of the TD peers.

Word Duration (WD).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by the P2 and the TD peers are presented in Table 5.20. The results show significantly longer duration on two words (shop and spot).

Table 5.20

Mann-Whitney test Results and Descriptive Data (Means and Standard deviations) of the Pre-Intervention Word Duration Measures Comparing P2 with the TD Peers

	Duration		TD 21	TD 22	P2 A
Word	U	**p*	M(SD)	M(SD)	M(SD)
Mine	0.002	**.98**	0.49(0.05)	0.66(0.10)	0.56(0.13)
Man	0.017	.92	0.50(0.06)	0.60(0.09)	0.52(0.08)
Hat	0.379	.57	0.55(0.06)	0.65(0.05)	0.61(0.06)
Up	3.089	.08	0.41(0.04)	0.50(0.08)	0.48(0.06)
Off	0.232	.66	0.47(0.09)	0.46(0.10)	0.45(0.08)
Shop	5.592	**.02**	0.54(0.04)	0.54(0.04)	0.60(0.09)
Spot	8.661	**.00**	0.67(0.07)	0.79(0.07)	0.79(0.10)
Six	0.242	.67	0.67(0.03)	0.72(0.09)	0.72(0.08)
Push	0.017	.92	0.52(0.09)	0.72(0.09)	0.60(0.10)
Beep	1.742	.20	0.40(0.03)	0.40(0.13)	0.46(0.10)
Two	0.071	.82	0.42(0.03)	0.54(0.06)	0.46(0.07)

Note. TD = typically developing
*= two-tailed tests, boldface = $p \leq .05$

Post intervention.

The results obtained using Friedman’s ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data for word duration are presented in Table 5.21.

In summary, the results indicate minimal effect in average duration across the phases of the study. Three words (man, spot and beep) recorded a main treatment effect.

Table 5.21

Friedman's ANOVA and Wilcoxon Signed-Rank Data for Velocity and Word Duration Measures for Each Word across the Study Phases for P2

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
								Jaw/Lip Opening Velocity (J/L Vel)									
Mine	2.04	.652	-0.13	0.50	0.16	-0.40	0.41	0.13	-0.40	0.41	0.13	-0.67	0.31	**0.67**	-0.13	0.50	0.16
Man	2.04	.652	-1.48	0.09	0.47	-1.21	0.16	0.38	-0.40	0.41	0.13	-1.21	0.16	0.38	-0.40	0.41	0.13
Hat	4.44	.226	-0.13	0.50	0.04	-1.21	0.16	0.38	-1.48	0.09	0.47	-1.75	0.06	**0.55**	-0.67	0.31	0.21
Up	3.00	.445	-0.13	0.50	0.04	-1.75	0.06	**0.55**	-1.21	0.16	0.38	-1.48	0.09	0.47	-0.40	0.41	0.13
Off	4.20	.260	-0.67	0.31	0.21	-1.21	0.16	0.38	-0.67	0.31	0.21	-2.02	**0.03**	**0.64**	-0.94	0.22	0.30
Shop	9.96	.009*	-0.94	0.22	0.30	-2.02	**0.03**	**0.64**	-1.75	0.06	**0.55**	-2.02	**0.03**	**0.64**	-0.13	0.50	0.04
Spot	5.40	.151	-1.21	0.16	0.38	-0.40	0.41	0.13	-1.21	0.16	0.38	-1.75	0.06	**0.55**	-2.02	**0.03**	**0.64**
Six	1.08	.857	-0.40	0.41	0.13	-0.13	0.50	0.04	-0.40	0.41	0.13	-0.13	0.50	0.04	-0.67	0.31	0.21
Beep	9.24	.017*	-2.02	**0.03**	**0.64**	-0.40	0.41	0.13	-2.02	**0.03**	**0.64**	-0.13	0.50	0.04	-0.40	0.41	0.13
Push	12.60	.001*	-1.21	0.16	0.38	-2.02	**0.03**	**0.64**	-2.02	**0.03**	**0.64**	-2.02	**0.03**	**0.64**	-0.94	0.22	0.30
Two	3.48	.372	-0.94	0.22	0.30	-0.13	0.50	0.04	-1.48	0.09	0.47	-1.48	0.09	0.47	-1.75	0.06	**0.55**
								Word Duration (W/D)									
Mine	4.2	.260	-0.67	0.31	0.21	-0.41	0.38	0.13	-1.75	0.06	**0.55**	-0.67	0.31	**0.67**	-0.67	0.31	-0.67
Man	10.68	**.005**	-2.03	**0.03**	**0.64**	-2.06	**0.03**	**0.65**	0.00	0.56	0.00	-1.35	0.13	0.43	-1.48	0.09	0.47
Hat	2.674	.485	0.00	0.63	0.00	-0.56	0.38	0.18	-0.68	0.31	0.21	-1.47	0.13	0.47	-0.81	0.25	0.26
Up	1.596	.704	-0.73	0.31	0.23	-0.41	0.41	0.13	-0.27	0.44	0.09	-0.18	0.50	0.06	-0.37	0.44	0.12
Off	1.239	.783	-1.22	0.13	0.39	-0.81	0.25	0.26	-0.13	0.50	0.04	-0.37	0.44	0.12	-1.47	0.13	0.47
Shop	1.313	.750	-0.41	0.44	0.13	-0.67	0.31	0.21	-0.38	0.50	0.12	-0.54	0.34	0.17	-0.54	0.34	0.17
Spot	9.188	.016*	-1.21	0.16	0.38	-2.03	**0.03**	**0.64**	-0.27	0.44	0.09	-2.03	**0.03**	**0.64**	-1.84	0.06	**0.58**
Six	1.531	.723	-0.27	0.44	0.09	-0.40	0.41	0.13	-0.68	0.34	0.22	-1.46	0.13	0.46	-1.49	0.09	0.47
Beep	9	.016*	-1.84	0.06	**0.58**	-1.21	0.16	0.38	-0.27	0.50	0.09	0.00	0.63	0.00	-2.03	**0.03**	**0.64**
Push	0.83	.870	0.00	0.63	0.00	-0.67	0.31	0.21	-0.13	0.50	0.04	-1.22	0.13	0.39	-1.34	0.25	0.42
Two	6.551	.080	-0.67	0.31	0.21	-1.10	0.19	0.35	-0.54	0.34	0.17	-1.63	0.09	**0.51**	-2.02	**0.03**	**0.64**

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one: labial-facial control), C = phase C (intervention priority two: lingual control), A2 = phase A2 (follow-up).

*= $p \leq .05$, two-tailed, boldface = large effect size.

Overall summary of P2's kinematic measures.

Subsequent to the PROMPT Intervention the following changes were evident:

Phase B - positive changes with a trend towards the TD peers on the measures of mandibular control.

Phase C –positive changes with a trend towards the TD peers on the measures of labial-facial control.

These results are consistent with the PROMPT intervention phases.

Phase A2 – post-intervention values differed from the pre-intervention values indicating the presence of a treatment effect.

The above results indicate P2's intervention program was successful in producing changes to the motor-speech movement patterns under investigation.

Participant 3

The following motor-speech movement patterns were targeted during the phases of the PROMPT intervention:

Phase B: (Intervention priority one: mandibular control) - Decrease range of jaw height positions 3/4 and excessive anterior jaw thrust, and facilitate control in jaw grading (i.e., reduce excessive closure as indicated through the lower lip position thrusting superior to the upper lip position).

Phase C: (Intervention priority two: labial-facial control) – Lip-to-lip contact on bilabials, inhibit excessive retraction and facilitate broad rounding.

Table 5.22 summarises the words that demonstrated significant impairment of the jaw and lip measures for P3 as compared with the TD peers at pre-intervention; and subsequently recorded significant change to these same measures following PROMPT intervention.

Results are based on five repetitions of each word, with the exception of TD33 where analysis of the word 'two' is based on two repetitions due to pronunciation errors.

The distance data (see Appendix K) at pre-intervention show substantially increased mean values in duration and distance measures of the jaw and lips as compared with the TD peers. The post-intervention data show a positive treatment effect with changes to the distance measure of LRR preceding the decrease in JOD targeted for this participant.

Table 5.22

Words that Recorded Significantly Different Pre (Mann-Whitney Test) and Post-Intervention (Friedman's ANOVA) Values on the Kinematic Measures of Distance, Velocity and Duration

	*Mandibular Control						Labial-Facial Control							
Word Stimuli	JPD		JOD		JLDM		LRR		BLC		J/LVEL		WD	
MSH	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Wordset 1														
Mine	X				X		X				X		X	
Man	X		X	✓			X	✓			X		X	
Hat	X		X	✓			X	✓					X	
Up	X		X	✓	X	✓	X						X	
Wordset 2											X			
Off	X		X				X						X	
Shop	X					✓	X					✓	X	✓
Beep	X		X	✓			X	✓			X		X	
Push	X						X	✓					X	
Two	X		X	✓			X						X	
Wordset 3														
Six	X		X	✓			X						X	
Spot	X						X						X	
Total	11	0	7	6	2	2	11	4			4	1	11	1

Note. Pre = pre-intervention comparison with peers, Post = post intervention comparison (phases B, C and A2), X = movement pattern significantly different to TD peers, ✓ = significant change recorded, MSH = motor speech hierarchy plane of movement, JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline, LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact, J/L VEL = jaw/lip opening velocity, WD =word duration.
* = *p* value ≤ .05, two-tailed, †= *p* value ≤ .05,one-tailed,

Distance measures.

Mandibular control measures.

Pre-intervention.

Analyses of the kinematic data presented in Table 5.23 indicate impaired mandibular control at pre-intervention. Specifically:

JPD – Mean values were significantly increased on all words relative to the TD peers.

JOD – Mean values were significantly increased on 3/4 and1/2 words of word-set one and three, respectively. In contrast, the mean values for word-set two were reduced relative to the TD peers.

JLDM – The word ‘up’ in word-set one exceeded the values obtained by the TD peers, with a mean value of 4mm recorded. This value is outside the range of typical deviation and therefore considered impaired. The word ‘shop’ recorded a value that was significantly less, but within the typical range (i.e. less than 2-3mm).

Table 5.23

Mann-Whitney Test Results of the Pre-Intervention Mandibular Distance Measures Comparing P3 with the TD Peers

		JPD		JOD		JLDM	
JHP	Word	U	**p*	U	**p*	U	**p*
4	Mine	4.00	**.002**	33.00	.735	12.00	**.025**
4	Man	3.00	**.001**	8.00	**.008**	35.00	.866
4	Hat	1.00	**.000**	3.00	**.001**	35.00	.866
3	Up	13.00	**.033**	10.00	**.015**	5.00	**.002**
(2)	Off	11.00	**.019**	13.00	**.033**	31.00	.612
2	Shop	0.00	**.000**	27.00	.395	17.00	.081
2	Spot	2.00	**.001**	22.00	.197	31.00	.612
1.5	Six	4.00	**.002**	1.00	**.000**	37.00	1.000
1	Beep	0.00	**.000**	15.00	**.053**	36.00	.933
1	Push	0.00	**.000**	33.00	.735	27.00	.395
1	Two	0.00	**.000**	4.00	**.002**	21.00	.168

Note. JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline. * = two- tailed test, boldface = $p \leq .05$.

Post intervention.

The results for the three distance measures, obtained using Friedman’s ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect sizes are presented in Table 5.21. Means and SDs are provided in Figures J.1, J.2 and J.3.

Table 5.24

Friedman's ANOVA and Wilcoxon- Signed-Rank-Test Data for Each Mandibular Distance Measure for Each Word across the Study Phases for P3

	Friedman's ANOVA		Pairwise comparisons - Wilcoxon Signed-Rank Test														
	Main Effect (df 3)		A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
								Path Distance (JPD)									
Mine	4.920	.210	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.67	0.63	0.21	-1.75	0.13	**0.55**	-0.40	0.81	0.13
Man	6.120	.107	-0.14	1.00	0.04	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-1.48	0.13	0.47	-0.41	0.81	0.13
Hat	0.600	.944	-0.67	0.63	0.21	-1.21	0.31	0.38	-1.75	0.13	**0.55**	-0.41	0.63	0.13	-1.48	0.19	0.47
Up	3.240	.408	-0.67	0.63	0.21	-0.13	1.00	0.04	-1.21	0.31	0.38	-0.13	1.00	0.04	-0.40	0.81	0.13
Off	3.000	.445	-1.75	0.13	**0.55**	-1.21	0.31	0.38	-1.75	0.13	**0.55**	-1.21	0.31	0.38	-0.67	0.63	0.21
Shop	5.400	.151	-0.67	0.63	0.21	-0.13	1.00	0.04	-1.48	0.19	0.47	-0.67	0.63	0.21	-1.75	0.13	**0.55**
Spot	1.080	.857	-1.21	0.31	0.38	-0.67	0.63	0.21	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-1.48	0.19	0.47
Six	5.400	.151	-0.67	0.63	0.21	-0.13	1.00	0.04	-1.48	0.19	0.47	-1.21	0.31	0.38	-1.75	0.13	**0.55**
Beep	3.240	.408	-1.48	0.19	0.47	-0.40	0.81	0.13	-0.13	1.00	0.04	-1.21	0.31	0.38	-1.75	0.13	**0.55**
Push	5.160	.162	-0.94	0.44	0.30	-0.67	0.63	0.21	-0.67	0.63	0.21	-0.13	1.00	0.04	-0.67	0.63	0.21
Two	1.560	.709	-0.94	0.44	0.30	-0.67	0.63	0.21	-0.40	0.81	0.13	-0.67	0.63	0.21	-0.94	0.44	0.30
								Jaw Open Distance (JOD)									
Mine	6.360	.093	-1.75	0.13	**0.55**	-1.75	0.13	**0.55**	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**
Man	7.800	.044*	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-1.21	0.31	0.38
Hat	9.000	.02*	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Up	11.880	.002*	-1.75	0.13	**0.55**	-1.48	0.19	0.47	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-1.75	0.13	**0.55**
Off	5.880	.123	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.67	0.63	0.21	-1.75	0.13	**0.55**	-0.13	1.00	0.04
Shop	6.360	.093	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-1.21	0.31	0.38	-1.21	0.31	0.38	-0.40	0.81	0.13
Spot	2.040	.652	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-0.40	0.81	0.13	-1.75	0.13	**0.55**
Six	8.040	.034*	-2.02	0.06	**0.64**	-0.13	1.00	0.04	-2.02	0.06	**0.64**	-1.21	0.31	0.38	-1.48	0.19	0.47
Beep	9.960	.009*	-0.13	1.00	0.04	-0.67	0.63	0.21	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-0.94	0.44	0.30
Push	10.680	.005*	-1.48	0.19	0.47	-0.40	0.81	0.13	-1.21	0.31	0.38	-1.48	0.19	0.47	-0.40	0.81	0.13
Two	10.200	.007*	-1.48	0.19	0.47	-2.02	0.06	**0.64**	-1.48	0.19	0.47	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**

Jaw Lateral Distance from Midline (JLDM)																
Mine	2.040	.652	-0.94	0.44	0.30	-0.40	0.81	0.13	-0.13	1.00	0.04	-2.02	0.06	**0.64**	-0.40	0.81	0.13
Man	4.200	.260	-0.67	0.63	0.21	-1.21	0.31	0.38	-0.67	0.63	0.21	-0.94	0.44	0.30	-1.75	0.13	**0.55**
Hat	3.240	.408	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.67	0.63	0.21
Up	12.120	.001*	-1.21	0.31	0.38	-1.75	0.13	**0.55**	-0.13	1.00	0.04	-0.13	1.00	0.04	-0.94	0.44	0.30
Off	0.600	.944	-2.02	0.06	**0.64**	-1.48	0.19	0.47	-1.75	0.13	**0.55**	-1.75	0.13	**0.55**	-0.67	0.63	0.21
Shop	9.000	.02*	-0.13	1.00	0.04	-0.40	0.81	0.13	-0.13	1.00	0.04	-0.13	1.00	0.04	-1.21	0.31	0.38
Spot	1.080	.857	-0.67	0.63	0.21	-0.94	0.44	0.30	-0.13	1.00	0.04	-1.75	0.13	**0.55**	-0.94	0.44	0.30
Six	2.040	.652	-0.67	0.63	0.21	-0.13	1.00	0.04	-0.40	0.81	0.13	-1.21	0.31	0.38	-0.67	0.63	0.21
Beep	0.600	.944	-1.21	0.31	0.38	-0.67	0.63	0.21	-1.21	0.31	0.38	-0.67	0.63	0.21	-0.94	0.44	0.30
Push	2.520	.521	-0.40	0.81	0.13	-0.94	0.44	0.30	-0.40	0.81	0.13	-0.67	0.63	0.21	-0.94	0.44	0.30
Two	7.080	.067	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-1.21	0.31	0.38	-0.13	1.00	0.04	-1.21	0.31	0.38

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).
*=*p* ≤ .05, two-tailed test, boldface = large effect size.

Jaw Path Distance (JPD).

The results obtained using Friedman’s ANOVA indicate no real treatment effect on any word subsequent to intervention. However, the pairwise-comparisons indicate a small to moderate treatment effect between phases A-B, with a decrease in mean values on 7/11 stimulus words.

This trend towards the TD peers was not maintained in phase C. The mean values increased in this phase, with 4/11 words recording large effect sizes, and a trend away from the TD peers.

Phase A2 yielded the most significant change. Large effect sizes were recorded on 8/11 words with the trend direction returning towards the TD peers in this phase. Pair-wise comparisons between phases A-D indicate 5/11 words recorded values lower than pre-intervention, thus indicating a clinically significant effect.

Jaw Open Distance (JOD).

The results obtained using Friedman’s ANOVA indicates a main effect on 6/8 words that differed significantly from the TD peers, at pre-intervention.

The pair-wise comparisons indicate the treatment effect occurred across all phase of the study. Between phases A-B an increase in mean values was recorded, whilst between phases B- C a significant decrease in values was recorded. However, for most words the mean values were higher than the values recorded at pre-intervention. The data indicate JOD values increased when the JPD decreased and vice versa.

Jaw Lateral Distance from Midline (JLDM).

The results obtained using Friedman’s ANOVA indicate the presence of a main effect on the two words (‘up’ and ‘shop’) that differed significantly to the TD peers at pre-intervention.

The pairwise comparisons show a significant decrease in the mean value of the word ‘up’ and an increase in the mean value of ‘shop’. Follow-up (phase A2) data show all words to be within the typical range with performance comparable to peers.

Labial-facial control.

Pre-intervention.

Analyses of the kinematic data presented in Table 5.25 indicate impaired labial-facial control at pre-intervention. Specifically:

LRR – Was significantly increased in all words in all word positions relative to the TD peers.

BLC– A statistically significant difference in inter-lip distance was recorded on 2/4 words. Positive values were recorded for the position of both the UL and LL position in 3/4 words. This indicates that, at the point of minimum bilabial lip contact, both lips were positioned superiorly to the rest position. In comparison the TD peers recorded negative values for the UL, thus indicating an inferior position from rest at the point of minimum contact.

Table 5.25

Mann-Whitney Test Results of the Pre-intervention Labial-Facial Distance Measures Comparing P3 with the TD Peers

		LRR			BLC	
JHP	Word	U	*†p*		U	*†p*
4	mine	8	**.008**	mine	24	.133
	man	7	**.005**	man	21	.084
	hat	4	**.002**	beep (b)	15	**.026**
3	up	5	**.002**	push	6	**.002**
2	off	0	**.00**			
	shop	1	**.00**			
	spot	4	**.002**			
1.5	six	3	**.001**			
1	beep	25	**<.000**			
	push	0	**<.000**			
	two	0	**<.000**			

Note. LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact.
†= one-tailed test, boldface = $p \leq .05$.

Post intervention.

The results obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data for the distance and position measures, are presented in Table 5.23.

In summary, the results (supported by the descriptive data shown in Figures J.4 and J.5) indicate the presence of a treatment effect on labial-facial movement patterns. During phase B (intervention priority: mandibular control) LRR values decreased significantly, with a trend towards the TD peers. Whilst no decrease in the bilabial inter-lip distance was achieved, a significant change in the position of the LL during bilabial contact was recorded.

Table 5.26

Friedman's ANOVA and Wilcoxon Signed Rank Data for each Labial-Facial Distance Measure for each Word for P3

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
							Lip Rounding/Retraction (LRR)										
Mine	3.96	.298	-1.48	0.09	0.47	-0.94	0.22	0.30	-0.67	0.31	**0.21**	-1.48	0.09	0.49	-1.21	0.16	0.40
Man	9.72	.012*	-2.02	0.03	**0.64**	-2.02	0.03	**0.64**	-1.48	0.09	**0.47**	**-2.02**	**0.03**	**0.67**	-0.13	0.50	0.04
Hat	9.24	.017*	-2.02	0.03	**0.64**	-1.48	0.09	0.47	-1.75	0.06	**0.55**	-2.02	0.03	**0.64**	-0.94	0.22	0.30
Up	9.24	.017*	-2.02	0.03	**0.64**	-2.02	0.03	**0.64**	-0.13	0.50	0.04	-2.02	0.03	**0.67**	-0.94	0.22	0.31
Off	7.32	.055	-2.02	0.03	**0.64**	-1.21	0.16	0.38	-2.02	0.03	**0.64**	**-0.67**	**0.31**	**0.21**	-0.67	0.31	0.21
Shop	7.08	.067	-2.02	0.03	**0.64**	-1.75	0.06	**0.55**	-0.67	0.31	0.21	-1.21	0.16	0.38	-2.02	0.03	**0.64**
Spot	3.96	.298	-2.02	0.03	**0.64**	-1.75	0.06	**0.55**	-0.67	0.31	**0.21**	-0.67	0.31	0.21	-0.40	0.41	0.13
Six	6.12	.107	-1.75	0.06	**0.62**	-2.02	0.03	**0.64**	-1.75	0.06	**0.62**	-1.75	0.06	**0.55**	-1.21	0.16	0.38
Beep	11.16	.002*	-1.75	0.03	**0.55**	-2.02	0.03	**0.64**	-1.75	0.31	**0.55**	-1.75	0.03	**0.55**	-1.21	0.03	0.38
Push	3.48	.372	-1.75	0.06	**0.55**	-1.75	0.06	**0.55**	-0.40	0.41	**0.13**	**-1.21**	**0.16**	**0.38**	-0.40	0.41	0.13
Two	3.48	.372	-0.67	0.31	0.21	-0.13	0.50	0.04	-0.94	0.22	0.30	-1.21	0.16	0.38	-0.94	0.22	0.30
							Bilabial Inter-lip Distance (BLC)										
Mine	1.560	.709	-0.67	0.31	0.21	-0.40	0.41	0.13	-1.48	0.09	0.47	-0.67	0.31	0.22	-1.21	0.16	0.40
Man	2.28	.561	-1.75	0.06	**0.55**	-0.67	0.31	0.21	-1.21	0.16	0.38	-1.21	0.16	0.40	-0.13	0.50	0.04
Push	2.280	.561	-0.67	0.31	0.21	-1.21	0.16	0.38	-0.94	0.22	0.30	-1.21	0.16	0.38	-1.21	0.16	0.38
Beep	4.440	.226	-1.48	0.09	0.47	-0.13	0.50	0.04	-1.21	0.16	0.38	-1.48	0.09	0.49	-1.48	0.09	0.49
							Upper Lip (UL) Position										
Mine	2.280	.561	-0.94	0.22	0.30	-0.13	0.50	0.04	-0.94	0.22	0.30	-0.13	0.50	0.04	-0.40	0.41	0.13
Man	6.120	.107	-1.21	0.16	0.38	-1.75	0.06	**0.55**	-1.48	0.09	0.47	-1.75	0.06	**0.58**	-0.67	0.31	0.22
Push	6.840	.075	-1.75	0.06	**0.55**	-1.75	0.06	**0.55**	-1.21	0.16	0.38	-2.02	0.03	**0.64**	-0.13	0.50	0.04
Beep	1.080	.857	-0.40	0.41	0.13	-0.13	0.50	0.04	-0.13	0.50	0.04	-0.13	0.50	0.04	-0.40	0.41	0.13
							Lower Lip (LL) Position										
Mine	10.920	.003*	-2.02	0.03	**0.64**	-0.13	0.50	0.04	-2.02	0.03	**0.64**	-2.02	0.03	**0.64**	-1.48	0.09	0.47
Man	4.920	.210	-2.02	0.03	**0.64**	-1.21	0.16	0.38	-0.13	0.50	0.04	-1.75	0.06	**0.55**	-1.21	0.16	0.38
Push	5.400	.151	-0.13	0.50	0.04	-0.40	0.41	0.13	-0.13	0.50	0.04	-2.02	0.03	**0.64**	-1.48	0.09	0.47
Beep	7.080	.044*	-2.02	0.03	**0.64**	-0.13	0.50	0.04	-2.02	0.03	**0.64**	-1.75	0.06	**0.55**	-1.48	0.09	0.47

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).
*= *p* ≤.05 one-tailed test, boldface = large effect size

Lip Rounding/Retraction (LRR).

The results obtained using Friedman's ANOVA indicate a main effect on 4/11 words – two words in each of word-sets one and two.

The pair-wise comparisons indicate phases A-B yielded the most significant change. Phase B (intervention priority: mandibular control) yielded a significant decrease in LRR values on 9/11 words. Phase C (intervention priority: labial facial control) was characterized by an increase in LRR values compared with phase B. However, all mean values remained lower than recorded at phase A1 (pre-intervention).

At follow-up (phase A2) 7/11 words recorded mean values that were significantly reduced in comparison to the pre-intervention values.

Inter-lip distance during Bilabial Contact (BLC).

The results obtained using Friedman's ANOVA indicate no significant main treatment effect in BLC. However, a significant main effect was recorded in the lower lip position during BLC for two words.

Plots of the average vertical positions of the upper lip (UL) and lower lip (LL) markers at the point of bilabial contact, for each of the four words, are shown in Figure 5.7. The LL is plotted on the X-axis and the UL is plotted on the y-axis. A negative value reflects a downward position, whilst a positive value reflects an upward position, from rest. UL and LL data shows a decrease in the positive values recorded in both the UL and LL across the study phases.

The pair-wise comparisons indicate Phase B yielded the most significant changes in the LL. The decreasing values recorded in the LL indicate a less superior position, and the negative values of the UL indicate inferior movement from the rest position, at the point of minimum BLC. During phase C, a return to increasing values were recorded on 2/4 words in the position of the LL, however, the UL continued to assume a more inferior position from rest on 2/4 words.

Phase A2 data shows improved bilabial lip contact as compared with pre-intervention. This is indicated by the decreased superior position of the LL, increased inferior position of the UL and the recording of inter-lip distance values comparable to TD peers on 3/4 words during BLC.

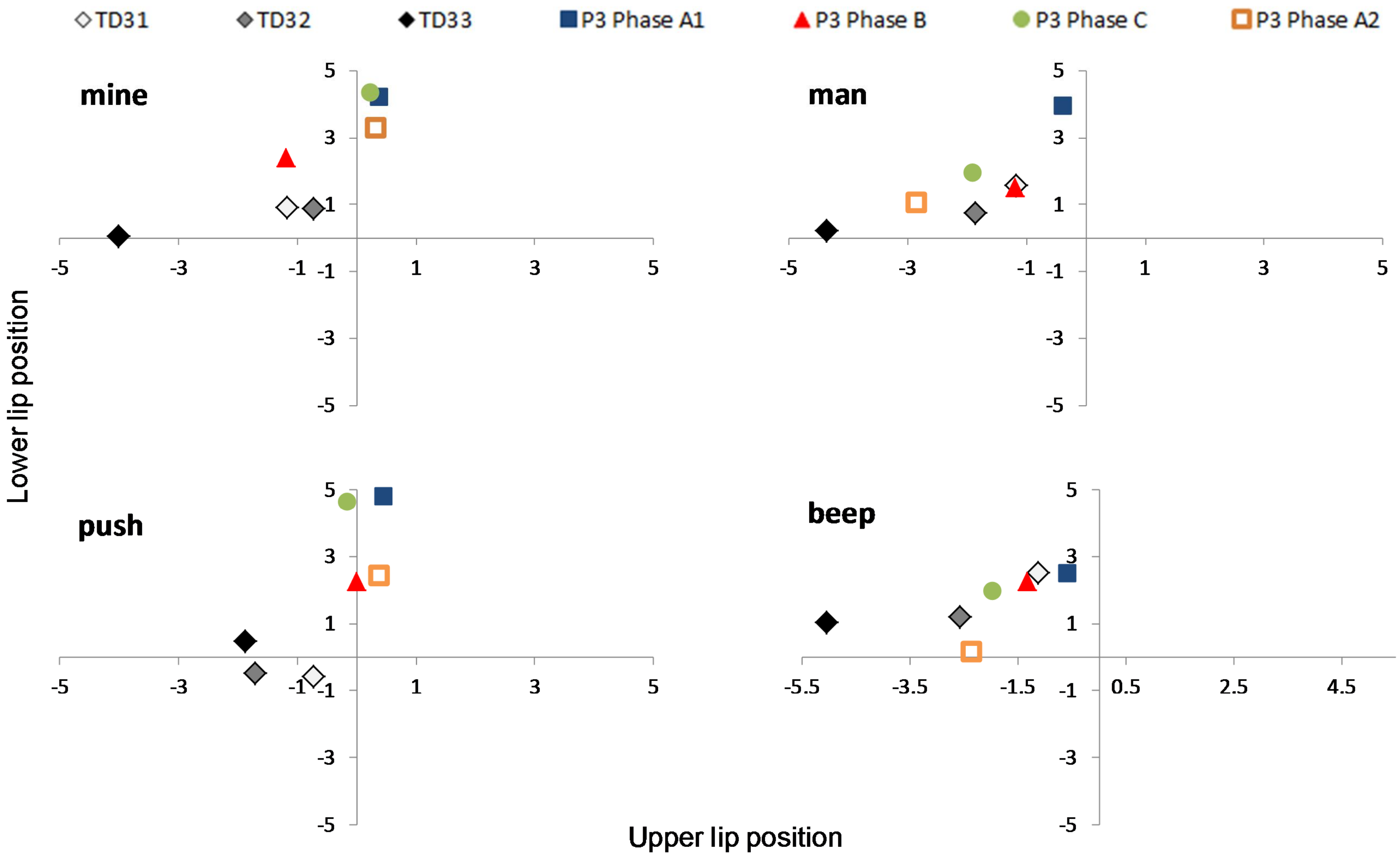


Figure 5.7. Average position of the upper lip (X axis) and lower lip (Y axis), across the study phases, as measured at minimum bilabial inter-lip distance (mms) for P3 and the TD peers.

Jaw/Lip Opening Velocity (J/L Vel).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by P3 and the TD peers are presented in Table 5.27. The data show 4/11 words recorded significantly increased values.

Table 5.27

Mann-Whitney test Results and Descriptive Data (Means and Standard Deviations) of the Pre-Intervention Jaw/Lip Opening Velocity Measures Comparing P3 with the TD Peers

	Velocity Mann-Whitney test		TD reference group			P3
			31	32	33	phase A1
	U	*p	M(SD)	M(SD)	M(SD)	M(SD)
				Velocity		
mine	4	**.002**	96.06(25.67)	58.79(8.12)	87.01(5.01)	125.81(17.30)
man	14	**.042**	110.88(39.46)	64.45(10.60)	88.71(20.46)	129.58(54.06)
hat	16	.066	19.47(9.36)	14.17(10.22)	7.46(3.64)	5.79(4.03)
up	33	**.735**	24.13(13.25)	9.69(4.41)	33.31(9.12)	23.06(16.90)
off	10	**.015**	2.85(2.57)	12.58(2.52)	3.29(2.49)	15.13(6.32)
shop	29	.497	41.44(14.51)	40.26(9.71)	53.41(9.99)	55.90(22.04)
spot	26	.349	74.36(9.10)	46.64(13.93)	80.46(14.10)	57.70(21.10)
six	20	**.142**	19.90(9.65)	12.98(3.68)	24.62(4.85)	24.99(4.17)
beep	3	**.001**	54.10(5.25)	30.28(4.12)	54.01(12.69)	74.36(7.34)
push	22	**.197**	22.44(4.06)	14.97(6.99)	24.07(10.86)	28.59(12.47)
two	16	**.160**	8.66(4.50)	9.99(7.02)	25.45(14.01)	15.45(5.12)

Note. TD = typically developing
*= two-tailed tests, boldface = $p \leq .05$

Post intervention.

The results obtained using Friedman’s ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data for peak jaw/lip opening velocity are presented in Table 5.29. In summary, the results indicate a main effect was recorded on word (shop) only, which was characterised by a trend away from the TD peers.

Word Duration (WD).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by P3 and the TD peers are presented in Table 5.25. The results show significantly longer duration on all words.

Table 5.28

Mann-Whitney test Results and Descriptive Data (means and standard deviations) of the Pre-Intervention Word Duration Measures Comparing P3 with the TD Peer

	Word Duration Mann-Whitney test		TD reference group			P3
			31	32	33	phase A1
	U	**p*	M(SD)	M(SD)	M(SD)	M(SD)
				Duration		
mine	0	**.000**	0.68(0.09)	0.68(0.03)	0.68(0.09)	0.92(0.08)
man	4	**.000**	0.66(0.12)	0.69(0.07)	0.76(0.10)	1.15(0.20)
hat	0	**.000**	0.67(0.02)	0.60(0.06)	0.70(0.14)	1.00(0.10)
up	4	**.001**	0.39(0.06)	0.52(0.08)	0.52(0.06)	0.88(0.24)
off	0	**.000**	0.46(0.10)	0.61(0.02)	0.56(0.08)	0.82(0.09)
shop	0	**.000**	0.64(0.09)	0.71(0.07)	0.78(0.08)	1.61(0.47)
spot	0	**.000**	0.81(0.10)	0.85(0.06)	1.03(0.07)	1.24(0.06)
six	4	**.001**	0.89(0.05)	0.83(0.07)	1.02(0.13)	1.21(0.15)
beep	0	**.000**	0.44(0.09)	0.57(0.06)	0.54(0.08)	1.04(0.12)
push	0	**.000**	0.66(0.09)	0.69(0.06)	0.77(0.05)	1.08(0.05)
two	0	**.000**	0.58(0.04)	0.54(0.01)	0.51(0.04)	0.88(0.13)

Note. TD = typically developing
*= two-tailed tests, boldface = $p \leq .05$

Post intervention.

The results obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data for the measure of word duration are presented in Table 5.29.

In summary, the results indicate minimal effect on duration across the phases of the study. One word (shop) recorded a main treatment effect. However, the descriptive data indicate a decrease in the duration values, of each word, thus indicating a trend towards the TD peers.

Table 5.29

Friedman's ANOVA and Wilcoxon Signed-Rank Data for Velocity and Word Duration Measures for Each Word across the Study Phases for P3

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test															
			A1-B			A1-C			B-C			A1-A2			C-A2		
	$\chi2$	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
Jaw/Lip Opening Velocity (J/L Vel)																	
Mine	2.04	.652	-0.94	0.44	0.30	-0.67	0.63	0.21	-0.13	1.00	0.04	-0.13	1.00	0.04	-0.94	0.44	0.31
Man	1.08	.857	-0.13	1.00	0.04	-0.13	1.00	0.04	-0.13	1.00	0.04	-0.13	1.00	0.04	-0.94	0.44	0.31
Hat	5.4	.151	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-0.13	1.00	0.04	-0.67	0.63	0.22	-1.75	0.13	**0.58**
Up	6.12	.107	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-1.48	0.19	0.47	-0.13	1.00	0.04
Off	7.08	.067	-0.67	0.63	0.21	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-0.94	0.44	0.30
Shop	9.96	.009*	-0.40	0.81	0.13	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.40	0.81	0.13
Spot	5.16	.162	-2.02	0.06	**0.64**	-0.13	1.00	0.04	-1.48	0.19	0.47	-0.13	1.00	0.04	-0.13	1.00	0.04
Six	0.12	1.000	-0.40	0.81	0.14	-1.21	0.31	0.38	-0.13	1.00	0.05	-0.13	1.00	0.04	-0.67	0.63	0.21
Beep	2.52	.521	-0.13	1.00	0.04	-1.75	0.13	**0.55**	-1.48	0.19	0.47	-0.13	1.00	0.04	-1.21	0.31	0.38
Push	2.04	.652	-0.67	0.63	0.21	-0.40	0.81	0.13	-0.67	0.63	0.21	-0.13	1.00	0.04	-0.94	0.44	0.30
Two	2.52	.521	-0.67	0.63	0.21	-1.48	0.19	0.47	-0.67	0.63	0.21	-0.67	0.63	0.21	-0.13	1.00	0.04
Word Duration (W/D)																	
Mine	4.92	.100	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-1.21	0.31	0.38	-1.22	0.25	0.41	-1.48	0.19	0.49
Man	6.36	.093	-1.21	0.31	0.38	-0.81	0.50	0.26	-2.02	0.06	**0.64**	-0.81	0.50	0.27	-1.75	0.13	**0.58**
Hat	5.939	.112	-0.67	0.63	0.21	-1.48	0.19	0.47	-1.48	0.19	0.47	-0.73	0.63	0.23	-2.03	0.06	**0.64**
Up	3.367	.374	-0.67	0.63	0.21	-0.40	0.81	0.13	-1.35	0.25	0.43	-0.94	0.44	0.31	-1.46	0.25	0.49
Off	0.918	.848	-0.67	0.63	0.21	-0.37	0.88	0.12	-0.13	1.00	0.04	-0.40	0.81	0.13	-1.08	0.38	0.34
Shop	11.57	.002*	-2.02	0.06	**0.64**	-2.03	0.06	**0.64**	-1.48	0.19	0.47	-2.02	0.06	**0.64**	-1.83	0.13	**0.58**
Spot	5.809	.119	-1.75	0.13	**0.55**	-0.37	0.75	0.12	-2.02	0.06	**0.64**	-1.07	0.50	0.34	-0.40	0.81	0.13
Six	5.688	.126	-1.75	0.13	**0.62**	-1.22	0.31	0.39	-1.63	0.19	**0.57**	-0.73	0.63	0.23	-1.83	0.13	**0.58**
Beep	0.6	.921	-0.55	0.75	0.17	0.00	1.00	0.00	-1.07	0.50	0.34	-0.54	0.69	0.17	-0.92	0.50	0.29
Push	3.913	.288	-1.24	0.31	0.39	-1.07	0.50	0.34	-1.84	0.13	**0.58**	-1.29	0.38	0.41	-1.21	0.31	0.38
Two	4.977	.178	-0.73	0.63	0.23	-0.73	0.63	0.23	0.00	1.00	0.00	-1.83	0.13	**0.58**	-0.95	0.38	0.30

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one: labial-facial control), C = phase C (intervention priority two: lingual control), A2 = phase A2 (follow-up).

*= $p \leq .05$, two-tailed, boldface = large effect size.

Overall summary of P3’s kinematic measures.

Subsequent to the PROMPT intervention, the following changes were evident across the study phases:

Phase B - was characterised by a significant decrease in the lip rounding/retraction (LRR) values, indicating a trend towards the TD peers. Changes to jaw measures included an increase in jaw open distance (JOD), which indicates a trend away from the TD peers. However, a decrease in jaw path distance (JPD) values was recorded, although these changes were not statistically significant.

Phase C - LRR values continued to decrease in this phase with some values moving within the range of the TD peers. A return to decreased mean values was recorded on the measure of JOD and lateral deviation from midline (JLDM) also indicating a trend towards the TD peers.

Phase A2 - The results indicate continued improvement on the measures of duration, lip rounding/retraction LRR and inter-lip distance during bilabial contact (BLC). However, maintenance of the changes to the mandibular measures was variable with evidence of some measures recording values higher than pre-intervention.

The above results indicate P3’s intervention program was successful in producing changes to the motor-speech movement patterns under investigation.

Participant 4

The following motor-speech movement patterns were targeted during the phases of the PROMPT Intervention:

Phase B: (Intervention priority one: labial-facial) – inhibit excessive retraction to promote increased jaw open distance and; increase broad facial rounding and improve activity of the upper lip.

Phase C: (Intervention priority two: lingual control) – facilitate anterior and mid-tongue control for the production of: /t/, /d/, /ʃ/ and /ʧ/. As Peak Motus (9.1) does not record lingual movements, kinematic data collected during this phase reflects changes in mandibular and labial-facial measurements subsequent to intervention that targeted a higher level on the motor-speech hierarchy.

Table 5.30 summarises the words that recorded significant impairment of the jaw and lip measures for P4 as compared with the typically developing (TD) peers pre-intervention; and significant changes post-intervention for these words. Results are based on five repetitions of each word, with the exception of one trial of the word ‘spot’ by TD 41. This word was deleted due to articulation error (the consonant blend ‘sp’ was produced as a voiced stop ‘b’).

The distance data (Appendix L) at pre-intervention show a predominant pattern of decreased jaw open distance (JOD) and increased lip rounding/retraction (LRR) values, in comparison to the TD peers. Data also show a lower peak velocity and longer mean duration. The post-intervention data show a positive treatment effect with changes to the measures of JOD and LRR in phase B reflective of the intervention priorities.

Table 5.30

Words that Recorded Significantly Different Pre (Mann-Whitney Test) and Post-Intervention (Friedman's ANOVA) Values on the Kinematic Measures of Distance, Velocity and Duration

	*Mandibular Control						†Labial-Facial Control							
Word Stimuli	JPD		JOD		JLDM		LRR		BLC		J/L VEL		WD	
MSH	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Wordset 1														
Mine			X	✓			X	✓			X	✓		
Man			X	✓				✓	X		X	✓	X	✓
Hat			X	✓			X	✓	-	-				
Up	X		X	✓					-	-	X			
Off			X	✓					-	-	X			
Wordset 2														
Shop			X	✓					-	-	X	✓		
Beep			X	✓					X	✓		✓		
Push									X		X	✓		
Two							X		-	-	X	✓	X	✓
Wordset 3														
Six			X	✓				✓	-	-	X	✓		
Spot	X		X	✓					-	-	X	✓	X	
Total	2	0	9	9	0	0	3	4	3	1	9	8	3	2

Note. * = p value ≤ .05, two-tailed, †= p value ≤ .05,one-tailed, Pre = pre-intervention comparison with peers, Post = post intervention comparison (phases B, C and A2), X = movement pattern significantly different to TD peers, ✓ = significant change recorded, MSH = motor speech hierarchy plane of movement, JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline, LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact, J/L VEL = jaw/lip opening velocity, WD =word duration.

Distance.

Mandibular control measures.

Pre-intervention.

Analyses of the kinematic data presented in Table 5.31 indicate impaired mandibular control at pre-intervention. Specifically:

JPD – Whilst mean values were decreased relative to the TD peers, a statistically significant difference was recorded on 2/11 words, only.

JOD – Mean values were significantly reduced, relative to the TD peers, on 9/11 words.

JLDM – All mean values (and SDs) were comparable to the TD peers.

Table 5.31

Mann-Whitney Test Results of the Pre-Intervention Mandibular Distance Measures Comparing P4 with the TD Peers

		JPD		JOD		JLDM	
JHP	Word	U	**p*	U	**p*	U	**p*
4	Mine	5	.151	.000	**.008**	12	1.000
4	Man	4	.095	.000	**.008**	6	.222
4	Hat	5	.151	1	**.016**	11	.841
3	Up	0	**.008**	.000	**.008**	11	.841
2	Off	11	.841	.000	**.008**	6	.222
2	Shop	3	.056	.000	**.016**	9	.548
2	Spot	0	**.016**	.000	**.016**	6	.413
1.5	Six	7	.310	.000	**.008**	3	.056
1	Beep	8	.421	.000	**.008**	8	.421
1	Push	4	.095	4	.095	11	.841
1	Two	7	.310	4	.095	4	.095

Note. JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline. * = two- tailed test, boldface = $p \leq .05$.

Post intervention.

The results for the three distance measures, obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect sizes, are presented in Table 5.32. Means and SDs are provided in Figures K.1, K.2 and K.3.

Table 5.32

Friedman's ANOVA and Wilcoxon Signed-Rank-Test Data for Each Mandibular Distance Measure for Each Word across the Study Phases for P4

	Friedman's Test (df 3)		Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ	p	Z	p	ES	Z	p	ES	Z	p	ES	Z	p	ES	Z	p	ES
Jaw Path Distance (JPD)																	
Mine	1.56	.709	-.674	.625	0.21	-1.753	.125	**0.55**	-.944	.438	0.30	-1.214	.313	0.38	-.135	1.000	0.04
Man	3.96	.298	-.135	1.000	0.04	-1.483	.188	0.47	-.674	.625	0.21	-.674	.625	0.21	-1.753	.125	**0.55**
Hat	4.2	.260	-1.483	.188	0.47	-1.753	.125	**0.55**	-.405	.813	0.13	-1.483	.188	0.47	-.135	1.000	0.04
Up	3.24	.408	-1.483	.188	0.47	-1.483	.188	0.47	-.674	.625	0.21	-.944	.438	0.30	-.135	1.000	0.04
Off	7.08	.067	-1.753	.125	**0.55**	-1.214	.313	0.38	-.674	.625	0.21	-1.483	.188	0.47	-1.214	.313	0.38
Shop	5.4	.151	-1.214	.313	0.38	-.944	.438	0.30	-.944	.438	0.30	-.135	1.000	0.04	-1.483	.188	0.47
Spot	1.08	.857	-1.483	.188	0.47	-2.023	.063	**0.64**	-.674	.625	0.21	-1.753	.125	**0.55**	-.405	.813	0.13
Six	3.48	.372	-.405	.813	0.13	-.944	.438	0.30	-2.023	.063	**0.64**	-1.214	.313	0.38	-.135	1.000	0.04
Beep	4.44	.226	-1.214	.313	0.38	-.135	1.000	0.04	-1.483	.188	0.47	-.135	1.000	0.04	-.674	.625	0.21
Push	5.88	.123	-.405	.813	0.13	-.405	.813	0.13	-.405	.813	0.13	-.674	.625	0.21	-.135	1.000	0.04
Two	7.08	.067	-1.753	.063	**0.55**	-.674	.313	0.21	-.674	.313	0.21	-1.753	.063	**0.55**	-1.753	.063	**0.55**
Jaw Open Distance (JOD)																	
Mine	13.56	<.001*	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-1.214	.313	0.38	-2.023	.063	**0.64**	-2.023	.063	**0.64**
Man	12.6	<.001*	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-.405	.813	0.13
Hat	9.96	.009*	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-.405	.813	0.13
Up	13.56	<.001*	-1.214	.313	0.38	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-.674	.625	0.21
Off	7.8	.044*	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-1.214	.313	0.38
Shop	12.12	.001*	-1.483	.188	0.47	-1.753	.125	**0.55**	-.674	.625	0.21	-2.023	.063	**0.64**	-1.214	.313	0.38
Spot	10.68	.005*	-1.753	.125	**0.55**	-1.753	.125	**0.55**	-.405	.813	0.13	-2.023	.063	**0.64**	-1.214	.313	0.38
Six	10.68	.005*	-1.483	.188	0.47	-2.023	.063	**0.64**	-1.214	.313	0.38	-2.023	.063	**0.64**	-1.214	.313	0.38
Beep	10.92	.003*	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-1.214	.313	0.38	-2.023	.063	**0.64**	-1.214	.313	0.38
Push	6.12	.107	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-.135	1.000	0.04
Two	4.92	.210	-.674	.313	0.21	-1.753	.063	**0.55**	-1.753	.063	**0.55**	-1.483	.094	0.47	-.135	.500	0.04

Jaw Lateral Distance from Midline (JLDM)																	
Mine	2.04	.652	-.405	.813	0.13	-.405	.813	0.13	-1.214	.313	0.38	-.405	.813	0.13	-1.214	.313	0.38
Man	3.24	.408	-.405	.813	0.13	-1.753	.125	**0.55**	-1.753	.125	**0.55**	-1.214	.313	0.38	-.405	.813	0.13
Hat	1.56	.709	-.405	.813	0.13	-.944	.438	0.30	-1.214	.313	0.38	-.405	.813	0.13	-1.483	.188	0.47
Up	2.52	.521	-.135	1.000	0.04	-.944	.438	0.30	-.135	1.000	0.04	-.405	.813	0.13	-.674	.625	0.21
Off	4.44	.226	-.674	.625	0.21	-1.214	.313	0.38	-.135	1.000	0.04	-1.214	.313	0.38	-.135	1.000	0.04
Shop	1.32	.771	-1.483	.188	0.47	-1.214	.313	0.38	-.944	.438	0.30	-1.214	.313	0.38	-.944	.438	0.30
Spot	3.24	.408	-.405	.813	0.13	-.674	.625	0.21	-.135	1.000	0.04	-.135	1.000	0.04	-1.483	.188	0.47
Six	3	.445	-1.214	.313	0.38	-.405	.813	0.13	-.944	.438	0.30	-2.023	.063	**0.64**	-1.214	.313	0.38
Beep	7.32	.055	-.674	.625	0.21	-2.023	.063	**0.64**	-.405	.813	0.13	-.674	.625	0.21	-.944	.438	0.30
Push	0.6	.944	-1.214	.313	0.38	-.674	.625	0.21	-1.753	.125	**0.55**	-.944	.438	0.30	-1.483	.188	0.47
Two	1.32	.771	-1.753	.125	**0.55**	-.674	.625	0.21	-.135	1.000	0.04	-.944	.438	0.30	-.944	.438	0.30

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).

*=*p* ≤ .05 one-tailed test, boldface = large effect size.

Jaw Path Distance (JPD).

The results obtained using Friedman's ANOVA indicate no presence of a main effect. However, the pairwise comparisons indicate moderate to large effect sizes on 8/11 words, with a trend towards increasing mean values between phases A-C. Six of eleven words maintained these effects sizes between phases A-D. The descriptive data therefore suggests a trend towards the TD peer across the study phases. The data therefore indicate the presence of a positive treatment effect, with phase C yielding the most substantial change.

Jaw Open Distance (JOD).

The results obtained using Friedman's ANOVA indicate the presence of a main effect on all nine words that differed significantly from the TD peer, at pre-intervention.

Results on the pair-wise comparisons indicate an increase in mean JOD values occurred between phases A-B (intervention priority one: labial-facial control). Seven of eleven words yielded large effect sizes and a trend towards the TD peers. This treatment effect continued in phase C with 6/11 words continuing to yield large effect sizes between phases B-C. All words recorded large effect sizes between phases A1-A2 indicating the treatment effect was maintained at follow-up.

Jaw Lateral Distance from Midline (JLDM).

The results obtained using Friedman's ANOVA show no presence of a main effect on any word. The results indicate comparable performance with the TD peer.

Labial-facial measures.

Pre-intervention.

Analyses of the kinematic data presented in Table 5.33 indicate impaired labial-facial control at pre-intervention. Specifically:

LRR – A statistically significant increase was recorded on 3/11words in comparison to the TD peer. Excessive retraction was evidenced on 2/4 words in word-set one at jaw height position four as well as the word 'two' in word-set two.

BLC – A statistically significant increase in inter-lip distance was recorded on 3/4 words.

Table 5.33

Mann-Whitney Test Results of the Pre-intervention Labial-Facial Distance Measures Comparing P4 with the TD Peers

	LRR			BLC	
Word	U	†*p*		U	†*p*
Mine	.000	**.004**	Mine	8	.210
Man	10	.345	Man	2	**.016**
Hat	4	**.048**	Push	4	.048
Up	12	.500	Beep	.000	**.004**
Off	9	.274			
Shop	11	.421			
Spot	9	.452			
Six	9	.274			
Beep	9	.274			
Push	7	.155			
Two	2	**.016**			

Note. LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact.
†= one-tailed test, boldface = $p \leq .05$.

Post intervention.

The results obtained using Friedman’s ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data for the two distance measures are presented in Table 5.31. In summary, these results (supported by the descriptive data shown in Figures K.4 and K.5) indicate the presence of a treatment effect on labial-facial measures.

Table 5.34

Friedman's ANOVA and Wilcoxon Signed Rank Data for each Labial-Facial Distance Measure for each Word for P4

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test															
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
Lip Rounding/Retraction (LRR)																	
Mine	7.08	.044*	-0.67	0.31	0.21	-1.48	0.09	0.47	-1.48	0.09	0.47	-1.48	0.09	0.47	-2.02	**0.03**	**0.64**
Man	7.80	.044*	-1.48	0.09	0.47	-1.48	0.09	0.47	-2.02	**0.03**	**0.64**	-1.48	0.09	0.47	-1.75	0.06	**0.55**
Hat	12.60	.001*	-0.40	0.41	0.13	-2.02	**0.03**	**0.64**	-2.02	**0.03**	**0.64**	-2.02	**0.03**	**0.64**	-0.94	0.22	0.30
Up	1.08	0.86	-0.13	0.50	0.04	-0.13	0.50	0.04	-0.13	0.50	0.04	-0.67	0.31	0.21	-0.40	0.41	0.13
Off	1.32	0.77	-0.13	0.50	0.04	-0.13	0.50	0.04	-0.94	0.22	0.30	-1.21	0.16	0.38	-1.21	0.16	0.38
Shop	1.08	0.86	-0.40	0.41	0.13	-1.75	0.06	**0.55**	-0.40	0.41	0.13	-0.13	0.50	0.04	-0.94	0.22	0.30
Spot	3.96	0.30	-1.21	0.16	0.38	-1.21	0.16	0.38	-0.67	0.31	0.21	-0.67	0.31	0.21	-0.13	0.50	0.04
Six	10.68	.005*	-0.67	0.31	0.21	-2.02	**0.03**	**0.64**	-2.02	**0.03**	**0.64**	-0.67	0.31	0.21	-2.02	**0.03**	**0.64**
Beep	4.20	0.26	-0.40	0.41	0.13	-1.48	0.09	0.47	-1.75	0.06	**0.55**	-1.21	0.16	0.38	-1.75	0.06	**0.55**
Push	3.96	0.30	-1.21	0.16	0.38	-0.67	0.31	0.21	-0.40	0.41	0.13	-0.67	0.31	0.21	-0.67	0.31	0.21
Two	5.40	0.15	-1.75	0.06	**0.55**	-2.02	**0.03**	**0.64**	-0.94	0.22	0.30	-1.75	0.06	**0.55**	-0.13	0.50	0.04
Bilabial Inter-lip Distance (BLC)																	
Mine	4.44	0.23	-0.40	0.41	0.13	-1.21	0.16	0.38	-1.21	0.16	0.38	-1.75	0.06	**0.55**	-0.40	0.41	0.13
Man	4.92	0.21	-2.02	**0.03**	**0.64**	-1.75	0.06	**0.55**	-0.13	0.50	0.04	-1.75	0.06	**0.55**	-0.40	0.41	0.13
Push	7.32	0.06	-1.75	0.06	**0.55**	-1.21	0.16	0.38	-0.40	0.41	0.13	-0.13	0.50	0.04	-1.21	0.16	0.38
Beep	3.48	0.37	-1.48	0.09	0.47	-1.75	0.06	**0.55**	-0.13	0.50	0.04	-2.02	**0.03**	**0.64**	-1.21	0.16	0.38
Upper Lip (UL) Position																	
Mine	4.44	0.23	-0.40	0.81	0.13	-1.48	0.19	0.47	-1.21	0.31	0.38	-1.48	0.19	0.47	-0.40	0.81	0.13
Man	4.92	0.21	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-0.40	0.81	0.13	-2.02	0.06	**0.64**	-1.48	0.19	0.47
Push	7.32	0.06	-1.21	0.31	0.38	-1.21	0.31	0.38	-0.67	0.63	0.21	-0.94	0.44	0.30	-1.21	0.31	0.38
Beep	3.48	0.37	-0.67	0.63	0.21	-0.94	0.44	0.30	-0.67	0.63	0.21	-1.75	0.13	**0.55**	-1.21	0.31	0.38
Lower Lip (LL) Position																	
Mine	0.60	0.94	-0.67	0.63	0.21	-0.94	0.44	0.30	-0.40	0.81	0.13	-0.40	0.81	0.13	-0.40	0.81	0.13
Man	1.08	0.86	-0.67	0.63	0.21	-0.13	1.00	0.04	-0.40	0.81	0.13	-0.40	0.81	0.13	-0.40	0.81	0.13
Push	3.00	0.39	-1.48	0.19	0.47	-1.48	0.19	0.47	-0.13	1.00	0.04	-0.67	0.63	0.21	-0.94	0.44	0.30
Beep	3.48	0.37	-1.21	0.19	0.38	-1.48	0.19	0.47	-0.94	1.00	0.30	-0.40	0.63	0.13	-0.67	0.44	0.21

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).
* = $p \leq .05$ one-tailed test, boldface = large effect size

Lip Rounding/Retraction (LRR).

The results obtained using Friedman's ANOVA indicate the presence of a main effect on 2/3 words that differed significantly at pre-intervention.

The descriptive data show phase B (intervention priority: labial-facial control) was characterised by a decrease in mean values on 5/11 words, with a trend towards the TD peers. This indicates the presence of a treatment effect on the intervention priority in this phase. Phase C (intervention priority two: lingual control) however, was characterised by a trend away from the TD peer, with four words yielding large effect sizes. Pair-wise comparisons between phases A1-A2 indicate a clinically significant change with 6/11 words recording smaller mean values than pre-intervention.

Inter-lip distance during Bilabial Contact (BLC).

The results obtained using Friedman's ANOVA indicate the presence of a main effect on one word (push).

However, the pair-wise comparisons and positional data indicate a change in the interaction between the UL and LL, across the study phases. The data indicate phase B (intervention priority: labial-facial control) yielded the most significant change, with a decrease in inter-lip distance at the point of minimum BLC on 3/4 words.

Plots of the average vertical positions of the UL and LL markers at the point of bilabial contact, for each of the four words, are shown in Figure 5.4. The LL is plotted on the X-axis and the UL is plotted on the y-axis. A negative value reflects an inferior (downward) position, whilst a positive value reflects a superior (upward) position, from rest. Figure 5.4 illustrates the decrease in BLC was associated with the UL assuming a more inferior lip position, across the study phases. This treatment effect was maintained at follow-up (phase A2), with 3/4 words recording large effect sizes.

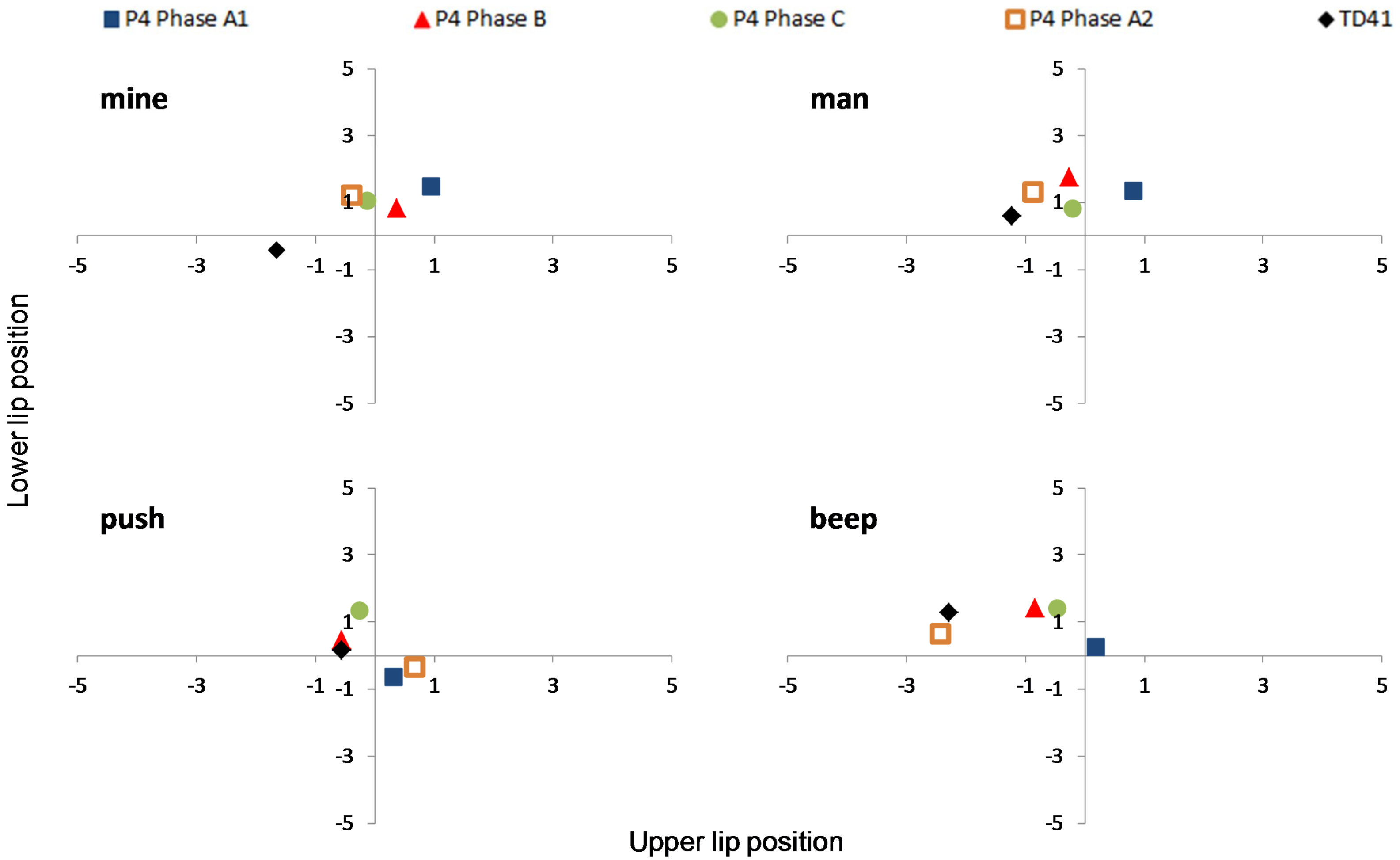


Figure 5.8. Average position of the upper lip (X axis) and lower lip (Y axis), across the study phases, as measured at minimum inter-lip distance (mms) at the point of bilabial contact for P4 and the TD peer.

Jaw/Lip Opening Velocity (J/L Vel).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by the P4 and the TD peers are presented in Table 5.35. The results show the peak velocity values were significantly less on 9/11 words.

Table 5.35

Mann-Whitney test Results and Descriptive Data (Means and Standard Deviations) of the Pre-Intervention Jaw/Lip Opening Velocity Measures Comparing P4 with the TD Peers

	Velocity		TD Peers TD 41	P4 Phase A
Word	U	**p*	M(SD)	M(SD)
Mine	0	**.008**	87.00(10.91)	33.63(11.63)
Man	2	**.032**	77.64(19.18)	43.31(12.39)
Hat	6	.222	10.17(8.98)	3.39(2.17)
Up	0	**.008**	35.02(6.86)	3.28(1.64)
Off	0	**.008**	28.92(11.57)	4.01(3.99)
Shop	0	**.008**	33.08(6.27)	2.97(3.52)
Spot	0	**.016**	77.68(17.20)	2.46(1.93)
Six	0	**.008**	17.64(10.85)	2.65(1.39)
Beep	3	.056	50.35(5.89)	23.50(20.22)
Push	1	**.016**	15.84(6.04)	3.99(1.60)
Two	2	**.032**	12.63(9.98)	2.22(0.66)

Note. TD = typically developing
* = two-tailed tests, boldface = significant ≤ .05

Post intervention.

The results obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data are presented in Table 5.37.

The results indicate a significant main treatment effect, with a progressive trend towards the TD peers on 8/9 words that differed significant from the TD peer, at pre-intervention. Whilst the pair-wise comparisons do not record statistically significant changes, moderate-to-large effect sizes are evidenced across the intervention phases, with phase C yielding the greatest change. However, the follow-up data (phase A2) show the treatment effect was not maintained and some words recorded lower values than at pre-intervention.

Word Duration (WD).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by P4 and the TD peers are presented in Table 5.33. The results show significantly longer duration on 3/11 words.

Table 5.36

Mann-Whitney test Results and Descriptive Data (means and standard deviations) of the Pre-Intervention Word Duration Measures Comparing P4 with the TD Peers

	Duration		TD 41	P4 Phase A
Word	U	**p*	M(SD)	M(SD)
Mine	6	.159	0.48(0.02)	0.54(0.08)
Man	3	**.040**	0.57(0.06)	0.67(0.06)
Hat	11	.730	0.52(0.05)	0.54(0.28)
Up	5	.127	0.40(0.02)	0.34(0.16)
Off	10	.595	0.43(0.09)	0.50(0.21)
Shop	11	.722	0.56(0.03)	0.58(0.24)
Spot	0	**.016**	0.81(0.05)	0.50(0.18)
Six	6	.222	0.82(0.09)	0.64(0.32)
Push	10	.651	0.46(0.04)	0.54(0.24)
Beep	10	.683	0.56(0.03)	0.53(0.12)
Two	2	**.040**	0.45(0.04)	0.54(0.06)

Note. TD = typically developing
* = two-tailed tests, boldface = significant ≤ .05

Post intervention.

The results obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data, are presented in Table 5.37.

In summary, the results show a main effect on only two words: one word (man) showing a decrease in duration and the other (two) recording an increase. The pairwise comparisons indicate variable performance across the intervention phases with no clear trend directions.

Table 5.37

Friedman's ANOVA and Wilcoxon Signed Rank Data for Velocity and Duration Measures for Each Word across the Study Phases for P4

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	$\chi 2$	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
						Jaw/Lip Opening Velocity (J/L Vel)											
Mine	12.12	.001*	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Man	12.12	.001*	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Hat	6.36	.093	-1.48	0.19	0.47	-0.94	0.44	0.30	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Up	5.4	.151	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-1.21	0.31	0.38	-0.67	0.63	0.21	-0.13	1.00	0.04
Off	4.92	.210	-0.13	1.00	0.04	-0.13	1.00	0.04	-0.13	1.00	0.04	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**
Shop	11.88	.002*	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-1.48	0.19	0.47	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Spot	12.12	.001*	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-1.21	0.31	0.38
Six	10.68	.005*	-1.48	0.19	0.47	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-0.94	0.44	0.30
Beep	10.2	.007*	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-0.67	0.63	0.21	-2.02	0.06	**0.64**
Push	8.28	.031*	-2.02	0.06	**0.64**	-1.48	0.19	0.47	-0.13	1.00	0.04	-0.67	0.63	0.21	-1.21	0.31	0.38
Two	10.68	.005*	-1.75	0.13	**0.55**	-0.13	1.00	0.04	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
						Word Duration (W/D)											
Mine	2.755	.466	-1.36	0.25	0.43	-0.81	0.50	0.26	-1.83	0.13	**0.58**	0.00	1.00	0.00	-0.41	0.81	0.13
Man	11.88	.002*	-2.02	0.06	**0.64**	-2.03	0.06	**0.64**	-2.03	0.06	**0.64**	-2.02	0.06	**0.64**	-1.63	0.19	**0.51**
Hat	2.28	.561	-1.21	0.31	0.38	-1.75	0.13	**0.55**	-0.67	0.63	0.21	-1.21	0.31	0.38	-0.67	0.63	0.21
Up	3.367	.373	-1.21	0.31	0.38	-1.21	0.31	0.38	-0.37	0.88	0.12	-0.68	0.63	0.21	-0.27	0.94	0.09
Off	3.96	.298	-0.94	0.44	0.30	-0.41	0.81	0.13	-1.21	0.31	0.38	-0.95	0.38	0.30	-1.21	0.31	0.38
Shop	1.56	.709	-1.08	0.38	0.34	-0.67	0.63	0.21	-0.14	1.00	0.04	-0.94	0.44	0.30	-1.75	0.13	**0.55**
Spot	0.796	.888	-0.27	0.88	0.09	0.00	1.00	0.00	-0.67	0.63	0.21	-0.68	0.63	0.21	-0.14	1.00	0.04
Six	3.735	.314	-0.95	0.38	0.30	-0.67	0.63	0.21	-1.75	0.13	**0.55**	-0.14	1.00	0.04	-0.37	0.88	0.12
Beep	7.163	.057	-1.46	0.25	0.46	-0.14	1.00	0.04	-2.03	0.06	**0.64**	-0.68	0.56	0.21	-0.67	0.63	0.21
Push	7.041	.064	-0.94	0.44	0.30	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-1.83	0.13	**0.58**	-0.41	0.81	0.13
Two	9.98	.009*	-2.03	0.06	**0.64**	-0.14	1.00	0.04	-1.84	0.13	**0.58**	-1.76	0.13	**0.56**	-1.48	0.19	0.47

Note. A = phase A1 (pre-intervention), B = phase B (intervention priority one: labial-facial control), C = phase C (intervention priority two: lingual control), A2= phase A2 (follow-up).

*=$p \leq .05$ two-tailed, boldface = large effect size

Overall summary of P4's kinematic measures.

Subsequent to the PROMPT intervention, the following changes were evident across the study phases:

Phase B - A significant increase in JOD and velocity across all word-sets, and a decrease in LRR and BLC values characterised this intervention phase. These data indicate a trend towards the TD peers, and the presence of a positive treatment effect on the intervention priorities.

Phase C – The JOD values and velocity continued to increase this phase, with a continued trend towards the TD peers. However, an increase in LRR values indicated a trend away from the TD peers, on this measure.

Phase A2 – Data indicate a return to decreasing LRR values and maintenance of the treatment effect on JOD.

The above results indicate P4's intervention program was successful in producing changes to the motor-speech movement patterns under investigation.

Participant 5

The following motor-speech movement patterns were targeted during the phases of the PROMPT Intervention:

Phase B: (Intervention priority one: mandibular control) – Increase range of movement at jaw height positions 3 and 4 (word-set one), increase the distance between the four jaw height positions, improve midline control (i.e., decrease lateral movement from midline), increase duration.

Phase C: (Intervention priority two: labial-facial control) – Facilitate appropriate neutral and rounded lip movements (inhibit excessive retraction); and independent use of lips (as opposed to through jaw motion) to make bilabial contact.

Table 5.35 summarises the words that recorded significant impairment of the jaw and lip measures for P5 as compared with the TD peers pre-intervention; and significant changes post-intervention for these words. Results are based on 5 repetitions of each word, with exceptions in phase C and A2 as detailed as follows: Phase C required the elicitation of 6 full trials[3] to obtain 5 repetitions of each word.

---

[3] One full trial = uninterrupted repetition of the 11 words.

Trial 3 was removed due to shouting and excessive movement resulting in missing markers. Further, analysis of the word ‘man’ is based on 4 repetitions only. One repetition was removed due to production varying substantially from all other productions (that is, 2/3 phonemes differed from previous productions). In phase A2, analysis of the word ‘shop’ and ‘push’ are based on 4 repetitions due to a yawn at the end of the word and excessive movement, respectively resulting in missing markers.

In addition, analysis of the word ‘shop’ for TD 53 is based on 3 repetitions due to incorrect pronunciation that differed from the TD peers.

The distance data (Appendix M) at pre-intervention show a predominant pattern of decreased path distance (JPD). The jaw open distance (JOD) was also reduced with limited difference in values across the four jaw height positions. In contrast, deviation from midline (JLDM) and lip rounding/retraction (LRR) values were increased, in comparison to the TD peers. Data also shows a lower peak velocity and shorter mean duration. The post-intervention data show a positive treatment effect with changes to the measures of JOD in phase B and LRR in phase C reflective of the intervention priorities.

Table 5.38

Words that Recorded Significantly Different Pre (Mann-Whitney Test) and Post-Intervention (Friedman's ANOVA) Values on the Kinematic Measures of Distance, Velocity and Duration

	*Mandibular Control						†Labial-Facial Control							
Word Stimuli	JPD		JOD		JLDM		LRR		BLC		J/LVEL		WD	
MSH	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Wordset 1														
Mine	X	✓	X	✓					X	-	X	✓		✓
Man			X				X	✓	-	-	X			
Hat					X		X		-	-			X	
Up									-	-	X		X	
Off									-	-			X	
Wordset 2														
Shop	X								-	-		✓		
Beep		✓			X			✓					X	
Push								✓	X		X			
Two											X			
Wordset 3														
Six	X			✓								✓	X	✓
Spot	X							✓			X	✓	X	✓
Total	4	2	4	2	2	0	2	4	2	0	6	4	6	3

Note. * = *p* value ≤ .05, two-tailed, †= *p* value ≤ .05,one-tailed, Pre = pre-intervention comparison with peers, Post = post intervention comparison (phases B, C and A2), X = movement pattern significantly different to TD peers, ✓ = significant change recorded, MSH = motor speech hierarchy plane of movement, JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline, LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact, J/L VEL = jaw/lip opening velocity, WD =word duration.

Distance measures.

Mandibular control measures.

Pre-intervention.

Analyses of the kinematic data presented in Table 5.39 indicate impaired mandibular control at pre-intervention. Specifically:

JPD – Mean values were reduced relative to the TD peers, with a statistically significant difference on 4/11 words (mine, shop, six, spot).

JOD – Mean values were reduced relative to the TD peers, with a statistically significant difference on 4/11 words (mine, man, push, two).

JLDM –Mean values were increased, in comparison to the TD peers, on 6/11 words. A statistically significant difference was recorded on two words (hat, beep).

Table 5.39

Mann-Whitney Test Results of the Pre-Intervention Mandibular Distance Measures Comparing P5 with the TD Peers

		JPD		JOD		JLDM	
JHP	Word	U	**p*	U	**p*	U	**p*
4	Mine	14	**.042**	11	**.019**	37	1
4	Man	25	.306	6	**.004**	16	.066
4	Hat	26	.349	31	.612	7	**.005**
3	Up	29	.497	34	.800	34	.800
2	Off	31	.612	32	.672	30	.553
2	Shop	11	**.035**	14	.075	23	.387
2	Spot	31	**.000**	31	.612	25	.306
1.5	Six	22	**.033**	22	.197	27	.395
1	Beep	28	.395	28	.445	15	**.053**
1	Push	5	.306	5	**.001**	28	.445
1	Two	.000	.866	.000	**.000**	35	.866

Note. JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline. * = two- tailed test, boldface = $p \leq .05$.

Post intervention.

The results for the three distance measures, obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect sizes are presented in Table 5.37. Means and SDs are provided in Figures L.1, L.2 and L.3.

Table 5.40

Friedman's ANOVA and Wilcoxon- Signed-Rank-Test Data for Each Mandibular Distance Measure for Each Word across the Study Phases for P5

	Friedman's (df 3)		Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	$\chi2$	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	*Z*	*p*	ES
Jaw Path Distance (JPD)																	
Mine	7.32	.055*	-1.483	.188	0.47	-2.023	**.063**	**0.64**	-.944	.438	0.30	-2.023	**.063**	**0.67**	-1.214	.313	0.40
Man	0.9	.900	-.674	.625	0.21	-.730	.625	0.23	-.730	.625	0.23	-1.753	.125	**0.58**	-.730	.625	0.24
Hat	2.04	.652	-.405	.813	0.13	-1.753	.125	**0.55**	-.405	.813	0.13	-.405	.813	0.13	-1.483	.188	0.47
Up	1.08	.857	-.135	1.000	0.04	-.405	.813	0.13	-.674	.625	0.21	-1.214	.313	0.40	-.405	.813	0.13
Off	2.5	.521	-.944	.438	0.30	-.135	1.000	0.04	-.674	.625	0.21	-.405	.813	0.13	-1.214	.313	0.38
Shop	5.4	.158	-1.214	.313	0.38	-2.023	**.063**	**0.64**	-.405	.813	0.13	-1.826	.125	**0.58**	-1.095	.375	0.35
Spot	5.88	.123	-.135	1.000	0.04	-.674	.625	0.21	-.944	.438	0.30	-2.023	**.063**	**0.64**	-1.214	.313	0.38
Six	6.36	.093	-1.214	.313	0.43	-1.753	.125	**0.55**	-.135	1.000	0.05	-2.023	**.063**	**0.64**	-.944	.438	0.30
Beep	9.24	.017*	-1.214	.313	0.38	-1.753	.125	**0.55**	-2.023	**.063**	**0.64**	-1.753	.125	**0.55**	-.405	.813	0.13
Push	3	.432	-.944	.438	0.30	-1.753	.125	**0.55**	-.674	.625	0.21	-1.461	.250	0.46	-1.461	.250	0.46
Two	4.2	.260	-.674	.625	0.21	-.405	.813	0.13	-1.214	.313	0.38	-1.214	.313	0.38	-2.023	**.063**	**0.64**
Jaw Open Distance (JOD)																	
Mine	9.72	.012*	-.405	.813	0.13	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-2.023	.063	**0.67**	-.135	1.000	0.04
Man	5.1	.190	-.405	.813	0.13	-1.826	.125	**0.58**	.000	1.000	0.00	-2.023	**.063**	**0.67**	-1.095	.375	0.37
Hat	2.52	.521	-1.214	.156	0.38	-.135	.500	0.04	-.674	.313	0.21	-.944	.219	0.30	-1.483	.094	0.47
Up	6.12	.107	-.944	.438	0.30	-.135	1.000	0.04	-.674	.625	0.21	-.944	.438	0.31	-.944	.438	0.31
Off	3.48	.372	-.135	1.000	0.04	-.674	.625	0.21	-.944	.438	0.30	-1.483	.188	0.47	-1.214	.313	0.38
Shop	5.1	.190	-1.753	.125	**0.55**	-1.483	.188	0.47	-.944	.438	0.30	-1.826	.125	**0.58**	.000	1.000	0.00
Spot	4.44	.226	-.944	.438	0.30	-1.214	.313	0.38	-2.023	**.063**	**0.64**	-1.214	.313	0.38	-.135	1.000	0.04
Six	8.28	.031*	-1.214	.313	0.43	-.135	1.000	0.04	-.944	.438	0.33	-2.023	**.063**	**0.64**	-2.023	**.063**	**0.64**
Beep	4.2	.260	-.674	.625	0.21	-1.214	.313	0.38	-1.483	.188	0.47	-1.753	.125	**0.55**	-.135	1.000	0.04
Push	5.1	.190	-1.483	.188	0.47	-1.483	.188	0.47	-.674	.625	0.21	-1.826	.125	**0.58**	-1.461	.250	0.46
Two	3.48	.372	-.405	.813	0.13	-1.753	.125	**0.55**	-1.483	.188	0.47	-.674	.625	0.21	-1.483	.188	0.47

	Jaw Lateral Distance from Midline (JLDM)														
Mine	2.04	.652	-1.483	.188	0.47	-.135	1.000	0.04	-.674	.625	0.21	-.135	1.000	0.04	-.135	1.000	0.04
Man	5.1	.190	-.674	.625	0.21	-.365	.875	0.12	-.365	.875	0.12	-2.023	.063	**0.67**	-1.461	.250	0.49
Hat	0.6	.944	-.135	1.000	0.04	-1.214	.313	0.38	-.674	.625	0.21	-.405	.813	0.13	-.135	1.000	0.04
Up	2.04	.652	-1.214	.313	0.38	-1.753	.125	**0.55**	-.135	1.000	0.04	-1.214	.313	0.40	-.674	.625	0.22
Off	0.12	1.000	-.135	1.000	0.04	-.405	.813	0.13	-1.214	.313	0.38	-.944	.438	0.30	-.674	.625	0.21
Shop	1.5	.754	-.405	.813	0.13	-1.214	.313	0.38	-1.753	.125	**0.55**	-1.461	.250	0.46	-.730	.625	0.23
Spot	1.08	.857	-1.214	.313	0.38	-.674	.625	0.21	-1.483	.188	0.47	-.944	.438	0.30	-.405	.813	0.13
Six	3.48	.372	-.135	1.000	0.05	-1.214	.313	0.38	-1.753	.125	**0.62**	-.135	1.000	0.04	-1.753	.125	**0.55**
Beep	5.1	.190	-.944	.438	0.30	-.674	.625	0.21	-.674	.625	0.21	-1.826	.125	**0.58**	-1.461	.250	0.46
Push	4.92	.210	-.135	.500	0.04	-.944	.219	0.30	-.944	.219	0.30	-2.023	.031	**0.64**	-1.753	.063	**0.55**
Two	7.08	.067	-2.023	.063	**0.64**	-.135	1.000	0.04	-2.023	.063	**0.64**	-.135	1.000	0.04	-.674	.625	0.21

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2= phase A2 (follow-up).
*=*p* ≤ .05, two-tailed test, boldface = large effect size.

Jaw Path Distance (JPD).

The results obtained using Friedman's ANOVA indicate a statistically significant positive main effect subsequent to intervention on four words (mine, off, push, six).

Pairwise comparisons indicate the presence of a treatment effect across all three word-sets. Between phases A-B an increase in mean value and trend towards the TD peers was evidenced. Six of eleven words recorded a moderate effect size. This trend continued in phase C, with 5/6 of the aforementioned words recording a large effect size. Maintenance of treatment effects was indicated with 6/11 words recording large effect sizes between phases A1-A2.

Jaw Open Distance (JOD).

The results obtained using Friedman's ANOVA indicate the presence of a main effect on two words only ('mine' and 'six').

Despite the lack of statistical significance, the effect size results indicate the presence of a positive treatment effect. Moderate-to-large effect sizes were recorded on 7/11 words between phases A-B (intervention priority one: mandibular control). The descriptive data show this phase was characterized by a decrease in mean values, and a trend way from the TD peers. Phase C (intervention priority two: labial-facial control), was characterized by a return to increased values with 7/11 words recording moderate-to-large effect sizes. Maintenance of the treatment effect was indicated with 6/11 and 4/11 words between phases A1-A2 maintaining large and moderate effect sizes, respectively.

Additional analysis to examine the distance between each of the four jaw height positions across the study phases was undertaken using a linear mixed model of analysis. In this model, the words were nested within the phases and treated as a random effect; and the jaw positions were treated as a fixed effect. The data indicate a significant increase in the range between jaw height positions 1, 2 and 4 subsequent to intervention $t(146) = 4.005$, $p = <.001$. The contrasts reveal an increasing range between jaw height position across the study phases: phase B $t(146) = -0.39$, $p=0.69$, phase C $t(146) = 1.76$, $p = 0.07$ and phase A2 $t(146) = 2.287$, $p = 0.024$.

Jaw Lateral Distance from Midline (JLDM).

The results obtained using Friedman's ANOVA indicated no presence of a main effect on any word, thus indicating no statistically significant changes.

However, clinically significant changes were indicated. Phase C (intervention priority: labial-facial control) yielded the most significant change with a trend towards the TD peers. Phase A2 (follow-up) showed evidence of continued improvement in midline stability, with a decrease in mean values and continued trend towards the TD peers.

Labial-facial measures.

Pre-intervention.

Analyses of the kinematic data presented in Table 5.38 indicate impaired labial-facial control at pre-intervention. Specifically:

LRR - Descriptive data show the mean values were increased in comparison to the TD peers. A statistically significant difference was recorded on three words (man, hat, shop).

BLC – A statistically significant difference in inter-lip distance was recorded on two words (mine, push).

Table 5.41

Mann-Whitney Test Results of the Pre-Intervention Labial-Facial Distance Measures comparing P2 with the TD Peers

	LRR			BLC	
Word	U	†*p*		U	†*p*
Mine	33	.368	mine	12	**.013**
Man	4	**.001**	man	20	.071
Hat	16	**.033**	push	17	**.040**
Up	29	.249	beep	24	.133
Off	28	.222			
Shop	16	**.044**			
Spot	22	.099			
Six	37	.50			
Beep	20	.071			
Push	22	.099			
Two	26	.174			

Note. LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact
†=one-tailed test, boldface = $p \leq .05$

Post intervention.

The results obtained using Friedman’s ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data, for the two distance measures are presented in Table 5.39. In summary, these results (supported by the descriptive data figures L.4 and L.5) indicate the presence of a treatment effect on the labial-facial measures.

Table 5.42

Friedman's ANOVA and Wilcoxon Signed Rank Data for Each Labial-Facial Distance Measure for Each Word for P5

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
Lip Rounding/Retraction (LRR)																	
Mine	2.28	.561	-0.13	0.50	0.04	-0.40	0.41	0.13	-0.13	0.50	0.04	-0.94	0.22	0.31	-1.21	0.16	0.40
Man	7.5	.052	-0.67	0.31	0.21	-1.83	0.06	**0.58**	-1.46	0.13	0.46	-2.02	0.03	**0.67**	-1.83	0.06	**0.61**
Hat	1.08	.857	-0.94	0.22	0.30	-1.21	0.16	0.38	-0.67	0.31	0.21	-0.40	0.41	0.13	-0.40	0.41	0.13
Up	0.6	.944	-0.67	0.31	0.21	-1.21	0.16	0.38	-0.40	0.41	0.13	-0.40	0.41	0.13	-0.40	0.41	0.13
Off	4.44	.226	-1.75	0.06	**0.55**	-0.94	0.22	0.30	-0.94	0.22	0.30	-1.75	0.06	**0.55**	-1.48	0.09	0.47
Shop	0.3	.992	-0.40	0.41	0.13	-0.40	0.41	0.13	-0.40	0.41	0.13	-0.73	0.31	0.23	-1.10	0.19	0.35
Spot	11.88	.002*	-0.94	0.22	0.30	-2.02	0.03	**0.64**	-0.40	0.41	0.13	-2.02	0.03	**0.64**	-2.02	0.03	**0.64**
Six	0.36	.975	-0.67	0.31	0.24	-0.40	0.41	0.13	-0.13	0.50	0.05	-0.94	0.22	0.30	-1.21	0.16	0.38
Beep	10.68	.005*	-2.02	0.03	**0.64**	-0.40	0.41	0.13	-2.02	0.03	**0.64**	-0.94	0.22	0.30	-1.48	0.09	0.47
Push	8.1	.033*	-2.02	0.03	**0.64**	-0.13	0.50	0.04	-2.02	0.03	**0.64**	-1.83	0.06	**0.58**	-1.10	0.19	0.35
Two	2.28	.561	-1.21	0.16	0.38	-1.75	0.06	**0.55**	-0.13	0.50	0.04	-1.21	0.16	0.38	-0.40	0.41	0.13
Bilabial Inter-lip Distance (BLC)																	
Mine	5.880	.123	-1.75	0.06	**0.55**	-0.94	0.22	0.30	-1.48	0.09	0.47	-0.67	0.31	0.21	-0.13	0.50	0.04
Man	0.9	.900	-0.67	0.31	0.21	0.00	0.56	0.00	-1.10	0.19	0.37	-0.67	0.31	0.21	-0.73	0.31	0.23
Push	3.900	.324	-2.02	0.03	**0.64**	-1.48	0.09	0.47	-1.75	0.06	**0.55**	-0.73	0.31	0.24	0.00	0.56	0.00
Beep	4.920	.210	-2.02	0.03	**0.64**	-1.21	0.16	0.38	-0.67	0.31	0.21	-0.67	0.31	0.21	-0.40	0.41	0.13
Upper Lip (UL) Position																	
Mine	1.560	.709	-0.67	0.31	0.21	-0.94	0.22	0.30	-0.40	0.41	0.13	-0.40	0.41	0.13	-0.67	0.31	0.21
Man	0.300	.992	-0.13	0.50	0.04	-0.37	0.44	0.12	-0.37	0.44	0.12	-0.67	0.31	0.21	-0.37	0.44	0.12
Push	3.600	.355	-0.67	0.31	0.21	-0.67	0.31	0.21	-1.75	0.06	**0.55**	0.00	0.56	0.00	-0.73	0.31	0.24
Beep	0.360	.975	-0.40	0.41	0.13	-0.67	0.31	0.21	-0.67	0.31	0.21	-1.21	0.16	0.40	-0.67	0.31	0.22
Lower Lip (LL) Position																	
Mine	6.120	.107	-1.75	0.06	**0.55**	-0.94	0.22	0.30	-0.67	0.31	0.21	-0.94	0.22	0.30	-0.40	0.41	0.13
Man	1.800	.677	-1.48	0.09	0.47	0.00	0.56	0.00	-1.46	0.13	0.49	-0.13	0.50	0.04	0.00	0.56	0.00
Push	3.900	.324	-2.02	0.03	**0.64**	-1.75	0.06	**0.55**	-0.94	0.22	0.30	-0.73	0.31	0.24	0.00	0.56	0.00
Beep	4.920	.210	-2.02	0.03	**0.64**	-0.94	0.22	0.30	-0.67	0.31	0.21	-0.40	0.41	0.13	-0.40	0.41	0.13

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).*= $p \leq .05$ one-tailed test, boldface = large effect size

Lip Rounding/Retraction (LRR).

The results obtained using Friedman’s ANOVA indicate a main effect on 4/11 words.

The descriptive data show phase B (intervention priority: Mandibular control) was characterised by a decrease in mean values on 7/11 words. Three of these yielded large effect sizes and indicated a trend towards the TD peers. This trend continued in phase C (intervention priority two: labial-facial control), with 6/11 words yielding large and moderate effect sizes. Pair-wise comparisons between phases A1-A2 indicate a clinically significant change in all words:

Word-set one – Increased retraction on the words mine and man that exceeded pre-intervention values was evidenced. These values accompany significantly increased JODs.

Word-set two – A trend towards the TD peers was indicated by increased rounding (as indicated by a decrease in mean values) on the words ‘shop’ and ‘push’, and increased retraction (as indicated by an increase in mean values) on the word ‘beep’. This indicates an increased contrast between rounded and retracted movements was evident subsequent to the PROMPT intervention.

Word-set three – Whilst statistically non-significant, an increase in mean LRR values indicates increased retraction on this word-set, and a trend away from the TD peers.

Inter-lip distance during Bilabial Contact (BLC).

The results obtained using Friedman’s ANOVA indicate no presence of a main effect on any word, thus indicating no statistically significant changes. However, the pair-wise comparisons indicate the presence of a statistically significant decrease between phases A-B in the words (push and beep), with a trend towards the TD peers.

The positional data indicate the change in BLC is associated with a change in the interaction between the UL and LL, across the study phases. Plots of the average vertical positions of the UL and LL markers at the point of bilabial contact, for each of the four words, are shown in Figure 5.5. The LL is plotted on the X-axis and the UL is plotted on the y-axis. A negative value reflects an inferior (downward) position, whilst a positive value reflects a superior (upward) position, from rest.

Figure 5.9. Average position of the upper lip (X axis) and lower lip (Y axis), across the study phases, as measured at minimum inter-lip distance (mms) at the point of bilabial contact for P5 and the TD peers.

During phase B the LL assumed an increased superior position at the point of minimum BLC, in comparison with the pre-intervention data. Between study phases C (intervention priority: labial-facial control) and A2 (follow-up) the position of the LL at the point of minimum BLC returned to a less superior position. Small changes were observed in the positioning of the UL during BLC, across the study phases. The UL initially assumed a more superior position during minimum BLC during phase B. There was an increase in negative values between phases A1-A2 on three of four words, thus indicating at the point of minimum BLC, the UL had a more inferior position than evidenced at pre-intervention.

Jaw/Lip Opening Velocity (J/L Vel).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by the P5 and the TD peers are presented in Table 5.43. The results show the peak velocity values were significantly different on 6/11 words, with the rate of movement faster on some words and slower on others.

Table 5.43

Mann-Whitney test Results and Descriptive Data (Means and Standard Deviations) of the Pre-Intervention Jaw/Lip Opening Velocity Measures Comparing P5 with the TD Peers

			TD peers			P5
	Velocity		TD 51	TD 52	TD53	Phase A
Word	U	*p	M(SD)	M(SD)	M(SD)	M(SD)
Mine	.000	**.000**	110.01(24.19)	105.88(25.83)	61.39(7.48)	31.85(8.46)
Man	6	**.004**	112.24(18.63)	116.60(19.49)	65.47(26.79)	50.39(8.27)
Hat	32	.672	15.59(8.61)	32.70(14.47)	25.90(12.54)	22.01(14.32)
Up	9	**.011**	34.75(29.95)	25.92(8.34)	23.50(16.13)	58.42(16.92)
Off	23	.230	36.47(55.75)	25.14(28.34)	14.80(11.83)	31.40(20.00)
Shop	13	.059	53.60(18.63)	37.67(14.61)	29.60(9.26)	27.39(6.77)
Spot	14	**.042**	65.17(17.01)	58.40(20.95)	42.58(14.40)	33.05(17.34)
Six	31	.612	11.27(7.57)	32.26(12.34)	15.19(11.50)	22.40(11.87)
Beep	34	.800	40.08(22.32)	39.41(14.25)	30.65(11.55)	37.17(8.91)
Push	1	**.000**	15.20(8.22)	9.35(0.92)	13.06(5.34)	44.86(15.82)
two	5	**.002**	2.39(2.02)	12.76(3.87)	3.79(3.32)	22.21(8.89)

Note. TD = typically developing
p = two-tailed tests, boldface = ≤ .05

Post intervention.

The results obtained using Friedman’s ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data are presented in Table 5.45.

The results show a significant main effect on three words (mine, off, beep). Whilst the pair-wise comparisons do not record statistically significant changes, moderate-to-large effect sizes are evidenced across each of the phases with phase C yielding the greatest change. The descriptive data show a progressive trend towards the TD peers on all words except ‘beep’.

Word Duration (WD).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by P5 and the TD peers are presented in Table 5.44. The results show significantly shorter duration on 7/11 words.

Table 5.44

Mann-Whitney test Results and Descriptive Data (Means and Standard Deviations) of the Pre-Intervention Word Duration Measures Comparing P5 with the TD Peers

				TD peers		P5
	Duration		TD 11	TD12	TD13	Phase A
Word	U	*p	M(SD)	M(SD)	M(SD)	M(SD)
mine	23.5	.237	0.62(0.12)	0.60(0.11)	0.50(0.07)	0.51(0.08)
man	35.5	.884	0.66(0.08)	0.55(0.09)	0.52(0.08)	0.60(0.14)
hat	2	**.001**	0.62(0.06)	0.84(0.08)	0.64(0.09)	0.45(0.09)
up	7	**.005**	0.46(0.08)	0.67(0.05)	0.48(0.08)	0.36(0.09)
off	4.5	**.002**	0.49(0.10)	0.68(0.07)	0.51(0.09)	0.37(0.05)
shop	25	.295	0.60(0.12)	0.81(0.15)	0.41(0.37)	0.54(0.16)
spot	.000	**.000**	0.85(0.06)	1.06(0.21)	0.92(0.09)	0.46(0.04)
six	1	**.000**	0.77(0.11)	0.96(0.05)	0.74(0.08)	0.56(0.07)
push	1.5	**.000**	0.60(0.08)	0.69(0.12)	0.58(0.07)	0.40(0.07)
beep	.500	**.000**	0.63(0.09)	0.85(0.08)	0.54(0.07)	0.44(0.03)
two	32	.688	0.43(0.05)	0.54(0.04)	0.52(0.12)	0.56(0.17)

Note. TD = typically developing
p = two-tailed tests, boldface = ≤ .05

Post intervention.

The results obtained on Friedman’s ANOVA (main effect), Wilcoxon signed-rank tests (pair-wise comparisons) and effect size data, are presented in Table 5.45.

The data show a main effect on three words (mine, spot, six). Whilst the pair-wise comparisons do not show statistically significant changes, moderate-to-large effect sizes are evident across each of the phases, with phase C yielding the greatest change. The descriptive data show a progressive trend towards the TD peers on all words.

Table 5.45

Friedman's ANOVA and Wilcoxon Signed-Rank Data for Velocity and Word Duration Measures for Each Word across the Study Phases for P5

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
								Jaw/Lip Opening Velocity (J/L Vel)									
Mine	12.12	.001*	-2.023	.063	**0.64**	-2.02	0.06	**0.64**	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-0.13	1.00	0.04
Man	3.90	.324	-.405	.813	0.13	-0.73	0.63	0.24	-0.37	0.88	0.12	-2.02	0.06	**0.64**	-1.46	0.25	0.46
Hat	3.48	.372	-.135	1.000	0.04	-0.40	0.81	0.13	-0.13	1.00	0.04	-0.94	0.44	0.30	-1.75	0.13	**0.55**
Up	3.48	.372	-.944	.438	0.30	-1.75	0.13	**0.55**	-0.67	0.63	0.21	-0.67	0.63	0.21	-0.67	0.63	0.21
Off	1.32	.771	-.135	1.000	0.04	-0.13	1.00	0.04	-1.48	0.19	0.47	-0.40	0.81	0.13	-0.40	0.81	0.13
Shop	9.30	.012*	-2.023	.063	**0.64**	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-1.83	0.13	**0.61**	-1.83	0.13	**0.61**
Spot	9.24	.017*	-1.214	.313	0.38	-1.48	0.19	0.47	-1.48	0.19	0.47	-2.02	0.06	**0.64**	-1.21	0.31	0.38
Six	1.56	.709	-.135	.125	0.04	-0.41	0.06	0.13	-0.67	0.88	0.21	-0.67	0.06	0.21	-0.67	0.88	0.21
Beep	13.56	.004*	-.135	1.000	0.04	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Push	4.50	.242	-.674	.625	0.21	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-1.46	0.25	0.49	-0.37	0.88	0.12
Two	4.20	.260	-1.214	.313	0.38	-1.48	0.19	0.47	-1.48	0.19	0.47	-0.13	1.00	0.04	-1.75	0.13	**0.55**
								Word Duration (W/D)									
Mine	8.27	.03*	-2.023	.063	**0.64**	-1.84	0.13	**0.58**	-0.13	1.00	**0.04**	-1.21	0.31	0.38	-1.63	0.19	**0.51**
Man	5.10	.190	-.944	.438	0.30	0.00	1.00	0.00	-0.73	0.63	**0.24**	-0.27	0.88	**0.09**	-1.84	0.13	**0.58**
Hat	4.84	.188	-1.289	.375	0.04	-1.51	0.25	0.13	-0.94	0.44	0.04	-1.21	0.31	0.30	-1.76	0.13	**0.55**
Up	1.89	.641	-1.625	.188	**0.51**	-1.10	0.38	0.35	-0.13	1.00	0.04	-0.68	0.63	0.21	-0.14	1.00	0.04
Off	5.19	.160	-.813	.500	0.26	-2.12	0.06	**0.67**	0.00	1.00	0.00	-2.02	0.06	**0.64**	-0.73	0.63	0.23
Shop	3.00	.457	-.730	.625	0.23	-0.14	1.00	0.04	-1.22	0.31	**0.39**	-1.07	0.50	**0.36**	-1.46	0.25	0.49
Spot	8.56	.024*	-.921	.500	0.29	-0.95	0.44	0.30	-0.37	0.88	**0.12**	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**
Six	7.41	.05*	-1.753	.125	**0.55**	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-0.81	0.50	0.26
Beep	6.06	.110	-.813	.500	0.26	-1.35	0.25	0.43	-1.75	0.13	**0.55**	-1.47	0.25	0.47	-0.94	0.44	0.30
Push	3.87	.300	-1.761	.125	**0.56**	0.00	1.00	0.00	-0.68	0.63	**0.21**	-1.46	0.25	0.49	-1.60	0.25	**0.53**
Two	4.31	.243	-.552	.750	0.17	-0.40	0.81	0.13	-0.13	1.00	0.04	-1.21	0.31	0.38	-1.75	0.13	**0.55**

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one: labial-facial control), C = phase C (intervention priority two: lingual control), A2 = phase A2 (follow-up).

*= $p \leq .05$, two-tailed, boldface = large effect size.

Overall summary of P5’s kinematic measures.

Subsequent to PROMPT intervention, the following changes were evident:

Phase B – Increases to the mean values of duration, velocity and JPD. Whilst an initial decrease in the mean JOD values was evidenced, distance between the four jaw-height-positions increased, thus indicating an improvement in jaw grading. Lateral deviation of the jaw from midline and LRR values decreased.

Phase C – Decreased lateral deviation from midline and an increase in JOD consistent with a trend toward the TD peer.

Phase A2 – Improvement continued on the measures of JOD and JPD within word-set one (Mandibular), LRR within word-set two (labial-facial), JLDM (6/11 words), duration (9/11 words) and velocity.

The above results indicate P5’s intervention program was successful in producing changes to the motor-speech movement patterns under investigation.

The above results indicate P5’s intervention program was successful in producing changes to the motor-speech movement patterns under investigation.

Participant 6

The following motor-speech movement patterns were targeted during the phases of the PROMPT Intervention:

Phase B: (Intervention priority one: mandibular control) – Increase the range of movement at jaw height positions 3 and 4 (word-set one), increase the distance between the four jaw height positions and decrease excessive labial-facial retraction.

Phase C: (Intervention priority two: labial-facial control) – Active engagement of the UL and LL, separate from the jaw to achieve bilabial lip contact. Pre-intervention observations suggested excessive jaw action was used to achieve bilabial lip contact. Specifically, the LL moved excessively superior, whilst the UL moved inferiorly and pushed over the LL to achieve bilabial contact.

Table 5.46 summarises the words that evidenced significant impairment of the jaw and lip measures for P6 as compared with the typically developing (TD) peers pre-intervention; and significant changes post-intervention for these words. Results are based on five repetitions of each word, with the exception of TD 53.

Analysis for the word ‘shop’ for this participant is based on 3 repetitions due to incorrect pronunciation that differed from the TD peers.

The distance measures (Appendix N) at pre-intervention show a predominant pattern of decreased jaw open distance (JOD) and increased lip rounding/retraction (LRR) values, in comparison to the TD peers. The results also show a lower peak velocity and longer mean duration. The post-intervention data show a positive treatment effect with changes to the kinematic measures of distance, duration and velocity reflective of the intervention priorities.

Table 5.46

Words that Recorded Significantly Different Pre (Mann-Whitney Test) and Post-Intervention (Friedman’s ANOVA) Values on the Kinematic Measures of Distance, Velocity and Duration

	*Mandibular Control						†Labial-Facial Control							
Word Stimuli	JPD		JOD		JLDM		LRR		BLC		J/L VEL		WD	
MSH	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Wordset 1														
Mine		✓				✓	X	✓					X	✓
Man	X	✓	X				X	✓			X	✓	X	✓
Hat		✓					X	✓	-	-				
Up		✓		✓			X		-	-		✓		
Off			X				X	✓	-	-		✓	X	✓
Wordset 2														
Shop		✓					X	✓	-	-		✓	X	✓
Beep	X	✓	X	✓			X	✓	X				X	✓
Push							X	✓			X	✓	X	✓
Two							X		-	-	X		X	✓
Wordset 3														
Six	X	✓					X	✓	-	-	X			
Spot	X			✓					-	-		✓	X	
Total	4	7	3	3	0	1	10	8	1		4	6	8	8

Note. * = p value ≤ .05, two-tailed, †= p value ≤ .05,one-tailed, Pre = pre-intervention comparison with peers, Post = post intervention comparison (phases B, C and A2), X = movement pattern significantly different to TD peers, ✓ = significant change recorded, MSH = motor speech hierarchy plane of movement, JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline, LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact, J/L VEL = jaw/lip opening velocity, WD =word duration.

Distance measures.

Mandibular measures.

Pre-intervention.

Analyses of the kinematic data provided in Table 5.47 indicate impaired mandibular control at pre-intervention. Specifically:

JPD – mean values were increased relative to the TD peers. Word-sets two and three recorded the largest mean values, with a statistically significant difference on 5/11 words.

JOD – Mean values were reduced relative to the TD peers on word-set one, and increased on word-sets two and three. A statistically significant difference was recorded on 3/11 words (man, beep, six).

JLDM – All mean values (and SDs) were comparable to the TD peers.

Table 5.47

Mann-Whitney Test Results of the Pre-Intervention Mandibular Distance Measures Comparing P6 with the TD Peers

		JPD		JOD		JLDM	
JHP	Word	U	**p*	U	**p*	U	**p*
4	Mine	19	.119	24	.266	35	.866
4	Man	7	**.005**	10	**.015**	28	.445
4	Hat	23	.230	36	.933	37	1
3	Up	24	.266	26	.349	25	.306
2	Off	19	.119	9	**.011**	30	.553
2	Shop	28	.703	31	.924	28	.703
2	Spot	.000	**.000**	25	.306	19	.119
1.5	Six	3	**.001**	18	.098	34	.800
1	Beep	11	**.019**	5	**.002**	31	.612
1	Push	15	.053	15	.053	16	.066
1	Two	.000	**.000**	15	.053	19	.059

Note. JPD = jaw path distance, JOD = jaw open distance, JLDM = jaw lateral distance from midline. * = two- tailed test, boldface = $p \leq .05$.

Post intervention.

The results for the three distance measures, obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect sizes are presented in Table 5.45. Means and SDs are provided in Figures L.1, L.2 and L.3.

Table 5.48

Friedman’s ANOVA and Wilcoxon- Signed-Rank-Test Data for Each Mandibular Distance Measure for Each Word across the Study Phases for P6

	Friedman’s Test (df 3)		Wilcoxon Signed-Ranks Test															
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	*Z*	*p*	ES	*Z*	*p*	ES	*Z*	*p*	ES	*Z*	*p*	ES	*Z*	*p*	ES
									Jaw Path Distance (JPD)								
Mine	7.8	.044*	-.135	1.000	0.04	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-1.753	.125	**0.55**	-.674	.625	0.21
Man	12.12	.009*	-1.214	.313	0.38	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.67**	-1.214	.313	0.40
Hat	9.24	.017*	-1.214	.313	0.38	-.135	1.000	0.04	-.944	.438	0.30	-2.023	.063	**0.64**	-2.023	.063	**0.64**
Up	12.84	0*	-1.214	.313	0.38	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.64**
Off	7.32	.055	-1.483	.188	0.47	-.944	.438	0.30	-.405	.813	0.13	-2.023	.063	**0.64**	-1.483	.188	0.47
Shop	6.12	.107	-.405	.813	0.13	-.135	1.000	0.04	-.944	.438	0.30	-1.483	.188	0.47	-1.753	.125	**0.55**
Spot	5.4	.151	-2.023	.063	**0.64**	-.405	.813	0.13	-1.483	.188	0.47	-.674	.625	0.21	-.944	.438	0.30
Six	9	.02*	-.135	1.000	0.04	-.405	.813	0.13	-.674	.625	0.21	-2.023	.063	**0.64**	-2.023	.063	**0.64**
Beep	10.68	.005*	-.674	.625	0.21	-1.483	.188	0.47	-1.483	.188	0.47	-2.023	.063	**0.64**	-2.023	.063	**0.64**
Push	7.8	.044	-1.214	.313	0.38	-1.214	.313	0.38	-.405	.813	0.13	-2.023	.063	**0.64**	-1.753	.125	**0.55**
Two	6.84	.075	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-.135	1.000	0.04	-.674	.625	0.21	-.135	1.000	0.04
									Jaw Open Distance (JOD)								
Mine	5.16	.162	-1.483	.188	0.47	-.674	.625	0.21	-2.023	.063	**0.64**	-.944	.438	0.31	-.674	.625	0.22
Man	6.36	.093	-1.753	.125	**0.55**	-.944	.438	0.30	-2.023	.063	**0.64**	-1.214	.313	0.40	-1.753	.125	**0.58**
Hat	5.4	.151	-1.214	.313	0.38	-1.483	.188	0.47	-1.483	.188	0.47	-.405	.813	0.13	-2.023	.063	**0.64**
Up	12.6	.001*	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.67**	-.674	.625	0.22
Off	7.08	.067	-.944	.438	0.30	-1.753	.125	**0.55**	-1.753	.125	**0.55**	-2.023	.063	**0.64**	-1.214	.313	0.38
Shop	4.92	.210	-.944	.438	0.30	-1.214	.313	0.38	-1.753	.125	**0.55**	-1.753	.125	**0.55**	-.944	.438	0.30
Spot	9.72	.012*	-.944	.438	0.30	-.135	1.000	0.04	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-.674	.625	0.21
Six	2.52	.521	-.674	.625	0.24	-.944	.438	0.30	-.674	.625	0.24	-.674	.625	0.21	-.405	.813	0.13
Beep	13.56	.001*	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-.135	1.000	0.04
Push	4.2	.260	-1.753	.125	**0.55**	-.135	1.000	0.04	-1.214	.313	0.38	-.135	1.000	0.04	-.674	.625	0.21
Two	3.48	.372	-.674	.625	0.21	-1.214	.313	0.38	-1.214	.313	0.38	-1.214	.313	0.38	-1.214	.313	0.38

								Jaw Lateral Distance from Midline (JLDM)								
Mine	12.11	.001*	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-1.483	.188	0.49	-.674	.625	0.22
Man	1.32	.771	-.405	.813	0.13	-.135	1.000	0.04	-.674	.625	0.21	-.674	.625	0.22	-.405	.813	0.13
Hat	1.32	.771	-.405	.813	0.13	-.405	.813	0.13	-.135	1.000	0.04	-1.214	.313	0.38	-1.483	.188	0.47
Up	5.16	.162	-1.483	.188	0.47	-.944	.438	0.30	-1.753	.125	**0.55**	-.674	.625	0.22	-.674	.625	0.22
Off	2.52	.521	-.944	.438	0.30	-.944	.438	0.30	-.135	1.000	0.04	-1.753	.125	**0.55**	-.405	.813	0.13
Shop	3.24	.408	-1.483	.188	0.47	-.135	1.000	0.04	-1.483	.188	0.47	-.674	.625	0.21	-1.214	.313	0.38
Spot	2.28	.561	-.944	.438	0.30	-.674	.625	0.21	-.405	.813	0.13	-1.214	.313	0.38	-.674	.625	0.21
Six	1.56	.709	-.135	1.000	0.05	-1.483	.188	0.47	-.944	.438	0.33	-.405	.813	0.13	-.944	.438	0.30
Beep	0.6	.944	-.674	.625	0.21	-.944	.438	0.30	-.405	.813	0.13	-.135	1.000	0.04	-1.214	.313	0.38
Push	7.32	.055	-2.023	.063	**0.64**	-2.023	.063	**0.64**	-1.483	.188	0.47	-.944	.438	0.30	-1.214	.313	0.38
Two	2.52	.521	-.944	.438	0.30	-.135	1.000	0.04	-.135	1.000	0.04	-1.214	.313	0.38	-1.214	.313	0.38

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).
*=$p \leq .05$, two-tailed test, boldface= large effect size

Jaw Path Distance (JPD).

The results obtained using Friedman's ANOVA indicates a statistically significant positive main effect subsequent to intervention on 7/11 words.

The pairwise comparisons indicate an initial treatment effect occurred between phases A-B, with 4/7 (man, hat, up, push) and 3/7 (spot, two, off) words recording a moderate to large effect size, respectively. The trend direction was varied, with 75% of word-set one and two indicating a trend towards the TD peers, whilst the values on word-set three increased and indicated a trend away. Phase C was characterized by a decrease in mean values on all words and a reduction in variability (as indicated by a decrease in SDs). Phase A2 yielded the largest difference and indicated maintenance of the treatment effects, with 8/11 words yielding a large effect size between phases A-D.

Jaw Open Distance (JOD).

The results obtained using Friedman's ANOVA indicate the presence of a main effect on three words (up, beep, spot) – one word from each word-set.

Despite the lack of statistical significance, the pair-wise comparisons and effect size indicate the presence of a treatment effect. Between phases A-B (intervention priority one: mandibular control) all word-sets recorded a change in JOD values with moderate-to-large effect sizes recorded on 9/11 words. Word-set one was characterized by an increase in values whilst word-sets two and three were varied, with 50% recording decreased values. These results indicate a trend towards the TD peers. Phase C (intervention priority two: labial-facial control) results indicate the treatment effect on word-set one was not maintained. Between phases B-C all words recorded a decrease in mean values that were less than pre-intervention values.

The pairwise comparisons indicate phase A2 data yielded the most significant change. The descriptive data indicate word-sets two and three continued to record decreased values between phases C-A2, whilst a return to increasing values were recorded on 4 words of word-set one. Pairwise comparisons between phases A1-A2indicate a positive treatment effect with 9/11 words recording large effect sizes.

Additional analysis to examine the distance between each of the four jaw height positions across the study phases was undertaken using a linear mixed model of analysis. In this model, the words were nested within the phases and treated as a random effect; and the jaw positions were treated as a fixed effect. The results indicate a significant increase in the range between jaw height positions 1, 2 and 4 subsequent to intervention t(149) =9.04, *p* = <0.001. Contrasts revealed an increasing range between the jaw height positions across the study phases: phase B t(149) = 1.95, *p* = .053, phase C t(149) = -3.16, *p* =.001 and A2 t(149) = -3.34, *p* =.001.

Jaw Lateral Distance from Midline (JLDM).

The results obtained using Friedman's ANOVA indicated the presence of a main effect on only one word. Thus, all words continued to record values that were comparable with the TD peers.

Labial-facial measures.

Pre-intervention.

Analyses of the kinematic data provided in Table 5.49 indicate impaired labial-facial control at pre-intervention. Specifically:

LRR –Descriptive data show the mean values were increased in comparison to the TD peers. A statistically significant difference was recorded on 10/11 words.

BLC – A statistically significant difference in inter-lip distance was recorded on one word only.

Table 5.49

Mann-Whitney Test Results of the Pre-Intervention Labial-Facial Distance Measures Comparing P6 with the TD Peers

	LRR			BLC	
Word	U	†*p*	Word	U	†*p*
Mine	4	**.001**	Mine	37	.500
Man	0	**.000**	Man	28	.222
Hat	3	**.000**	Push	21	.084
Up	10	**.007**	Beep	30	.028
Off	8	**.004**			
Shop	5	**.002**			
Spot	32	.336			
Six	15	**.026**			
Beep	.000	**.000**			
Push	7	**.003**			
Two	15	**.026**			

Note. LRR = lip rounding/retraction, BLC = inter-lip distance during bilabial contact.
†= one-tailed test, boldface = $p \leq .05$.

Post intervention.

The results obtained using Friedman’s ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data, for the two distance measures are presented in Table 5.50. In summary, these data (supported by the descriptive data in Figures M.4 and M.5) indicate the presence of a treatment effect on labial-facial measures.

Table 5.50

Friedman's ANOVA and Wilcoxon Signed Rank Data for each Labial-Facial Distance Measure for each Word for P6

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test															
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
Lip Rounding/Retraction (LRR)																	
Mine	8.04	.034*	-1.75	0.06	**0.55**	-0.94	0.22	0.30	-2.02	0.03	**0.64**	-0.94	0.22	0.30	-0.13	0.50	0.04
Man	10.68	.005*	-0.67	0.31	0.21	-2.02	0.03	**0.64**	-1.21	0.16	0.38	-1.75	0.06	**0.55**	-1.21	0.16	0.38
Hat	7.800	.044*	-0.94	0.22	0.30	-1.48	0.09	0.47	-0.94	0.22	0.30	-0.13	0.50	0.04	-2.02	0.03	**0.64**
Up	5.4	.151	-0.40	0.41	0.13	-0.67	0.31	0.21	-0.40	0.41	0.13	-0.13	0.50	0.04	-0.13	0.50	0.04
Off	9.72	.012*	-0.40	0.41	0.13	-1.75	0.06	**0.55**	-1.48	0.09	0.47	-2.02	0.03	**0.64**	-1.48	0.09	0.47
Shop	10.68	.005*	-1.21	0.16	0.38	-1.21	0.16	0.38	-1.75	0.06	**0.55**	-0.94	0.22	0.30	-0.40	0.41	0.13
Spot	5.88	.123	-0.94	0.22	0.30	-0.94	0.22	0.30	-0.40	0.41	0.13	-0.67	0.31	0.21	-0.40	0.41	0.13
Six	9.96	.009*	-0.13	0.50	0.04	-0.40	0.41	0.13	-0.67	0.31	0.21	-0.13	0.50	0.04	-0.13	0.50	0.04
Beep	9.72	.012*	-1.75	0.06	**0.55**	-2.02	0.03	**0.64**	-0.13	0.50	0.04	-0.40	0.41	0.13	-1.75	0.06	**0.55**
Push	10.2	.007*	-0.40	0.41	0.13	-0.13	0.50	0.04	-1.21	0.16	0.38	-0.13	0.50	0.04	-0.40	0.41	0.13
Two	6.12	.107	-0.67	0.31	0.21	-0.13	0.50	0.04	-1.21	0.16	0.38	-0.13	0.50	0.04	-0.13	0.50	0.04
Bilabial Inter-lip Distance (BLC)																	
Mine	7.320	.055	-1.75	0.06	**0.55**	-0.94	0.22	0.30	-2.02	0.03	**0.64**	-0.94	0.22	0.30	-0.13	0.50	0.04
Man	6.36	.093	-0.67	0.31	0.21	-2.02	0.03	**0.64**	-1.21	0.16	0.38	-1.75	0.06	**0.55**	-1.21	0.16	0.38
Push	4.920	.210	-0.40	0.41	0.13	-0.67	0.31	0.21	-0.40	0.41	0.13	-0.13	0.50	0.04	-0.13	0.50	0.04
Beep	0.600	.944	-0.94	0.22	0.30	-1.48	0.09	0.47	-0.94	0.22	0.30	-0.13	0.50	0.04	-2.02	0.03	**0.64**
Upper Lip (UL) Position																	
Mine	0.600	.944	-0.13	0.50	0.04	-0.40	0.41	0.13	-0.67	0.31	0.21	-0.13	0.50	0.04	-0.13	0.50	0.04
Man	1.560	.709	-0.94	0.22	0.30	-0.94	0.22	0.30	-0.40	0.41	0.13	-0.67	0.31	0.21	-0.40	0.41	0.13
Push	3.480	.372	-0.67	0.31	0.21	-0.13	0.50	0.04	-1.21	0.16	0.38	-0.13	0.50	0.04	-0.13	0.50	0.04
Beep	2.520	.521	-0.67	0.31	0.21	-0.40	0.41	0.13	-0.94	0.22	0.30	-0.67	0.31	0.21	-2.02	0.03	**0.64**
Lower Lip (LL) Position																	
Mine	6.360	.093	-1.21	0.16	0.38	-1.21	0.16	0.38	-1.75	0.06	**0.55**	-0.94	0.22	0.30	-0.40	0.41	0.13
Man	6.840	.075	-0.40	0.41	0.13	-1.75	0.06	**0.55**	-1.48	0.09	0.47	-2.02	0.03	**0.64**	-1.48	0.09	0.47
Push	6.360	.095	-0.40	0.41	0.13	-0.13	0.50	0.04	-1.21	0.16	0.38	-0.13	0.50	0.04	-0.40	0.41	0.13
Beep	0.600	.944	-1.75	0.06	**0.55**	-2.02	0.03	**0.64**	-0.13	0.50	0.04	-0.40	0.41	0.13	-1.75	0.06	**0.55**

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C = phase C (intervention priority two), A2 = phase A2 (follow-up).
*= *p* ≤.05 one-tailed test, boldface = large effect size.

Lip Rounding/Retraction (LRR).

The results obtained using Friedman's ANOVA indicates a main effect on 8/11 words.

The descriptive data show phase B (intervention priority: Mandibular control) was characterised by a decrease in mean values on 9/11 words, with a trend towards the TD peers. This trend continued in phase C (intervention priority two: labial-facial control), with 6/11 words yielding moderate-to-large effect sizes. The descriptive data also indicate a decrease in variability (reduced SDs) between phases B-C. Pair-wise comparisons between phases A1-A2 indicate a clinically significant change with 10/11 words recording smaller mean values than pre-intervention.

Inter-lip distance during Bilabial Contact (BLC).

The results obtained using Friedman's ANOVA indicate no presence of a main effect on any word, thus indicating no statistically significant changes. However, the pair-wise comparisons and positional data indicate a change in the interaction between the UL and LL, across the study phases. Plots of the average vertical positions of the UL and LL markers at the point of bilabial contact, for each of the four words, are shown in Figure 5.6. The LL is plotted on the X-axis and the UL is plotted on the y-axis. A negative value reflects an inferior (downward) position, whilst a positive value reflects a superior (upward) position, from rest.

The data indicate, during phase B at the point of minimum BLC the LL assumed an increased superior position, in comparison with the pre-intervention data. Between study phases C (intervention priority: labial-facial control) and A2 (follow-up) the position of the LL at the point of minimum BLC returned to a less superior position. No real changes were observed in the positioning of the UL during BLC, across the study phases.

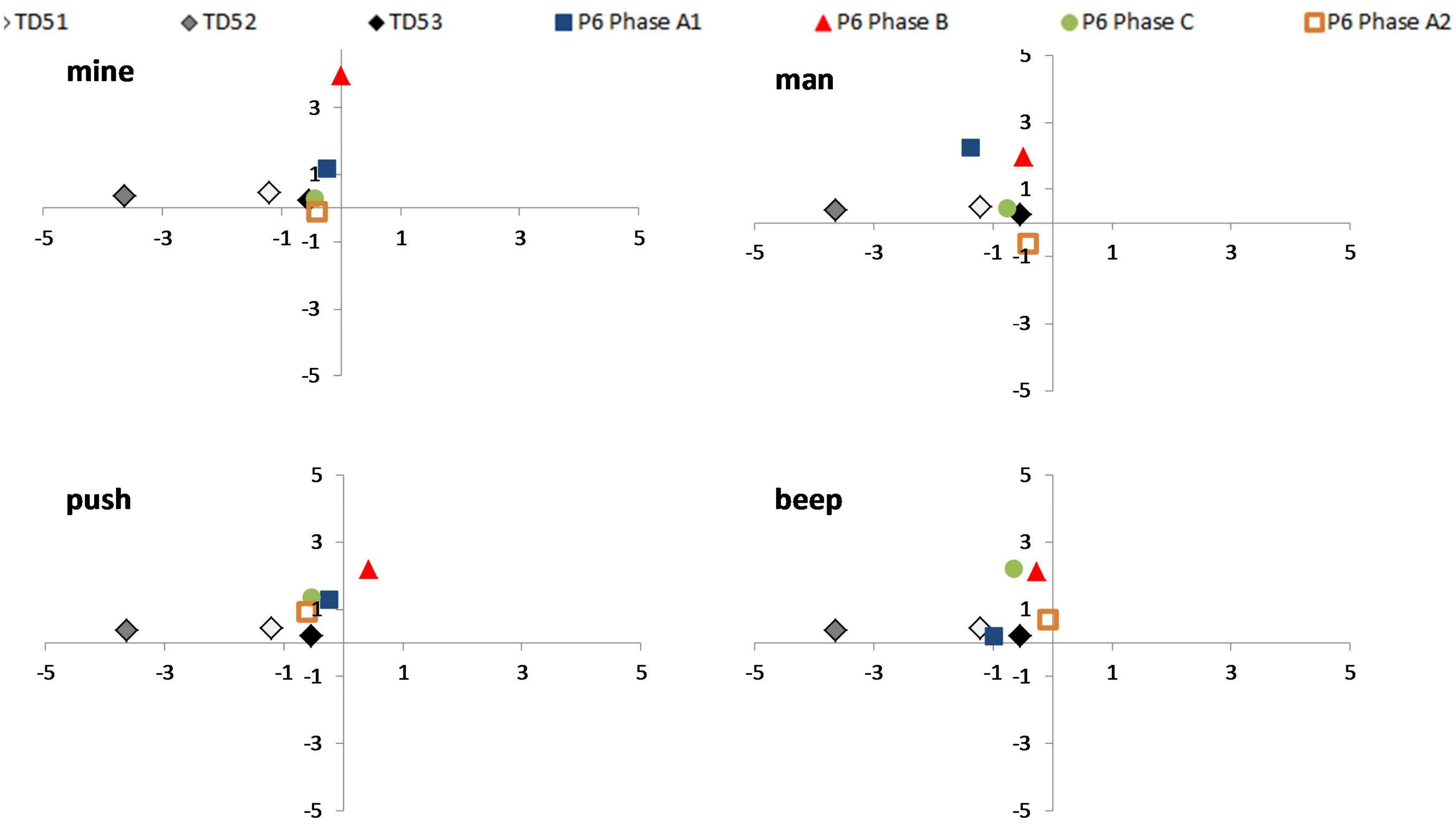


Figure 5.10. Average position of the upper lip (X axis) and lower lip (Y axis), across the study phases, as measured at minimum inter-lip distance (mms) at the point of bilabial contact for P6 and the TD peers

Jaw/Lip Opening Velocity (J/L Vel).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by the P6 and the TD peers are presented in Table 5.48. The results show the peak velocity values were significantly different on 4/11 words. Of these words, the word man (word-set one) recorded a slower peak velocity, whilst the remaining three words (word-sets two and three) recorded a faster peak velocity.

Table 5.51

Mann-Whitney test Results and Descriptive Data (means and standard deviations) of the Pre-Intervention Jaw/Lip Opening Velocity Measures Comparing P6 with the TD Peers

			TD peers			P6
	Velocity		TD 51	TD 52	TD53	Phase A
Word	U	*p	M(SD)	M(SD)	M(SD)	M(SD)
Mine	25	.306	110.01(24.19)	105.88(25.83)	61.39(7.48)	64.11(49.67)
Man	13	**.033**	112.24(18.63)	116.60(19.49)	65.47(26.79)	56.91(36.62)
Hat	24	.266	15.59(8.61)	32.70(14.47)	25.90(12.54)	35.80(21.21)
Up	35	.866	34.75(29.95)	25.92(8.34)	23.50(16.13)	25.12(14.70)
Off	23	.230	36.47(55.75)	25.14(28.34)	14.80(11.83)	33.54(17.30)
Shop	17	.143	53.60(18.63)	37.67(14.61)	29.60(9.26)	26.44(20.71)
Spot	16	.066	65.17(17.01)	58.40(20.95)	42.58(14.40)	35.29(12.41)
Six	15	**.053**	11.27(7.57)	32.26(12.34)	15.19(11.50)	37.93(18.36)
Beep	24	.266	40.08(22.32)	39.41(14.25)	30.65(11.55)	46.83(22.19)
Push	13	**.033**	15.20(8.22)	9.35(0.92)	13.06(5.34)	25.77(14.08)
Two	9	**.011**	2.39(2.02)	12.76(3.87)	3.79(3.32)	35.32(24.24)

Note. TD = typically developing,
* = two-tailed test, boldface = $p \leq .05$

Post intervention.

The results obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data are presented in Table 5.53. The results indicate a significant main treatment effect on all words. Whilst the pair-wise comparisons do not record statistically significant changes, moderate-to-large effect sizes are evidenced across each of the phases, with phase C yielding the greatest change. The descriptive data show a progressive trend towards the TD peers on all words except one (beep).

Word Duration (WD).

Pre-intervention.

The Mann-Whitney test results and data (M, SD) for each word spoken by P6 and the TD peers are presented in Table 5.49. The data show a significantly longer duration on 8/11 words.

Table 5.52

Mann-Whitney test Results and Descriptive Data (Means and Standard Deviations) of the Pre-Intervention Word Duration Measures Comparing P6 with the TD Peers

			TD peers			P6
	Duration		TD 51	TD52	TD53	Phase A
Word	U	*p	M(SD)	M(SD)	M(SD)	M(SD)
Mine	2	**.000**	0.62(0.12)	0.60(0.11)	0.50(0.07)	1.00(0.18)
Man	.000	**.000**	0.66(0.08)	0.55(0.09)	0.52(0.08)	0.94(0.11)
Hat	27	.382	0.62(0.06)	0.84(0.08)	0.64(0.09)	0.74(0.06)
Up	18	.094	0.46(0.08)	0.67(0.05)	0.48(0.08)	0.66(0.14)
Off	10	**.013**	0.49(0.10)	0.68(0.07)	0.51(0.09)	0.90(0.31)
Shop	6.5	**.004**	0.60(0.12)	0.81(0.15)	0.41(0.37)	0.98(0.20)
Spot	.000	**.000**	0.85(0.06)	1.06(0.21)	0.92(0.09)	0.62(0.04)
Six	29.5	.509	0.77(0.11)	0.96(0.05)	0.74(0.08)	0.88(0.11)
Push	9.5	**.011**	0.60(0.08)	0.69(0.12)	0.58(0.07)	0.83(0.19)
Beep	12	**.024**	0.63(0.09)	0.85(0.08)	0.54(0.07)	0.86(0.04)
Two	.000	**.000**	0.43(0.05)	0.54(0.04)	0.52(0.12)	0.97(0.14)

Note. TD = typically developing,
* = two-tailed test, boldface = $p \leq .05$

Post intervention.

The results obtained using Friedman's ANOVA (main effect), Wilcoxon signed-rank test (pair-wise comparisons) and effect size data, are presented in Table 5.53. The results show a main effect on all words.

Whilst pair-wise comparisons do not record statistically significant changes, moderate-to-large effect sizes are evidenced across each of the phases. Phase B (intervention priority: mandibular control) yielding the greatest change, with a decrease in duration with a trend towards the TD peers on 9/11 words. The duration continued to decrease on word-set one in phase C (intervention priority: labial-facial control). Word-set two, however, recorded a return to increasing duration although the values remained shorter than pre-intervention values. Evidence of maintenance of a positive treatment effect was indicated with 5/11 words recording a moderate-to-large effect size between phases A1-A2.

Table 5.53

Friedman's ANOVA and Wilcoxon Signed-Rank Data for Velocity and Word Duration Measures for Each Word for P6

	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test														
			A1-B			A1-C			B-C			A1-A2			C-A2		
	χ2	*p*	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES	Z	*p*	ES
								Jaw/Lip Opening Velocity (J/L Vel)									
Mine	5.880	.123	-1.75	0.13	**0.55**	-0.94	0.44	0.30	-1.75	0.13	**0.55**	-0.40	0.81	0.13	-0.13	1.00	0.04
Man	8.280	.031*	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.67	0.63	0.21
Hat	13.560	<.001*	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-0.67	-0.67	0.21	-2.02	-2.02	**0.64**
Up	5.400	.151	-2.02	0.06	**0.64**	-0.94	0.44	0.30	-0.94	0.44	0.30	-1.21	0.31	0.38	-0.13	1.00	0.04
Off	8.280	.031*	-2.02	0.06	**0.64**	-1.48	0.19	0.47	-0.94	0.44	0.30	-0.13	1.00	0.04	-1.75	0.13	**0.55**
Shop	10.680	.005*	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-0.94	0.44	0.30
Spot	9.240	.017*	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-0.40	0.81	0.13	-0.94	0.44	0.30
Six	9.720	.012*	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-0.40	0.81	0.13	-1.21	0.31	0.38
Beep	4.440	.226	-0.67	0.63	0.21	-1.75	0.13	**0.55**	-1.48	0.19	0.47	-1.48	0.19	0.47	-0.67	0.63	0.21
Push	9.240	.017*	-1.75	0.13	**0.55**	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.40	0.81	0.13
Two	6.840	.075	-0.40	0.81	0.13	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.67	0.63	0.21
								Word Duration (W/D)									
Mine	10.021	.008*	-2.03	0.06	**0.64**	-2.04	0.06	**0.65**	-1.76	0.13	**0.56**	-1.83	0.13	**0.58**	-1.07	0.50	0.34
Man	12.600	.001*	-1.75	0.13	**0.55**	-2.02	0.06	**0.64**	-2.03	0.06	**0.64**	-2.02	0.06	**0.64**	-0.27	0.88	0.09
Hat	5.939	.112	-0.40	0.81	0.13	-0.13	1.00	0.04	-0.27	0.88	0.09	-2.03	0.06	**0.64**	-1.75	0.13	**0.55**
Up	3.245	.385	-1.08	0.38	0.34	-1.83	0.13	**0.58**	-0.68	0.56	0.22	-1.76	0.13	**0.56**	-0.27	0.88	0.09
Off	10.469	.006*	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-1.21	0.31	0.38	-2.02	0.06	**0.64**	-0.56	0.75	0.18
Shop	9.367	.015*	-1.84	0.13	**0.58**	-1.21	0.31	0.38	-2.03	0.06	**0.64**	-2.03	0.06	**0.64**	-1.75	0.13	**0.55**
Spot	13.560	<.001*	-2.03	0.06	**0.64**	-2.03	0.06	**0.64**	-0.40	0.81	0.13	-2.03	0.06	**0.64**	-2.03	0.06	**0.64**
Six	13.560	<.001*	-2.02	0.06	**0.64**	-0.67	0.63	0.21	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-2.03	0.06	**0.64**
Beep	8.143	.035*	-1.83	0.13	**0.58**	-2.02	0.06	**0.64**	-0.27	0.88	0.09	-2.02	0.06	**0.64**	-0.27	0.88	0.09
Push	7.188	.057	-1.84	0.13	**0.58**	-2.02	0.06	**0.64**	-1.75	0.13	**0.55**	-0.67	0.63	0.21	-1.76	0.13	**0.56**
Two	12.918	<.001*	-2.02	0.06	**0.64**	-2.02	0.06	**0.64**	-2.24	0.06	**0.71**	-2.02	0.06	**0.64**	-1.84	0.13	**0.58**

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one: labial-facial control), C = phase C (intervention priority two: lingual control), A2 = phase A2 (follow-up).

*= $p \leq .05$, two-tailed, boldface = large effect size.

Overall summary of P6's kinematic measures.

Subsequent to PROMPT intervention, the following changes were evident:

Phase B – A significant increase in JOD (word-set one) and velocity; and decrease in LRR and duration. This indicates the presence of a treatment effect on the parameters targeted during intervention priority one (mandibular control).

Phase C – Changes to the mandibular control measures continued in this phase and included an increase in distance between the four jaw height positions increased, although the mean JOD values decreased. Duration continued to decrease on word-set one, however, a return to increased values was evidenced on word-set two and three. The labial-facial measure of LRR continued to record decreasing values. Thus the trend towards the TD peers that commenced in phase B continued in this phase. The positional data of the UL and LL indicated a change in interaction during bilabial lip contact. The data therefore indicate the presence of a treatment effect with the introduction of intervention priority two (labial-facial control).

Phase A2 – Continued improvement in mandibular, duration and velocity measures. A slight increase on LRR values was recorded, however all values remained lower than pre-intervention.

These data therefore suggest the presence of a positive treatment effect that was maintained 6-8 weeks post intervention.

Summary Overview All Participants

The magnitude of the treatment effect for each participant for each word on each measure of distance, velocity and duration, was compared. The treatment effect was calculated using the Wilcoxon signed-rank test and interpreted as moderate at .3 and large at .5 (Field, 2009).

The analyses of the kinematic measures across the study phases A-B show changes for all participants. Effect size data indicate the greatest magnitude of change between phases A-B was recorded on the measure of JOD on word-set one for participants P2, P3, P4, P5 and P6. Moderate-to-large effect sizes (.38-.64) were recorded on at least 65% of the words contained in this word-set for these five participants. Words contained within word-sets two and word-set three also showed treatment effects at the end of phase B, however, the percentage of words recording large effect sizes was substantially less (19% and 20%, respectively).

The word-set data also show all participants recorded changes to the kinematic measures across the study phases B-C. Effect size data indicate the greatest magnitude of change was recorded on the measure of LRR for participants P1, P2, P4, P5 and P6. Both word-sets one and two recorded moderate-to-large treatment effects whilst 75% of word-set three recorded small treatment effects.

Discussion

"…clinicians are beginning to appreciate the considerable advantages of instrumental analysis, which provide quantitative, objective data on a wide range of different speech parameters far beyond the scope of an auditory-based impressionistic judgment (Thompson-Ward & Murdoch, 1998, p. 68).

In this section the effectiveness of PROMPT in facilitating changes to the measures of distance, velocity and duration, of the jaw and lips of children with CP, was evaluated. It was hypothesised that changes in the movement patterns of the jaw and lips would be accompanied by improved speech intelligibility. The kinematic measures of the participants were also compared to a small group of TD peers. This was for the purposes of interpreting the functional movement synergies in the participants with CP compared to those exhibited by their TD peers *prior* to intervention and the trend direction of the changes *subsequent* to PROMPT intervention.

The pre-intervention findings suggested the use of motor-speech movement patterns indicative of functional impairment to jaw control. These movement patterns were associated with low levels of speech intelligibility in all participants.

All participants recorded significant changes in the jaw and lip measures that reflected those targeted across the phases of the study. These changes were associated with improved speech intelligibility for all participants.

The study results are discussed first by assessing the pre-existing motor-speech patterns then followed by discussing the changes observed subsequent to intervention. The use of PROMPT and specifically tactile-kinaesthetic input in the establishment of new motor-speech-movement patterns is subsequently evaluated.

Pre-Existing Motor-Speech Movement Patterns

All participants recorded jaw distance values that indicated reduced jaw movement space and grading (see animation ‘man’: viewable on the accompanying DVD). That is, four of the six participants (P2, P4, P5 and P6) recorded reduced jaw movements in words containing low vowels, and five participants (P1, P2, P3, P5 and P6) exhibited increased movements in words containing high vowels. Four participants also recorded measures that showed increased lateral deviation from midline, thus indicating jaw instability.

The jaw movement patterns of P3 differed markedly from the other participants. In contrast to the other participants all jaw movements were excessive across all words. Thus, there was limited difference between the mean values between words containing high and low vowels. These results are consistent with the interpretation of poor jaw grading and reduced movement space.

The use of reduced jaw movement space could be interpreted as either a compensation strategy aimed at achieving jaw stability or a function of the neurological damage associated with CP. The literature indicates increased precision in movement can be achieved through limiting the degrees of freedom of movement through voluntary increases in stiffness (displacement against resistance) (Nazari, Perrier, Chabanas, & Payan, 2011). Shiller, Laboissiére and Ostry (2002) found jaw positions that were closer to occlusion (e.g., high vowels) recorded increased stiffness whilst jaw movements associated with low vowels recorded lower levels of stiffness. Given the jaw provides postural support for the lips and tongue, the use of reduced jaw space observed in the participants in this study could be viewed as an adaptive strategy in an attempt to increase stability and precision of movement. Support for this hypothesis can be found in CP gait and upper limb literature (van Roon, Steenbergen, & Meulenbroek, 2005).

Alternatively, the reduced movement space could be considered a function of aberrant motor control, as a result of impairment in the central nervous system. Increased stiffness may be achieved through co-activation of agonist and antagonist muscles and is a feature of early motor learning (Darainy & Ostry, 2008). However, the literature reports evidence of excessive co-contraction in children with CP, as compared with TD peers (Tedroff, Knutson, & Soderberg, 2008). Neilson and O’Dwyer (1981) also propose the abnormal timing and sequence of muscle activity observed in their adult dysarthric speakers may be due to inappropriate contractions of antagonistic muscles reducing the effectiveness of agonist muscles. Thus, both interpretations for explaining the reduced movement space are plausible and suggest the need for further research.

In addition to reduced movement space, five participants demonstrated impaired interaction between the upper lip (UL) and lower lip (LL) during bilabial closure (see animation ‘shop’: viewable on the accompanying DVD). The vertical position of the UL and LL at minimum bilabial contact, as measured in the kinematic signal, was used to evaluate the interaction between the UL and LL in this study (Löfqvist & Gracco, 1997). Five participants demonstrated significantly different inter-lip distance measures on at least 2/4 words. Three participants (P3, P4 and P6) recorded excessive elevation of the LL in comparison to the age-and-gender-matched TD peers, with P3 recording values that indicated the LL exceeded the UL during bilabial closure. All participants recorded values that indicated limited engagement of the UL. The age-and-gender matched peers in this study recorded mean negative values between -1and-5mm. This value indicates that at the point of minimum bilabial contact the UL was positioned inferiorly to rest. The participants with CP however, recorded positive values that indicated an elevated UL position. Empirical research has shown that whilst considerable variability exists in individual movement patterns, the UL displacement is influenced by the position of the LL (Green et al., 2002; Löfqvist & Gracco, 1997). The results obtained here suggest either the LL forced the UL superiorly or that lack of bilabial contact resulted in an absence of compression. These results indicate the jaw was the principle articulator driving bilabial closure.

In addition to difficulty with bilabial lip contact, all participants used an excessive pattern of lip retraction across neutral, rounded and retracted phonemes in comparison to the TD peers. This may suggest difficulty grading lip movements or possible recruitment of additional muscles to maintain jaw opening and closing movements. The generation of compensatory labial movements to maintain jaw control (Folkins & Canty, 1986; Gomi, Honda, Ito, & Murano, 2002) lend support to this interpretation. The difficulties observed on two measures of lip rounding/retraction and bilabial closure suggest poor integration of lip and jaw movements.

Motor-Speech Movement Patterns Subsequent to PROMPT

The PROMPT intervention protocol was designed to acknowledge the inter-hierarchical relationship between existing and developing behaviours, and the stages of motor acquisition and consolidation. When intervention focuses on establishing a skill that is within an existing coordination synergy, both an increase in performance accuracy and stabilisation is expected. These newly established behaviours are vulnerable to competition. Consequently, when intervention focuses on developing a skill that requires re-organisation of existing co-ordination synergies, competition between the existing synergies may occur as a result of learning being biased to the "to-be-learned" behaviour. Consolidation defines the post-training phase where continued gains in performance may be observed and susceptibility to interference/competition decreases (Kelso & Zanone, 2002).

The results obtained in Phase B (intervention priority one) of this study are consistent with the expected early stages of motor learning. The data for all participants indicate a trend towards the performance patterns of their age-and-gender-matched TD peers on the targeted intervention priority. These motor-speech movement changes were accompanied by gains to speech intelligibility between 8% and 22%. In addition, the kinematic data were collected one week post-intervention, thus indicating the new functional synergy had been established and retained in the short-term.

The results obtained in phase C represent not only acquisition of a new functional synergy but also the impact of training this new behaviour on a recently acquired skill. All participants recorded a trend direction toward their age-and-gender-matched typically developing (TD) peers on the behaviour targeted during intervention priority two, accompanied by changes in speech intelligibility. Again, the testing was conducted one week-post intervention, similarly suggesting retention of the newly established behaviours. At the end of phase C, five participants recorded further gains to speech intelligibility between 4% and 14%. Whilst some participants continued to record improvement on the first intervention priority, three participants (P1, P3 and P5) recorded a trend away from the TD peers on some behaviours targeted in phase B. One participant (P5) also recorded an associated decrease in speech intelligibility of 10%. These results suggest a change in the dynamics of the newly established coordination patterns on the earlier trained intervention priorities (of phase B) as indicated by the results obtained on intervention in phase C.

A number of possible processes may be considered as explanation for the trend away from the TD peers in phase C for skills previously acquired in phase B. The work of Zanone, Kostrubiec and Temprado (2006) indicates the “empirical signature” of skill acquisition is the concurrent improvement of both accuracy and stability. An a priori decision was made to continue to the next intervention phase regardless of performance. Thus, the newly acquired motor pattern may not have been sufficiently established or stable and consequently vulnerable to interference. However, the work of Dorfberger, Adi-Japha and Karni (2007), indicated children are less susceptible than adolescents and adults, to interference. Given these findings, a second plausible explanation is that the introduction of the second intervention priority imposed adaptation or re-calibration by establishing ‘a new attractive state of the underlying coordination dynamics close to the task requirement’ (Kelso and Zanone, 2002, p. 782). This adaptation may have been essential to the process of integration for the development of more functional movement synergies. Evidence of re-calibration has been reported in the motor literature in typical development. For example, Chen, Metcalfe, Jeka and Clark (2007) report disruption in the sitting of posture of infants subsequent to accommodating the newly emerging behaviour of independent walking.

An additional explanation drawn from neurophysiological research considers the potential for a relationship to exist between the type of cerebral palsy (and severity) and potential impact on retention of motor speech learning. Recent brain imaging studies have indicated a time course of differential plastic changes in the neural system throughout the process of motor learning. Specifically, the research of Doyon and Benali (2005) indicates that whilst both the cortico-striatal and cortico-cerebellar systems play a role in motor skill acquisition, the automatic execution of motor adaptation tasks produces long term plastic changes in the cortico-cerebellar system. One of the participants (P1), who recorded a decrease in earlier acquired behaviours between phase B and C, had a diagnosis of dyskinetic CP. This type of CP is characterised by impairment to the cerebellum and basal ganglia. This therefore raises the potential value of research into understanding the role of the cortico-cerebellar system in long-term retention of newly acquired motor skills in children with CP.

The data in this study suggest the potential need to consider the integration of consolidation periods into the design of intervention programs. Post intervention data (phase A2) show all participants continued to record changes to the movement patterns of the jaw and lips. The data indicate a trend towards the age-and-gender-matched TD peers, including those measures that had moved away during phase C. Four participants also recorded follow-up measures that indicated continued improvement in speech intelligibility in the absence of intervention. These data suggest the non-intervention period that occurred at the end of phase C provided a period of consolidation that resolved the competition between the motor-speech behaviours that were targeted across the two intervention priorities. These results are supported by recent research that found prior to adolescence, continued improvement during the consolidation phase occurred (Dorfberger et al., 2007). Continued learning in the rest periods between intervention phases has also previously been reported in children with CP. Trahan & Malouin (2002) implemented a multiple-baseline-across-participants (A, Bt1r1, Bt2r2, where t = treatment, r = rest for 8 weeks) design that manipulated intensity of intervention to evaluate the effects of both therapy dosage and learning during rest periods. During the baseline phase neurodevelopmental intervention was provided twice weekly for 8 weeks. During the first intervention phase, the same intervention was offered 4 times a week for 8 weeks. Therapy sessions were 45 minutes in duration. The authors report 3 of the 5 participants recorded data that indicated continued learning during the rest period. It is however, this author’s interpretation of the data that one of these 3 participants showed data consistent with an accelerating baseline (i.e., a trend direction towards the desired behaviour change), and as a result only two of the five participants can be considered as having clearly demonstrating continued learning in the rest periods.

Delayed post testing is recommended as a tool to assess acquisition and generalisation in treatment (Maas et al., 2008). However, the value of considering time as a critical piece in the development of an intervention protocol aimed at establishing new motor speech movement patterns, for children with impaired motor speech control, is possibly indicated.

Conclusion

It is concluded that the changes observed in the kinematic measures of distance, velocity and duration, of the jaw and lips for the six participants of this study, can be attributed to the PROMPT intervention.

Prior to intervention, all participants presented with speech movement patterns that showed impaired mandibular control, with reduced movement space. All participants recorded significant changes in the jaw and lip measures that reflected those targeted across the phases of the study. In addition, at follow-up these changes were generally in the direction towards the movement patterns of a cohort of typically developing peers.

Whilst kinematic analysis was not used to establish intervention priorities, the value of using instrumental analysis to tailor intervention to the individual needs of each participant was substantiated. These findings support recommendations in the literature that clinicians interpret the phonetic inventories and phonological processes, of children with motor speech disorders associated with CP, within the context of the movement competencies of the individual articulators (Netsell, 2001).

The outcome measures reported in this and the preceding chapter have focused at the impairment level of the ICF. The following chapter reports on the effectiveness of the PROMPT intervention in translating these changes into functional and meaningful improvements as measured by changes in the Activity and Participation domains of the ICF (Eadie et al., 2006).

CHAPTER 6 QUESTION THREE

WILL CHILDREN WITH CP SHOW CHANGES IN THE ACTIVITY AND PARTICIPATION DOMAINS OF THE ICF SUBSEQUENT TO PROMPT INTERVENTION?

Introduction

One of the primary goals of intervention for children with motor-speech disorders associated with CP is to improve communicative function in order to enhance activity and participation opportunities, and ultimate quality of life (Enderby, 2000; Hodge & Wellman, 1999; Hustad, 2006; Palmer & Enderby, 2007; Workinger, 2005). To achieve this objective, clinicians need an integrated holistic framework for both establishing therapy goals and evaluating therapy outcomes.

The World Health Organisation’s (WHO) International Classification of Functioning, Disability and Health for Children and Youth (ICF- CY) is the accepted framework used by speech pathologists in the management of communication disorders. This acceptance is indicated through the adoption by the American Association of Speech Language and Hearing (ASHA, 2007) and Speech Pathology Australia (SPA, 2003) Scope of Practice.

Recognition of the ICF-CY as a framework for structuring and informing intervention services has highlighted the need for outcome measures to not only identify changes at the level of the impairment but also positive changes in activity limitations and participation restrictions (McLeod, 2006; McLeod & Bleile, 2004; Morris, 2009; Rosenbaum & Stewart, 2004; Threats & Worrall, 2004). Outcome measures need to be multidimensional with emphasis placed on evaluating the impact of intervention on *each* of the ICF domains. As stated by Morris et al. (2006), the instruments used to assess these changes needs to “adequately cover the relevant domains, have salience for the children and families, and demonstrated validity and reliability” (p. 961) of the child’s personal experiences, subsequent to intervention. Outcome measures therefore need to reflect changes to all domains of impairment, activity and participation and evaluate the enhancement of an individual’s life experiences.

The focus of this chapter of the thesis is to evaluate changes to the ICF domains of activity and participation for each of the participants, subsequent to participation in the PROMPT intervention.

Two outcome measures were selected. The first measure focused specifically on changes to speech intelligibility. This entailed the repeated administration of a formalised assessment (The Children’s Speech Intelligibility Measure,Wilcox & Morris, 1999) that utilises a closed set task format scored by an unfamiliar listener. Recent evidence suggests the use of forced-choice format reduces variability in listener judgments of speech intelligibility (McHenry, 2011). This is particularly relevant when assessing the speech of speakers with moderate to severe speech impairment. In addition, this test has been shown to have an established validity and sensitivity in detecting changes to speech intelligibility in children with CP (Pennington et al., 2009; Pennington et al., 2006).

Whilst the use of formalised speech intelligibility measurements, as a means to assess the activity domain of the ICF, has a long history, the application of assessment measures relevant to the evaluation of changes in participation is less established (Eadie et al., 2006; McLeod & Bleile, 2004).

McLeod and Bleile (2004) suggest a viable tool available for speech pathologists in the evaluation of the participation domain of the ICF is the gathering of qualitative descriptions of participation in family, school and social situations.

The Canadian Occupational Performance Measure (Law et al., 2005) is one such tool that has established robustness and validity in the field of CP (De Rezze et al., 2008). This second measure was utilised to focus more globally on evaluating changes to activity and participation within the context of a child’s daily routine.

The COPM was designed specifically as an outcome measure using a semi-structured interview and has 3 main categories that are further divided into a 13 subcategories. The three categories include daily living (self-care, mobility, communication, and other daily activities), productivity (e.g., education) and leisure (e.g., play, leisure and social participation. These three sections of the COPM reflect the 9 subdomains of the Activity and Participation domains of the ICF that include: learning and applying knowledge, general tasks and demands, communication, mobility, self-care, domestic life, interpersonal interactions and relationships, major life areas, and community, social and civic life.

The research questions addressed in this chapter are:

Will children with CP show changes in the Activity and Participation domains of the ICF subsequent to intervention? The following two specific questions were posed:

3.1 Will unfamiliar listeners identify improvements in speech intelligibility subsequent to intervention?

3.2 Will children with CP show improved participation in tasks and actions of daily life with family members and friends subsequent to the PROMPT intervention?

Method

Participants

The reader is referred to chapter 4 for a full description of the participants.

Measures

Children’s Speech Intelligibility Measure (CSIM) (Wilcox and Morris, 1999).

The Children’s Speech Intelligibility Measure (CSIM) (Wilcox & Morris, 1999) is a standardised test of speech intelligibility available for children aged 3 to 10 years. The child is required to repeat 50 words modelled by the examiner. Only the child’s responses are recorded. An independent unfamiliar adult identifies the word spoken by the child by circling the word on a multi-choice checklist. The test has 100 different versions of the stimulus list. This allowed the investigator to select randomly from a number of word lists and prevent practice effects during the study.

The test yields a raw score that is converted to a percentage correct score. The manual provides a table with 90% confidence intervals across the age groups. The presence of non-overlapping data between occasions of testing suggests a significant change in behaviour.

Wilcox and Morris (1999) report same form test-retest reliability correlation coefficients between .79 and .91; and alternate form correlation coefficients between .64 and .86. Correlations were weakest for the younger age-groups. Previous research evaluating treatment effectiveness in children with CP, has found this test to be sensitive to change in a similar time frame to this study (Pennington et al., 2006)

The Canadian Occupational Performance Measure (COPM) (Law et al., 2005).

The COPM is a client-centred outcome measure designed to evaluate an individual's perception of "occupational performance" (as described in the literature review) over the course of a therapeutic intervention. The use of the COPM as a measure for assessing change to the ICF domains of activity and participation in children with CP has previously been reported in the literature (A. Martin, Burtner, Poole, & Phillips, 2008). It is an individualised measure, designed for use with clients of all ages. The COPM utilises a semi-structured interview format that takes approximately 15-30 minutes to administer.

Law et al. (2005) identified a four step administration process – client identification of goals, rating of importance, scoring and reassessment:

Goal identification - Occupational performance is typically categorised under the areas of self-care (personal, functional mobility and community), productivity (paid/unpaid work, household management and play/school) and leisure (quiet recreation, active recreation and socialisation). These categories are not obligatory and the authors (Law et al., 2005) state the therapist should not be constrained by them. However, it is important the client is encouraged to identify priority goals/activities based on what the client needs, wants or is expected to do *within their daily activities.*

Importance – The client is asked to use a 10-point evaluation scale to rate each goal/activity, where 1 = not important at all, and 10 = extremely important. This rating scale is used to identify intervention priorities.

Scoring – Each goal/activity is scored for both satisfaction and performance using the 10-point evaluation scale. Law et al. (2005) suggest a maximum of five goals.

Reassessment – Each goal is re-evaluated for both satisfaction and performance using the same 10-point scale.

The COPM is not norm-referenced and therefore does not yield standardized scores. Two scores are obtained – a satisfaction score and a performance score. Change in performance and change in satisfaction is calculated by subtracting assessment occasion one from assessment occasion two for each item. The authors report test-retest reliability of .8.

Administration of the COPM for the purposes of this study differed in the following ways:

1. Goal identification – Group goals were identified for this study. Permission to do so was obtained from the first author (Law, personal communication, 2009).

Upon establishment of suitability for inclusion in this study, the parents of each participant were given a copy of what was termed the “parent satisfaction survey” (Appendix C). This parent satisfaction survey formed the basis of the interview. During the first interview, parents were asked to rate the importance of 13 items. These 13 items represented five subdomains of the activity and participation domains of the ICF. All parents rated all items as highly important, with no item scoring less than 8/10.

2. Occupational Performance Areas – For the purposes of this study the occupational performance areas were selected to represent the Activity and Participation domain of the ICF-CY (WHO, 2007) and coded using the three domains of the PROMPT framework - that is the physical-sensory, cognitive-linguistic and social-emotional domains. The first four items on the survey were classified within the physical-sensory domain and directly targeted during the intervention protocol. These were considered the COPM goals. Items 5 through 13 were not directly targeted in intervention and represented the cognitive-linguistic and social-emotional domains.

3. Parents as respondents – Law et al. (2005) acknowledge the role of parents as responders in the “Special applications of the COPM” section of the manual. Given the age range of the participants in this study (3 – 11 years) parents were selected as the respondents.

Cusick, Lannin and Lowe (2007) reported on the internal consistency and construct validity of an adapted COPM. In this study, the occupational performance domains were modified and parents of children with CP acted as proxies. Using the Cronbach alpha statistic, internal consistency reliability was .73 and .83 for total performance and satisfaction, respectively. These results indicate the COPM is a robust tool that was not negatively affected by the modifications.

Procedure

The reader is referred to Table 4.4 for a summary of the testing occasions of these measures throughout the study phases. The chief investigator administered the speech intelligibility measure and COPM at the end of each study phase as detailed in chapter 4.

Reliability and Fidelity

Children's Speech intelligibility Measure (CSIM) (Wilcox & Morris, 1999).

An independent untrained naïve listener scored all the participants on each testing occasion. The scoreforms were randomly presented to the scorer who was blinded to the participants, testing occasion and purpose of the study.

Twenty percent of the sample was randomly selected for re-scoring. Intra-rater agreement was 100%.

The Canadian Occupational Performance Measure (COPM) (Law et al., 2005).

In order to administer the COPM, a therapist is required to adhere to the principles of client-centredness (Law et al., 2005).

The chief investigator administered the COPM. In addition to completing the COPM training manual and video, the chief investigator has also worked within a family-centred practice model for in excess of 10 years. This has involved attending a variety of specific family-centred practice workshops.

The chief investigator also required the same parent, for each participant, complete the questionnaire on each re-assessment occasion.

Data Analysis

The Children's Speech Intelligibility Measure (CSIM) (Wilcox & Morris, 1999).

An untrained unfamiliar listener blinded to the purpose and phases of the study scored all participants performance on the Children's Speech Intelligibility Measure (CSIM) (Wilcox and Morris, 1999).

The test was scored by tallying the number of correctly identified words and calculating a percentage intelligibility score. A statistically significant change was determined by the absence of non-overlapping data in the 90% confidence intervals provided in the examiner manual.

In addition to the confidence intervals, the magnitude of the treatment effect was calculated using Cohen's d.

The Canadian Occupational Performance Measure (COPM) (Law et al., 2005).

Two scores were calculated on the performance and satisfaction items of the COPM: a "domain change" score and an "item change" score.

To calculate the domain change score the ratings of each of the items within each of the domains were summed for each participant and divided by the total number to get a mean total score.

To calculate the item change score, the rating on each of the 13 individual items for each participant was summed and divided by the total number of items to get a mean total score.

Friedman's ANOVA ($p \leq .05$) was used to test whether changes in both performance and satisfaction were recorded in each of the domains as well as the individual items subsequent to the PROMPT intervention. Bonferroni-corrected pairwise comparisons using the Wilcoxon signed-rank test ($p \leq .016$) were used to evaluate the significance of the differences across the study phases.

Results

Speech Intelligibility

Speech intelligibility was measured at a single word level using the Children's Speech Intelligibility Measure (CSIM) (Wilcox & Morris, 1999). The test was administered on four occasions: pre-baseline (pre Phase-A), end of phases B and C, and at 6-8 weeks follow-up (phase A2).

Intelligibility scores for each participant are shown in Table 4.33. The test score and confidence intervals are reported as scored by an independent, untrained naive listener.

Table 6.1

Percentage Scores [and 90% Confidence Intervals] Obtained by each of the Participants on the Children's Speech Intelligibility Measure (CSIM)

Participant	Phase A1 (baseline)	Phase B (intervention block 1)	Phase C (intervention block 2)	Phase A2 (follow-up)
P1	54	68	72	78
	[.42, .66]	[.54, .76]	[.52, .74]	*[.66, .84]
P2	54	76	88	78
	[.42, .66]	[.62, .82]	*[.74, .90]	[.50, .72]
P3	36	54	64	62
	[.28, .50]	[.42, .66]	*[.50, .72]	[.48, .70]
P4	20	28	32	36
	[.16, .34]	[.22, .44]	[.24, .46]	[.28, .50]
P5	34	56	46	74
	[.24, .46]	[.40, .64]	[.32, .56]	*[.50, .62]
P6	30	52	70	64
	[.22, .44]	[.36, .60]	*[.50, .72]	[.46, .68]

Note. * = statistically significant (*p*=<.05).

All participants recorded improved speech intelligibility, with five participants recording an increase in speech intelligibility greater than 14% at the end of the first intervention (phase B). Continued improvement was observed for 5 participants at the end of the second intervention (phase C), whilst P6 recorded a 10% decrease. Three participants (P1, P4 and P5) continued to make gains post-intervention.

Non-overlapping confidence intervals indicate 5/6 participants demonstrated a significant difference in speech intelligibility between the pre-intervention and follow-up phases. P4 was the only participant who did not record a significant increase in performance level. All participants maintained speech intelligibility scores at 6 -8 weeks post-intervention that exceeded pre-intervention scores.

Effect size data show the greatest magnitude of change occurred between phases A-B (.79), with a small incremental increase phase B-C (.3). An effect size of 1.1 was recorded post intervention (phase A1-A2).

Activity and Participation in Daily Routines

In this section the data are presented as group data. Changes to the ICF domains of activity and participation were assessed through the administration of the

Canadian Occupational Performance Measure (COPM) (Law et al., 2000). This was administered on four occasions: pre-baseline (pre Phase A), at the end of phases B and C, and at 6-8 weeks follow-up (phase A2).

The COPM was administered as an interview that consisted of 13 questions divided into three domains: physical-sensory (4 questions), cognitive-linguistic (4 questions) and social-emotional (5 questions). The first four questions represented the goals that were directly targeted during the intervention program.

Each question was scored for both performance and satisfaction using a 10-point evaluation scale. Two scores were calculated on the performance and satisfaction items: a “domain change” score and an “item change” score. To calculate the domain change score, the rating of each participant for each domain was summed and divided by the total number to get a mean total score. To calculate the item change score, the rating on each individual item for each participant was summed and divided by the total number of items to get a mean total score. Friedman’s ANOVA ($p \leq .05$) was used to test whether changes in both performance and satisfaction were recorded in each of the domains as well as the individual items subsequent to the PROMPT intervention. Bonferroni-corrected pairwise comparisons using the Wilcoxon signed-rank test ($p \leq .016$) were used to evaluate the differences across the study phases.

The data in Table 6.2 show a statistically significant change was achieved in both performance and satisfaction for items in the sensory-motor domain of the COPM, subsequent to intervention. The pairwise-comparisons indicate the change reached statistical significance at phase A2 between phases A1-A2 (follow-up), thus indicating a cumulative treatment effect.

Table H1 in Appendix H details the results obtained using Friedman’s ANOVA and Wilcoxon signed-rank tests for the individual items. The analyses show that all four items of the sensory-motor domain recorded a statistically significant change. In addition, item 12 in the social-emotional domain (ability to express emotions and feelings to family members and friends) recorded a statistically significant difference in performance subsequent to intervention. Table H2 and H3 contains the performance and satisfaction scores respectively, each individual participant.

Table 6.2

Friedman’s ANOVA and Wilcoxon Signed-Rank Test Data for the Domain Analysis of the COPM across the Study Phases

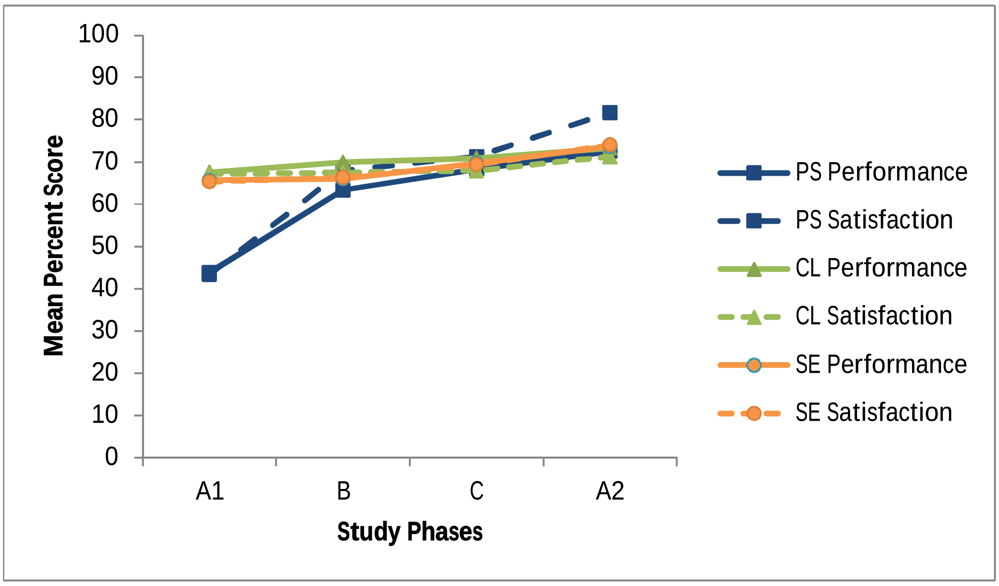
	Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons - Wilcoxon Signed-Rank Test					
			A1-B		B-C		A1-A2	
COPM: Domain Analysis	χ2	*p*	Z	*p*	Z	*p*	Z	*p*
			Performance					
Physical-Sensory	9.621	.013*	-1.753	.063	-.524	.344	-2.207	.016*
Cognitive-Linguistic	2.66	.473	-.843	.250	-.216	.438	-1.761	.063
Social-Emotional	4.38	.238	-.412	.406	-.948	.188	-1.473	.125
			Satisfaction					
Physical-Sensory	15.263	<.001*	2.201	.016	0.542	.344	2.201	.016*
Cognitive-Linguistic	1.415	.739	0.105	.500	0.271	.438	1.069	.250
Social-Emotional	5.579	.130	0.106	.500	0.841	.234	1.625	.094

Note: * = *p* value ≤ .016

Further analysis was undertaken to evaluate the differences between the domains across the study phases.

Figure *6.1* illustrates the mean percentage scores for each of the domains across the study phases, with the physical-sensory domain weaker than both the cognitive-linguistic and social-emotional domains. Friedman's ANOVA show the difference recorded between the three domains was statistically significant at pre-intervention χ^2 (2) = 9.652, *p* =.003. The Wilcoxon signed-rank tests, with Bonferroni correction (*p* = 0.0167), reveal the physical-sensory domain differed significantly from the cognitive-linguistic and sensory-emotional domains, Z=-2.201, *p* =.016, however the difference between the cognitive-linguistic and social-emotional domains was not significant.

Subsequent to intervention, the Friedman's ANOVA show the difference between the domains is no longer statistically significant: Phase B, χ^2 (2) = 5.545, *p* =.073, 2. Phase C, χ^2 (2) = 2.348, *p*=.335, and Phase A2, χ^2 (2) = 6.333, *p*=.052.



Note. PS = physical-sensory domain, CL = cognitive-linguistic domain, SE = sensory-emotional domain

Figure 6.1. Mean percentage increase in performance and satisfaction measures across the study phases for the Canadian Occupational Performance Measure.

Discussion

"Relationships between impairments and function may not be linear" (Abel et al., 2003, p. 540).

The purpose of this chapter was to investigate changes to the Activity and Participation domains of the ICF in six children with CP, across the phases of the PROMPT intervention. It was hypothesised that therapy aimed at maximising motor-speech control would result in improved speech intelligibility and increased participation in the actions and tasks of the daily routine.

This section will examine and discuss the results obtained on the two measures utilized to test this hypothesis.

Speech Intelligibility

"Intelligible speech is a complex product of language formulation, phonological organisation, and motor execution" (R.D Kent et al., 1994, p. 82).

In this section, the impact of improved motor speech movement precision on speech intelligibility is discussed. It was hypothesized that changes to the motor speech movement patterns would result in improved speech intelligibility.

The findings of this study show all participants recorded improved speech intelligibility, with five participants recording statistically significant changes, as measured on a closed-set test using an unfamiliar listener. One participant (P4) recorded improvements to speech intelligibility that did not reach statistical significance. Mean percentage increases of 15% and 23% between phases A-B and A-A2 respectively, were recorded. Effect size data indicate the greatest magnitude of change occurred between phases A-B, with a large effect size of 0.79. A small incremental increase between phases B-C was achieved, as indicated by the small effect size (0.3). Overall, post-intervention data indicates the intervention was effective in improving the speech intelligibility of the participants with a large effect size of 1.1 recorded between phases A-A2. All participants maintained speech intelligibility scores at 6-8 weeks post-intervention that exceeded pre-intervention scores.

The gains in speech intelligibility in this study are consistent with those reported in the literature using a more intensive therapy dosage than provided in this study. For example, Marchant et al. (2008) reported a 9% increase in speech intelligibility as obtained on a single-word speech intelligibility measure, in a participant with spastic quadraparesis. Therapy was attended 5x weekly for 2 weeks and phonetic placement therapy was administered. Pennington, Miller, Robson and Steen (2009) reported a mean performance increase of approximately 15% in speech intelligibility post-intervention in 16 children aged between 12 to 18 years-of-age. Therapy was attended x3 weekly for a period of 6 weeks and focused on phonation and respiration.

Given the importance of speech intelligibility for day-to-day interaction, the speech intelligibility gains of the participants in this study are encouraging. Research indicates that at least 40% of school-aged children with CP have compromised speech intelligibility (Kennes et al., 2002). Further, speech impairment in children with CP has been associated with activity limitations and participation restrictions due to reduced interpersonal interactions and relationships; and limitations in learning and applying knowledge (McConachie et al., 2006; McCormack, McLeod, Harrison, & McAllister, 2010). Given these findings, the importance of improving speech intelligibility cannot be understated.

The intelligibility measure (CSIM) used in this study was selected to reflect changes in the competency of the speaker, as measured in the auditory mode, based on a closed-set test using an unfamiliar listener in a quiet setting. The CSIM is a standardized assessment that has been reported in the literature to be sensitive to change in children with severe speech impairment associated with CP. However, it is acknowledged that speech intelligibility is a multifaceted, bi-directional process, and the role of the listener in understanding the speaker’s execution of the speech motor act is also a critical component of speech intelligibility (Keintz, Bunton, & Hoit, 2007; R.D Kent et al., 1994; Lindblom, 1990).

Though not considered in this study, there is evidence to suggest a listener’s ability to understand spoken words can be facilitated or impaired by the congruency between the auditory signal and articulatory movements of the speaker (Hustad & Cahill, 2003; Kamachi, Hill, Lander, & Vatikiotis-Bateson, 2003; Keintz et al., 2007; McGurk & MacDonald, 1976). The phenomenon of discrepancy between the auditory and the visual signal is known as the McGurk effect. For example, McGurk and MacDonald (1976) illustrated that a listener’s perception of a syllable can be modified to perceive /da/ by creating an audio-visual discrepancy through the combination of the auditory signal of /ba/ with the visual movement of /ga/.

There is evidence to suggest that the lack of congruency between the visual and auditory signals may negatively impact speech intelligibility in children with speech impairments associated with motor impairment. For example, Nelson and Hodge (2000) examined the effects of auditory and auditory-visual information on listeners’ perceptions of bilabial and lingual-alveolar stop items, in a child with bilateral facial paralysis (BFP) and a typically developing similarly age-matched peer (TD). The child with BFP was unable to move her lips for speech production. This would therefore affect the child’s ability to achieve not only lip compression for bilabials but also rounding and retraction in the production of vowels. Two findings in the data are particularly relevant to this study. Firstly, the data show that listeners’ perceptions were significantly distorted by the ambiguous presentation of the visual signal with the auditory information. That is, the perceptual ratings in the auditory only condition were significantly more accurate than when presented in the combined auditory-visual condition. Secondly, the child with BFP had adopted a compensatory gesture to achieve perceptual accuracy. The authors report the modification entailed using lingual actions in the absence of lip movement, to achieve bilabial productions. Whilst these modifications were successful in the acoustic signal, it increased confusion in the auditory-visual signal.

The relationship between speech intelligibility and the audio-visual signal indicates the need for further research to evaluate the effectiveness of intervention approaches aimed at speech intelligibility in children with motor speech impairment using auditory, visual and auditory-visual information. The treatment approach evaluated in this thesis focuses on facilitating more “normalized” movements to achieve improved speech intelligibility. The data in the study by Nelson and Hodge (2000) provide some evidence to suggest that whilst some compensatory behaviours may be successful in improving the perceptual signal, these same behaviours may in fact contribute to degrading speech intelligibility in face-to-face interactions.

The literature has identified children with speech impairments are at risk of reduced participation in age-appropriate activities due to reduced interpersonal interactions and relationships (McCormack et al., 2010). Given children typically engage in face-to-face interaction, it is conceivable that an intervention approach specifically structured to facilitate improved motor-speech accuracy would result in improved speech intelligibility at a more functional level than intervention approaches that focus on the perceptual and acoustic outcomes only.

It is possible that had this study included a multidimensional assessment of speech intelligibility, and evaluated changes to each participant's speech intelligibility across three conditions (i.e., auditory only, auditory-visual and visual only), a more complete evaluation of the effectiveness of PROMPT in contributing to functional changes in speech intelligibility could have been undertaken. The data recorded in this study provide some support for this hypothesis. For example, one participant (P3) recorded labial-dental movement patterns for the production of bilabials. The acoustic recordings suggest accurate transcription using APA broad transcription, however, visual presentation of the same word shows incongruency.

In conclusion the improved speech intelligibility measures pre-and-post-intervention obtained in this study indicate the intervention was effective at a single word level.

Activity and Participation

Participant performance.

"Measurement across many domains may be necessary to address the lingering question of understanding change in CP" (Vargus-Adams & Martin, 2009, p. 2095).

The Canadian Occupation Performance Measure (COPM) (Law et al., 2005) was used to examine changes in activity and performance within each participant's daily routine, as measured within the physical-sensory (P-S), cognitive-linguistic (C-L) and social-emotional (S-E) domains, outside the therapy context. The COPM was scored in terms of the participant's change in performance as well as parent satisfaction with that change. The results on participant performance will precede the discussion on the results obtained for parent satisfaction.

It was hypothesized that the participants would show a positive change in each of the domains subsequent to the PROMPT Intervention. More specifically, it was hypothesized that improvements in the P-S would result in positive changes in the S-E domain. Changes in the C-L domain were recorded to determine whether improvements in the ability to follow instructions and increased attention to tasks would be evidenced subsequent to intervention (McCormack et al, 2010). This was considered a functionally relevant outcome for the participants of this study that would contribute to facilitating inclusion in the pre-school/school routine (for the younger participants particularly), but not an intervention focus.

The results indicate that the therapy aimed at improving speech production accuracy and motor control had a positive impact on improving the ability of family members and peers to understand the individual participants. The statistically significant change recorded on the P-S domain of the COPM indicates that family members and friends/peers were better able to understand the speech of the participants subsequent to the PROMPT intervention.

The data recorded on the S-E and C-L domains indicate a trend towards improvement but the change was not statistically significant. The lack of a statistically significant change in the S-E domain can be interpreted in a number of ways. Firstly, it could be suggested that whilst an improvement in speech intelligibility was achieved, this did not translate into a functional improvement in participation. That is, there was a poor translation of positive changes at the level of the impairment to the activity/participation domains of the ICF. This outcome has been reported in the literature for children with CP with physical therapy intervention approaches that have been grounded in developmental theory and paid limited attention to functional impact (Butler & Darrah, 2001).

Another interpretation is that the time frame given to observe the change was too short. The literature documents the finding that children with CP experience slower growth and development than their TD peers (Siebes et al., 2002). Given this, it may be that the timeframe of this study was too short to demonstrate any change in the C-L and S-E domains. It may be that with a longer time frame, changes in these domains would have been observed.

A further alternative interpretation considers the readiness of the participants to undergo change as explored within the construct of dynamic systems theory (systems, self-organisation, and emergence). Within the construct of DST, growth and development is driven by continuous change within the inter-dependent domains/subsystems that are both within and external to an individual. In order for a new behaviour to develop there must be a state of disequilibrium that functions to move the system to reorganise.

This re-organisation results in the emergence of new behaviours at a higher level of complexity and moves the system back to a new level of equilibrium. This process of self-organisation evolves in a hierarchical manner, building on lower levels of organisation (Fidler, Lunkenheimer, & Hahn, 2011; Howe & Lewis, 2005; Newman & Newman, 2007; Schore, 1997; Thelen & Smith, 2003). As stated by Howe and Lewis (2005) “all developmental outcomes are a result of the spontaneous emergence of higher order structures from the recursive interaction among simpler components” (p. 248). Within the construct of DST it is possible that a child with a neurological impairment such as CP could present with an extreme state of disequilibrium that results in poor integration and coordination between the subsystems/domains. Thus, in order for the system to move to a higher level of complexity a level of integration between the subsystems needs to be established.

It could be argued that the focus on building development within the P-S domains contributed to redressing that imbalance between the P-S, C-L and S-E domains. Examination of the data offers some support to this hypothesis. For example, the pre-intervention data show the mean values of the P-S domains were significantly less than the C-L and S-E domains. Post intervention block 1 (phase B) data recorded a substantial increase in the P-S values, thus resulting in a decrease in the disparity between the three domains. Post intervention block 2 (phase C) data recorded a trend towards improvement in both the C-L and S-E domains. An accelerating trend is observed in the follow-up data (phase A2) with near parity in mean performance between each of the domain.

Parent satisfaction with performance.

The data show a statistically significant change in satisfaction with the participants’ performance within the P-S domain. No significant change was recorded in the C-L or S-E domain. Despite the speech impairment, a low level of concern regarding participation and activity was expressed. These findings are consistent with the findings of McCormack et al. (2010) who reported that although parents identified speaking and conversation as an area of difficulty, only 5% of respondents on their survey identified family relationships and 11% identified informal social relationships as difficult.

Examination of the satisfaction data in the S-E domain seems to suggest the possibility of a ceiling effect that resulted in the lack of significant change being recorded across the intervention phases. Whilst all parents reported dissatisfaction at pre-intervention in the P-S domain, most parents recorded a satisfaction rating higher than 8/10 within the S-E domain. Thus, at pre-intervention, parents were satisfied with the level of activity and participation for their children. This finding is consistent with data reported by McCormack et al. (2010). In a survey completed by parents of children with speech and language impairment, 98.8% of the parents reported satisfaction with the level of recreation and leisure in which their children participated.

Conclusion

The findings of this study show all participants recorded improved speech intelligibility, with five participants recording statistically significant changes, as measured on a closed-set test using an unfamiliar listener. Further, the results indicate that the therapy had functional and meaningful outcomes. This was indicated by the improvements in the ability of family members and peers to understand the individual participants. The follow-up data also suggested a trend towards improvements in the ability to express emotions/frustrations and problem solving.

These outcomes support the implementation of intervention protocols that address all domains (body function and structure, activity and participation, and environmental factors) of the ICF. A current trend in the literature advocates therapists focus on functional outcomes as opposed to impairment (Duchan, 2001; Gibson et al., 2009; Ibragimova et al., 2007; Rosenbaum & Stewart, 2004). This call for intervention approaches to focus on function not impairment and the use of terms such as ‘contemporary’ versus ‘traditional’ assigned to the respective approaches suggests an intervention aimed at addressing impairment is no longer appropriate (Duchan, 2001; Gibson et al., 2009; Ibragimova et al., 2007; Rosenbaum & Stewart, 2004). As stated by Gibson et al. (2009) “Rehabilitation goals of improving well-being and maximizing children’s participation can potentially be met by combining both approaches”. That is, therapy aimed at targeting both the impairment as well as activity and impairment may equally be appropriate. The data in this study raise the possibility of considering a differential time line for focusing on the different aspects of the ICF dependent on critical periods (e.g., transitions with life events) that are unique for each individual.

CHAPTER 7 GENERAL DISCUSSION

Overview

The purpose of this thesis was to investigate the effectiveness of PROMPT therapy in six children with moderate-to-severe speech disorder associated with Cerebral Palsy (CP).

Three main research questions were posed:

1. Is PROMPT effective in making changes to speech production accuracy in children with CP with moderate-to-severe speech impairment? The following two specific questions were posed:

    1.1 Will speech production accuracy improve subsequent to intervention?

    1.2 Will phonetic accuracy increase?

2. Will children with moderate-to-severe speech impairments associated with CP show changes in distance, velocity and duration measures of the jaw and lips subsequent to PROMPT intervention?

3. Will children with CP show changes in the Activity and Participation domains of the ICF subsequent to intervention? The following two specific questions were posed:

    3.1 Will unfamiliar listeners identify improvements in speech intelligibility subsequent to intervention?

    3.2 Will children with CP show improved participation in tasks and actions of daily life with family members and friends subsequent to the PROMPT intervention?

The outcome measures, selected to evaluate the three main research questions were framed to reflect part 1 of the ICF framework as follows:

Structure/Function

1. Speech Production Accuracy
2. Phonetic Accuracy
3. Kinematic Measures

Activity/Participation

4. Speech Intelligibility
5. Activity and Participation within daily routines.

The results of this thesis show that all participants recorded positive changes within each of the domains of part 1 of the ICF, subsequent to participation in the PROMPT intervention. Specifically, the data from the perceptual measures show all participants recorded improvements in speech production accuracy and speech intelligibility, with five of the six participants recording statistically significant changes subsequent to PROMPT intervention.

The gains recorded on the perceptual measures were further supported by the findings of the kinematic data. The results obtained show that although participants were heterogeneous in presentation, changes to the distance, velocity and duration measures of the jaw and lips reflected the intervention priorities for the individual participants.

Further, all participants showed learning profiles that were consistent with two phases of motor learning: skill acquisition phase and consolidation. In particular, the data show all six participants were able to acquire and consolidate motor learning in a manner consistent with motor learning reported in the literature for typical development. Five of the six participants in this study showed a rapid acquisition phase on the first intervention priority that was followed by a consolidation phase. In addition, the level of skill mastery on the first intervention priority at approximately 65% was adequate for introducing a second intervention priority. Whilst one participant (P1) demonstrated a slower acquisition phase to the other participants on the first intervention priority, the consolidation pattern was similar.

Finally, the data show all participants recorded changes in their level of activity and participation, within their daily routine. The results obtained on the COPM indicate that the therapy, aimed at improving speech production accuracy and motor control had a positive impact on improving the ability of family members and peers to understand the individual participants. The statistically significant change recorded on the Physical-Sensory domain of the COPM indicates that family members and friends/peers were better able to understand the speech of the participants subsequent to the PROMPT intervention, thus indicating improved functional outcomes were achieved.

In this chapter, the results reported in this thesis are considered within the theoretical framework of the PROMPT approach. First, the alignment of this approach with the tenets of DST and framed within the ICF is discussed. This is followed by an interpretation of the role of the tactile-kinaesthetic input in facilitating change in the motor-speech movement patterns.

The chapter concludes with a discussion on the limitation and strengths of the study, clinical implications, directions for future research and conclusion.

A Systems Approach to Intervention

Within the constructs of Dynamic Systems Theory (DST), impairments in body structure and function associated with CP have the potential to prevent integration between interdependent domains/subsystems and prevent a system to emerge to a higher level behaviour (Juarrero, 1999). This may result in children with CP continuing to select the same inefficient motor solution as compared to typically developing children (Hadders-Algra, 2000). The continued and persistent use of inefficient behaviour can create rate-limiting systems that maintain deep stable attractor states resistant to change.

Based on this theory, it was hypothesised that intervention focused on strengthening the weakest subsystem, with consideration given to individual, environmental and task constraints, would result in the emergence of new higher level functional behaviours. This would occur as a result of the establishment of a new set of boundary conditions enhancing the search for stable and adaptive coordination solutions to task demands (Newell & Valvano, 1998).

As previously stated, the core principles of DST acknowledge that:

- Growth and development is driven by continuous change within the inter-dependent domains/subsystems that are both within and external to an individual. In order for a new behaviour to develop there must be a state of disequilibrium that functions to move the system to reorganise.
- Sub-system re-organisation results in the emergence of new behaviours at a higher level of complexity and moves the system back to a new level of equilibrium. This process of self-organisation evolves in a hierarchical manner, building on lower levels of organisation (Fidler et al., 2011; Howe & Lewis, 2005; Newman & Newman, 2007; Schore, 1997; Thelen & Smith, 2003).
- Individual, task and environmental constraints function as a means to (re)structure the system and guide emerging behaviours.

The PROMPT intervention approach is aligned with the tenets of DST and provides a PROMPT trained clinician with the practical tools to:

- Assess the influence of the interdependent relationships operating between the cognitive-linguistic, social-emotional, physical-sensory domains and the environment on communication; and
- Act as an agent of change to influence the selection of more efficient motor solutions by acting on three major sources of constraints (e.g., individual, task and environmental).

Intervention focuses on strengthening the weakest domain and re-structuring the domains/subsystems, with the ultimate goal of achieving integration between and within the subsystems (i.e., physical-sensory (P-S), cognitive-linguistic (C-L), social-emotional (S-E) and environmental) for functional communication. To achieve this end the clinician works to identify and manipulate the constraints/solutions to effect positive functional change.

The subsystem of articulation within the P-S domain was identified as the weakest domain for each of the participants in this thesis. When the subsystem of articulation is identified as the weakest, the PROMPT therapist works to facilitate appropriate degrees of freedom of movement and inhibit maladaptive attractor states in order to improve articulatory accuracy. For example, for P3 the PROMPT trained therapist inhibited hyper-extension of the jaw and facilitated grading of jaw movements. Phonetic targets used to achieve this articulatory goal included the bilabials /p/, /b/ and/ m/. Initially lip contact was targeted through the mechanical action of the jaw. During the second intervention priority the therapist subsequently focused on achieving bilabial closure through active engagement of the upper and lower lip. Thus the therapist worked to systematically refine motor speech control and decrease the constraints operating within that participant’s motor speech system.

The literature pertaining to the management of motor speech disorders associated with CP, has long advocated for a subsystems approach to intervention (Dworkin, 1991; Hodge & Wellman, 1999; Pennington et al., 2009). The recommendation for a hierarchical subsystems approach was proposed and detailed by Dworkin (1991). He advocated for a bottom-up approach in which respiration, phonation and articulation were proposed as the first, second and third intervention priorities, respectively. He further recommended that intervention should establish a suitable level of control at the lower level priority before targeting a higher level priority.

Support for this approach has recently been provided by Pennington (2006; 2009) in the management of phonation and respiration to support speech intelligibility in children with CP. The findings of this thesis provide further evidence to support a systems approach to intervention; and in particular the need to address the subsystems of mandibular, labial-facial and lingual within an inter-hierarchical framework when targeting impaired articulation.

The premise of DST that positive changes in one domain (i.e., physical-sensory) would translate to a higher level subsystem re-organisation, was also supported. This was demonstrated by the changes measured on the COPM. For example, at pre-intervention the P-S domain recorded performance values that were significantly poorer than the C-L and S-E domains, thus indicating poor integration between these domains. At the end of the intervention phases (B and C), all three domains recorded values that indicated the difference between the domains was not significant and therefore indicative of a new level of integration/equilibrium. However, during the follow-up phase, the P-S domain recorded values that exceeded the S-E and C-L domains, thus suggesting the system had moved to a new state of disequilibrium.

The tenets of DST state these patterns of behaviour (equilibrium and disequilibrium) are necessary for growth and development to occur; and as such suggest this is an optimal time for intervention protocols to effect change (Darrah & Bartlett, 1995). The findings reported above therefore suggest a therapy approach grounded in principles of DST has not only the potential to inform immediate intervention priorities, but also enables clinicians to identify periods of transition and change, thus providing a context for determining future priorities.

Tactile Kinaesthetic Input

"The mouth's sensory experiences are generated principally by its own actions, and its actions are responsive to sensory experiences" (Bosma (1970) as cited by Barlow, 1999 p. 144).

The results of this study demonstrate the use of tactile-kinaesthetic input, applied systematically and actively during speech, contributed to modifying the speech-movement patterns of the participants and led to increased intelligibility. These findings are consistent with other studies that have targeted increased somatosensory-input in the management of motor speech disorders. For example, Katz and McNeil (2010) report on studies that have augmented attention to somatosensory feedback through the use of instrumentation (e.g., EMA) in adults with acquired apraxia of speech. They report that effect sizes pooled for the participants across these studies exceed those of other treatment approaches that have not augmented somato-sensory feedback. Similarly, Strand et al. (2006) reported positive treatment outcomes in three of four children diagnosed with childhood apraxia of speech, subsequent to participation in an intervention approach that also augmented somatosensory feedback. These studies therefore lend support to the effectiveness of tactile information for active postural shaping during speech.

The difference between the intervention approach evaluated in this study and that of other approaches that augment somatosensory input is the development of specific types of PROMPTs that are used to target 1. joint receptors and muscle spindles for postural stabilisation and 2. cutaneous afferents to stimulate specific motor speech postures. A PROMPT trained clinician uses specific tactile-kinaesthetic input *during active speech* directed to specific orofacial regions that are richly innervated with slowly adapting, cutaneous mechanoreceptors that are responsive to external low level inputs during motor activity (Andreatta & Barlow, 2009; Feng et al., 2011; Trulsson & Johansson, 2002).

Whilst the role of cutaneous afferents in providing an abundant supply of kinaesthetic information is clearly recognised, more current research has examined the explicit role of the facial mechanoreceptors in motor speech learning. For example, Ito and Ostry (2010) conducted a series of experiments that applied a constant force load to stretch the skin at the corners of the mouth to examine the contribution of cutaneous inputs and muscle receptors in response to facial skin perturbation. They provide evidence that articulatory motion is influenced by changes in somatosensory input; and that learning of a newly acquired movement pattern generalised to another speech task. Wong, Wilson and Gribble (2011) also provide empirical data that indicates proprioception can be modulated to provide greater acuity for limb positions when the information is paired with a functionally relevant and active motor task.

Further, it is possible that the use of tactile-kinaesthetic input facilitated learning by imposing constraints that aided learning of the “perceptual/motor workspace” (Newell, 1991a; Shumway-Cook & Woollacott, 2012). The savings experiments conducted by Huang et al. (2011) offer some support toward this hypothesis. Huang et al. (2011) examined use-dependent plasticity and concluded that repetition of a task that resulted in reduced error, in the presence of perturbation, may “in itself generate reward that modulated use-dependent plasticity” (p. 795).

It is plausible to consider that the proprioceptive input, coupled to specific movements in active speech, may have provided additional somato-sensory representation that facilitated change to the motor speech output (Kelso et al., 2001). Though data pertaining to speech kinematics and muscle activation patterns in children with CP is limited, researchers have hypothesised that the differing patterns of muscle activity observed in individuals with cerebral palsy may be a result of impaired sensory-motor feedback (R.D Kent & Netsell, 1978; Milloy & Morgan-Barry, 1990; Neilson & O'Dwyer, 1981). Recent research using diffusion tensor imaging (DTI) studies support this by revealing children with CP show deficits in proprioception as a result of abnormalities in thalamocortical pathways (Hoon et al., 2009).

Other interventions that do not provide tactile-kinaesthetic input have also reported changes to the displacement of the jaw, lips and tongue. For example, the Lee Silverman Voice Treatment (LSVT®) is also a treatment technique framed within the principles of DST. Whilst the focus of this treatment approach is increased loudness, changes to movements of the jaw, lips and tongue have been inferred from acoustic measures. Further research is required to understand the contribution of the different approaches into modifying the speech motor behaviours.

Kinematic Analysis to Support Perceptual Analysis as an Outcome Measure

The results obtained through kinematic analysis further supported the findings of the perceptual outcomes measures, thus reinforcing the appropriateness of the therapy strategies implemented for each of the participants.

In the absence of kinematic data, intervention strategies aimed at improving speech intelligibility through the modification of motor-speech behaviours, have been based on inferences drawn from data obtained through acoustic measures. For example, a significant body of data show individuals with CP use a reduced vowel space area (VSA) in comparison with controls. A reduced VSA is associated with reduced speech intelligibility whilst a larger vowel working space is correlated with improved speech intelligibility. For example a restricted VSA in F1 has been associated with restricted jaw/tongue movements, whilst a narrower F1-F2 range has been associated with restricted anterior-posterior movements. Typically, the VSA is identified in the first two formants and “constructed as the Euclidian distances between the first formant (F1) and the second formant (F2) coordinates of the corner vowels in the F1-F2 plane (C. Higgins & Hodge, 2002; H. M. Liu, Tsao, & Kuhl, 2005; Tjaden, Rivera, Wilding, & Turner, 2005; Wenke et al., 2010; Yunusova et al., 2010).

Researchers have hypothesised (Wenke, Cornwell and Theodoros, 2010) that increasing displacement of the jaw and lips, and retraction of the tongue could be used to increase the VSA. Whilst all participants in this study showed reduced articulatory space, the kinematic measures of distance indicated that for some participants the movement space was reduced due to excessive jaw open distance across the jaw height positions; and poor grading. Thus, further increasing the jaw open distance could potentially exacerbate the use of a maladaptive compensatory pattern further impairing timing and coordination in the articulatory subsystems.

In summary, these findings highlight the benefit of using kinematic data to support perceptual data for the ultimate selection of intervention priorities. Further, the kinematic data also provide evidence that the tactile-kinaesthetic input facilitated change to the jaw and lip movements of the participants in this study; and highlights the value of therapists being trained to systematically observe and evaluate the potential impact of these movement patterns on speech intelligibility.

Study Limitations

Experimental Control

The SCED scale (Tate et al., 2008) and guidelines for rating the quality of SSRD proposed by Logan et al. (2008) were used to evaluate the methodological controls in this thesis.

Whilst nine of the ten scored items of the SCED scale were adequately addressed in this thesis, aspects within some of these items could be strengthened and are discussed below.

- Design (Items 3, 4, 5 and 6). Experimental controls were used to manage threats to the internal validity through the use of a multiple base-line design across participants and behaviours, repeated testing conducted in the same environment at the same time and continuous sampling of speech probes that contained a generalization and control word set, across all phases of the study. The analyses of skill acquisition and consolidation data could however, have been strengthened through the administration of a larger word-set and multiple repetitions of the same word.

In addition, the evaluation of the effectiveness of the PROMPT approach could have been further strengthened through the use of a randomized alternating treatment with concurrent multiple baseline design. The use of a randomized alternating design where the PROMPT approach was applied using tactile input in one condition only would have provided the opportunity to specifically evaluate the effectiveness of the tactile-kinaesthetic input (i.e., tactile/ no tactile input phases).

- Statistical Analysis (Item 9). Visual inspection of results was supported by the use of statistical analyses. This included the establishment of a stable baseline using statistical process control, prior to participation in the intervention phases of the study. Continuous weekly measures of trained, untrained and control goals were collected throughout all study phases.

This study could have been further strengthened with additional follow-up data points. Additional data points for the follow-up phases would have increased the robustness of the effect size data calculations. Whilst there currently appears to be no consensus regarding the method used, and one data collection point is sufficient for the calculation of an effect size using a modified Cohen's *d* calculated using the pooled standard deviation (Dunst, Hamby & Trivette, 2004), analysis of the data are considered more robust with an equal number of data points in the baseline and follow-up phases (Beeson & Robey, 2006; Logan et al., 2008).

- Replication (Item 10). This study was completed on six participants with the therapy protocols administered by four therapists.

Despite this, it is acknowledged that assessment of the effectiveness of the intervention could have been further enhanced had six therapists (as opposed to four) administered the intervention to a single participant each.

Treatment fidelity could have been further strengthened by evaluating the *quality* of adherence to the therapy protocol. For example, whilst clinicians were required to adhere to a minimum number of productions per word, this requirement was not part of the fidelity measure. Further, measures regarding the amount of tactile prompting required to elicit an accurate target could also have been gathered.

In addition, whilst the provision of home practice was integrated into the treatment protocol there was no formal monitoring of this component of the treatment protocol. This therefore limits the ability to determine how this component of the protocol contributed to observed changes.

- Generalization (Item 11). The diversity in the range of ages, level of impairment on the GMFCS and disability type/severity make it difficult to generalize the results outside the group of children who participated in this study.

The following item of the SCED scale indicated a potential threat to internal validity:

- Target behaviours (Item 2). Single word measures were used in this study due to the severity of the speech impairment in the participants. However, speech intelligibility is a multi-dimensional construct influenced by factors that include linguistic complexity. For example, Hustad (2012, in press) reports data that indicates children with CP experience decreased speech intelligibility with increasing sentence length. This study could have been strengthened through the use of an outcome measure designed to enable the systematic evaluation of changes to speech intelligibility with increasing linguistic complexity.

Despite this, the literature also identifies that whilst different contexts, listeners and tasks impact speech intelligibility differently, it is also important that the measurement used needs to be appropriately matched to the competency of the speaker (Hodge & Whitehall, 2010).

In conclusion, based on the level of evidence guidelines proposed by Logan et al. (2008), this thesis is consistent with SSRD level II non-randomised, controlled, concurrent multiple baseline across participants design. This thesis could have been strengthened using a randomized alternating treatment with concurrent multiple baseline design, a larger sample size and inclusion of a control group.

Kinematics

Limitations of the motion analysis system.

The motion analysis system used to evaluate the kinematic measures in this system does not record lingual motion. Further analysis using a system that records tongue measures in addition to lip and jaw changes, would have allowed for clearer interpretation of the data for the participants that targeted lingual control. Two participants commenced at the labial-facial level of control and moved to the lingual level of control as measured on the PROMPT motor speech hierarchy. Direct measurement of changes to the targeted intervention priority (lingual control) was not possible. Thus, the phase C data reflected changes in mandibular and labial-facial control subsequent to intervention targeting lingual control.

Limitations of the speech sample.

The inability to embed stimulus words in carrier phrases limited possible analysis of the data. For example, the literature identifies the importance of evaluating variability - not only as a measure of the process of skill acquisition but also in terms of stability of motor skills. The repetition of this study with children with less severe speech impairment would enable such an analysis.

Strengths of the Study

Experimental Control

The experimental control of this SSRD study was strengthened by the extended concurrent multiple-baseline-design across the following two key aspects:

1. A multiple-baseline-across participants design.

Portney and Watkins (2009) state a minimum of three concurrent data points are required, before intervention is applied to the first data series. In this study a minimum of five concurrent data points were collected before the first participant commenced the intervention phase. Participants 2 to 6 were subsequently staggered to the intervention phase to a maximum of 8 baseline data points for the last participant.

The data show no change occurred in the baseline periods for any of the participants until the commencement of the intervention phase. This systematic change in behaviour for each of the participants across the different baseline periods suggests the treatment effect can be attributed to the intervention.

2. A multiple-baseline-across-behaviours design.

In this study, the continuous assessment of the two intervention priorities and a control priority further strengthened the study design. The results indicate no significant change in the control behaviour was observed across the study phases. This again indicates the intervention was responsible for the change in behaviours.

Visual inspection supported by statistical analysis.

Visual inspection of the speech probe data was supported by statistical analysis to evaluate change in variability, trend, slope and level. In addition, effect size data were calculated to determine the clinical significance of the magnitude of change. The literature is increasingly requiring statistical measures accompany visual inspection (Logan et al., 2008; Olive & Smith, 2005; Portney & Watkins, 2009; Zhan & Ottenbacher, 2001). Conservative statistical measures were used in this study, and included the conservative dual-criteria (CDC) method for the split middle binomial (Fisher et al., 2003), and three consecutive data points on the 2SD band. Agreement between the visual inspection and statistics strengthens data interpretation.

Demonstrated fidelity to the intervention approach.

> *"… treatment research is not informative to the field if one does not know what treatment was tested; nor can researchers replicate undefined treatment intervention. For this reason, research projects for which a treatment manual was not written and followed are of limited utility in terms of assessment of treatment efficacy" (Chambless & Hollon, p.11).*

Four different clinicians administered the treatment approach and were frequently and randomly assessed for fidelity to the intervention by an independent PROMPT Instructor blinded to the intervention phases. This therefore strengthens the findings that the intervention was responsible for causing the change.

The field of speech-language pathology is increasingly acknowledging the need for researchers to both demonstrate and document fidelity to a therapy approach, as a critical component of evidence-based practice (Kaderavek and Justice (2010, McCauley, Willams and McLeod, 2010 others). Kaderavek and Justice (2010) state that in order to achieve treatment fidelity, intervention approaches should be manualised. Specifically they declare “the treatment manual describes the gold standard of treatment implementation against which fidelity can be assessed” (p. 372).

To achieve fidelity to PROMPT clinicians are required to undertake significant training. This requires participation in both formal training courses conducted by the PROMPT Institute, and informal mentoring. Three formal training courses are provided by the PROMPT Institute and include: Introduction to Technique (3 days), PROMPT Bridging to Intervention (3 days) and PROMPT Certification (case study project).

Upon completion of the 3-day Introduction to Technique course, a clinician is considered suitably skilled to administer the technique, but in the absence of ongoing mentoring would not meet requirements for fidelity to the approach. Participants of the Introduction to Technique course are therefore encouraged to undertake the Bridging to Intervention course.

Whilst it is possible for a clinician to meet fidelity upon completion of the PROMPT Bridging to intervention, successful completion of PROMPT Certification course (3 months in duration) signifies the PROMPT Institute has assessed and determined that the clinician has demonstrated fidelity to the intervention approach.

The results of this study confirm adherence to fidelity and supports the attribution of the treatment effects to the intervention and not maturation or chance.

Repeated and varied measures.

Measurements of target behaviours were taken repeatedly both across and between study phases. Thus, trends in data could be explored. In addition, kinematic measures were used to support the perceptual measures. This is the first study to evaluate changes in kinematic measures subsequent to intervention in children with CP.

Clinical Implications

"Further research is needed to describe this client group… Research is also needed to investigate the effectiveness of new and established interventions and their acceptability to families" (Pennington, 2009, p.2).

The findings of this study have implications for clinicians, service provider funding bodies and clinical researchers. The implications will be discussed in terms of the contribution this study makes to the current evidence base for clinicians working in the field, consideration for the potential change to therapy protocols to integrate principles of motor learning and the potential impost on therapist time to complete specialist training.

A Contribution to the Evidence-Base

The findings of this study make a contribution to the limited evidence base currently available to clinicians for evaluating and planning treatment options for the effective management of motor speech disorders associated with cerebral palsy. In 2011, Pennington, Goldbart and Marshall updated a clinical review of the literature evaluating the effectiveness of speech and language intervention for children with cerebral palsy. Their findings supported the conclusion reached in 2003, that there was insufficient data available to confirm or refute the effectiveness of speech-language rehabilitation in children with CP.

The results of this study support the PROMPT intervention approach for the participants in this study. At the start of the research, all participants presented with moderate-to-severe motor speech impairment. Two of the older participants were no longer receiving therapy focused on articulatory changes due to the intransigence of the articulatory errors. The results show that all participants made changes subsequent to an intervention protocol offered on a once-weekly basis for 10 weeks.

This study is also the first to describe the motor-speech- movement patterns in children with CP using kinematic analysis pre and post-intervention. The pre-intervention data made a further contribution to the evidence base by describing pre-intervention movement patterns of the jaw and lips, in six participants of varying age. The data showed all participants were able to make changes in their speech-movement patterns that resulted in improved speech intelligibility.

Implications for the Design of Intervention Protocols

Consolidation phases.

The findings of this study support the need for therapy protocols to be designed to accommodate different phases of motor-learning when targeting motor-speech strategies in children with CP. The application of the principles of motor learning in speech-language intervention protocols is strongly recommended (Ludlow et al., 2008; Maas et al., 2008). However, there are limited data available to support the application of these principles in children with CP. The results of this study show that participants not only exhibited the two phases of skill acquisition and consolidation consistent with the general motor control literature, but that they also continued to record improvements during the non-intervention follow-up phase. This phenomenon has been documented in the motor learning literature for adults (Huang & Shadmehr, 2007), typically developing children learning a new motor skill (Liu, Luo, Mayer-Kress and Newell, 2011), and children with CP subsequent to physiotherapy intervention (Trahan & Malouin, 2002).

Thus, further research aimed at understanding motor-speech development in between the intervention periods would potentially influence the design of intervention protocols for possibly more efficient treatment outcomes (i.e., scheduling of consolidation phases that are separate to follow-up phases).

Data collection and the determination of intervention success.

Therapists need to assess not only change in performance level but also change in stability when evaluating the processes of skill acquisition in children with CP. Contemporary empirical data indicates clinicians need to develop procedures that are designed to evaluate change in stability/variability over the course of the intervention. Typically intervention studies focused on improving speech production and intelligibility emphasise change in performance level with a criterion of between 80% and 90% accuracy required. However, the work of Zanone, Kostrubiec and Temprado (2006) indicates the “empirical signature” of skill acquisition is the concurrent improvement of both accuracy and stability. The data obtained in this study seem to suggest that for the four participants who commenced intervention (phase B) at the mandibular level of control and moved to the labial-facial level of control (phase C), a success criterion of 60% or above was adequate for the first intervention priority, provided the behavior stabilised early in the subsequent phase that addresses the second priority. This assumption is based on the data that show during phase C improvement occurred on the second intervention priority when stability was recorded in the data of the first intervention priority.

The collection of speech probe data at both the beginning and end of an intervention session, with more than one repetition per target, would allow a clinician to not only track changes in performance level but also track changes in performance stability within and between therapy sessions.

The use of tactile-kinaesthetic input.

The kinematic data obtained in this study supports the hypothesis that changes to the speech-movement patterns of the participants would occur subsequent to intervention. This is an encouraging finding for three reasons:

1. The effectiveness of reducing excessive mouth opening movement. Excessive mouth opening has been identified with lateral jaw slide (Miyamoto et al., 1999; Ortega et al., 2008) which places individuals with CP at increased risk of temperomandibular joint disorder.
2. The ability to improve perception of speech by increasing the degree of congruency between the auditory and visual stimuli. The use of tactile-kinaesthetic input to facilitate changes in the motor-speech patterns of the participants in this study raises the possibility of improving speech intelligibility in individuals with CP.
3. The results show that even the oldest participant, who had been prescribed a communication device (that she refused to use) and was no longer considered a candidate for therapy aimed at improving speech production, made positive gains subsequent to intervention. All but the younger participants in this study had been the recipients of traditional intervention approaches.

Therapist Training

The findings of this study provide some justification for the time and costs incurred by individual clinicians and organisations in providing specialist training.

The development and provision of specialist intervention training programs suggests an enhanced awareness of the need to ensure a clinician is equipped to administer an intervention with integrity and fidelity to the approach. This should ultimately result in a strengthening of the evidence available regarding treatment approaches.

PROMPT has been criticised in the literature for being an “exclusive” approach. Bowen (2009) states “…qualified, certified speech and language professionals must pay to gain additional basic and advanced training and accreditation in order to own ‘the knowledge’ in the form of special techniques (the prompts), therapy administration manuals, and material” (p. xviii).

However, to be eligible to use the title of “Certified Practicing Speech Pathologist in Australia”, speech-language pathologists must demonstrate the active pursuit of professional development. This includes, but is not limited to, attendance at workshops, conferences and seminars. A review of the “upcoming events” calendar 2012 for Speech Pathology Australia (http://clearspeechalbury.com.au/upcoming-cpd-events/) indicates fee-paying attendance at workshops that run over the course of 2-3 days is an established and accepted standard of practice within the profession. Examples of intervention approaches that require 2-3 days for training include the The Hanen Approach (Hanen, 2011), and LSVT® (LSVT®, 2011).

Service providers and clinicians need to make informed evidence-based decisions when giving consideration to the time and financial commitments required for specialist training (Reilly, 2004). Further research aimed at evaluating the longer term maintenance and gains to speech intelligibility using this approach as compared with the outcome (and training expectations) with another intervention would further provide information regarding the efficacy of this approach.

Translation of Research into the Clinic

> *“Policy makers and the academic research community must come to a clearer understanding of the distinction between inventing treatments and getting them used in practice (Woolf, 2008, p. 212).*

Many barriers have been identified for the poor translation of current scientific research and evidence-based practice into the clinical setting (Elliot, 2004; Nakaya, Shimizu, Tanaka, & Shigetaka, 2005; Zipoli & Kennnedy, 2005). However, a study by Zippoli and Kennedy (2005) found exposure to research was a highly significant positive predictor to clinicians engaging in evidence-based practice.

Despite this finding, Sullivan and Goldmann (2011) report the implementation of SSRDs in the clinical field still appears to be an under-utilised opportunity.

The implementation of this intervention study in the clinical setting therefore made a contribution towards facilitating the translation of current research principles and theory into the clinical setting in a number of ways:

1. Training. The clinicians who participated in this study were required to undertake specialised training that focused on (a) teaching contemporary constructs in motor control and principles of motor learning, (b) a specialised technique, and (c) efficient data collection principles.
2. Management support. The management and the board of TCCP during the time of this study demonstrated a commitment to engaging in evidence-based practice through the provision of additional funding to purchase equipment and extra staff hours for training and therapy time. Without this additional funding this study would not have been possible.
3. Appropriate environment. Space was made available and equipment purchased for data to be collected on site. Specifically, the collection of the kinematic data in the clinical setting was successful due to:

3.1. The familiarity of the participant with the surroundings. This had the added benefit of removing any potential anxiety/fear factor.

3.2. Decreased travel time for family. There was no loss to follow-up which may have been facilitated by the fact the parents did not need to undertake an additional journey to the University Lab (which for one participant would have exceeded 1 hour, one-way).

Future Research

There is a need for much more good clinical research based on well-established principles founded in basic research in motor control and learning (Winstein, Wing and Whitall, 2003, p.81).

Treatment Efficacy

The participants.

Further research using a larger sample size and varying level of motor speech impairment would improve generalisation of the results obtained in this study. The results of this study demonstrate the PROMPT intervention approach was effective in facilitating positive changes to speech intelligibility in six children with moderate-to-severe motor speech impairment associated with CP.

Further research to determine whether this intervention approach results in the most change over the shortest period of time as compared with another intervention approach is warranted. For example, the literature indicates the LSVT approach, that focuses on rate and loudness manipulations, has also been found to have successful impact on speech intelligibility in children with CP (Fox, 2002; Tjaden et al., 2005).

The Clinicians.

There is a need for further research to evaluate the viability of this treatment approach with respect to intervention gains and therapist training. Typically effectiveness studies focus on the evaluation of outcome measures directed at the study participants. However, the increasing trend that requires therapist’s commit to post-graduate training for the development of specialist skills [e.g., Relationship Development Intervention (Gutstein, 2009), The Hanen Approach (Hanen, 2011), LSVT® (LSVT®, 2011)] indicate the need for researchers to also evaluate therapy effectiveness not only in terms of participant gains but also participant gains in association with the cost of therapist training requirements.

In order to participate in this study, therapists were required to complete both the Introduction to Technique and Bridging to Intervention courses as well as complete a mentoring day with Deborah Hayden. The therapist’s fidelity to the PROMPT intervention approach was assessed by an independent senior PROMPT Instructor through completion of a PROMPT technique practicum on a client that was not a participant in the study. The data show that one clinician who expressed interest to participate in the study, required additional mentoring and completed a second technique practicum in order to achieve fidelity. During the study one clinician also recorded a fidelity measure slightly below the required 80%. These measures attest to the complexity of this intervention approach. Wambaugh, Duffy, McNeil, Robin and Rogers (2006) described PROMPT as “possibly the most sophisticated of the stimulation techniques for providing direct instruction for speech production …” (p. xliv).

In conclusion, a clinician who embarks upon training in the PROMPT approach needs a high level of commitment to achieve competency. In addition, access to mentoring seems to be necessary to facilitate the process of achieving fidelity. Thus, further research to evaluate therapist training and participant gain with different treatment approaches is required.

The Visual Aspect of Speech Intelligibility

Further analysis of the current data could be undertaken to evaluate the impact of the visual changes to speech motor production and speech intelligibility. The literature concerning the benefit of audiovisual versus audio only is unclear. The literature suggests the need for further research to evaluate what aspects of the visible movement characteristics contribute to speech intelligibility. In addition, research aimed at evaluating this in young children is warranted. It is expected that the audiovisual signal may detract from speech intelligibility in young children with motor impairment given the dominance of bilabials in the phonemic repertoire (Green & Nip, 2010).

Further, additional analysis of the data using acoustic analysis would provide the opportunity to explore whether changes that were not perceived perceptually had occurred acoustically.

Principles of Motor Learning

The results obtained for both the perceptual and kinematic data in this study show that the participants in this study were are able to acquire and consolidate motor learning in a manner consistent with that reported in the literature for typical development. The PROMPT intervention approach was selected because it is aligned with current thinking regarding principles of motor control and motor learning. Whilst the principles of motor learning (PML) are considered essential components of intervention approaches focused on the development of motor skills, research of these principles has been largely limited to the typically developing population.

Whilst the results of this study were encouraging, the evaluation of the PML was outside the scope of this study. Further research aimed at evaluating the significance of distributed versus massed practice and feedback schedule and type is indicated.

Therapy protocols.

Further research aimed at evaluating skill acquisition on the basis of both performance success and change in variability is indicated. Therapy protocols are currently aimed at evaluating success predominantly on the basis of performance. It is suggested that the reporting of data that demonstrate rate of change and variability/stability has the potential to offer further insights into the acquisition of motor speech skills in children with neurological impairment. Increasingly, the literature that advocates for a dynamic systems approach to the management of motor disorders associated with CP, suggests identification of transition periods may be an indicator of readiness to learn a new skill (Darrah & Bartlett, 1995). Additionally, it is also possible that establishing an intervention protocol to track changes not only in performance accuracy but also performance stability may facilitate improved skill maintenance.

Further research for comparative evidence to determine whether increased frequency and intensity would have resulted in greater gains is required. The variability in the current literature regarding therapy intensity confounds interpretation of intervention outcomes.

The Role of Tactile-Kinaesthetic Input

The importance of sensorimotor feedback for speech and the task specific role of sensorimotor adaptation in motor learning, coupled with the findings of this study, indicate the need for further research. The findings of this study show six participants responded to the tactile kinaesthetic input. Further research on a larger sample size is required. In addition, further evaluation (possible using MRI) would facilitate our understanding of how the tactile-kinaesthetic input promoted change in the motor speech systems of the participants in this study.

Conclusion

The aim of this thesis was to make a further contribution to the evidence-base pertaining to motor-speech disorders in children with cerebral palsy.

The significance of the data detailed in this thesis are summarised as follows:

1. This thesis makes a contribution to the emerging literature regarding the speech-movement patterns of children with CP.

The motor speech disorder most commonly associated with cerebral palsy is that of dysarthria. Whilst the literature identifies "changes in articulatory movements associated with dysarthria lead to aberrant speech acoustics and a perceptually recognisable disorder", empirical data describing these movement patterns is lacking.

The data from this thesis enabled a description of the jaw and lip movement patterns, based on objective measures of distance, velocity and duration, in 6 children with CP. The findings add further support to the earlier work of researchers who considered the patterns of articulatory imprecision in speakers with CP to be related to physiological complexity (Byrne, 1959; R.D Kent & Netsell, 1978; H. Kim et al., 2010; Love, 1992). The kinematic data suggest impaired control of a lower order synergy (such as the mandible/lower lip) prevents refinement and control of higher order synergies. This is consistent with the developmental motor-speech literature.

2. This is the first study to describe kinematic changes in the movement patterns of the jaw and lips before, during and after participation in a motor-speech intervention program.

Typically, therapy recommendations to modify motor-speech patterns are based on perceptual and acoustic outcome measures. The kinematic data provided here suggest a valuable source of information that has the potential to more fully inform therapy recommendations. For example:

2.1. The finding that some children may use an increased jaw open distance to achieve mandibular stability suggests the therapeutic recommendation to increase jaw open distance for improving speech intelligibility, may in fact contribute to increased timing and coordination difficulties for some children. The compensatory strategies used to achieve stability varied amongst the participants, and therapeutic recommendations aimed at modifying the motor-speech movement patterns need to be aimed at improving timing and coordination specific to the needs of each individual.

2.2. Clinicians need to be encouraged to not only make judgements about perceptual accuracy but also movement quality. For example, production of /p/ through the ballistic motion of the jaw may result in the achievement of the perceptual target for some words (e.g., “up”) but would be inadequate for more refined production requiring lip-to-lip contact independent of the jaw (e.g., “push”).

3. The data from this thesis show that therapy aimed at reintegrating and re-organising the subsystems of motor-speech control can be successful in achieving improvements to speech intelligibility, at a single word level. The outcomes obtained on the perceptual and kinematic measures of this thesis are supported by the principles of dynamic systems theory that indicate development occurs in the direction of increasing hierarchical structure, with order maintained through the presence of specific boundary conditions (Newell et al., 2001; Newman & Newman, 2007; Thelen & Smith, 2006).

4. The data from this thesis provide some insight into the learning patterns of the six participants. Whilst it has been previously reported that children with CP do not engage in off-line learning (Garvey, 2007), the participants of the PROMPT intervention not only demonstrated patterns of learning and consolidation consistent with the typically developing population but also showed off-line learning during the follow-up phase. The findings therefore support a subsystems approach to intervention within an integrated inter-hierarchical framework.

In conclusion, the data from this study provide evidence to support the effectiveness of the PROMPT intervention approach in supporting changes to the motor speech movement patterns of 6 children with CP.

References

Abel, T., & Lattal, M. (2001). Molecular mechanisms of memory acquisition, consolidation and retrieval. *Current Opinion in Neurobiology, 11,* 180-187.

Andreatta, R. D., & Barlow, S. M. (2009). Somatosensory gating is dependent on the rate of force recruitment in the human orofacial system. *Journal of Speech, Language and Hearing Research, 52*, 1566-1578.

Araújo, D., & Davids, K. (2011). What exactly is acquired during skill acquisition? *Journal of Consciousness Studies, 18*(3-4), 7-23.

America Speech-Language Hearing Association (ASHA). (2007). *Scope of practice in speech-language pathology*. Rockville.

Ashwal, S., Russman, B. S., Blasco, P. A., Miller, G., Sandler, A., Shevell, M., & Stevenson, R. (2004). Practice parameter: Diagnostic assessment of cerebral palsy. *Neurology, 62*(2), 851-863.

Atchy-Dalama, P., Peper, C. E., Zanone, P., & Beek, P. J. (2005). Movement-related sensory feedback mediates the learning of a new bimanual relative phase pattern. *Journal of Motor Behavior, 37*(3), 186-196.

Baas, B., Strand, E.A., Elmer, L. M., & Barbaresi, W. J. (2008). Treatment of severe childhood apraxia of speech in a 12-year-old male with CHARGE association. *Journal of Medical Speech-Language Pathology, 16*(4), 181-190.

Balas, M., Roitenberg, N., Giladi, N., & Karni, A. (2007). When practice does not make perfect: well-practiced handwriting interferes with the consolidation phase gains in learning a movement sequence. *Experimental Brain Research, 178,* 499-508.

Balkom, H. V., & Verhoeven, L. (2010). Literacy Learning in Users of AAC: A neurocognitive perspective. *Augmentative and Alternative Communication, 26*(3), 149-157.

Ball, M. J., Müller, M. J., Klopfenstein, M., & Rutter, B. (2009). The importance of narrow phonetic transcription for highly unintelligible speech: Some examples. *Logopedics Phoniatrics Vocology, 34*(3), 84-90.

Ballard, K., Granier, J., & Robin, D. (2000). Understanding the nature of apraxia of speech: Theory, analysis and treatment. *Aphasiology, 14*(10), 969-995.

Bar-Haim, S., Harries, N., Nammourah, I., Oraibi, S., Malhees, W., Loeppky, J., . . . Lahat, E. (2010). Effectiveness of motor learning coaching in children with cerebral palsy: a randomized controlled trial. *Clinical Rehabilitation, 24,* 1009-1020.

Barlow, S. (1999). *Handbook of clinical speech physiology.* San Diego: Singular Publishing Group.

Barnes, E., Roberts, J., Long, S. H., Martin, M. A., Berni, M. C., Mandulak, K. C., & Sideris, J. (2009). Phonological accuracy and intelligibility in connected speech of boys with fragile X syndrome or Down Syndrome. *Journal of Speech, Language and Hearing Research, 52*(4), 1048-1061.

Barnes, S. B., & Whinnery, K. W. (2002). Effects of functional mobility skills training for young students with physical disabilities. *Council for Exceptional Children, 68*(3), 313-324.

Barreiros, J., Figueiredo, T., & Godinho, M. (2007). The contextual interference in applied settings. *European Physical Education Review, 13*(2), 195-208.

Bartle-Meyer, C., Goozée, J. V., Murdoch, B. E., & Green, J. R. (2009). Kinematic analysis of articulatory coupling in acquired apraxia of speech post-stroke. *Brain Injury, 23*(2), 133-145.

Bashir, A., Grahamjones, R., & Bostwick, R. (1984). A touch-cue method for developmental verbal apraxia. *Seminars in Speech and Language, 5*(2), 127-137.

Bax, M. (1964). Terminology and classification of cerebral palsy. *Developmental Medicine and Child Neurology, 6,* 295-307.

Bax, M., Goldstein, M., Rosenbaum, P., & Paneth, N. (2005). Proposed definition and classification of cerebral palsy, April 2005. *Developmental Medicine and Child Neurology, 47*(8), 571-576.

Beeson, P. M., & Robey, R. R. (2006). Evaluating single-subject treatment research: lessons learned from aphasia literature. *Neuropsychological Review, 16*(4), 161-169.

Bleile, K. M. (Ed.). (2004). *Manual of Articulation and phonological disorders: Infancy through adulthood (2nd edition).* New York: Thomson Delmar Learning.

Booth, A. (2010). On hierarchies, malarkeys and anarchies of evidence. *Health Information & Libraries Journal, 27*(1), 84-88.

Bose, A., Square, P., Schlosser, R., & Lieshout, P. (2001). Effects of PROMPT therapy on speech motor function in a person with aphasia and apraxia of speech. *Aphasiology, 15*(8), 767-785.

Boudreau, S. A., Farina, D., & Falla, D. (2010). The role of motor learning and neuroplasticity in designing rehabilitation approaches for musculoskeletal pain disorders. *Manual Therapy, 15,* 410-414.

Brien, M., & Sveistrup, H. (2011). An intensive virtual reality program improves functional balance and mobility of adolescents with cerebral palsy. *Pediatric Physical Therapy, 23,* 258-266.

Bronnikov, V. A., & Kravtsov, Y. I. (2006). Non-specific brain systems and the rehabilitation of children with cerebral palsy. *Neuroscience and Behavioral Physiology, 36*(9), 1003-1008.

Brossard-Racine, M., Hall, N., Majnemer, A., Shevell, M. I., Law, M., & Poulin, C., & Rosenbaum, P. (2012). Behavioural problems in school age children with cerebral palsy. *European Journal of Paediatric Neurology, 16(1),* 35-41

Bukowska, M., Essick, G. K., & Trulsson, M. (2010). Functional properties of low-threshold mechanoreceptive afferents in the human labial mucosa. *Experimental Brain Research, 201*(1), 59-64.

Bult, M. K., Verschuren, O., Jongmans, M. J., Lindeman, E., & Ketelaar, M. (2011). What influences participation in leisure activities of children and youth with physical disabilities? A systematic review. *Research in Developmental Disabilities*, *32*(5), 1521-1529.

Butler, C., & Darrah, J. (2001). Effects of neurodevelopmental treatment (NDT) for cerebral palsy: an AACDM evidence report. *Developmental Medicine and Child Neurology, 43*(11), 778-790.

Byrne, M. (1959). Speech and language development of athetoid and spastic children. *Journal of Speech and Hearing Disorders, 24,* 231-240.

Cahill, L., Murdoch, B., & Theodorus, D. (2005). Articulatory functioning following traumatic brain injury. *Brain Injury, 19*(1), 41-58.

Caldognetto, E. M., Cosi, P., Drioli, C., Tisato, G., & Cavicchio, F. (2004). Modifications of phonetic labial targets in emotive speech: effects of the co-production of speech and emotions. *Speech Communication, 44,* 173-185.

Campbell, J. M., & Herzinger, C. V. (2010). Statistics and single subject research methodology. In D. L. Gast (Ed.), *Single subject research methodology in behavioral sciences.* New York Routledge.

Caruso, A., & Strand, E.A. (Eds.). (1999). *Motor speech disorders in children: Definitions, background and a theoretical framework.* New York: Thieme Medical Publishers Inc.

Castro, J., Medina-Carnicer, R., & Galisteo, A. (2006). Design and evaluation of a new three-dimensional motion capture system based on video. *Gait and Posture, 24*, 126-129.

Chambless, D. L., & Hollon, S. D. (1998). Defining empirically supported therapies. *Journal of Consulting & Clinical Psychology, 66*(1), 7-18.

Chen, L.-C., Metcalfe, J. S., Jeka, J. J., & Clark, J. E. (2007). Two steps forward and one back: learning to walk affects infants' sitting posture. *Infants Behavior and Development, 30*, 16-25.

Chenery, H. J. (1998). *Perceptual analysis of dysarthric speech.* Cheltenham: Stanley Thornes.

Cheng, H. Y., Mudoch, B. E., Goozée, J. V., & Scott, D. (2007). Electropalatographic assessment of tongue-to-palate contact patterns and variability in children, adolescents, and adults. *Journal of Speech, Language and Hearing Research, 50*, 375-392.

Chumpelik, D. (1984). The PROMPT system of therapy: Theoretical framework and applications for developmental apraxia of speech. *Seminars in Speech and Language, 5*(2), 139-155.

Clarke, W. M., & Hoops, H. R. (1980). Predictive measures of speech proficiency in cerebral palsied speakers. *Journal of Communication Disorders, 13*, 385-394.

Clement, M., & Twitchell, T. E. (1959). Dysarthria in cerebral palsy. *Journal of Speech and Hearing Disorders, 24*, 118-122.

Connor, N., & Abbs, J. (1998). Movement-related skin strain associated with goal oriented lip actions. *Experimental Brain Research, 123*(3), 235-241.

Corbetta, D., & Bojczyk, K. E. (2002). Infants return to two-handed reaching when they are learning to walk. *Journal of Motor Behavior, 31*(1), 83-95.

Costa, R. M., Cohen, D., & Nicholelis, M. A. L. (2004). Differential corticostriatal plasticity during fast and slow motor skill learning in mice. *Current Biology, 14*, 1124-1134.

Cowry, G. J. (2007). The dependence of spinal cord development on corticospinal input and its signficance in understanding and treating spastic cerebral palsy. *Neuroscience and Behavioral Reviews, 18*, 1114-1124.

Cox, F. (2008). Vowel transcripton systems: An Australian perspective. *International Journal of Speech-Language Pathology, 10*(327-333).

Cox, F., & Palethorpe, S. (2007). An illustration of the IPA: Australian English. *Journal of the International Phonetic Association, 37*(3), 341-350.

Crickmay, M. C. (1966). *Speech therapy and the bobath approach to cerebral palsy*. Springfield: Charles C Thomas.

Cusick, A., Lannin, N. A., & Lowe, K. (2007). Adapting the Canadian Occupational Performance Measure for use in a paediatric clinical trial. *Disability and Rehabilitation, 29*(10), 761-766.

Darainy, M., & Ostry, D. J. (2008). Muscle co-contraction following dynamics learning. *Experimental Brain Research, 190*, 153-163.

Darrah, J., & Bartlett, D. (1995). Dynamic systems theory and management of children with cerebral palsy: Unresolved issues. *Infants and Young Children, 8*(1), 52-59.

Darrah, J., Wiart, L., & Magill-Evans, J. (2008). Do therapists' goals and interventions for children with cerebral palsy reflect principles in contemporary literature? *Paediatric Physical Therapy, 20*, 334-339.

Davids, K., Savelsbergh, G. J. P., & Miyahara, M. (2010). Identifying constraints on children with movement difficulties: implications for pedagogues and clinicians. In I. Reshaw, K. Davids & G. J. P. Savelsbergh (Eds.), *Motor learning in practice: a constraints led approach*. London: Routledge.

Davis, B. L., Jacks, A., & Marquardt, T. P. (2005). Vowel patterns in developmental apraxia of speech: three longitudinal studies. *Clinical Linguistics and Phonetics, 19*(4), 249-274.

De Boor, C. (2001). *A practical guide to splines (revised edition)*. New York: Springer-Verlag.

De Leon, R. D., Hodgson, J. A., Roy, R. R., & Edgerton, V. R. (1999). Retention of hindlimb stepping ability in adult spinal cats after the cessation of step training. *Journal Neurophysiology, 81*, 85-94.

De Rezze, B., Wright, V., Curran, C. J., Campbell, K. A., & Macarthur, C. (2008). Individualized outcome measures for evaluating life skill groups for children with disabilities. *Canadian Journal of Occupational Therapy, 75*(5), 282-287.

Deffeyes, J. E., Harbourne, R. T., Kyvelidou, A., Stuberg, W. A., & Stergiou, N. (2009). Nonlinear analysis of sitting postural sway indicates developmental delay in infants. *Clinical Biomechanics, 24*(7), 564-570.

Dodd, B., & Bradford, A. (2000). A Comparison of three therapy methods for children with different types of developmental phonological disorder. *International Journal of Language and Communication Disorders, 35*(2), 180-209.

Dorfberger, S., Adi-Japha, E., & Karni, A. (2007). Reduced susceptibility to interference in the consolidation of motor memory before adolescence. *PLoS ONE, 2*(2), e240.

Doyon, J. (2008). Motor sequence learning and movement disorders. *Current Opinion in Neurobiology, 21*, 478-483.

Doyon, J., & Benali, H. (2005). Reorganization and plasticity in the adult brain during the learning of motor skills. *Current Opinion in Neurobiology, 15*(161-167).

Duchan, J. F. (2001). Impairment and social views of speech-language pathology: clinical practices re-examined. *Advances in Speech-Language Pathology, 3*(1), 37-45.

Dunst, C. J., Hamby, D. W., & Trivette, C. (2004). Guidelines for calculating effect sizes for practice-based research syntheses. *Centrescope: Evidence-based approaches to early childhood development, 3*(1), 1-10.

Dworkin, J. P. (1991). *Motor speech disorders: a treatment guide*. St Louis: Mosby Inc.

Eadie, T. L., Yorkston, K. M., Klasner, E. R., Dudgeon, B. J., Deitz, J.C., . . . Amtmann, D. (2006). Measuring Communicative Participation: A Review of Self-Report Instruments in Speech-Language Pathology. *American Journal of Speech - Language Pathology, 15*(4), 307.

Ehrich, J. F. (2006). Vygotskian inner speech and the reading process. *Australian Journal of Educational and Developmental Psychology, 6*, 12-25.

Elliot, E. J. (2004). Evidence-based speech pathology: barriers and benefits. *International Journal of Speech-Language Pathology, 6*(2), 127-130.

Enderby, P. M. (2000). Assessment and treatment of functional communication in dysarthria. In L. E. Worrall & C. M. Frattali (Eds.), *Neurogenic communication disorders: a functional approach*. New York: Thieme.

Estep, M. (2009). Modulation, adaptation, and control of orofacial pathways in healthy adults. *Journal of Communication Disorders, 42*, 280-285.

Estep, M., & Barlow, S. M. (2007). Modulation of the trigeminofacial pathway during syllabic speech. *Brain Research, 1171*, 67-74.

Eyre, J. A. (2007). Corticospinal tract development and its plasticity after perinatal injury. *Neuroscience and Biobehavioral Reviews, 31*(8), 1136-1149.

Eyre, J. A., Smith, M., Dabydeen, L., Clowry, G. J., Petacchi, E., Battini, R., . . . Cioni, G. (2007). Is hemiplegic cerebral palsy equivalent to amblyopia of the corticospinal system? *Annals of Neurology, 62*(5), 493-503.

Faraway, J. J. (2004). Modelling continuous change for facial animation. *Statistics and Computing, 14,* 357-363.

Feng, Y., Gracco, V. L., & Max, L. (2011). Integration of auditory and somatosensory error signals in the neural control of speech movements. *Journal of Neurophysiology, 106*(2), 667-679.

Fetters, L. (2010). Perspective on variability in the development of human action. *Physical Therapy, 90*(12), 1860-1867.

Fidler, D., Lunkenheimer, E., & Hahn, L. (2011). Emerging behavioral phenotypes and dynamic systems theory. In D. J. Fidler (Ed.), *International Review of Research into developmental disabilities: Development in genetic disorders associated with intellectual disabilities*. San Diego: Elsevier.

Field, A. (2009). *Discovering statistics using SPSS*. London: SAGE Publications Ltd.

Finan, D. S., & Smith, A. (2005). Jaw stretch reflexes in children. *Experimental Brain Research, 164*(1), 58-66.

Fisher, W. W., Kelley, M. E., & Lomas, J. E. (2003). Visual aids and structured criteria for improving visual inspection and interpretation of single-case designs. *Journal of Applied Behaviour Analysis, 36,* 387-406.

Folkins, J., & Canty, J. (1986). Movements of the upper and lower lips during speech: interactions between lips with the jaw fixed at different positions. *Journal of Speech and Hearing Research, 29,* 348-356.

Foran, J., Stienman, S., Barash, I., Chambers, H., & Lieber, R. (2005). Structural and mechanical alterations in spastic skeletal muscle. *Developmental Medicine and Child Neurology, 47*(10), 713-717.

Fox, C. M. (2002). *Intensive voice treatment for children with spastic cerebral palsy* (Doctoral Dissertation). Retrieved from ProQuest Dissertations and Theses database. (UMI 3073219).

Francis, A. L., Ciocca, V., & Yu, J. M. C. (2003). Accuracy and variability of acoustic measures of voicing onset. *Journal of the Acoustical Society of America, 113*(2), 1025-1032.

Freed, D., Marshall, R., & Frazier, K. (1997). Long-term effectiveness of PROMPT treatment in a severely apractic-aphasic speaker. *Aphasiology, 11*(4-5), 365-372.

Frood, T. T. (2011). The use of treadmill training to recover locomotor ability in patients with spinal cord injury. *Bioscience Horizons, 4*(1), 108-117.

Fudala, J. (2001). *Arizona Articulation Proficiency Scale, Third Revision*. Los Angeles: Western Psychological Services.

Gagliardi, C., Tavano, A., Turconi, A. C., Pozzoli, U., & Borgatti, R. (2011). Sequence learning in cerebral palsy. *Pediatric Neurology, 44*, 207-213.

Garvey, M. A., Giannetti, M. L., Alter, K. E., & Lum, P. S. (2007). Cerebral palsy: new approaches to therapy. *Current Neurology and Neuroscience Reports, 7*, 147-155.

Ghilardi, M. F., Moisello, C., Silvestri, G., Ghez, C., & Krakauer, J. W. (2009). Learning of a sequential motor skill comprises explicit and implicit components that consolidate differently. *Journal of Neurophysiology, 101*, 2218-2229.

Gibson, B. E., Darrah, J., Cameron, D., Hashemi, G., Kingsnorth, S., Lepage, C., & Menna-Dack, D. (2009). Revisiting therapy assumptions in children's rehabilitation: clinical and research assumptions. *Disability and Research, 31*(7), 1446-1453.

Gick, B., Ikegami, Y., & Derrick, D. (2010). The temporal window of audio-tactile integration in speech perception. *Journal of the Acoustical Society of America, 125*(5), EL342-EL346.

Gierut, J. (1998). Treatment efficacy: functional phonological disorders in children. *Journal of Speech, Language and Hearing Research, 41*(1), S85-S100.

Gilman, S. (2002). Joint position sense and vibration sense: anatomical organisation and assessment. *Journal of Neurology, Neurosurgery & Psychiatry, 73*(5), 473-477.

Glasziou, P., & Vandernbroucke, J. P. (2004). Assessing the quality of research. *British Medical Journal, 328,* 39-41.

Goffman, L., & Smith, A. (1999). Development of phonetic differentiation of speech movement patterns. *Journal of Experimental Psychology: Human Perception and Performance, 25*(3), 649-660.

Gomi, H., Honda, M., Ito, T., & Murano, E. Z. (2002). Compensatory articulation during bilabial fricative production by regulating muscle stiffness. *Journal of Phonetics, 30*, 261-279.

Gordon-Brannan, M. E., & Hodson, B. W. (2000). Intelligibility/Severity Measurements of Prekindergarten Children's Speech. *American Journal of Speech-Language Pathology, 9*(2), 141-150.

Gordon-Brannan, M. E., & Weiss, C. E. (2007). *Clinical management of articulatory and phonologic disorders (3rd ed.)*. Baltimore: Lippincott Williams and Wilkins.

Gracco, V. L. (1992). Analysis of speech movements: practical considerations and clinical applications. *Haskins Laboratories Status Report on Speech Research, 110*, 45-58.

Green, J. R., Moore, C., Higashikawa, M., & Steeve, R. (2000). The physiologic development of speech motor control: lip and jaw coordination. *Journal of Speech, Language and Hearing Research, 43,* 239-255.

Green, J. R., Moore, C., & Reilly, K. (2002). The sequential development of jaw and lip control. *Journal of Speech, Language and Hearing Research, 45,* 66-79.

Green, J. R., & Nip, I. S. B. (2010). Some organising priniciples in early speech development: Catalysts, constraints and synergy. In B. Massen & P. H. H. M. Van Lieshout (Eds.), *Speech motor control: New developments in basic and applied research.* New York: Oxford University Press.

Green, J. R., & Wilson, E. (2006). Spontaneous facial motility in infancy: A 3D kinematic analysis. *Developmental Psychobiology, 48,* 16-28.

Grigos, M., Hayden, D., & Eigen, J. (2010). Perceptual and articulatory changes in speech production following PROMPT treatment. *Journal of Medical Speech-Language Pathology, 18*(4), 46-53.

Grigos, M., & Patel, R. (2007). Articulator movement associated with the development of prosodic control in children. *Journal of Speech Language and Hearing Research, 50,* 119-130.

Grigos, M., Saxman, J., & Gordan, A. (2005). Speech motor development during acquisition of the voicing contrast. *Journal of Speech Language and Hearing Research, 48*(4), 739-752.

Grossman, J., & Mackenzie, F. J. (2005). The randomized controlled trial: gold standard, or merely standard? *Perspectives in Biology and Medicine, 48*(4), 516-534.

Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of Motor Behavior* (36), 2.

Gutstein, S. E. (2009). Empowering families through relationship development intervention: an important part of the biopsychosocial management of autism spectrum disorders. *Annals of Clinical Psychiatry, 21*(3), 174-182.

Hadders-Algra, M. (2000). The neuronal group selection theory: promising principles for understanding and treating developmental motor disorders. *Developmental Medicine and Child Neurology, 42,* 707-715.

Hadders-Algra, M. (2001). Early brain damage and the development of motor behaviour in children: Clues for therapeutic intervention? *Neural Plasticity, 8*(1-2), 31-49.

Hadders-Algra, M. (2008). Reduced variability in motor behaviour: an indicator of impaired cerebral connectivity? *Early Human Development, 84*, 787-789

Hadders-Algra, M. (2010). ariation and variability: key words in human development. *Physical Therapy, 90*(12), 1823-1837.

Havstam, C., Buchholz, M., & Hartelius, L. (2003). Speech recognition and dysarthria: a single subject study of two individuals with profound impairment of speech and motor control. *Logopedics Phoniatrics Vocology, 28*(2), 81-90.

Hayden, D. (2003). *PROMPT introduction to technique manual*. Sante Fe: The PROMPT Institute.

Hayden, D., & Square, P. (1994). Motor speech treatment hierarchy: A systems approach. *Clinics in Communication Disorders., 4*(3), 162-174.

Hayden, D., & Square, P. (1999). *Verbal Motor Production Assessment for Children. Examiner's Manual.* United States of America: The Psychological Corporation.

Heriza, C. B. (1991). *Motor development: traditional and contemporary theories.* Alexandria: Foundation for Physical Therapy.

Higgins, C., & Hodge, M. (2002). Reduced vowel area and intelligibility in children with and without dysarthria. *Journal of Medical Speech-Language Pathology, 10*, 271-277.

Higgins, J. P. T., & Green, S. (2011). *Cochrane handbook for systematic reviews of interventions version 5.1.0*: The Cochrane Collaboration.

Hixon, T., & Hardy, J. (1964). Restricted motility of the speech articulators in cerebral palsy. *Journal of Speech and Hearing Disorders, 29*(3), 293-306.

Hodge, M. (2010). Stability of intelligibility measures for children with dysarthria and cerebral palsy. *Journal of Medical Speech-Language Pathology, 18*(4), 61.

Hodge, M., & Wellman, L. (1999). Management of children with dysarthria. In E.A. Strand & A. Caruso (Eds.), *Clinical management of motor speech disorders in children* (pp. 209-280). New York: Thieme.

Hodge, M., & Whitehall, T. (Eds.). (2010). *Intelligibility impairments*: Wiley-Blackwell.

Hodson, B. (2004). *Hodson assessment of phonological patterns. Third Edition*. Austin, Texas: Pro-Ed.

Hodson, B., Scherz, J., & Strattman, K. (2002). Evaluating communicative abilities of a highly unintelligible preschooler. *American Journal of Speech Language Pathology, 11*, 232-242.

Hojem, M. A., & Ottenbacher, K. J. (1988). Empirical investigation of visual-inspection versus trend-line analysis of single-subject data. *Physical Therapy, 68*(6), 983-988.

Hollenstein, T. (2007). State space grids: analyzing dynamics across development. *International Journal of Behavioral Development, 3*(4), 384-396.

Holmstrom, L., Vollmer, B., Tedroff, K., Islam, M., Ke Persson, J., Forssberg, H., & Eliasson, A.-C. (2010). Hand function in relation to brain lesions and corticomotor-projection pattern in children with unilateral cerebral palsy. *Developmental Medicine and Child Neurology, 52*(2), 145-152.

Honda, K. T., S, & Takemoto, H. (2010). Effects of side cavities and tongue stabilization: possible extensions of the quantal theory. *Journal of Phonetics, 38*, 33-43.

Hong, W.-H., Chen, H.-C., Yang, F.-P., Wu, C.-Y., Cheng, C.-L., & Wong, A. M. (2011). Speech-associated labiomandibular movement in Mandarin-speaking children with quadriplegic cerebral palsy: A kinematic study. *Research in Developmental Disabilities, 32*(6), 2595-2601.

Hoon, A. H., Stashinko, E. E., Nagae, L. M., Lin, D. D., Keller, J., Bastian, A., . . . Johnson, M. V. (2009). Sensory and motor deficits in children with cerebral palsy born preterm correlate with diffusion tensor imaging abnormalities in thalamocortical pathways. *Developmental Medicine and Child Neurology, 51*(9), 697-704.

Houghton, M. (2003). *The effect of the PROMPT system of therapy on a group of children with severe persistent sound system disorders.* (Master's thesis). University of Queensland, Brisbane.

Howe, M. L., & Lewis, M. D. (2005). The importance of dynamic systems approaches for understanding development. *Developmental Review, 25*, 247-251.

Howell, P., Anderson, A. J., Bartrip, J., & Bailey, E. (2009). Comparison of acoustic and kinematic approaches to measuring utterance-level speech variability. *Journal of Speech, Language and Hearing Research, 52*, 1088-1096.

Huang, V. S., Haith, A., Mazzoni, P., & Krakauer, J. W. (2011). Rethinking motor learning and savings in adaptation paradigms: Model-free memory for successful actions combines wiht internal models. *Neuron, 70*, 787-801.

Hustad, K. (2006). Estimating the intelligibility of speakers with dysarthria. *Folia Phoniatrica et Logopaedica, 58*, 217-228.

Hustad, K., & Cahill, M. (2003). Effects of presentation mode and repeated familiarization on intelligibility of dysarthric speech. *American Journal of Speech-Language Pathology, 12*(2), 198-208.

Hustad, K., Gorton, K., & Lee, J. (2010). Classification of speech and language profiles in 4-year-old children with cerebral palsy: A prospective preliminary study. *Journal of Speech, Language and Hearing Research, 53*, 1496-1513.

Hustad, K. C., Schueler, B., Schultz, L., & DuHadway, C. (2012, in press). Intelligibility of 4 year old children with and without cerebral palsy. *Journal* *of Speech Language and Hearing Research*, 1092-4388_2011_1011-0083. doi: 10.1044/1092-4388(2011/11-0083).

Ibragimova, N., Lillvist, A., Pless, M., & Granlund, M. (2007). The utility of ICF for describing interaction in non-speaking children with disabilities - caregiver ratings and perceptions. *Disability and Rehabilitation, 1*, 1-12.

Imms, C., Reilly, S., Carlin, J., & Dodd, K. J. (2009). Characteristics influencing participation of Australian children with cerebral palsy. *Disability and Rehabilitation, 31*(26), 2204-2215.

Ingram, T. T. S., & Barn, J. (1961). A description and classification of common speech disorders associated with cerebral palsy. *Cerebral Palsy Bulletin, 3*(1), 57-69.

Iskarous, K., Shadle, C. H., & Proctor, M. I. (2011). Articulatory-acoustic kinematics: the production of American english /s/. *Journal of the Acoustical Society of America, 129*(2), 944-954.

Ito, T., & Ostry, D. J. (2010). Somatosensory contribution of motor learning due to facial skin deformation. *Journal of Neurophysiology, 104*, 1230-1238.

Iverson, J. M., & Thelen, E. (1999). Hand, mouth and brain: The dynamic emergence of speech and gesture. *Journal of Consciousness Studies, 6*(11-12), 19-40.

Johnston, M. V., Ishida, A., Ishida, W. N., Matsushista, H. B., Nishimura, A., & Tsuji, M. (2009). Plasticity and injury in the developing brain. *Brain and Development, 31*, 1-10.

Juarrero, A. (1999). *Dynamics in action: intentional behavior as a complex system*. Cambridge: MIT Press.

Kaderavek, J. N., & Justice, L. M. (2010). Fidelity: An essential component of evidence-based practice in speech-language pathology. *American Journal of Speech-Language Pathology, 19*(4), 369-379.

Kamachi, M., Hill, H., Lander, K., & Vatikiotis-Bateson, E. (2003). Putting the face to the voice: Matching identify across modality. *Current Biology, 13*(19), 1709-1714.

Katz, W. F., & McNeil, M. R. (2010). Studies of articulatory feedback treatment for apraxia of speech based electromagnetic articulatography. *Perspectives on Neurophysiology and Neurogenic Speech and Language Disorders, 20*, 73-79.

Kearns, K. P., & Simmons, N. N. (1988). Interobserver reliability and perceptual ratings: more than meets the ear. *Journal of Speech and Hearing Research, 31*, 131-136.

Keintz, C. K., Bunton, K., & Hoit, D. (2007). Influence of visual information on the intelligibility of dysarthric speech. *American Journal of Speech Language Pathology, 16*(3), 224-234.

Kelso, J. A. S. (1984). Phase transitions and critical behavior in human bimanual coordination. *The American Journal of Physiology, 246*(6), R1000-R1004.

Kelso, J. A. S. (2003). Cognitive coordination dynamics. In W. Tschacher & J.-P. Dauwalder (Eds.), *The dynamical systems approach to cognition: concepts and empirical paradigms based on self-organisation, embodiment, and coordination dynamics*: Toh Tuck Link: World Scientific Publishing.

Kelso, J. A. S., Fink, P. W., DeLaplain, C. R., & Carson, R. G. (2001). Haptic information stabilizes and destabilizes coordination dynamics. *Proceedings of the Royal Society of London, 268*, 1207-1213.

Kelso, J. A. S., Tuller, B., Vatikiotis-Bateson, E., & Fowler, C. (1984). Functionally specific articulatory cooperation following jaw perturbations druing speech: evidence for coordinative structures. *Journal of Experimental Psychology: Human Perception and Performance, 10*(6), 812-832.

Kelso, J. A. S., & Zanone, P. (2002). Coordination dynamics of learning and transfer across different effector systems. *Journal of Experimental Psychology: Human Perception and Performance, 28*(4), 776-797.

Kennes, J., Rosenbaum, P., Hanna, S. E., Walter, S., Russell, D., Raina, P., . . . Galuppi, B. (2002). Health status of school-aged children with cerebral palsy: information from a population-based sample. *Developmental Medicine and Child Neurology, 44*(4), 240-247.

Kent, R. D. (1992). The biology of phonological development. In C. Ferguson, L. Menn & C. Stoel-Gammon (Eds.), *Phonological development: Models, research, implications*: Timonium, MD: York Press.

Kent, R. D., & Kent, J. (2000). Task-based profiles of the dysarthrias. *Folia Phoniatrica et Logopaedica, 52*(1-3), 48-53.

Kent, R. D., & Kim, Y. (2003). Toward an acoustic typology of motor speech disorders. *Clinical Linguistics and Phonetics, 17*(6), 427-445.

Kent, R. D., Miolo, G., & Bloedel, S. (1994). The intelligibility of children's speech. *American Journal of Speech Language Pathology, 3*, 81-95.

Kent, R. D., & Netsell, R. (1978). Articulatory abnormalities in athetoid cerebral palsy. *Journal of Speech and Hearing Disorders, 43*, 353-373.

Kent, R. D., Weismer, G., Kent, F. J., Vorperian, H., & Duffy, J. (1999). Acoustic studies of dysarthric speech: methods, progress, and potential. *Journal of Communication Disorders, 32*(141-186).

Kim, H., Martin, K., & Hasegawa-Johnson, M. P., A. (2010). Frequency of consonant articulation errors in dysarthric speech. *Clinical Linguistics and Phonetics, 24*(10), 759-770.

Kim, Y., Kent, R. D., & Weismer, G. (2011). An acoustic study of the relationships among neurologic disease, dysarthria type, and severity of dysarthria. *Journal of Speech, Language and Hearing Research, 54*(417-429).

King, S., Teplicky, R., King, G., & Rosenbaum, P. (2004). Family-centered service for children with cerebral palsy and their families: a review of the literature. *Seminars in Pediatric Neurology, 11*(1), 78-86.

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent plasticity: implications for rehabilitation after brain damage. *Journal of Speech, Language and Hearing Research, S51*, S225-S239.

Klein, E., & Flint, C. (2006). Measurement of intelligibility in disordered speech. *Language Speech and Hearing Services in Schools, 37*(3), 191-199.

Kleinow, J., & Smith, A. (2006). Potential interaction among linguistic, autonomic, and motor speech factors in speech. *Developmental Psychobiology, 48*, 275-287.

Kolb, B., & Whishaw, I. Q. (1996). Brain plasticity and behavior. *Annual Review of Psychology, 49*(43-46).

Korzeniewski, S. J., Birbeck, G., Delano, M. C., Potchen, M. J., & Paneth, N. (2008). A systematic review of neuroimaging for cerebral palsy. *Journal of Child Neurology, 23*(2), 216-227.

Kostrubiec, V., Tallet, J., & Zanone, P. (2006). How a new behavioral pattern is stabilized with learning determines its persistence and flexibility in memory. *Experimental Brain Research, 170*, 238-244.

Krakauer, J. W. (2006). Motor learning: its relevance to stroke recovery and neurorehabilitation. *Current Opinion in Neurobiology, 19*, 84-90.

Krakauer, J. W., Mazzoni, P., Ghazisadeh, A., Ravindran, R., & Shadmehr, R. (2006). Generalization of motor learning depends on the history of prior action. *PLoS Biology, 4*(10), e316.

Krigger, K. (2006). Cerebral Palsy: An overview. *American Family Physician, 73*(1), 91-100.

Landi, S. M., Baguear, F., & Della-Maggiore, V. (2011). One week of motor adaptation induces structural changes in primary motor cortex that predict long-term memory one year later. *The Journal of Neuroscience, 31*(33), 11808-11813.

Latash, M. L., Levin, M. F., Scholz, J. P., & Schöner, G. (2010). Motor control theories and their applications. *Medicina (Kaunas), 46*(6), 382-392.

Law, M., Baptiste, S., Carswell, A., McColl, M. A., Polatajko, H., & Pollock, N. (2005). *Canadian Occupational Peformance Meausure*. Ottawa: CAOT Publications, ACE.

Lee, T. D., Wulf, G., & Schmidt, R. A. (1992). Contextual interference in motor learning: dissociated effects due to the nature of task variations. *The Quarterly Journal of Experimental Psychology Section A, 44*(4), 627-644.

Lewis, M. D. (2011). Dynamic systems approaches: Cool enough? Hot enough? *Child Development Perspectives, 5*(4), 279-285.

Lin, E. L., Chen, C. L., & Lee, C. C. (2007). *Speech motor deficits in cerebral palsied children: An acoustic-perceptual approach*. Paper presented at the The 5th Asia Pacific Conference on Speech, Language and Hearing, Brisbane.

Lin, J. (2003). The cerebral palsies: A physiological approach. *Journal of Neurology, Neurosurgery and Psychiatry, 74*(Supplement 1), i23-29.

Lindblom, B. (1990). On the communication process: speaker-listener interaction and the development of speech. *Augmentative and Alternative Communication, 6*, 220-230.

Lindstrom, C. (2002). Objective facial motion analysis in patients with facial nerve dysfunction. *The Laryngoscope, 112,* 1129 -1147.

Liu, H. M., Tsao, F. M., & Kuhl, P. K. (2005). The effect of reduced vowel working space on speech intelligibility in Mandarin-speaking young adults with cerebral palsy. *Journal of the Acoustical Society of America, 117*(6), 3879-3889.

Liu, Y.-T., Mayer-Kress, G., & Newell, K. M. (2010). Bi-stability of movement coordination as a function of skill level and task difficulty. *Journal of Experimental Psychology: Human Perception and Performance, 36*(6), 1515-1524.

Löfqvist, A., & Gracco, V. L. (1997). Lip and jaw kinematics in bilabial stop production. *Journal of Speech, Language and Hearing Research, 40*(4), 877-893.

Logan, L. R., Hickman, R. R., Harris, S. R., & Heriza, C. B. (2008). Single-subject research design: recommendations for levels of evidence and quality rating. *Developmental Medicine and Child Neurology, 50*, 99-103.

Loucks, T., & De Nil, L. (2001). The effects of massester tendon vibration on nonspeech movements and vowel gestures. *Journal of Speech, Language and Hearing Research, 44*(2), 306-316.

Love, R. (1992). *Childhood speech disability*. New York: Macmillan Publishing Company.

LSVT®. (2011). LSVT Workshops Retrieved 29.12.2011, from http://www.lsvtglobal.com/index.php?action=schedule

Ludlow, C. L., Hoit, J., Kent, R., Ramig, L. O., Shrivastav, R., Strand, E., . . . Sapienza, C. M. (2008). Translating principles of neural plasticity into research on speech motor control recovery and rehabilitation. *Journal of Speech, Language and Hearing Research, 51*, S240-S258.

Luft, A. R., & Buitrago, M. M. (2005). Stages of motor skill learning. *Molecular Neurobiology, 32*(3), 205-216.

Maas, E., Robin, D. A., Austermann Hula, S., N, Wulf, G., Ballard, K. J., & Schmidt, R. A. (2008). Principles of motor learning in treatment of motor speech disorders. *American Journal of Speech Language Pathology, 17*, 277-298.

Macefield, V. (2005). Physiological characteristics of low-threshold mechanoreceptors in joints, muscle and skin in human subjects. *Clinical and Experimental Pharmacology and Physiology, 32*, 135-144.

Majnemer, A., & Mazer, B. (2004). New directions in the outcome evaluation of children with cerebral palsy. *Seminars in Pediatric Neurology, 11*(1), 11-17.

Majnemer, A., Shevell, M., Law, M., Birnbaum, R., Chilingaryan, G., Rosenbaum, P., & Poulin, C. (2008). Participation and enjoyment of leisure activities in school-aged children with cerebral palsy. *Developmental Medicine and Child Neurology, 50*(10), 751-758.

Maner, K., Smith, A., & Grayson, L. (2000). Influence of utterance length and complexity on speech motor performance in children and adults. *Journal of Speech Language and Hearing Research, 43*(2), 560-573.

Marchant, J., McCauliffe, M., & Huckabee, M. (2008). Treatment of articulatory impairment in a child with spastic dysarthria associated with cerebral palsy. *Developmental Neurorehabilitation, 11*(1), 81-90.

Martikainen, A.-L., & Korpilahti, P. (2011). Intervention for childhood apraxia of speech: A single-case study. *Child Language Teaching & Therapy, 27*(1), 9-20.

Martin, A., Burtner, P. A., Poole, J., & Phillips, J. (2008). Case Report: ICF-Level changes in a preschooler after constraint-induced movement therapy. *American Journal of Occupational Therapy, 62*(3), 282-288.

Martin, J. H. (2005). The corticospinal system: from development to motor control. *The Neuroscientist, 11*, 161-173.

Martin, J. H., Friel, K. M., Salimi, I., & Chakrabarty, S. (2007). Activity- and use-dependent plasticity of the developing corticospinal system. *Neuroscience and Biobehavioral Reviews, 31*(1125-1135).

Marx, N. (2008). Using goal attainment scaling as an outcome measure for PROMPT therapy. *ACQuiring Knowledge in Speech, Language and Hearing, 10*(2), 56-59.

Mattar, A. G., & Ostry, D. J. (2007). Modificability of generalization in dynamics learning. *Journal of Neurophysiology, 98*, 3321-3329.

McCauley, R. J., & Strand, E. A. (1999). Treatment of children exhibiting phonological disorder with motor speech involvement. In A. Caruso & E. A. Strand (Eds.), *Clinical management of motor speech disorders in children.* New York: Thieme Medical Publishers.

McClean, M. D., & Tasko, S. M. (2003). Association of orofacial muscle activity and movement during changes in speech rate and intensity. *Journal of Speech, Language and Hearing Research, 46*, 1387-1400.

McConachie, H., Colver, A. F., Forsyth, R. J., Jarvis, S. N., & Parkinson, K. N. (2006). Participation of disabled children: how should it be characterised and measured? *Disability and Rehabilitation, 18*, 1157-1164.

McCormack, J., McLeod, S., Harrison, L. J., & McAllister, L. (2010). The impact of speech impairment in early childhood: investigating parents' and speech-language pathologists' persepctives using the ICF-CY. *Journal of Communication Disorders, 43,* 378-396.

McDougall, J., Wright, V., & Rosenbaum, P. (2010). The ICF model of functioning and disability: Incorporating quality of life and human development. *Developmental Rehabilitation, 13*(3), 204-211.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature, 264,* 364-748.

McHenry, M. (2011). An exploration of listener variability in intelligibility judgments. *American Journal of Speech-Language Pathology, 20*(2), 119-123.

McLeod, S. (2004). Speech pathologists' application of the ICF to children with speech impairment. *Advances in Speech Language Pathology, 6*(1), 75-81.

McLeod, S. (2006). An holistic view of a child with unintelligible speech: Insights from the ICF and ICF-CY. *Advances in Speech Language Pathology, 8*(3), 293-315.

McLeod, S., & Bleile, K. (2004). The ICF: A framework for setting goals for children with severe speech impairment. *Child Language Teaching and Therapy, 20*(3), 199-219.

McLeod, S., van Doorn, J., & Reed, V. A. (2001). Consonant cluster development in two-year-olds: General trends and individual differences. *Journal of Speech, Language and Hearing Research, 44*, 1141-1171.

Mefferd, A. S., & Green, J. R. (2010). Articulatory-to-acoustic relations in response to speaking rate and loudness manipulations. *Journal of Speech, Language and Hearing Research, 53*(5), 1206-1219.

Ménard, L., Perrier, P., Aubin, J., Savariaux, C., & Thibeault, M. (2008). Compensation strategies for a lip-tube pertubration of French [u]: an acoustic and perceptual study of 4-year-old children. *The Journal of the Acoustical Society of America, 12*(2), 1192-1206.

Milloy, N., & Morgan-Barry, R. (1990). Developmental neurological disorders. In P. Grunwell (Ed.), *Developmental Speech Disorders*. Edinburgh: Wiley Publishers.

Miyamoto, K., Ishizuka, Y., Ueda, M., Saifuddin, M., Shikata, N., & Tanne, K. (1999). Masseter muscle activity during the whole day in children and young adults. *Journal of Oral Rehabilitation, 26*, 858-864.

Moher, D., Schulz, K. F., Altman, D., & Group, f. t. C. (2001). The CONSORT Statement: Revised recommendations for improving the quality of reports of parallel-group randomized trials. *The Journal of the American Medical Association, 285*(15), 1987-1991.

Monfils, M. H., Plautz, E. J., & Kleim, J. A. (2005). In search of the motor engram: motor map plasticity as a mechanism for encoding motor experience. *The Neuroscientist, 11*(5), 471-483.

Moore, C. A. (2004). Physiological development of speech production. In B. Maassen, R. D. Kent, H. F. M. Peters, P. H. H. M. van Lieshout & W. Hulstijn (Eds.), *Speech motor control in normal and disordered speech*. Oxford: Oxford University Press.

Morgan, A. T., & Vogel, A. P. (2008). Intervention for childhood apraxia of speech. *Cochrane Database of Systematic Reviews, 3*, 1-19.

Morris, C. (2009). Measuring participation in childhood disability: how does the capability approach improve our understanding? *Developmental Medicine and Child Neurology, 51*(2), 92-94.

Morris, C., Kurinczuk, J. J., Fitzpatrick, R., & Rosenbaum, P. (2006). Do the abilities of children with cerebral palsy explain their activities and participation. *Developmental Medicine & Child Neurology, 48*(12), 954-961.

Muchisky, M., Gershkoff-Stowe, L., Cole, E., & Thelen, E. (1996). The epigenetic landscape revisited: a dynamic interpretation. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in Infancy Research* (Vol. 10). New Jersey: Ablex Publishing Corporation.

Murdoch, B. (2011). Physiological investigation of dysarthria: recent advances. *International Journal of Speech-Language Pathology, 13*, 28-35.

Murdoch, B., & Horton, S. K. (Eds.). (1998). *Acquired and developmental dysarthria in childhood*. Cheltenham: Stanley Thornes.

Murray, G. M., & Klineberg, I. J. (1984). Electromyographic recordings of human jaw-jerk reflex characteristics evoked under standardized conditions. *Archives of Oral Biology, 29*(7), 537-549.

Mutlu, A., Akmese, P. P., Gunel, M. K., Karahn, S., & Livanelioglu, A. (2010). The importance of motor functional levels from the activity limitation perspective of ICF in children with cerebral palsy. *International Journal of Rehabilitation Research, 33*(4), 319-324.

Nadeau, L., & Tessier, R. (2009). Social adjustment at school: are children with cerebral palsy perceived more negatively by peers than other at-risk children? *Disability and Rehabilitation, 31*(4), 302-308.

Nakaya, J., Shimizu, T., Tanaka, H., & Shigetaka, A. (2005). Current translational research in Australia and national translational research supporting center in Japan. *Chiem-Bio Informatics Journal, 5*(2), 27-38.

Nazari, M. A., Perrier, P., Chabanas, M., & Payan, Y. (2011). Shaping by stiffening: a modeling study for lips. *Motor Control, 15*(1), 141-168.

Neilson, P. D., & O'Dwyer, N. J. (1981). Pathophysiology of dysarthria in cerebral palsy. *Journal of Neurology, Neurosurgery, and Psychiatry, 44*, 1013-1019.

Nelson, M. A., & Hodge, M. M. (2000). Effects of facial paralysis and audiovisual information on stop placement identification. *Journal of Speech, Language and Hearing Research, 43*, 158-172.

Netsell, R. (2001). Speech aeromechanics and the dysarthrias: implications for children with brain injury. *The Journal of Head Trauma Rehabilitation, 16*(5), 415-425.

Newell, K. M. (1991a). Motor learning in practice: a constraints led approach. *Annual Review of Psychology, 42*, 213-237.

Newell, K. M. (1991b). Motor skill acqusition. *Annual Review of Psychology, 42*, 213-237.

Newell, K. M. (2003). Changes in motor learning: a coordination and control perspective. *Motriz, Rio Claro, 9*(1), 1-6.

Newell, K. M., Broderick, M. P. D., K.M, & Slifkin, A. B. (2003). Task goals and change in dynamical degrees of freedom with motor learning. *Journal of Experimental Psychology: Human Perception and Performance, 29*(2), 379-387.

Newell, K. M., Deutsch, K. M., Sosnoff, J. J., & Mayer-Kress, G. (2006). Variability in motor output as noise: a default and erroneous proposition? In K. Davids, S. Bennett & K. M. Newell (Eds.), *Movement System Variability*. Champaign: Human Kinetics.

Newell, K. M., Liu, Y.-T., & Mayer-Kress, G. (2001). Time scales in motor learning and development. *Psychological Review, 108*(1), 57-82.

Newell, K. M., & Valvano, J. (1998). Therapeutic intervention as a constraint in learning and relearning movement skills. *Scandinavian Journal of Occupational Therapy, 5*(3), 51-57.

Newman, B. M., & Newman, P. R. (2007). *Theories of human development*. New Jersey: Lawrence-Erlbaum Associates, Inc.

NHMRC. (2009). *NHMRC levels of evidence and grades for recommendations for developers of guidelines*. Canberra: Retrieved from http://www.nhmrc.gov.au/_files_nhmrc/file/guidelines/evidence_statement_form.pdf.

Nip, I. S. B., Green, J. R., & Marx, D. B. (2009). Early speech motor development: cognitive and linguistic considerations. *Journal of Communication Disorders, 42*, 286-298.

Nip, I. S. B., Green, J. R., & Marx, D. B. (2011). The co-emergence of cognition, language and speech motor control in early development: a longitudinal correlation study. *Journal of Communication Disorders, 44*, 149-160.

Nourbakhsh, M. R., & Ottenbacher, K. J. (1994). The statisitcal analysis of single-subject data: a comparative examination. *Physical Therapy, 74*(8), 768-776.

Olive, M. L., & Smith, B. W. (2005). Effect size calculations and single subject designs. *Educational Psychology, 25*(2-3), 313-324.

Orme, J. G., & Cox, M. E. (2001). Analyzing single-subject design data using statistical process control charts. *Social Work Research, 25*(2), 115-127.

Ortega, A. O. L., Guimarães, A. S., Ciamponi, L., & Marie, S. K. N. (2008). Frequency of temporomandibular disorder signs in individuals with cerebral palsy. *Journal of Oral Rehabilitation, 35*(5), 191-195.

Ostry, D. J., Vatikiotis-Bateson, E., & Gribble, P. L. (1997). An examination of the degrees of freedom of human jaw motion in speech and mastication. *Journal of Speech, Language and Hearing Research, 40*, 1341-1351.

Ozsancak, C., Auzou, P., Jan, M., Defebvre, L., Derambure, P., & Destee, A. (2006). The place of perceptual analysis of dysarthria in the differential diagnosis of corticobasal degeneration and Parkinson's disease. *Journal of Neurology, 253*(1), 92-97.

Paatsch, L. E., Blamey, P. J., Sarant, J. Z., & Bow, C. P. (2006). The effects of speech production and vocabulary training on different components of spoken language performance. *Journal of Deaf Studies and Deaf Education, 11*(1), 39-55.

Palisano, R. J., Orlin, M., Chiarello, L. A., Oeffinger, D., Polansky, M., Maggs, J., . . . Stevenson, R. (2011). Determinants of Intensity of Participation in Leisure and Recreational Activities by Youth With Cerebral Palsy. *Archives of Physical Medicine and Rehabilitation, 92*(9), 1468-1476.

Palmer, M., & Enderby, P. M. (2007). Methods of speech therapy treatment for stable dysarthria: A review. *Advances in Speech-Language Pathology, 9*(2), 140-153.

Pannbacker, M. (1988). Management strategies for developmental apraxia of speech: A review of the literature. *Journal of Communication Disorders, 21*(5), 363-371.

Papavasiliou, A. S. (2009). Management of motor problems in cerebral palsy: a critical update for the clinician. *European Journal of Paediatric Neurology, 13,* 387-396.

Pascual-Leone, A., Amedi, A., Fregni, F., & Merabet, L. B. (2005). The plastic human cortex. *Annual Review of Neuroscience, 28,* 377-401.

Patel, R., & Campellone, P. (2009). Acoustic and perceptual cues to contrastive stress in dysarthria. *Journal of Speech, Language & Hearing Research, 52*(1), 206-222.

Peeters, R., Verhoeven, L., de Moor, J., & van Balkom, H. (2009). Importance of speech production for phonological awareness and word decoding: the case of children with cerebral palsy. *Research in Developmental Disabilities, 30,* 712-726.

Pennington, L., Goldbart, J., & Marshall, J. (2005). Direct speech and language therapy for children with cerebral palsy: Findings from a systematic review. *Developmental Medicine and Child Neurology, 47*(1), 57-63.

Pennington, L., Miller, N., & Robson, S. (2009). Speech therapy for children with dysarthria acquired before three years of age. *Cochrane Database of Systematic Reviews*(4).

Pennington, L., Smallman, C., & Farrier, F. (2006). Intensive dysarthria therapy for older children with cerebral palsy: findings from six cases. *Child Language Teaching and Therapy, 22*(3), 255 - 273.

Peters, H., Hulstijn, W., & Van Leishout, P. (2000). Recent developments in speech motor research into stuttering. *Folia Phoniatrica et Logopaedica, 52*(1-3), 103-119.

Piek, J. P. (2002). The role of variability in early motor development. *Infant Behavior and Development, 25,* 452-465.

Pinto-Zipp, G., & Gentile, A. M. (2010). Practice schedule and the learning of motor skills in children and adults: teaching implications. *Journal of College Teaching and Learning, 7*(2), 35-42.

Pirila, S., van der Meere, J., Pentikainen, T., Ruusu-Niemi, P., Korpela, R., Kilpinen, J., & Nieminen, P. (2007). Language and motor speech skills in children with cerebral palsy. *Journal of Communication Disorders, 40*, 116-128.

Platt, L., Andrews, G., Young, M., & Quinn, P. (1980). Dysarthria of adult cerebral palsy: 1. Intelligibility and articulatory impairment. *Journal of Speech and Hearing Research, 23,* 28-40.

Porter, R. J., & Hogue, D. M. (1998). Nonlinear dynamical systems in speech perception and production. *Nonlinear Dyhamics, Psychology, and Life Sciences, 2*(2), 95-131.

Portney, L., & Watkins, M. (2009). *Foundations of clinical research. Applications to practice.* (3rd ed.). Prentice Hall Health: New Jersey.

Powell, T. W., Elbert, M., Miccio, A. W., Strike-Roussos, C., & Brasseur, J. (1998). Facilitating [s] production in young children: an experimental evalaluation of motoric and conceptual treatment approaches. *Clinical Linguistics and Phonetics, 12*(2), 127-146.

Quené, H., & van den Bergh, H. (2004). On multi-level modeling of data from repeated measures designs: A tutorial. *Speech Communication, 43*(1-2), 103-121.

Reilly, S. (2004). The challenges in making speech pathology practice evidence based. *Advances in Speech-Language Pathology, 6*(2), 113-124.

Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin and Review, 12*(6), 969-992.

Riely, R. R., & Smith, A. (2003). Speech movements do not scale by orofacial structure size. *Journal of Applied Physiology, 94*, 2119-2126.

Robey, R. R. (2004). A five-phase model for clinical-outcome research. *Journal of Communication Disorders, 37*(5), 401-411.

Robey, R. R., & Schultz, M. C. (1998). A model for conducting clinical-outcome research: An adaptation of the standard protocol for use in aphasiology. *Aphasiology, 12*(9), 787-810.

Rogers, S., Hayden, D., Hepburn, S., Charlifue-Smith, R., Hall, T., & Hayes, A. (2006). Teaching young nonverbal children with autism useful speech: A pilot study of the Denver Model and PROMPT interventions. *Journal of Autism and Developmental Disorders, 36*, 1007-1024.

Roid, G., & Miller, L. (1997). *Leiter International Performance Scale-Revised*. Wood Dale, IL: Stoelting Company.

Rosenbaum, D. A. (2010). *Human Motor Control (2nd edition)*. San Diego: Elsevier Inc.

Rosenbaum, P. (2010). The randomized controlled trial: an excellent design, but can it address the big questions in neurodisability. *Developmental Medicine and Child Neurology, 52*(2), 111.

Rosenbaum, P., & Stewart, D. (2004). The World Health Organization International classification of functioning, disability and research: A model to guide clinical thinking, practice and research in the field of cerebral palsy. *Seminars in Pediatric Neurology, 11*(1), 5-10.

Roy, N., Leeper, H., Blomgren, H., & Cameron, R. (2001). A description of phonetic, acoustic and physiological changes associated with improved Intelligibility in a speaker with spastic dysarthria. *American Journal of Speech Language Pathology, 10*(3), 274-290.

Ruark, J. L., & Moore, C. A. (1997). Coordination of lip muscle activity by 2-year-old children during speech and non-speech tasks. *Journal of Speech, Language and Hearing Research, 40*(6), 1373-1385.

Rvachew, S., Rafaat, S., & Martin, M. (1999). Stimulability, speech perception skills, and the treatment of phonological disorders. *American Journal of Speech Language Pahtology, 8,* 33-43.

Sackett, D., Rosenberg, W., Gray, J., Haynes, R., & Richardson, S. (1996). Evidence based medicine: What it is and what it isn't. *British Medical Journal, 312*, 71-72.

Sanes, J. (2003). Neocortical mechanisms in motor learning. *Current Opinion in Neurobiology, 13*, 225-231.

Sanger, T. D., & Kukke, S. N. (2007). Abnormalities of tactile sensory function in children with dystonic and diplegic cerebral palsy. *Journal of Child Neurology, 22*(3), 289-293.

Satake, E., Jagaroo, V., & Maxwell, D. L. (2008). *Handbook of statistical methods: single subject design*. San Diego: Plural Publishing.

Savion-Lemieux, T., & Penhume, V. B. (2010). The effect of practice pattern on the acquisition, consolidation and transfer fo visual-motor sequences. *Experimental Brain Research, 204*, 271-281.

Schmidt, R. A., & Lee, D. (2005). *Motor control and learning: a behavioural emphasis*. Champaign: Human Kinetics.

Schore, A. N. (1997). Early organization of the nonlinear right brain and development of a predisposition to psychiatric disorders. *Development and Psychopathology, 9*, 595-631.

Seidler, R. D., & Noll, D. C. (2008). Neuroanatomical correlates of motor acquisition and motor transfer. *Journal of Neurophysiology, 99*(4), 1836-1845.

Seidler, R. D., Noll, D. C., & Chintalapati, P. (2006). Bilateral basal ganglia activation associated with sensorimotor adaptation. *Experimental Brain Research, 175*(3), 544-555.

Sellars, C., Hughes, T., & Langhorne, P. (2005). Speech and language therapy due to non-progressive brain damage. *Cochrane Database of Systematic Reviews*(3).

Semel, E., Wiig, E., & Secord, W. (1995). *Clinical Evaluation of Language Fundamentals. Fourth edition* San Antonio, Tx: The Psychological Corporation.

Serrien, D. (2009). Interactions between new and pre-existing dynamics in bimanual movement control. *Experimental Brain Research, 197*, 269-278.

Sessle, B., Yao, D., Nishiura, H., Yoshinok, K., Lee, J., Martin, R., & Murray, G. (2005). Properties of plasticity of the primate somatosensory motor cortex related to orofacial sensory motor function. *Clinical and experimental pharmacology and physiology, 32,* 109-114.

Shiller, D. M., Gracco, V. L., & Rvachews, S. (2010). Auditory-motor learning during speech production in 9-11-year-old children. *PLoS ONE, 59,* e12975.

Shiller, D. M., Laboissiére, R., & J, O. D. (2002). Relationship between jaw stiffness and kinematic variability in speech. *Journal of Neurophysiology, 88,* 2329-2340.

Shriberg, L. D., Fourakis, M., Hall, S. D., Karlsson, H. B., Lohmeier, H. L., McSweeney, J. L., . . . Wilson, D. L. (2010). Perceptual and acoustic reliability estimates for the speech disorders classification system (SDCS). *Clinical Linguistics and Phonetics, 24*(10), 825-846.

Shriberg, L. D., & Kwiatkowski, J. (1982). Phonological disorders III: A procedure for assessing severity of involvement. *Journal of Speech and Hearing Disorders, 47,* 256-270.

Shriberg, L. D., Lewis, B., McSweeny, J., & Wilson, P. (1997). The percentage of consonants correct (PCC) metric: Extensions and reliability data. *Journal of Speech, Language and Hearing Research, 40,* 708-722.

Shumway-Cook, A., Hutchinson, S., Kartin, D., Price, R., & Woollacott, M. (2003). Effect of balance recovery of stability in children with cerebral palsy. *Developmental Medicine and Child Neurology, 45*(9), 591-602.

Shumway-Cook, A., & Woollacott, M. (2012). *Motor control: translating research into clinical practice* (4th ed.). Philadelphia: Lippincott Williams and Wilkins.

Siebes, R., Wijnroks, L., & Vermeer, A. (2002). Qualitative analysis of therapeutic motor intervention programmes for children with cerebral palsy: an update. *Developmental Medicine and Child Neurology, 44*(9), 593-603.

Sing, G. C., & Smith, A. M. (2010). Reduction in learning rates associated with anterograde interference results from interactions between different timescales in motor adaptation. *PLoS Computation Bioloby, 6*(8), e1000893.

Singh, L., & Singh, N. C. (2008). The development of articulatory signatures in children. *Developmental Science, 11*(4), 467-473.

Smith, A. (1992). The control of orofacial movements in speech. *Critical Reviews in Oral Biology and Medicine, 3*(3), 233-267.

Smith, A. (Ed.). (2010). *Development of neural control of orofacial movements for speech*. West Sussex: John Wiley and Sons Ltd.

Smith, A., & Goffman, L. (Eds.). (2004). *Interactions of motor and language factors in the development of speech production*. New York: Oxford University Press.

Smith, A., & Zelaznik, H. N. (2004). Development of functional synergies for speech motor coordination in childhood and adolescence. *Developmental Psychobiology, 45*, 22-33.

Smith, M. A., Ghazisadeh, A., & Shadmehr, R. (2006). Interacting adapative processes with different timescales underlie short-term motor learning. *PLoS Biology, 4*(6), e179.

Solanas, A., Manolov, R., & Onghena, P. (2010). Estimating slope and level change in N=1 designs. *Behavior Modification, 34*(3), 195-218.

Soloman, N., & Charron. (1998). Speech breathing in able-bodied and children with cerebral palsy: A review of the literature and implications for clinical intervention. *Journal of Speech Language Pathology, 7*(2), 61-78.

Speech Pathology Association of Australia (SPA). (2003). *Scope of practice in speech pathology*. Melbourne, Victoria. Retrieved from http://www.speechpathologyaustralia.org.au/library/Core_Assoc_Doc/Scope_of_Practice.pdf.

Spencer, J., & Perone, S. (2008). Defending Qualitative Change: The view from dynamical systems theory. *Child Development, 79*(6), 1639-1647.

Square, P. A. (1999). Treatment of developmental apraxia of speech: tactile-kinesthetic, rhythmic, and gestural approaches. In A. J. Caruso & E. A. Strand (Eds.), *Clinical management of motor speech disorders in children*. New York: Thieme.

Square, P. A., Chumpelik (Hayden), D., Morningstar, D., & Adams, S. G. (1986). *Efficacy of the PROMPT system of therapy for the treatment of apraxia of speech: A follow-up intestigation*. Paper presented at the Clincial aphasiology: conference proceedings, Minneapolis.

Stamer, M. (2000). *Posture and movement of the child with cerebral palsy*. United States of America: Therapy Skill Builders.

Steeve, R. W., & Moore, C. A. (2009). Mandibular motor control during the early development of speech and nonspeech behaviours. *Journal of Speech, Language and Hearing Research, 52*, 1530-1554.

Steeve, R. W., Moore, C. A., Green, J. R., Reilly, K. J., & McMurtrey, J. (2008). Babbling, chewing, and sucking: Oromandibular coordination at 9 months. *Journal of Speech, Language and Hearing Research, 51,* 1390-1404

Stein, B. E., Wallace, M. T., & Stanford, T. R. (1999). Development of multisensory integration: transforming sensory input into motor output. *Mental Retardation and Developmental Disabilities Research Reviews, 5,* 72-85.

Stergiou, N., Harbourne, R., & Cavanaugh, J. (2006). Optimal Movement Variability: A new theoretical perspective for neurologic physical therapy. *Journal of Neurological Physical Therapy, 30*(3), 120-129.

Stinchfield, S. M., & Young, E. H. (1938). *Children with delayed or defective speech:Motor-kinesthetic factors in their training*. Stanford, California: Stanford University Press.

Stone, M., & Murano, E. Z. (2007). *Speech patterns in a muscular hydrostat: Lip, tongue and glossectomy movement.* Paper presented at the Proceedings of the Third B-J-K Symposium on Biomechanics, Healthcare and Information Science, Kanazawa, Japan.

Strand, E.A., Stoekel, R., & Baas, B. (2006). Treatment of severe childhood apraxia of speech: a treatment efficacy study. *Journal of Medical Speech-Language Pathology, 14*(4), 297-307.

Strand, E. A., & Skinder, A. (1999). Treatment of developmental apraxia of speech: integral stimulation methods. In A. J. Caruso & E. A. Strand (Eds.), *Clinical management of motor speech disorders in children.* New York: Thiemes

Sullivan, P., & Goldmann, D. (2011). The promise of comparative effectiveness research. *Journal of the American Medical Association, 305*(4), 400-401.

Tasko, S., & McClean, M. (2004). Variations in articulatory movement with changes in speech tasks. *Journal of Speech Language and Hearing Research, 47,* 85-100.

Tate, R. L., McDonald, S., Perdices, M., Togher, L., Schultz, R., & Savage, S. (2008). Rating the methodological quality of single-subject designs and n-of-1 trials: Introducing the single-case experimental design (SCED) scale. *Neuropsychological Rehabilitation, 18*(4), 385-401.

Tedroff, K., Knutson, L., & Soderberg, G. (2008). Co-activity during maximum voluntary contraction: a study of four lower-extremity muscles in children with and without cerebral palsy. *Developmental Medicine and Child Neurology, 50*, 377-381.

Temprado, J., Zanone, P. G., Monno, A., & Laurent, M. (2001). A dynamical framework to understand performance trade-offs and interference in dual tasks. *Journal of Experimental Psychology: Human Perception and Performance, 27*(6), 1303-1313.

Terband, H., Maassen, B., Van Lieshout, P. H. H. M., & Nijland, L. (2010). Stability and composition of functional synergies for speech movements in children with developmental speech disorders. *Journal of Communication Disorders, 44*(1), 59-74.

The Hanen Centre ®. (2011). Hanen Programs Retrieved 29.12.2011, from http://www.hanen.org/About-Hanen.aspx

Thelen, E., & Smith, A. (2003). Development as a dynamic system. *Trends in Cognitive Sciences, 7*(8), 343-348.

Thelen, E., & Smith, L. B. (Eds.). (2006). *Dynamic Systems Theories*: John Wiley and Sons.

Theodorus, D., Murdoch, B., & Horton, S. (1999). Assessment of dysarthric speech: A case for combined perceptual and physiological approach. *Language Testing, 16*(3), 315-351.

Thomas, B., Eyssen, M., Peeters, R., Molenaers, G., Van Hecke, P., De Cock, P., & Sunaert, S. (2005). Quantitative diffusion tensor imaging in cerebral palsy due to periventricular white matter injury. *Brain, 128*, 2562-2577.

Thompson-Ward, E. C., & Murdoch, B. E. (1998). Instrumental assessment of the speech mechanism. In B. E. Murdoch (Ed.), *Dysarthria: a physiological approach to assessment and treatment*. Cheltenham: Stanley Thornes.

Threats, T., & Worrall, L. (2004). Classifying communication disability using the ICF. *Advances in Speech Language Pathology, 6*, 53-62.

Timoszyk, W. K., deLeon, R. D., London, N., Roy, R. R., Edgerton, V. R., & Reinkensmeyer, D. J. (2002). The rat lumbosacral spinal cord adapts to robotic loading applied during stance. *Journal of Neurophysiology, 88*(6), 3108-3117.

Tjaden, K., Rivera, D., Wilding, G., & Turner, G. S. (2005). Characteristics of the lax vowel space in dysarthria. *Journal of Speech, Language and Hearing Research, 48,* 554-466.

Trahan, J., & Malouin, F. (2002). Intermittent intensive physiotherapy in children with cerebral palsy: a pilot study. *Developmental Medicine and Child Neurology, 44*(4), 233-239.

Trivedi, R., Gupta, R. K., Shah, V., Tripathi, M. R., Rathore, R. K. S., Kumar, M., . . . Narayana, P. A. (2008). Treatment-induced plasticity in cerebral palsy: a diffusion tensor imaging study. *Pediatric Neurology, 39*(5), 341-349.

Trulsson, M., & Essick, G. K. (2010). Sensations evoked by microstimulation of single mechanoreceptive afferents innervating the human face and mouth. *Journal of Neurophysiology, 103,* 1741-1747.

Trulsson, M., & Johansson, R. (2002). Orofacial mechanoreceptors in humans: encoding characteristics and responses during natural orofacial behaviors. *Behavioural Brain Research, 135,* 227-233.

Tsatanis, K., Dartnall, N., Cicchetti, D., Sparrow, S., Klin, A., & Vokmar, F. (2003). Concurrent validity and classification accuracy of the Leiter and Leiter-R in low functioning children with autism. *Journal of Autism and Developmental Disorders, 33,* 23-30.

Tsutsui, S., Lee, D. L., & Hodges, N. J. (1998). Contextual interference in learning new patterns of bimanual coordination. *Journal of Motor Behavior, 30*(2), 151-157.

Türker, K. S. (2002). Reflex Control of Human Jaw Muscles. *Critical Reviews in Oral Biology & Medicine, 13*(1), 85-104.

Türker, K. S., Johnsen, S. E., Sowman, P. F., & Trulsson, M. (2006). A study on synaptic coupling between single orofacial mechanoreceptors and human masseter muscle. *Experimental Brain Research, 170*(4), 488-500.

Ungerleider, L. G., Doyon, J., & Karni, A. (2002). Imaging brain plasticity during motor skill learning. *Neurobiology of Learning and Memory, 78*(553-564).

Van Agt, H., Verhoeven, L., Van Den Brink, G., & De Koning, H. (2010). The impact on socio-emotional development and qulaity of life of language impairment in 8-year-old children. *Developmental Medicine and Child Neurology, 53,* 81-88.

van der Merwe, A. (2009). A theoretical framework for the characterisation of pathological speech sensorimotor control. In M. R. McNeil (Ed.), *Clinical management of sensorimotor speech disorders*. New York: Thieme.

Van Lieshout, P. H. H. M. (2004). Dynamical systems theory and its application in speech. In B. Maassen, R. D. Kent, H. F. M. Peters, P. H. H. M. Van Lieshout & W. Hulstijn (Eds.), *Speech motor control in normal and disordered speech*. Oxford: Oxford University Press.

van Roon, D., Steenbergen, B., & Meulenbroek, R. G. J. (2005). Trunk use and co-contraction in cerebral palsy as regulatory mechanisms for accuracy control. *Neuropsychologica, 43*, 497-508.

Vargus-Adams, J. N., & Martin, L. K. (2009). Measuring what matters in cerebral palsy: a breadth of important domains and outcome measures. *Archives of Physical Medicine and Rehabilitation, 90*, 2089-2095.

Vereijken, B. (2010). The complexity of childhood development: variability in perspective. *PHysical Therapy, 90*(12), 1850-1859.

Vereijken, B., van Emmerik, R. E., Whiting, H. T. A., & Newell, K. M. (1992). Free(z)ing Degrees of Freedom in Skill Acquisition. *Journal of Motor Behavior, 24*(1), 133-142.

Voorman, J. M., Dallmeijer, A. J., Van Eck, M., & Schuengel, C. (2010). Social functioning and communication in children with cerebral palsy: association with disease characteristics and personal and environmental factors. *Developmental Medicine and Child Neurology, 52*, 441-447.

Walsh, B., Smith, A., & Weber-Fox. (2006). Short-term plasticity in children's speech motor systems. *Developmental Psychobiology, 48*(8), 660-674.

Wambaugh, J. L., Duffy, R., McNeil, M., Robin, D., & Rogers, S. (2006). Treatment guidelines for acquired apraxia of speech: Treatment descriptions and recommendations. *Journal of Medical Speech Language Pathology, 14*(2), xxxxv-lxvii.

Wambaugh, J. L., & Ferguson, M. (2007). Application of semantic feature analysis to retrieval of action names in aphasia. *Journal of Rehabilitation Research and Development, 44*(5), 381-394.

Wambaugh, J. L., & Mauszycki, S. (2010). Sound treatment: Application with severe apraxia of speech. *Aphasiology, 24*, 814-825.

Warren, W. H. (2006). The dynamics of perception and action. *Psychological Review, 113*(2), 358-389.

Watson, L., Blair, E., & Stanley, F. (2006). Report of the Western Australian Cerebral Palsy Register to birth year 1999. Perth: Telethon Institute for Child Health Research.

Weismer, G. (2006). Philosophy of research in motor speech disorders. *Clinical Linguistics and Phonetics, 20*(5), 315-349.

Wenke, R., Cornwell, P., & Theodoros, D. (2010). Changes to articulation following LSVT® and traditional dysarthria therapy in non-progressive dysarthria. *International Journal of Speech-Language Pathology, 12*(3), 203-220.

Whinnery, K. W., & Whinnery, S. B. (2007). MOVE systematic programming for early motor intervention. *Infants and Young Children, 20*(2), 102-198.

Whitehall, T. L. (2009). Spastic cerebral palsy. In M. R. McNeil (Ed.), *Clinical Management of sensorimotor speech disorders (2nd edition)*. New York: Thieme.

WHO. (2002). *Towards a common language for functioning, disability and health: ICF*. World Health Organization (Ed.), Retrieved from http://www.who.int/classifications/icf/site/beginners/bg.pdf

WHO. (2007). *International classification of functioning, disability and health: children and youth version (ICF-CY)*. Geneva: WHO Press.

Wichers, M., Hilbrink, S., Roebroeck, M. E., van Nieuwhuizen, O., & Stam, H. J. (2009). Motor impairments and activity limitations in children with spastic cerebral palsy: a dutch population-based study. *Journal of Rehabilitation Medicine, 41*(367-374).

Wiig, E., Secord, W., & Semel, E. (1992). *Clinical evaluation of language fundamentals - Preschool (CELF-P)*. San Antonio, Texas: The Psychological Corporation.

Wilcox, K., & Morris, S. (1999). *Children's Speech Intelligibility Measure*. San Antonio: The Psychological Corporation.

Williams, A. L. (2000). Multiple oppositions: Case studies of variables in phonological intervention. *American Journal of Speech Language Pathology, 9*(9), 289-299.

Wilston, E. C., Reed, C. M., & Braida, L. D. (2010). Integration of auditory and vibrotactile stimuli: effects of frequency. *Journal of the Acoustical Society of America, 127*(5), 3044-3059.

Wittenberg, G. F. (2009). Neural plasticity and treatment across the lifespan for motor deficits in cerebral palsy. *Developmental Medicine and Child Neurology, 51*(S4), 130-133.

Wong, J., Wilson, E. T., & Gribble, P. L. (2011). Spatially selective enhancement of proprioceptive acuity following motor learning. *Journal of Neurophysiology, 105*, 2512-2521.

Woolf, S. H. (2008). The meaning of translational research and why it matters. *American Medical Association, 299*(2), 211-213.

Workinger, M. (2005). *Cerebral palsy resource guide for speech-language pathologists*. New York: Thomson Delmar Learning.

Workinger, M., & Kent, R. (1991). Perceptual analysis of the dysarthrias in children with athetoid and spastic cerebral palsy. In C. A. Moore, K. M. Yorkston & D. R. Beukelman (Eds.), *Dysarthria and apraxia of speech. Perspectives on management*. Baltimore: Paul H Brookes Publishing Co.

Wright, F. V., Rosenbaum, P., Goldsmith, C. H., Law, M., & Fehlings, D. L. (2008). How do changes in body functions and structures, activity, and participation relate in children with cerebral palsy? *Developmental Medicine and Child Neurology, 50*(4), 283-289.

Wu, P.-Y., & Jeng, J.-Y. (2004). Efficacy comparison between two articulatory intervention approaches for dysarthric cerebral palsy (CP) children. *Asia Pacific Journal of Speech, Language and Hearing, 9*, 28-32.

Wu, W. F. W., Young, D. E., Schandler, S. L., Meir, G., Judy, R. L. M., Perez, J., & Cohen, M. J. (2011). Contextual interference and augmented feedback: Is there an additive effect on motor learning? *Human Movement Science, 30*(6), 1092-1101.

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic Bulletin and Review, 9*(2), 185-211.

Yorkston, K., & Beukelman, D. (1978). A comparison of techniques for measuring intelligibility of dysarthric speech. *Journal of Communication Disorders, 11*, 499-512.

Yorkston, K., Beukelman, D., & Bell, K. (1988). *Clinical management of dysarthric speakers*. Austin: PRO-ED.

Yoshida, S., Hayakawa, K., Yamamoto, A., Okano, S., Kanda, T., Yamori, Y., . . . Hirota, H. (2010). Quantitative diffusion tensor tractography of the motor and sensory tract in children with cerebral palsy. *Developmental Medicine and Child Neurology, 52*(10), 935-940.

Yunusova, Y., Green, J. R., Lindstrom, M. J., Ball, L. J., Pattee, G. L., & Zinman, L. (2010). Kinematics of disease progression in bulbar ALS. *Journal of Communication Disorders, 43*(1), 6-20.

Yunusova, Y., Weismer, G., Westbury, J. R., & Lindstrom, M. J. (2008). Articulatory movements during vowels in speakers with dysarthria and healthy controls. *Journal of Speech, Language & Hearing Research, 51,* 596-611.

Zanone, P. G., & Kelso, J. A. S. (1997). Coordination dynamics of learning and transfer: collective and component levels. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(5), 1454-1480.

Zhan, S., & Ottenbacher, K. J. (2001). Single subject research designs for disability research. *Disability and Rehabilitation, 23*(1), 1-8.

Zhou, X., Epsy-Wilson, C. Y., Boyce, S., Tiede, M., Holland, C., & Choe, A. (2008). A magnetic resonace imaging-based articulatory and acoustic study of "retroflex" and "bunched" american english /r/. *Journal of the Acoustical Society of America*, *123*(6), 4466-4481.

Zipoli, R. P., & Kennnedy, M. (2005). Evidence-based practice among speech-language pathologists: attitudes, utilization, and barriers. *American Journal of Speech Language Pathology, 14*(3), 208-220.

Zwicker, J. G., & Harris, S. R. (2009). A reflection on motor learning theory in pediatric occupational therapy practice. *Canadian Journal of Occupational Therapy, 76*(1), 29-37.

Every reasonable effort has been made to acknowledge the owners of copyright material. I would be pleased to hear from any copyright owner who has been omitted or incorrectly acknowledged.

APPENDICES

Appendix A

Therapy History Questionnaire

Thank you for taking the time to complete this questionnaire. This questionnaire has been written to help us understand the type of therapy your child has received in the past and how this may differ to the therapy your child will receive as part of this project.

Child's Name: ______________________

D.O.B: ______________________

Date: ______________________

Diagnosis: ______________________

Age of Diagnosis: ______________________

Seizures: ☐ Yes ☐ No

Type of seizure? ______________________

Approximately how often? ______________________

Hearing:

My child has had his/her hearing tested ☐ Yes ☐ No

Results ______________________

My child suffers from colds frequently ☐ Yes ☐ No

Vision:

My child has a visual impairment ☐ Yes ☐ No

Type ______________________

My child wears glasses ☐ Yes ☐ No

FORM FILLED IN BY:

☐ Father ☐ Mother ☐ Carer

SPEECH HISTORY

Age speech therapy commenced? ______________________

Length of time receiving services from the Association? ______________________

No of years your child has attended speech therapy? ______________________

SPEECH THERAPY SERVICES RECEIVED AT TCCP

Please tick **all** the boxes that apply.

Type of speech therapy received?

☐ Individual sessions that encouraged parents/carers to participate
☐ Individual sessions where the therapist worked with my child on their own
☐ Parent information sessions only
☐ Home Programme
☐ Computer based program (eg 'Fast forWord')
☐ Group therapy sessions that focused on speech and language skills only
☐ Group therapy sessions that focused on skills other than speech and language
☐ Other skills addressed in therapy: ____
____

Length of therapy?

☐ Weekly sessions during the school term
☐ Weekly sessions during the holidays
☐ A block of weekly therapy for _____ weeks. Number of blocks of therapy received _________
☐ Parent information workshop for _____ weeks. Type of workshop ______________________
☐ Weekly
☐ Fortnightly
☐ Other (please specify): ____

Type of therapy?

☐ Group
☐ Individual
☐ Other (please specify): ____

Speech and language skills that have been addressed in therapy:

- ☐ Making my child's speech easier to understand. Strategies used in therapy have included:
  - ☐ Pictures
  - ☐ Working in front of a mirror, including mouth exercises
  - ☐ Listening to speech sounds and matching sound to pictures
  - ☐ Teaching different speech sounds
  - ☐ Teaching different speech patterns
  - ☐ Touch cues to the face (PROMPT)
- ☐ Helping my child to communicate using signs, pictures or a communication device
- ☐ Helping my child to speak using longer sentences, such as from single words to two word combinations
- ☐ Helping my child to speak to use a larger and more varied vocabulary
- ☐ Other (please specify): ____
  ____

Is your child currently receiving private speech pathology services in conjunction to services from CPAWA? ☐ Yes ☐ No

If so how frequently? ______________________________

SPEECH SKILLS

My child is:

- ☐ Nonverbal
- ☐ Using single words
- ☐ Using single signs
- ☐ Making sounds such as vowels
- ☐ Combining words (eg short sentences)
- ☐ Combining signs and using picture symbols

My child's speech is:

☐ Unintelligible to unfamiliar listeners

☐ Intelligible to familiar listeners

☐ Intelligible when I know what my child is talking about

☐ Intelligible when supported with gestures and other visual clues

☐ Totally unintelligible

If your child did not receive speech therapy services prior to attending TCCP thank you for completing this form. There is no need to proceed any further.

SPEECH THERAPY SERVICES PRIOR TO ATTENDING TCCP

Did your child receive therapy services from elsewhere? ☐ Yes ☐ No

If yes, please tick **all** the boxes that apply:

Type of speech therapy received?

☐ Individual sessions that encouraged parents/carers to participate

☐ Individual sessions where the therapist worked with my child on their own

☐ Parent information sessions only

☐ Home Programme

☐ Computer based program (eg 'Fast forWord')

☐ Group therapy sessions that focused on speech and language skills only

☐ Group therapy sessions that focused on skills other than speech and language

☐ Other skills addressed in therapy: ____

____

<u>Length of therapy</u>?

☐ Weekly sessions during the school term

☐ Weekly sessions during the holidays

☐ A block of weekly therapy for _____ weeks. Number of blocks of therapy received _________

☐ Parent information workshop for _____ weeks. Type of workshop ______________________

☐ Weekly

☐ Fortnightly

☐ Other (please specify): ____

<u>Type of therapy</u>?

☐ Group

☐ Individual

☐ Other (please specify): ____
____

<u>Speech and language skills that have been addressed in therapy</u>:

☐ Making my child's speech easier to understand. Strategies used in therapy have included:
  - ☐ Pictures
  - ☐ Working in front of a mirror, including mouth exercises
  - ☐ Listening to speech sounds and matching sound to pictures
  - ☐ Teaching different speech sounds
  - ☐ Teaching different speech patterns
  - ☐ Touch cues to the face (PROMPT)

☐ Helping my child to communicate using signs, pictures or a communication device

☐ Helping my child to speak using longer sentences, such as from single words to two word combinations

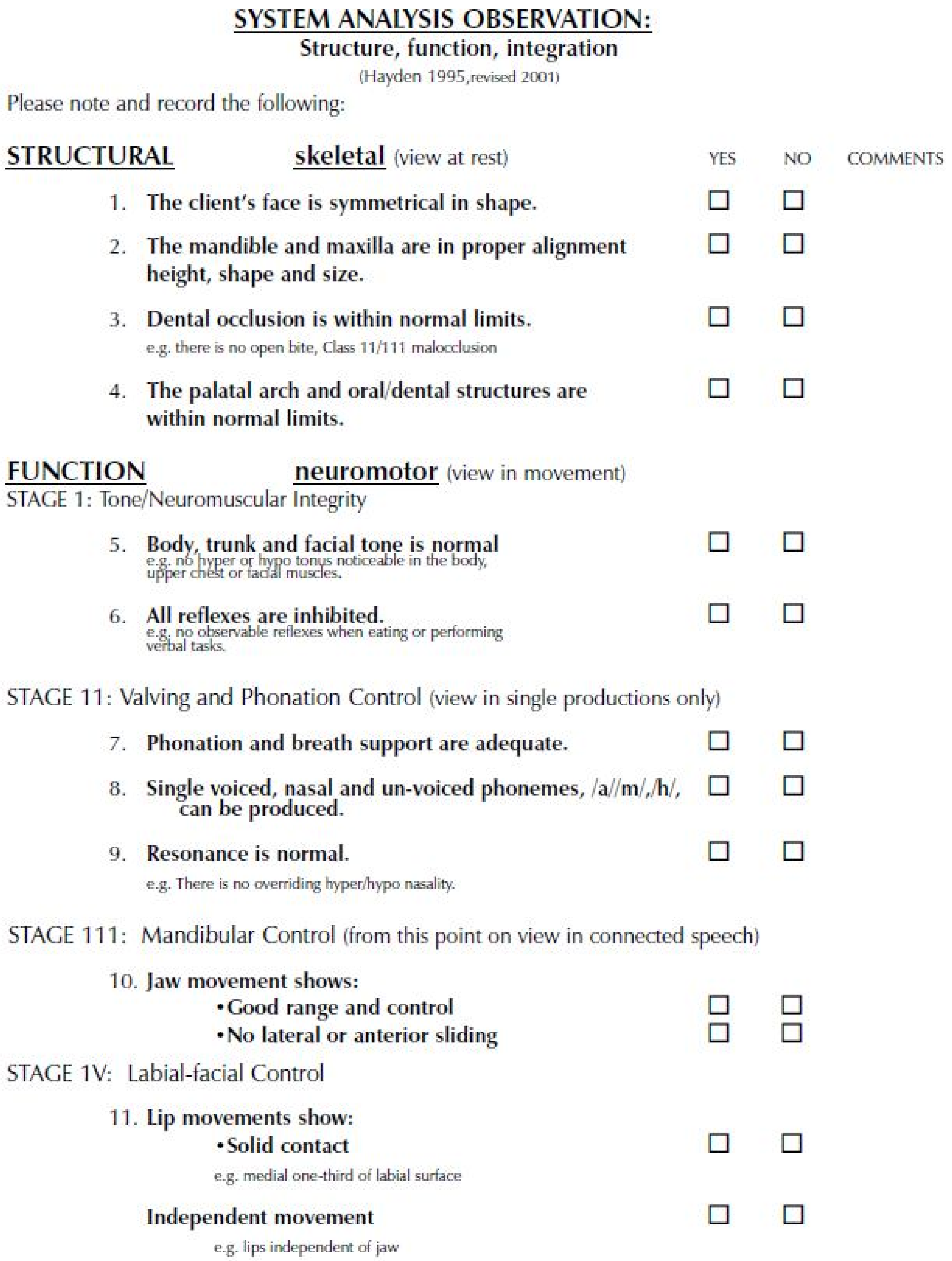
☐ Helping my child to speak to use a larger and more varied vocabulary

☐ Other (please specify): ____
____

Thank you for your time in completing this form.

Appendix B

Systems Analysis Observation



SYSTEM ANALYSIS OBSERVATION:

Structure, function, integration

(Hayden 1995,revised 2001)

Please note and record the following:

STRUCTURAL **skeletal** (view at rest)	YES	NO	COMMENTS
1. **The client's face is symmetrical in shape.**	☐	☐	
2. **The mandible and maxilla are in proper alignment height, shape and size.**	☐	☐	
3. **Dental occlusion is within normal limits.** e.g. there is no open bite, Class 11/111 malocclusion	☐	☐	
4. **The palatal arch and oral/dental structures are within normal limits.**	☐	☐	

FUNCTION **neuromotor** (view in movement)

STAGE 1: Tone/Neuromuscular Integrity

5. **Body, trunk and facial tone is normal** e.g. no hyper or hypo tonus noticeable in the body, upper chest or facial muscles.	☐	☐	
6. **All reflexes are inhibited.** e.g. no observable reflexes when eating or performing verbal tasks.	☐	☐	

STAGE 11: Valving and Phonation Control (view in single productions only)

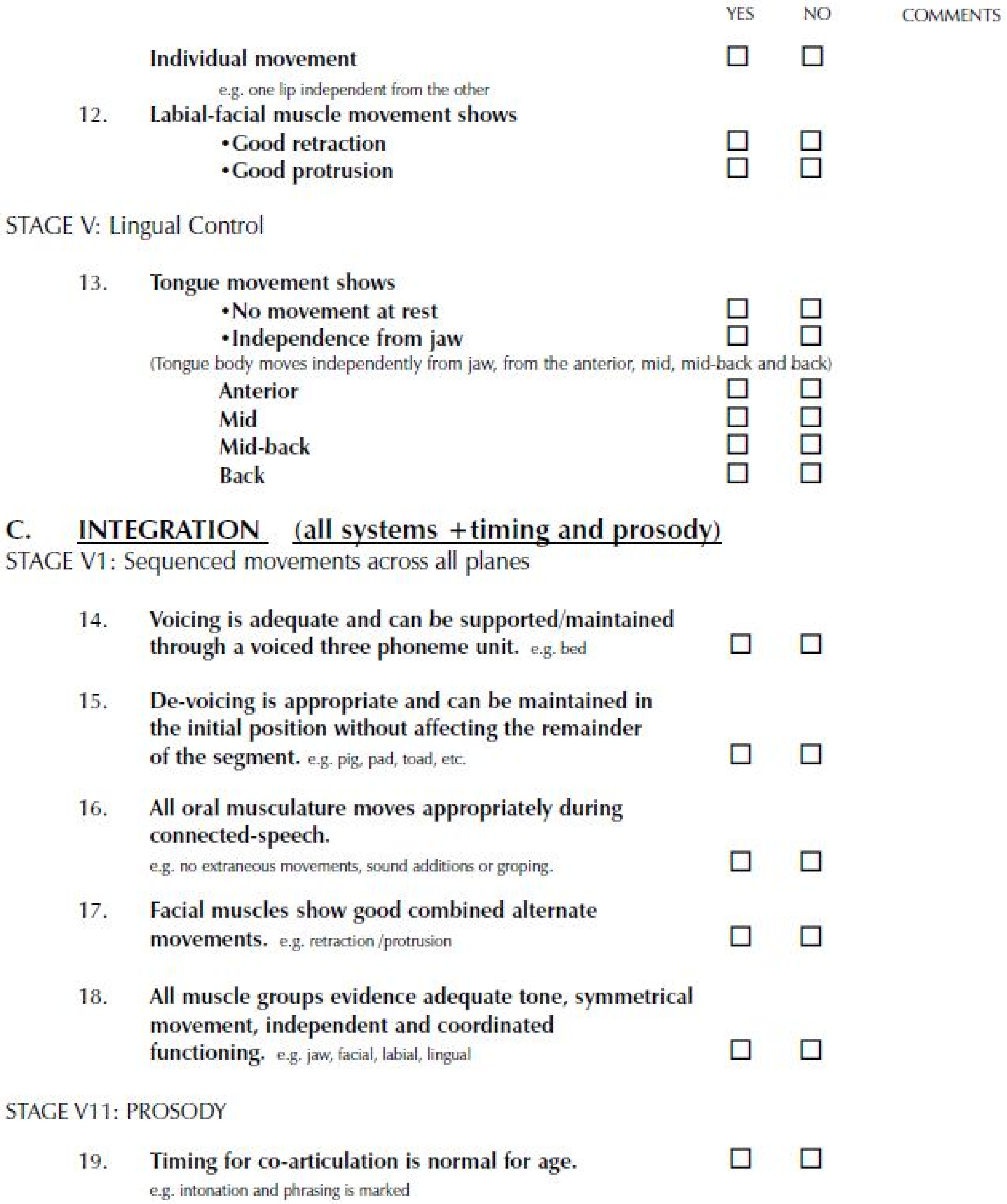
7. **Phonation and breath support are adequate.**	☐	☐	
8. **Single voiced, nasal and un-voiced phonemes, /a//m/,/h/, can be produced.**	☐	☐	
9. **Resonance is normal.** e.g. There is no overriding hyper/hypo nasality.	☐	☐	

STAGE 111: Mandibular Control (from this point on view in connected speech)

10. **Jaw movement shows:**			
•**Good range and control**	☐	☐	
•**No lateral or anterior sliding**	☐	☐	

STAGE 1V: Labial-facial Control

11. **Lip movements show:**			
•**Solid contact** e.g. medial one-third of labial surface	☐	☐	
Independent movement e.g. lips independent of jaw	☐	☐	



		YES	NO	COMMENTS
	Individual movement e.g. one lip independent from the other	☐	☐	
12.	**Labial-facial muscle movement shows**			
	•Good retraction	☐	☐	
	•Good protrusion	☐	☐	

STAGE V: Lingual Control

		YES	NO	COMMENTS
13.	**Tongue movement shows**			
	•No movement at rest	☐	☐	
	•Independence from jaw	☐	☐	
	(Tongue body moves independently from jaw, from the anterior, mid, mid-back and back)			
	Anterior	☐	☐	
	Mid	☐	☐	
	Mid-back	☐	☐	
	Back	☐	☐	

C. INTEGRATION (all systems +timing and prosody)

STAGE V1: Sequenced movements across all planes

		YES	NO	COMMENTS
14.	**Voicing is adequate and can be supported/maintained through a voiced three phoneme unit.** e.g. bed	☐	☐	
15.	**De-voicing is appropriate and can be maintained in the initial position without affecting the remainder of the segment.** e.g. pig, pad, toad, etc.	☐	☐	
16.	**All oral musculature moves appropriately during connected-speech.** e.g. no extraneous movements, sound additions or groping.	☐	☐	
17.	**Facial muscles show good combined alternate movements.** e.g. retraction /protrusion	☐	☐	
18.	**All muscle groups evidence adequate tone, symmetrical movement, independent and coordinated functioning.** e.g. jaw, facial, labial, lingual	☐	☐	

STAGE V11: PROSODY

		YES	NO	COMMENTS
19.	**Timing for co-articulation is normal for age.** e.g. intonation and phrasing is marked	☐	☐	

From The PROMPT Introduction to Technique Manual by Hayden (2003).

Copyright 1994 by the PROMPT Institute. Reprinted with permission.

Appendix C

Canadian Occupational Performance Measure

PARENT SATISFACTION SURVEY

Name: ______________________________

Date: ______________________________

Circle the relevant evaluation period:

1. Pre-treatment
2. End of first treatment cycle
3. End of second treatment cycle
4. Follow-up appointment

1. **Ability to be understood by immediate family members, using words:**

☐ Importance ☐ Performance ☐ Satisfaction

2. **Ability to be understood by extended family members, using words:**

☐ Importance ☐ Performance ☐ Satisfaction

3. **Ability to be understood by friends/ peers:**

☐ Importance ☐ Performance ☐ Satisfaction

4. **Normality of facial movements during speech:**

☐ Importance ☐ Performance ☐ Satisfaction

5. **Able to follow routine instructions at home:**

☐ Importance ☐ Performance ☐ Satisfaction

6. **Able to follow routine instructions at school:**

☐ Importance ☐ Performance ☐ Satisfaction

7. **Play opportunities outside of the family home with friends:**

☐ Importance ☐ Performance ☐ Satisfaction

9. **Able to attend to and complete table top activities for _____ minutes:**

☐ Importance ☐ Performance ☐ Satisfaction

10. **Enjoys going to school/kindy/childcare:**

☐ Importance ☐ Performance ☐ Satisfaction

11. **Able to respond to changes in routine without distress:**

☐ Importance ☐ Performance ☐ Satisfaction

12. **Able to express emotions and feelings to family members and friends :**

☐ Importance ☐ Performance ☐ Satisfaction

13. **Able to problem solve unexpected situations in the daily routine:**

☐ Importance ☐ Performance ☐ Satisfaction

RATING SCALE

IMPORTANCE

1 2 3 4 5 6 7 8 9 10

Not important at all Extremely Important

PERFORMANCE

1 2 3 4 5 6 7 8 9 10

Not able Does it extremely well

SATISFACTION

1 2 3 4 5 6 7 8 9 10

Not satisfied Extremely satisfied

Appendix D

Speech Probe Wordlists

Table D1

Speech Probes for P1

	LABIAL-FACIAL		**LINGUAL**		**SEQUENCING**
	TRAINED	**UNTRAINED**	**TRAINED**	**UNTRAINED**	**CONTROL**
1	POUR	MORE	NOT	NUT	BABY
2	BALL	BOUGHT	BAT	PAT	SCARF
3	WHY	YOU	MAN	MINE	SCOOP
4	WHO	WAY	TAP	PART	SNEAK
5	OFF	IF	MAT	MUT (DOG)	SNAKE
6	SHOE	CHEW	BAD	BAG	LITTLE
7	BOA(T)	MOA(T)	BIRD	BURNT	ORANGE
8	SHORE	SHOR(T)	HOUSE	HOSE	GREEN
9	PUSH	BUSH	PUT	POT	PARTY
10	PEEP	BEEP	HOT	HAT	SLEEP
11	WOR(K)	WAL(K)	BUT	PUT (GOLF)	CHOICE
12	WASH	WISH	DOT	KNOT	TACO
13	PUSH	BUSH	SHOT	SHOOT	TEACHER
14	BOAT	BOW	EIGHT	EAT	TOAST
15	OPEN	BONE	TOOL	FOOL	TRAIN
16	MOON	MOAN	SAD	LAD	BREAD
17	PIE	PEA	TOP	TYPE	SLICE
18	MATCH	WATCH	WATER	DAUGHTER	ANGRY
19	PUPPY	BABY	BUTTER	BETTER	CLEAN
20	DIRTY	FORTY	BAIT	BITE	DAMP

Table D2

Speech Probes for P2

	MANDIBULAR		**LABIAL-FACIAL**		**LINGUAL**
	TRAINED	**UNTRAINED**	**TRAINED**	**UNTRAINED**	**CONTROL**
1	POP	MOP	SHOE	CHEW	SAT
2	MUM	MAP	SHOP	SHUT	SPIN
3	NO	TOE	SHOO(T)	SHOE	COAT
4	HOP	HAM	B(L)UE	MOO	DIG
5	UP	HUM	WHY	WAY	SACK
6	MY	NIGH	YOU	DO	SIP
7	ON	ODD	SHIP	CHIP	PLAY
8	PAN	PAT	FOUR	DOOR	SMACK
9	HOT	POT	OFF	PUFF	NOTE
10	HOME	BONE	NOW	WOW	BRING
11	ONE	DONE	BEEP	BEAD	STOOL
12	MINE	MANE	WASH	WISH	SIT
13	DOWN	BROWN	PUSH	BUSH	SPOT
14	BUN	DONE	BOW	MOW	GOAT
15	ON	UNDER (UNDA)	OPEN	BONE	DOG
16	BAT	BAN	WHOA	WATER	SOCK
17	MAN	NAN	NO	DOUGH	SUN
18	PIE	BYE	ME	BEE	PLANE
19	PUT (golf)	BUT	PUPPY	BABY	SMOKE
20	BITE	BAIT	WHO	NEW	LIGHT

Table D3

Speech Probes for P3

	MANDIBULAR		**LABIAL-FACIAL**		**LINGUAL**
	TRAINED	**UNTRAINED**	**TRAINED**	**UNTRAINED**	**CONTROL**
1	POP	MOP	SHOE	CHEW	SAT
2	MUM	MAP	SHOP	SHUT	SPIN
3	MOON	HOOP	SHOOT	SHOE	COAT
4	HOP	HAM	B(L)UE	MOO	DIG
5	UP	HUM	WHY	WAY	SACK
6	MY	BYE	YOU	DO	SIP
7	POUR	MORE	SHIP	CHIP	PLAY
8	PAN	PAT	FOUR	DOOR	SMACK
9	HOT	POT	OFF	PUFF	NOTE
10	HOME	BONE	NOW	WOW	BRING
11	ONE	DONE	WOR(K)	WAL(K)	STOOL
12	MINE	MANE	WASH	WISH	SIT
13	DOWN	BROWN	PUSH	BUSH	SPOT
14	BUN	FUN	BOAT	BOW	GOAT
15	ON	UNDER (UNA)	OPEN	BONE	DOG
16	BAT	BAG	WHOA	WATER	SOCK
17	MAN	NAN	NO	DOUGH	SUN
18	POOH	BOO	ME	BEE	PLANE
19	PUT	ROUND	FOUND	POOP	SMOKE
20	BOOT	BOOK	BEED	BEEP	KNOT

Table D4

Speech Probes for P4

	LABIAL-FACIAL		**LINGUAL**		**SEQUENCING**
	TRAINED	**UNTRAINED**	**TRAINED**	**UNTRAINED**	**CONTROL**
1	HOME	HAM	BUTTER	BETTER	SOCCER
2	HOPE	HOP	BUSHES	PUSHES	BASKET
3	SHOOT	SHOE	PEACHES	BEACHES	BANDAID
4	SHOP	CHOP	BATTER (PANCAKES)	BITTER	BODY
5	PUSH	BUSH	HAPPY	HOPPY (NAME OF KANGAROO)	BLOCK
6	WASH	WATCH	SORE	DOOR	BROKE
7	WARM	WARN	SHOW ME	SEE SAW	CANDLE
8	SHEEP	CHEEP	SEE	TEA	CEREAL
9	BONE	PHONE	TEAM	SEAM	CHIMNEY
10	MOON	MOAN	WATER	WAITER	CIRCLE
11	POO	BOO	DOUGH	TOE	DONUT
12	WOA	BOW	EAT	MEAT	FINGER
13	MUMMY	MONEY	TOP	TAP	ICECREAM
14	BOA(T)	BOO(T)	SOCK	SACK	JUMP
15	BEAN	MEAN	BAT	BAD	LETTER
16	ME	BEE	BIKE	BAKE	LIGHT
17	BALL	MORE	RED	RAT	LITTLE
18	BEEP	PEEP	BUNNY	MONEY	MILK
19	WHO	WHOO	BED	PEG	NOODLE
20	PAY	NEIGH	MAT	MUD	ORANGE

Table D5

Speech Probes for P5

	MANDIBULAR		**LABIAL-FACIAL**		**LINGUAL**
	TRAINED	**UNTRAINED**	**TRAINED**	**UNTRAINED**	**CONTROL**
1	POP	MOP	SHOE	CHEW	SAT
2	PIG	BIT	SHOP	SHUT	TURN
3	MOON	BOOT	SHOOT	SHOE	COAT
4	HOP	HAM	BABY	PUPPY	DIG
5	UP	HUM	PUPPY	POPPY	SACK
6	MY	BYE	BUNNY	MUMMY	SIP
7	DOT	DIP	SHIP	CHIP	KISS
8	PAIN(T)	PANT	MATCH	CATCH	KICK
9	BEE	ME	HAPPY	NAPPY	NOTE
10	HOME	BONE	NOW	WOW	GOOD
11	ONE	DONE	WALK	WING	CAT
12	MINE	MANE	WASH	WISH	SIT
13	DOWN	B(R)OWN	PUSH	BUSH	LIGHT
14	BUN	(S)UN	BOAT	BOW	GOAT
15	ON	UNDER (UNA)	BOOK	BOOT	DOG
16	BAT	BACK	YOU	DO	SOCK
17	MAN	NAN	NO	NOSE	SUN
18	MORE	POUR	WHY	WAY	PLANE
19	WANT		PULL	PUT	LOOK
20	BOOK	BOOT	BEED	BEEP	KNOT

Table D6

Speech Probes for P6

	MANDIBULAR		**LABIAL-FACIAL**		**LINGUAL**
	TRAINED	**UNTRAINED**	**TRAINED**	**UNTRAINED**	**CONTROL**
1	BAA (SHEEP)	MAA (GOAT)	POOH	MOO	SAT
2	ARM	AM	NOW	WOW	CUP
3	ONE	DONE	YOU	DO	COAT
4	BUBBLE (BABAL)	PAPA	WASH	WISH	DUCK
5	UP	HA (HIGH)	PUSH	BUSH	SACK
6	MY	BYE	BOAT	BOW	SIP
7	BA (BALL)	MA (MUM)	NO	DOUGH	PLANE
8	PAN	PAT	WATER	OW OW (SORE)	HOUSE
9	HOT	POT	BOW	MOW	NOTE
10	POP	MOP	GO	WHOA	GIRL
11	ONE	DONE	SHOE	SHOW	BIG
12	MINE	MANE	MOON	(S)POON)	SIT
13	ON	UNA (UNDER)	BOW	BOA(T)	CHEESE
14	MORE	POUR	BEE	PEA	GOAT
15	MAN	NAN	OH OH	PO(LE)	DOG
16	PUP	BUB	EAR	HERE	SOCK
17	MY	EYE	B(L)UE	DO	SUN
18	DOWN	OU(T)	BIR(D)	PURR (CAT)	PLANE
19	BA(T)	PA(T)	HOME	WORM	CAKE
20	PAN	MAN	BEEP	PEEP	KNOT

Appendix E

Calculations used to Derive the Kinematic Measures

Movement Plane	Measures	Anatomical Plane	Word-boundary	Calculation	Words Analysed
DISTANCE					
Mandibular	1 JPD	3D	Acoustic	Sum of the 3D Euclidian distance between each time sample of the marker MM	All
	2 JOD	3D	Acoustic	Maximum jaw opening distance [Distance (MCAL - MM)] - [RestDistance (MCAL - MM)]	All
	3 JLDM	Horizontal	Acoustic	Average lateral deviation from midline [MBI-rest]	All
	4 JHP	Vertical		Derived from JOD during statistical analysis	All
Labial-Facial	5 LRR	Horizontal	Acoustic	Maximum distance between the right (ROO) and left (LOO) lip corners [Distance (ROO-LOO)-RestDistance(ROO-LOO)]	All
	6 BLC	Vertical	Movement.	Euclidian distance between the vMCA and MBI marker in the vertical plane [vMCA-MBI]	Mine, man, push, beep
POSITION	*LL	Vertical	Movement	Average position at point of minimum BLC MBI-MBI (Rest)	Mine, man, push, beep,
	UL	Vertical	Movement	Average position at point of minimum BLC vMCA-(Rest)	Mine, man, push, beep,
DURATION	7		Acoustic	Total duration in the acoustic boundary calculated using the MBI marker (LL + J)	All
VELOCITY	8		Acoustic	Peak velocity in the MBI marker (LL +J)	All

Appendix F

Position and Anatomical Location of the Facial Markers

Marker	**Marker Name**	**Anatomical Location**
2	MCAL	Calibration markers placed 2cm above marker 4.
1 and 3	LCAL and RCAL	Calibration markers located laterally 1cm either side of marker 2.
4	FCAL	Calibration marker located on the midline of the nasal bridge and in line with the medial canthi.
5	NOSE	Nasal tip.
6 and 10	LOO and ROO	The left and right corners of the mouth located on the commissure points.
7 and 9	LCA and RCA	Right and left upper lip points located on the peak of Cupid’s bow.
8	vMCA	Virtual marker half-way between LCA and RCA.
12	MBI	Mid-lower-point located on the lower lip vermillion.
11 and 13	LBI and RBI	Left and right lower lip points located below the lateral incisors on the lower lip vermillion.
14	MM	Mid-chin point located on the mental protuberance 2cm below marker 12.
15 and 16	LM and RM	Left and right chin points located laterally 2cm either side of marker 14.
17 and 18	LMC and RMC	Mandibular condyle left and right.

Appendix G

Performance on the Motor Speech Movement Patterns and Perceptual Accuracy across the Intervention Priorities and Study Phases for the Participants

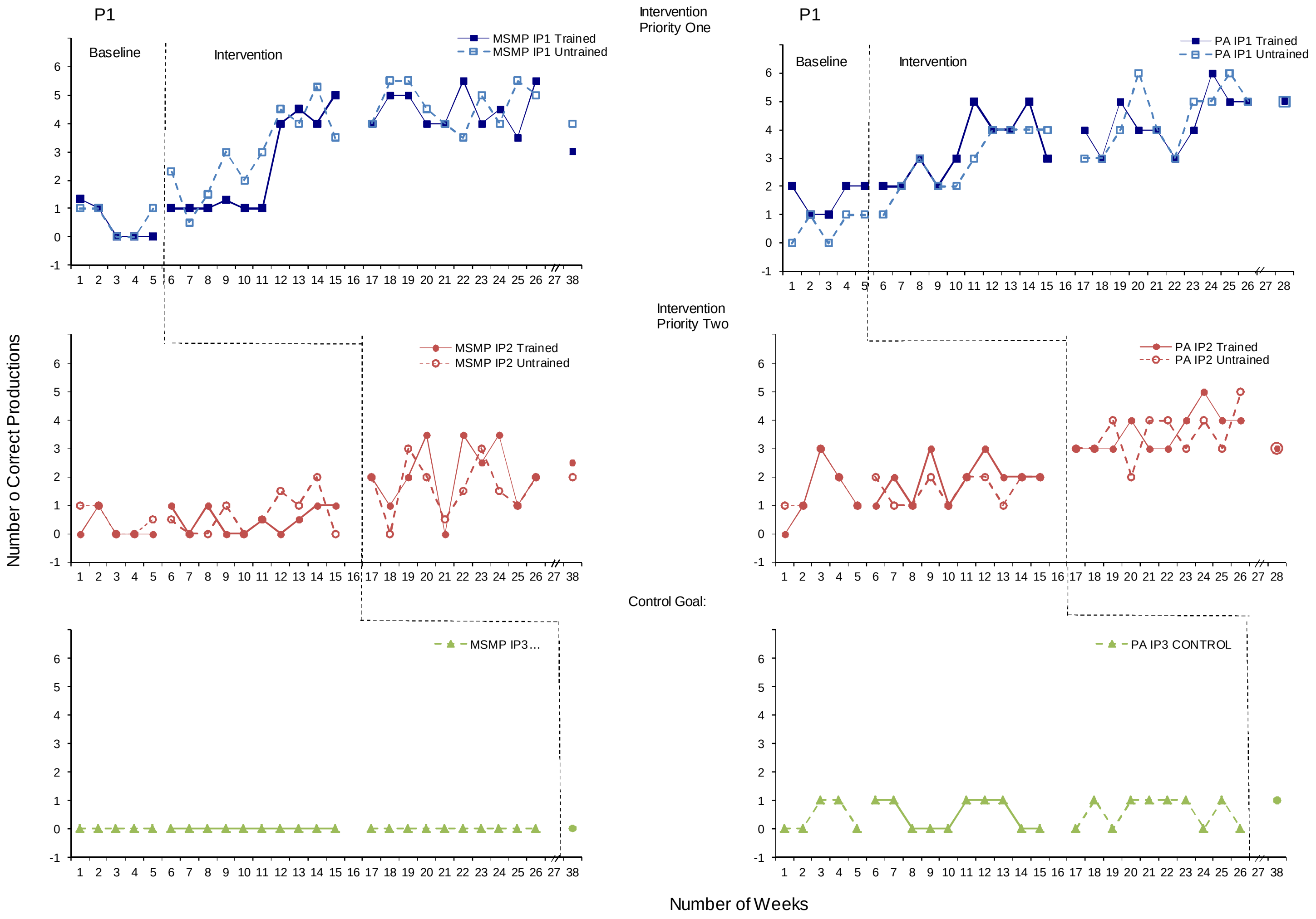


Figure G.1. Accuracy of performance on the speech probes as scored for motor speech movement patterns and perceptual accuracy across the intervention priorities and study phases for P1

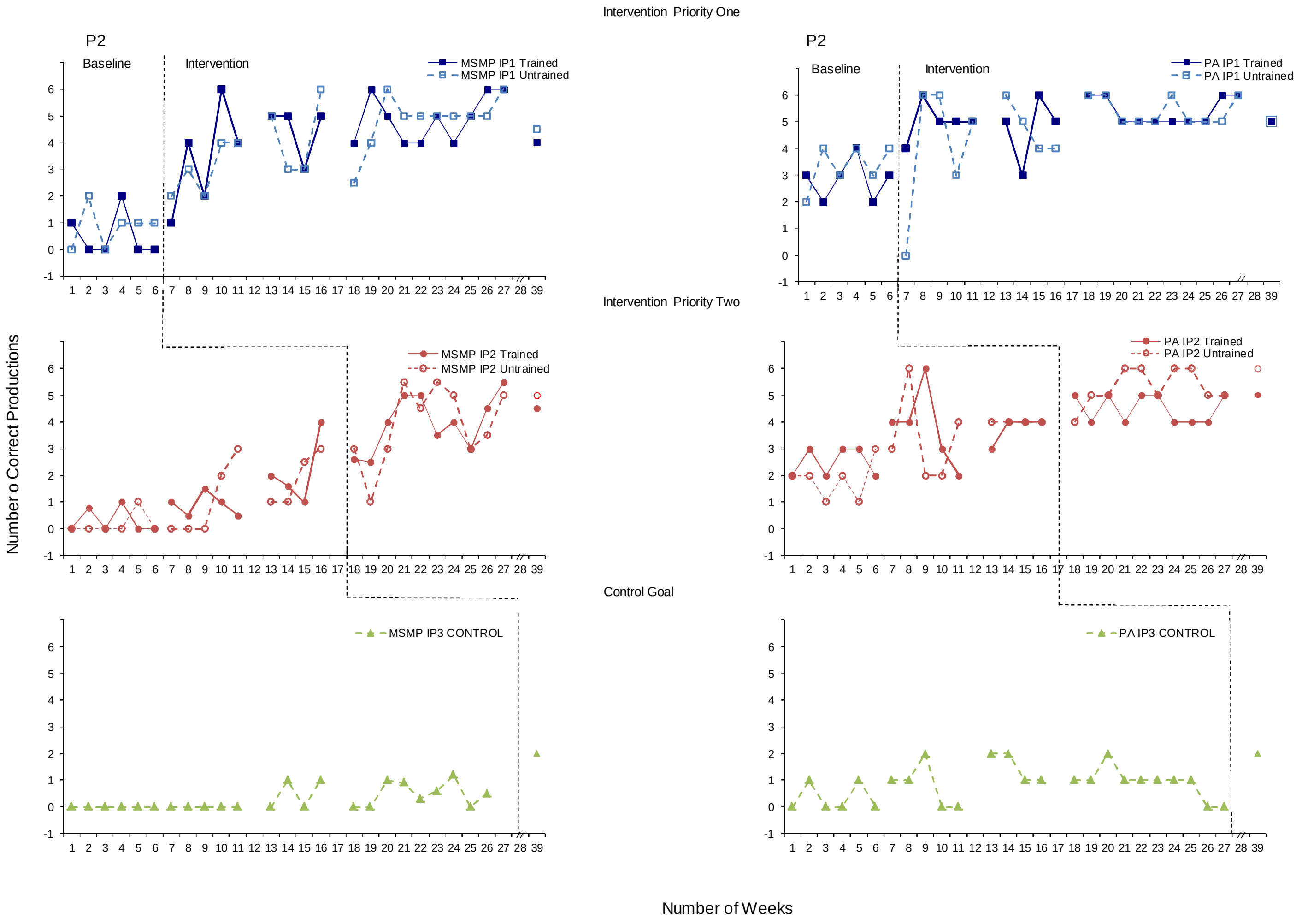


Figure G.2. Accuracy of performance on the speech probes as scored for motor speech movement patterns and perceptual accuracy across the intervention priorities and study phases for P2

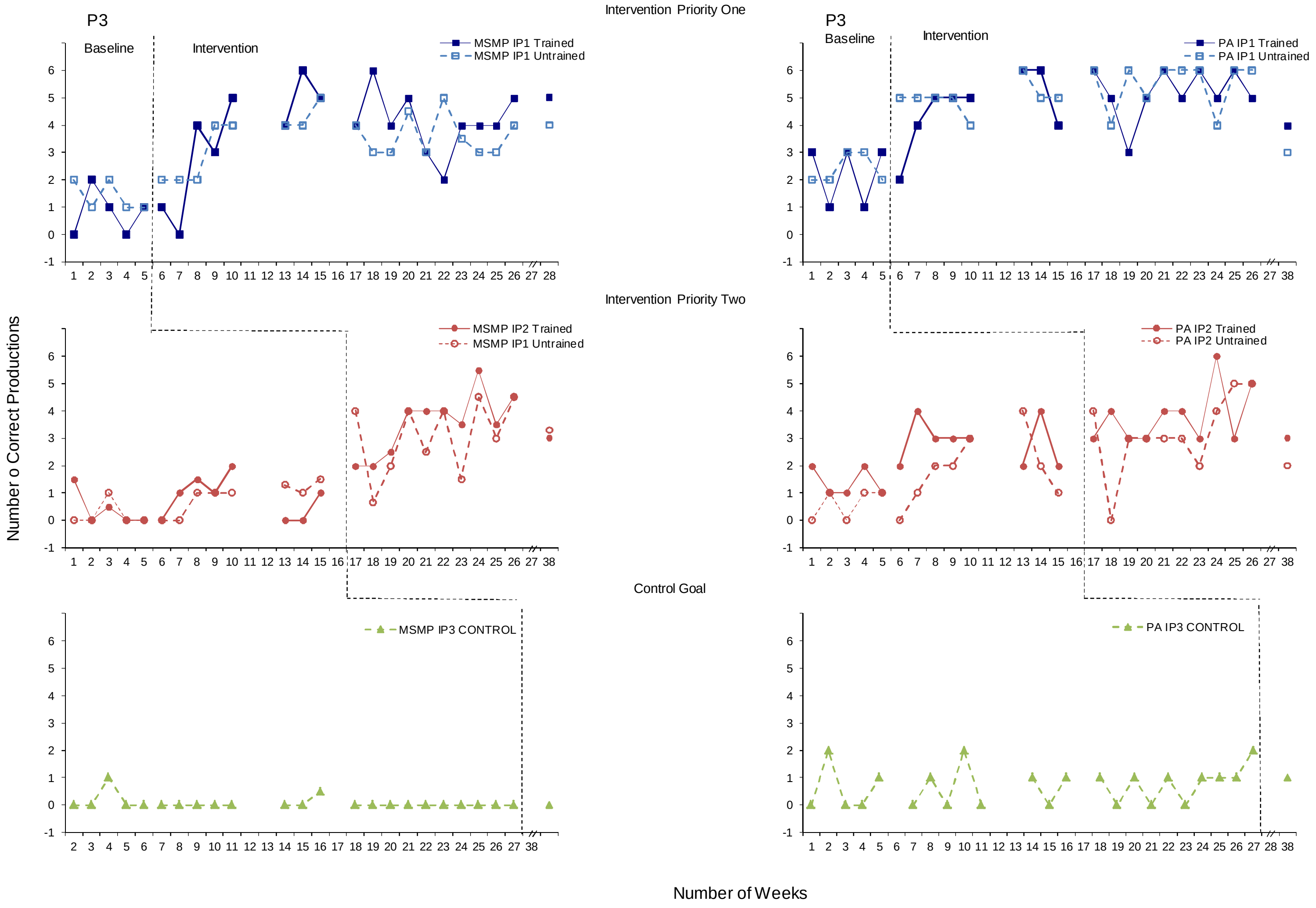


Figure G.3. Accuracy of performance on the speech probes as scored for motor speech movement patterns and perceptual accuracy across the intervention priorities and study phases for P2

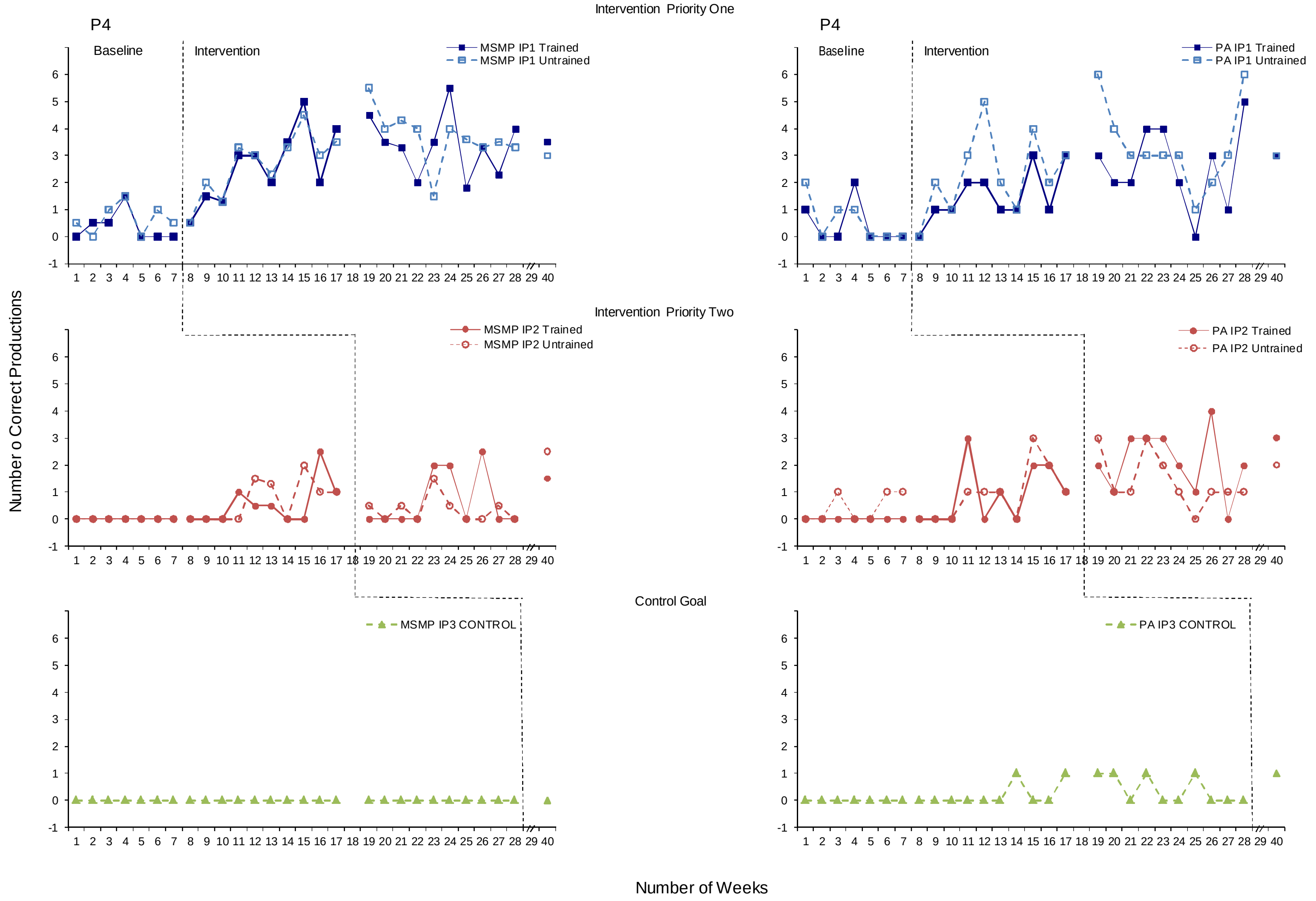


Figure G.4. Accuracy of performance on the speech probes as scored for motor speech movement patterns and perceptual accuracy across the intervention priorities and study phases for P4

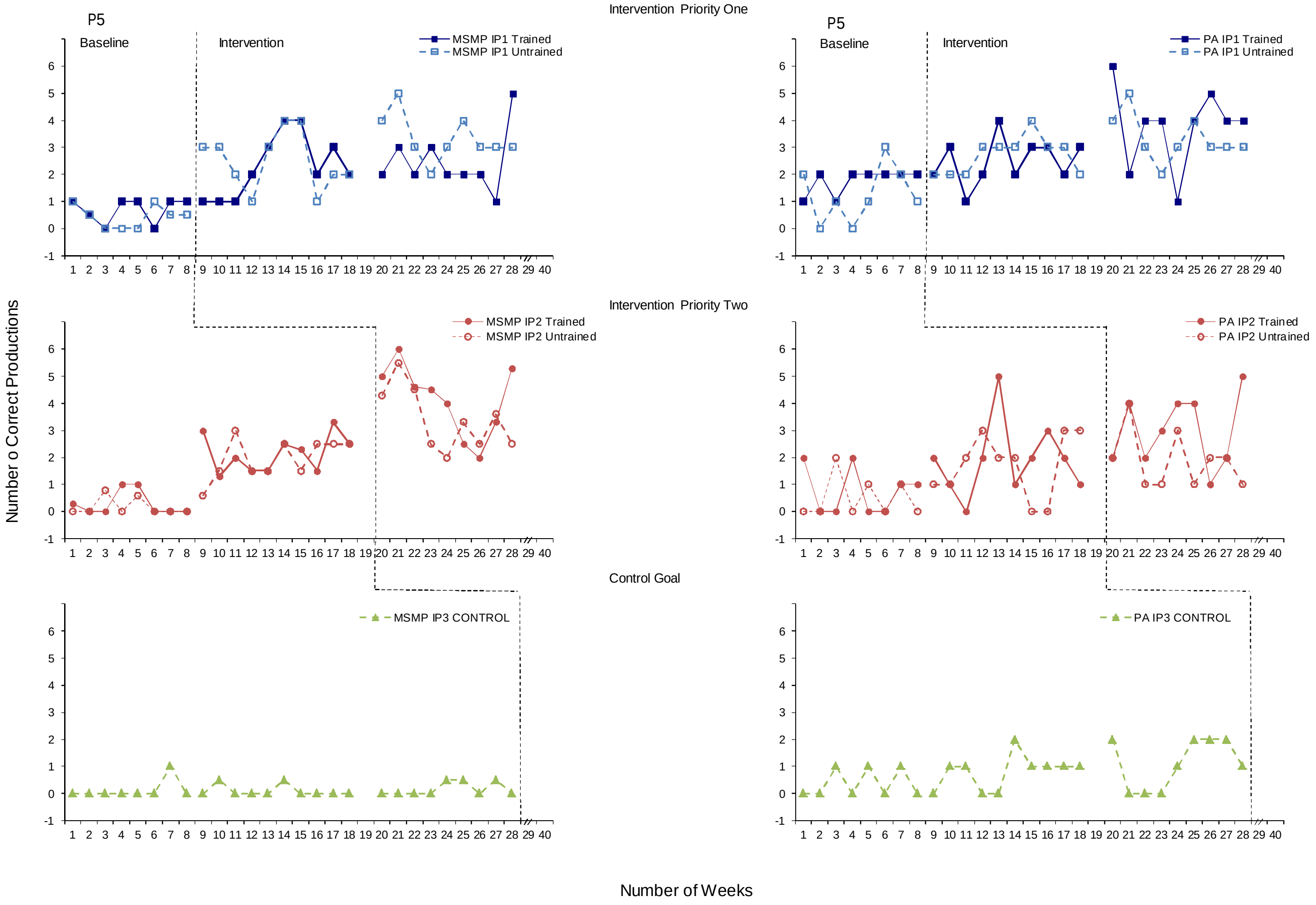


Figure G.5. Accuracy of performance on the speech probes as scored for motor speech movement patterns and perceptual accuracy across the intervention priorities and study phases for P5

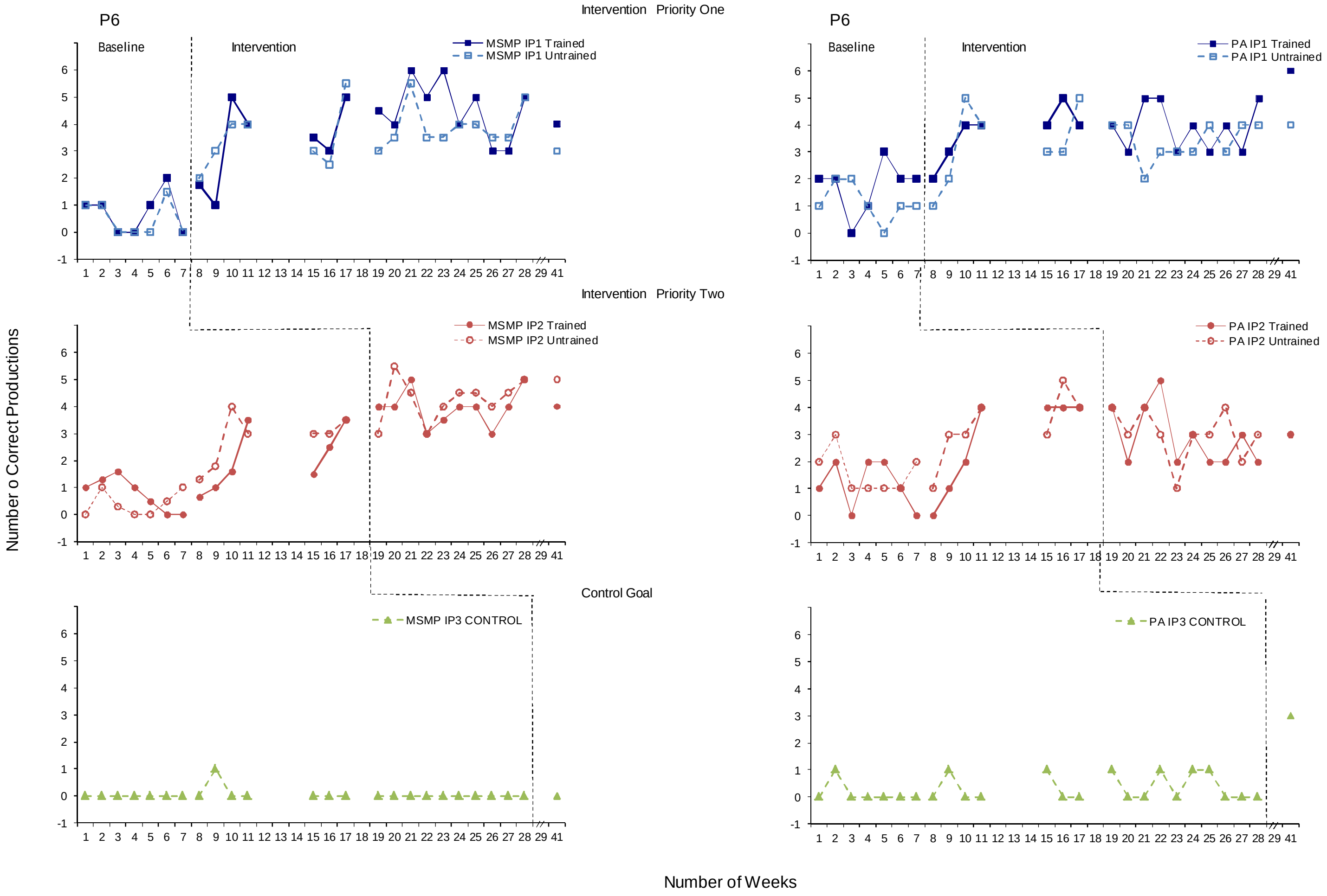


Figure G.6. Accuracy of performance on the speech probes as scored for motor speech movement patterns and perceptual accuracy across the intervention priorities and study phases for P6

Appendix H

Results obtained on the Canadian Occupational Performance Measure

Table H1

Results obtained on the Friedman's ANOVA and Wilcoxon Signed-Rank Test for the Individual Items of the Canadian Occupational Performance Measure

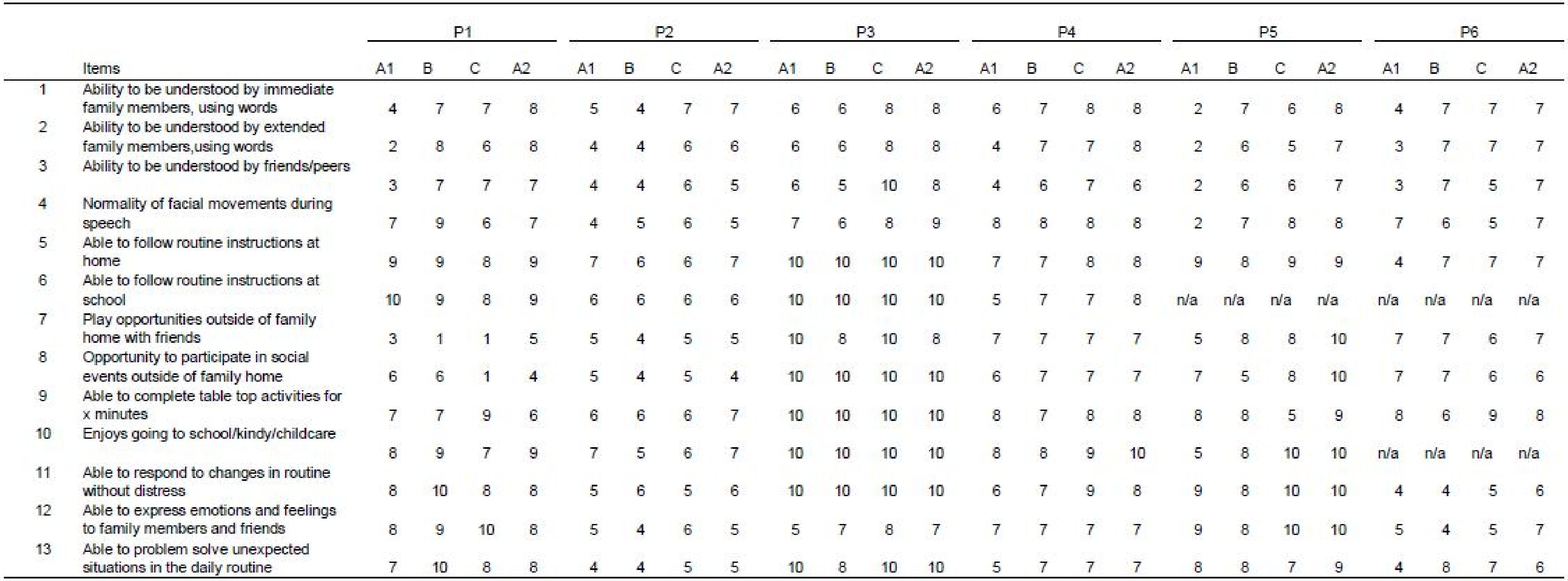
PROMPT	ICF		Friedman's ANOVA Main Effects (df 3)		Pairwise comparisons -Wilcoxon Signed-Rank Test					
					A1-B		B-C		A1-A2	
Domain	No.	COPM: Individual Questions	χ2	*p*	Z	*p*	Z	*p*	Z	*p*
						Performance				
P-S	3	Ability to be understood by immediate family members, using words	13.11	.001*	-1.633	.094	-1.289	.188	-2.226	.016*
P-S	3/7	Ability to be understood by extended family members, using words	13.02	.001*	-1.841	.063	-0.378	.500	-2.214	.016*
P-S	3/7	Ability to be understood by friends/peers	10.79	.006*	-1.786	.063	-0.921	.250	-2.214	.016*
P-S	-	Normality of facial movements during speech	2.54	.019*	-0.962	.250	-0.137	.500	-1.604	.125
C-L	2	Able to follow routine instructions at home	3.35	.443	0	.625	-0.577	.500	-1.342	.250
C-L	2	Able to follow routine instructions at school	1.50	.917	-0.447	.250	-1	.500	-0.447	.250
S-E	9	Play opportunities outside of family home with friends	3.16	.382	-0.368	.438	-0.816	.375	-0.816	.375
S-E	9	Opportunity to participate in social events outside of family home	0.22	.990	-0.816	.375	-0.184	.500	-0.137	.500
C-L	1	Able to complete table top activities for x minutes	2.85	.468	-1.342	.250	-0.552	.375	-0.577	.500
S-E	8	Enjoys going to school/kindy/childcare	4.75	.225	-0.535	.375	-0.557	.375	-1.604	.125
S-E	2	Able to respond to changes in routine without distress	5.00	.170	-1.134	.250	-0.552	.406	-1.857	.063
S-E	3	Able to express emotions and feelings to family members and friends	7.67	.047*	0	.625	-2.070	.031	-1.633	.125
C-L	1	Able to problem solve unexpected situations in the daily routine	4.50	.223	-1.289	.188	-0.276	.500	-2.07	.031
						Satisfaction				
P-S	3	Ability to be understood by immediate family members, using words	12.64	.001*	-1.826	.063	-.106	.500	-2.226	.016*
P-S	3/7	Ability to be understood by extended family members,using words	11.09	.005*	-2.032	.031	-.740	.297	-2.201	.016*
P-S	3/7	Ability to be understood by friends/peers	9.78	.012*	1.633	.125	1.518	.125	2.023	.031

P-S	-	Normality of facial movements during speech	14.31	<.001*	2.121	.031	1.069	.250	2.214	.016*
C-L	2	Able to follow routine instructions at home	7.53	.051	1	.312	1.732	.125	1.633	.125
C-L	2	Able to follow routine instructions at school	3.60	.354	0.272	.500	0	.750	0.447	.500
S-E	9	Play opportunities outside of family home with friends	2.06	.611	0	.625	0.447	.500	1.069	.250
S-E	9	Opportunity to participate in social events outside of family home	1.22	.806	0	.750	0	.625	0.447	.500
C-L	1	Able to complete table top activities for x minutes	1.98	.600	0.687	.281	0.368	.375	0.272	.500
S-E	8	Enjoys going to school/kindy/childcare	6.08	.113	0	.625	1.633	.125	1.289	.188
S-E	2	Able to espond to changes in routine without distress	4.50	.220	0.743	.250	0.577	.500	2.121	.031
S-E	3	Able to express emotions and feelings to family members and friends	1.36	.762	0.378	.500	0.378	.500	1.089	.188
C-L	1	Able to problem solve unexpected situations in the daily routine	4.66	.209	1.166	.141	0.687	.281	1.089	.188

Note: P-S =physical-sensory, C-L = cognitive-linguistic, S-E = social-emotional, ICF no = Activity and Participation subdomains of the ICF, where 1 = learning and applying knowledge, 2 = general tasks and demands, 3 = communication, 7 = interpersonal interactions and relationships, 8 = major life areas, 9 = community, social and civil life.
*=p<.05.

Table H2

Performance Scores for the Individual Items of the Canadian Occupational Performance Measure for Each Participant

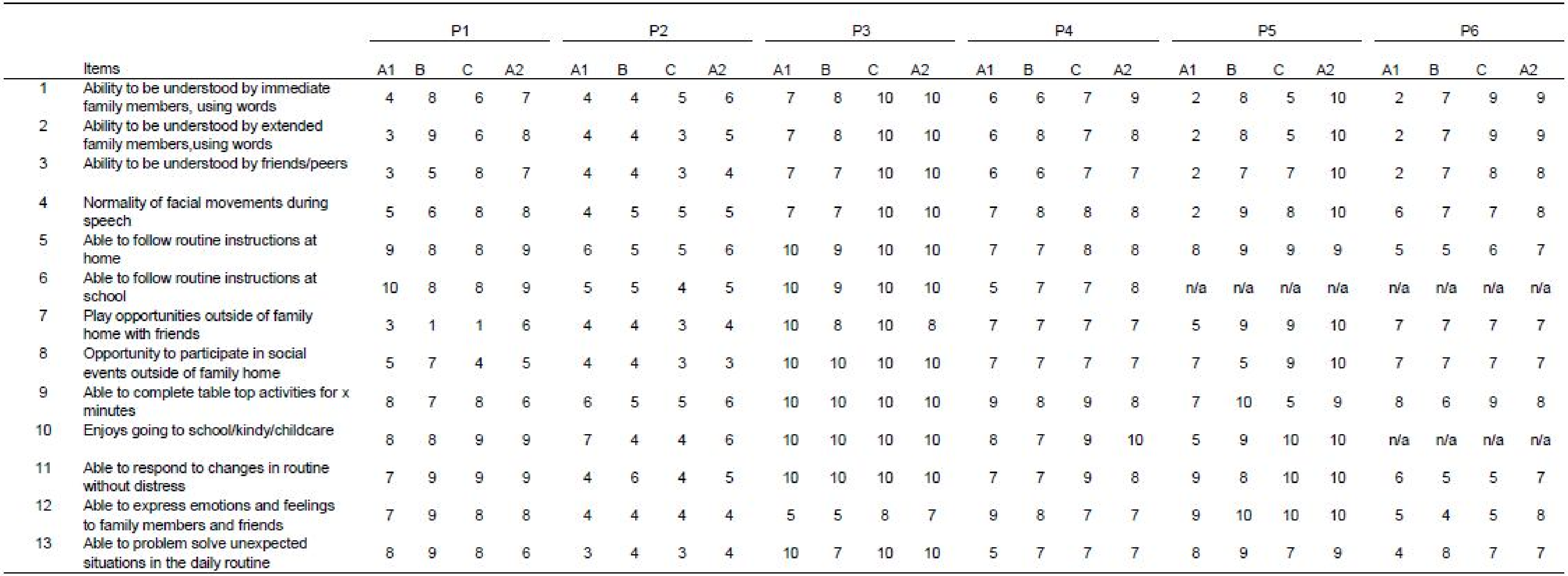


		P1				P2				P3				P4				P5				P6			
	Items	A1	B	C	A2	A1	B	C	A2	A1	B	C	A2	A1	B	C	A2	A1	B	C	A2	A1	B	C	A2
1	Ability to be understood by immediate family members, using words	4	7	7	8	5	4	7	7	6	6	8	8	6	7	8	8	2	7	6	8	4	7	7	7
2	Ability to be understood by extended family members,using words	2	8	6	8	4	4	6	6	6	6	8	8	4	7	7	8	2	6	5	7	3	7	7	7
3	Ability to be understood by friends/peers	3	7	7	7	4	4	6	5	6	5	10	8	4	6	7	6	2	6	6	7	3	7	5	7
4	Normality of facial movements during speech	7	9	6	7	4	5	6	5	7	6	8	9	8	8	8	8	2	7	8	8	7	6	5	7
5	Able to follow routine instructions at home	9	9	8	9	7	6	6	7	10	10	10	10	7	7	8	8	9	8	9	9	4	7	7	7
6	Able to follow routine instructions at school	10	9	8	9	6	6	6	6	10	10	10	10	5	7	7	8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7	Play opportunities outside of family home with friends	3	1	1	5	5	4	5	5	10	8	10	8	7	7	7	7	5	8	8	10	7	7	6	7
8	Opportunity to participate in social events outside of family home	6	6	1	4	5	4	5	4	10	10	10	10	6	7	7	7	7	5	8	10	7	7	6	6
9	Able to complete table top activities for x minutes	7	7	9	6	6	6	6	7	10	10	10	10	8	7	8	8	8	8	5	9	8	6	9	8
10	Enjoys going to school/kindy/childcare	8	9	7	9	7	5	6	7	10	10	10	10	8	8	9	10	5	8	10	10	n/a	n/a	n/a	n/a
11	Able to respond to changes in routine without distress	8	10	8	8	5	6	5	6	10	10	10	10	6	7	9	8	9	8	10	10	4	4	5	6
12	Able to express emotions and feelings to family members and friends	8	9	10	8	5	4	6	5	5	7	8	7	7	7	7	7	9	8	10	10	5	4	5	7
13	Able to problem solve unexpected situations in the daily routine	7	10	8	8	4	4	5	5	10	8	10	10	5	7	7	7	8	8	7	9	4	8	7	6

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C= phase C (intervention priority two), A2 = phase A2 (follow-up), n/a = not applicable.

Table H3

Satisfaction Scores for the Individual Items of the Canadian Occupational Performance Measure for Each Participant



		P1				P2				P3				P4				P5				P6			
	Items	A1	B	C	A2	A1	B	C	A2	A1	B	C	A2	A1	B	C	A2	A1	B	C	A2	A1	B	C	A2
1	Ability to be understood by immediate family members, using words	4	8	6	7	4	4	5	6	7	8	10	10	6	6	7	9	2	8	5	10	2	7	9	9
2	Ability to be understood by extended family members,using words	3	9	6	8	4	4	3	5	7	8	10	10	6	8	7	8	2	8	5	10	2	7	9	9
3	Ability to be understood by friends/peers	3	5	8	7	4	4	3	4	7	7	10	10	6	6	7	7	2	7	7	10	2	7	8	8
4	Normality of facial movements during speech	5	6	8	8	4	5	5	5	7	7	10	10	7	8	8	8	2	9	8	10	6	7	7	8
5	Able to follow routine instructions at home	9	8	8	9	6	5	5	6	10	9	10	10	7	7	8	8	8	9	9	9	5	5	6	7
6	Able to follow routine instructions at school	10	8	8	9	5	5	4	5	10	9	10	10	5	7	7	8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7	Play opportunities outside of family home with friends	3	1	1	6	4	4	3	4	10	8	10	8	7	7	7	7	5	9	9	10	7	7	7	7
8	Opportunity to participate in social events outside of family home	5	7	4	5	4	4	3	3	10	10	10	10	7	7	7	7	7	5	9	10	7	7	7	7
9	Able to complete table top activities for x minutes	8	7	8	6	6	5	5	6	10	10	10	10	9	8	9	8	7	10	5	9	8	6	9	8
10	Enjoys going to school/kindy/childcare	8	8	9	9	7	4	4	6	10	10	10	10	8	7	9	10	5	9	10	10	n/a	n/a	n/a	n/a
11	Able to respond to changes in routine without distress	7	9	9	9	4	6	4	5	10	10	10	10	7	7	9	8	9	8	10	10	6	5	5	7
12	Able to express emotions and feelings to family members and friends	7	9	8	8	4	4	4	4	5	5	8	7	9	8	7	7	9	10	10	10	5	4	5	8
13	Able to problem solve unexpected situations in the daily routine	8	9	8	6	3	4	3	4	10	7	10	10	5	7	7	7	8	9	7	9	4	8	7	7

Note. A1 = phase A1 (pre-intervention), B = phase B (intervention priority one), C= phase C (intervention priority two), A2 = phase A2 (follow-up), n/a = not applicable.

Appendix I

Descriptive Statistics for the Kinematic Measures of Distance, Jaw/Lip Opening Velocity and Word Duration for P1

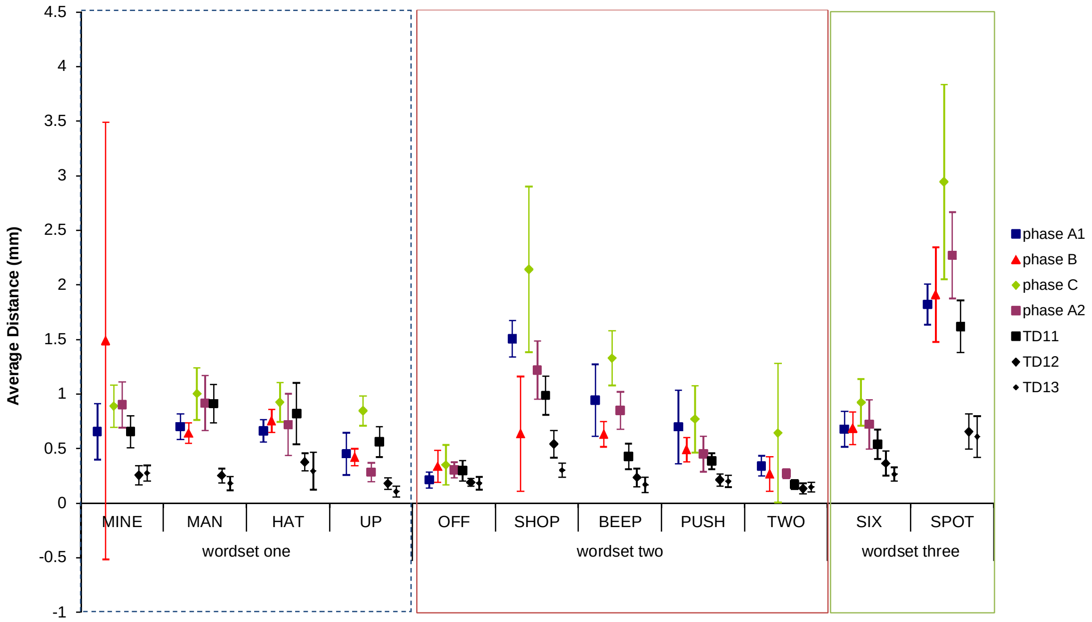


Figure I.1 Average Jaw Path Distance (JPD) for each of the words across the study phases for P1 and the TD peers. Error bars represent the standard deviations.

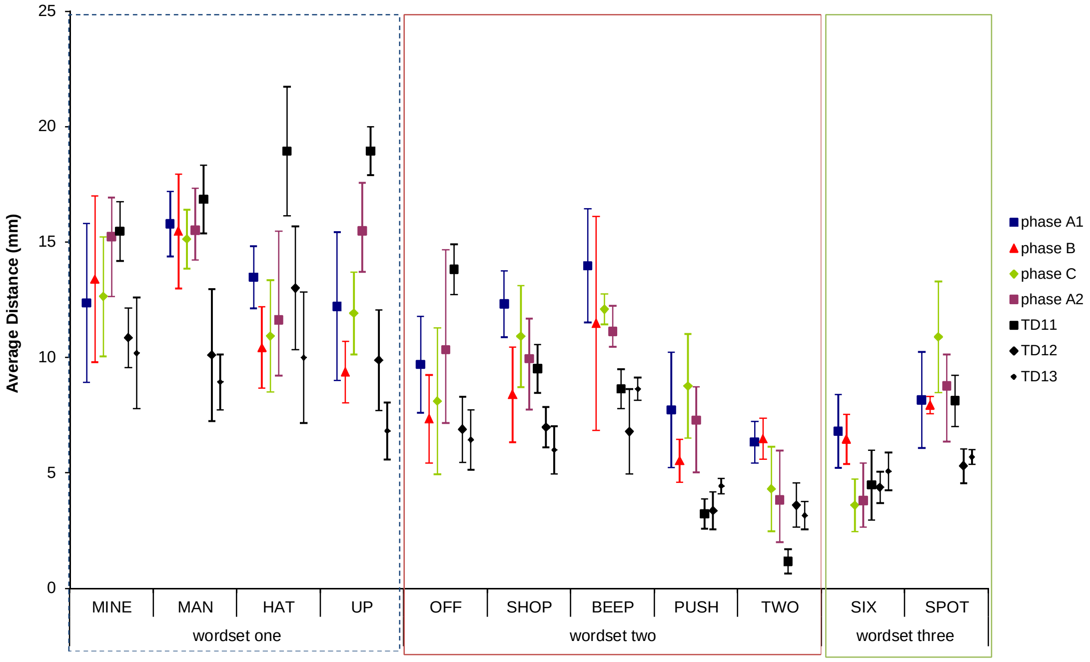


Figure I.2. Average Maximum Jaw Open Distance (JOD) for each of the words across the study phases for P1 and the TD peers. Error bars represent the standard deviations.

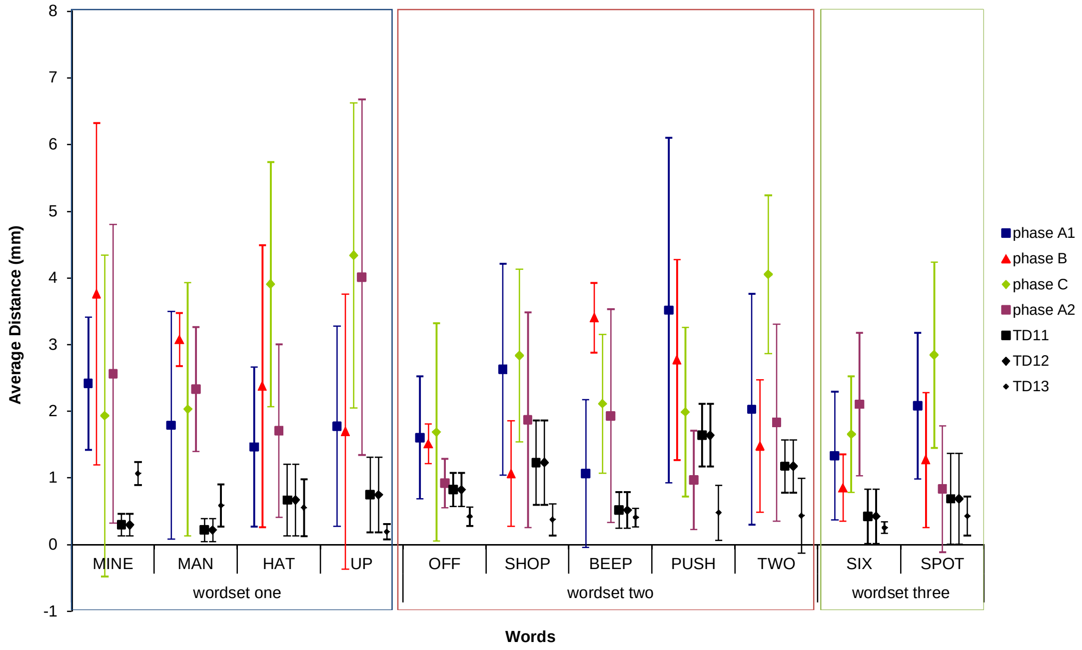


Figure I.3. Average Jaw Lateral Distance from Midline (JLDM) for each of the words across the study phases for P1 and the TD peers. Error bars represent the standard deviations.

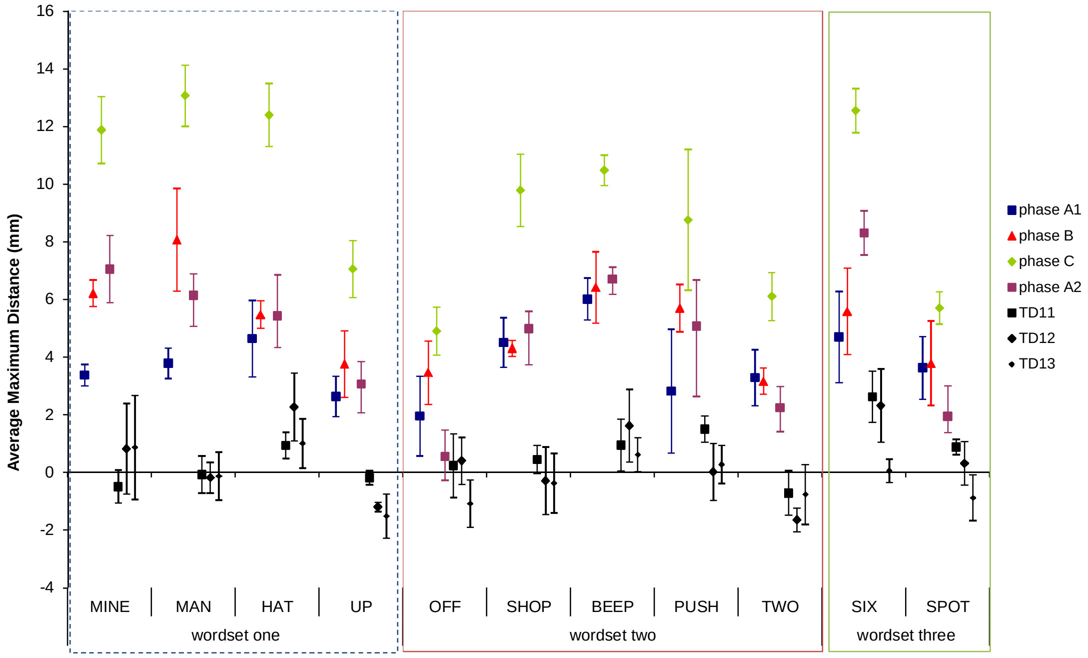


Figure I.4. Average Maximum Lip Rounding and Retraction Distance (LRR) for each word across the study phases for P1 and the TD peers. Error bars represent the standard deviations.

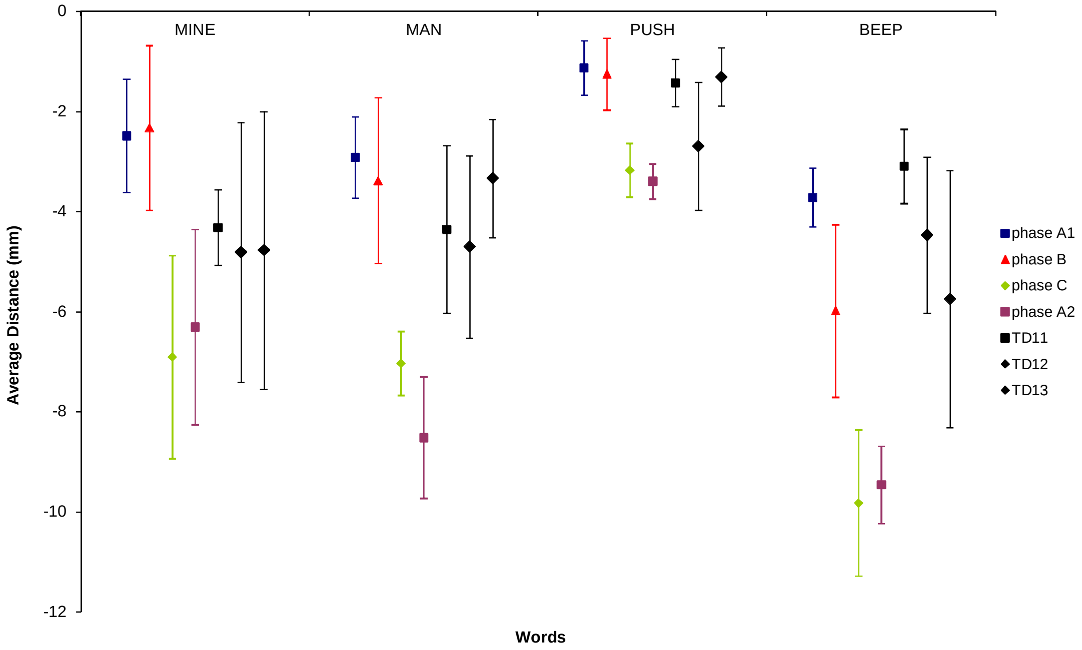


Figure I.5. Average Bilabial Inter-lip Distance (BLC) for all words across the study phases for P1 and the TD peers. Error bars represent the standard deviations.

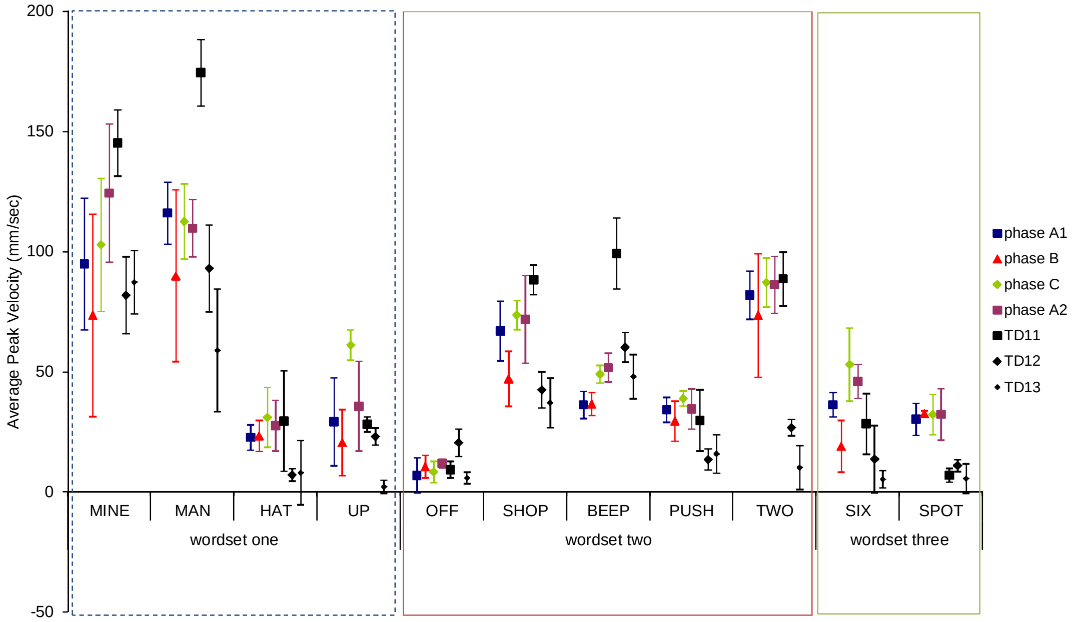


Figure I.6. Average Peak Jaw/Lip Opening Velocity (J/L Vel) for all words across the study phases for P1 and the TD peers. Error bars represent the standard deviations.

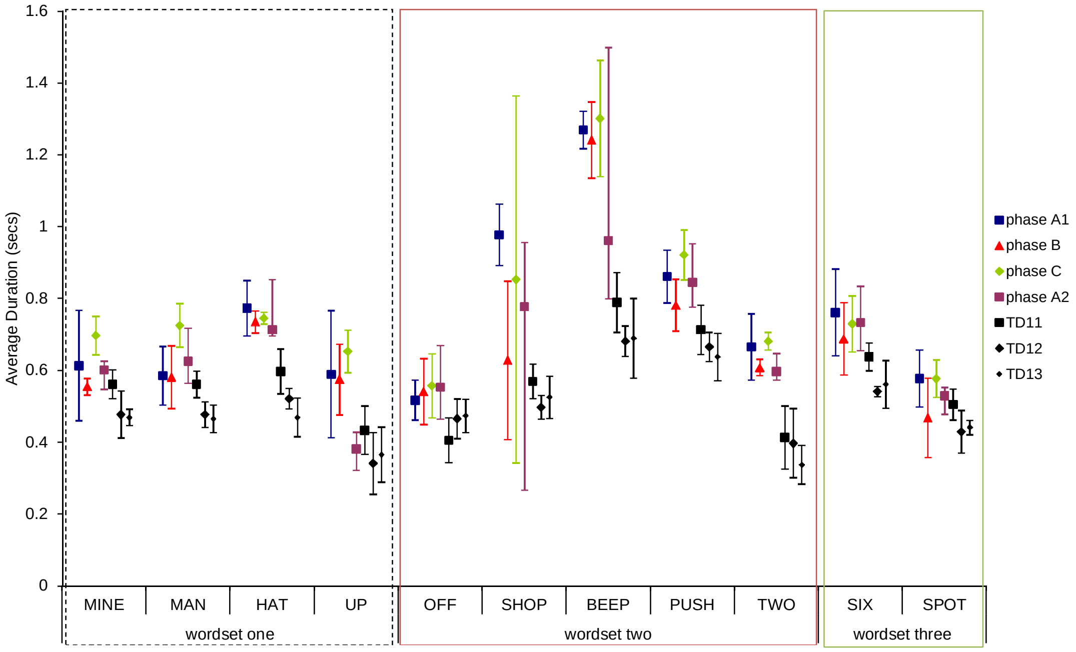


Figure I.7. Average Word Duration (WD) for each of the words across the study phases for P1 and the TD peers. Error bars represent the standard deviations.

Appendix J

Descriptive Statistics for the Kinematic Measures of Distance, Jaw/Lip Opening Velocity and Word Duration for P2

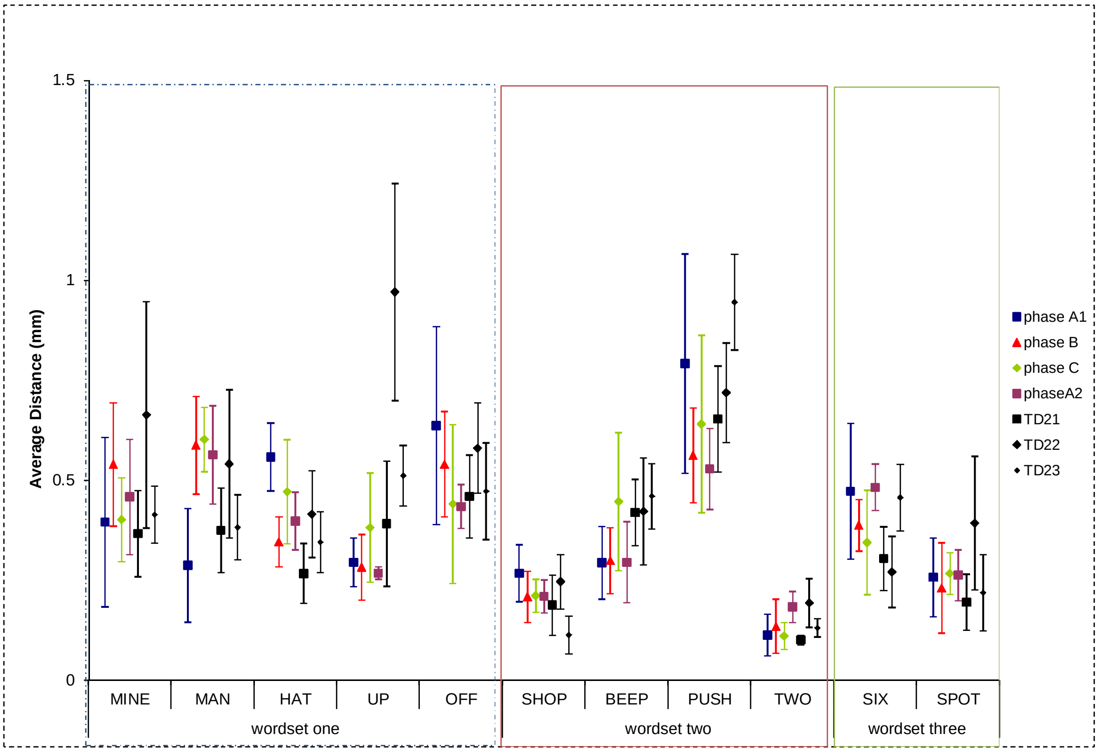


Figure J.1. Average Jaw Path Distance (JPD) for each of the words across the study phases for P2 and the TD peers. Error bars represent the standard deviations.

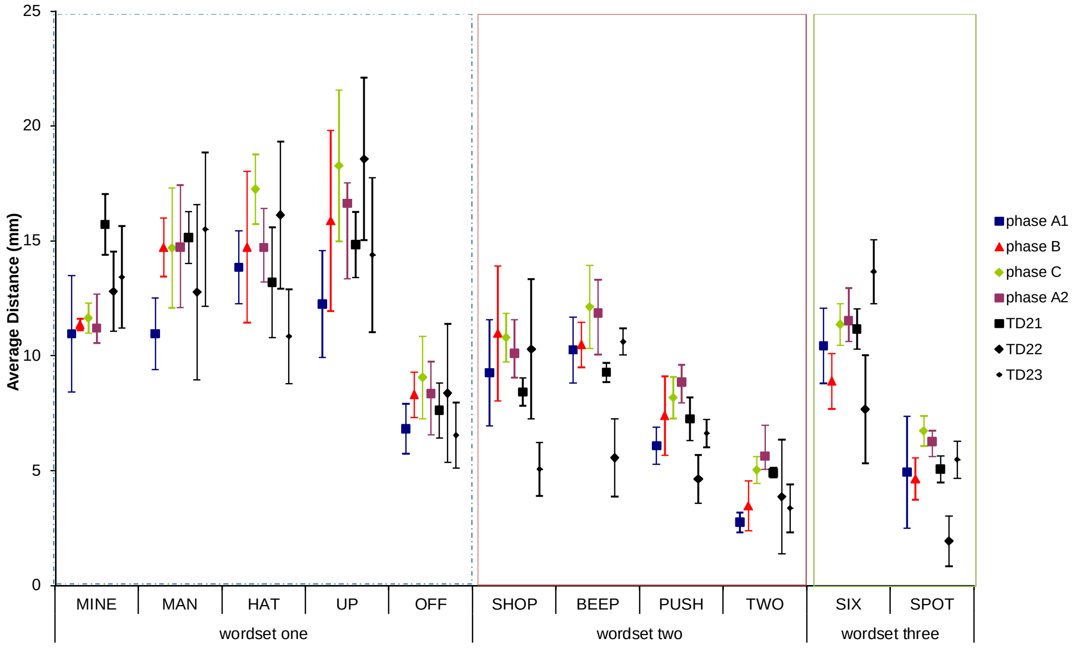


Figure J.2. Average Maximum Jaw Open Distance (JOD) for each of the words across the study phases for P2 and the TD peers. Error bars represent the standard deviations.

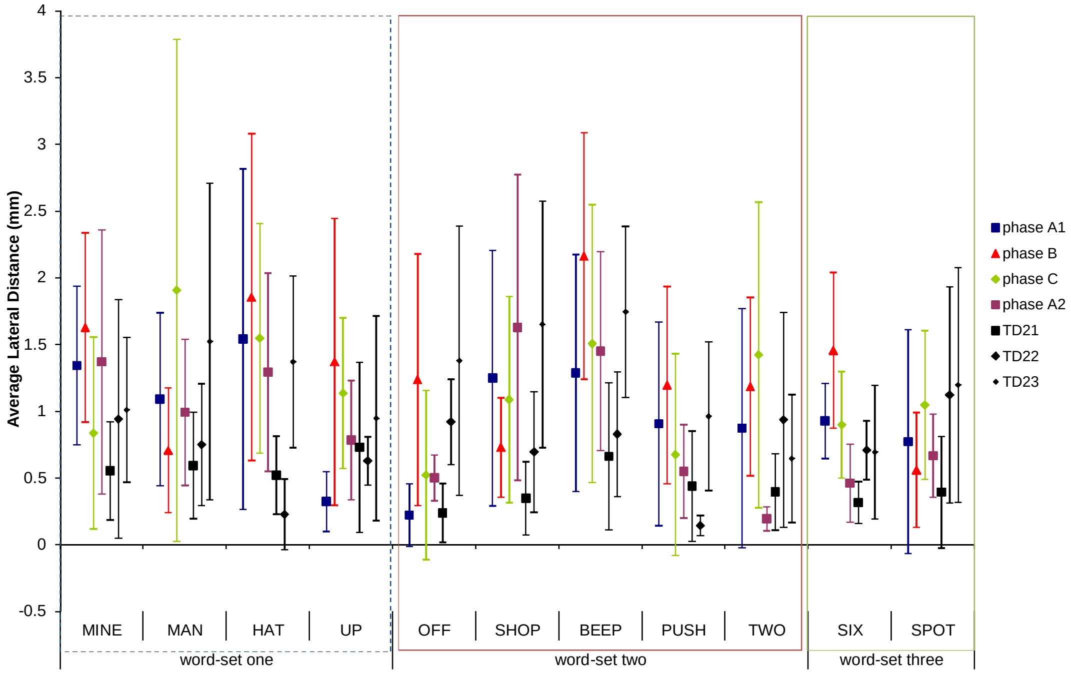


Figure J.3. Average Jaw Lateral Distance from Midline (JLDM) or each of the Words across the study phases for P2 and the TD peers. Error bars represent the standard deviations.

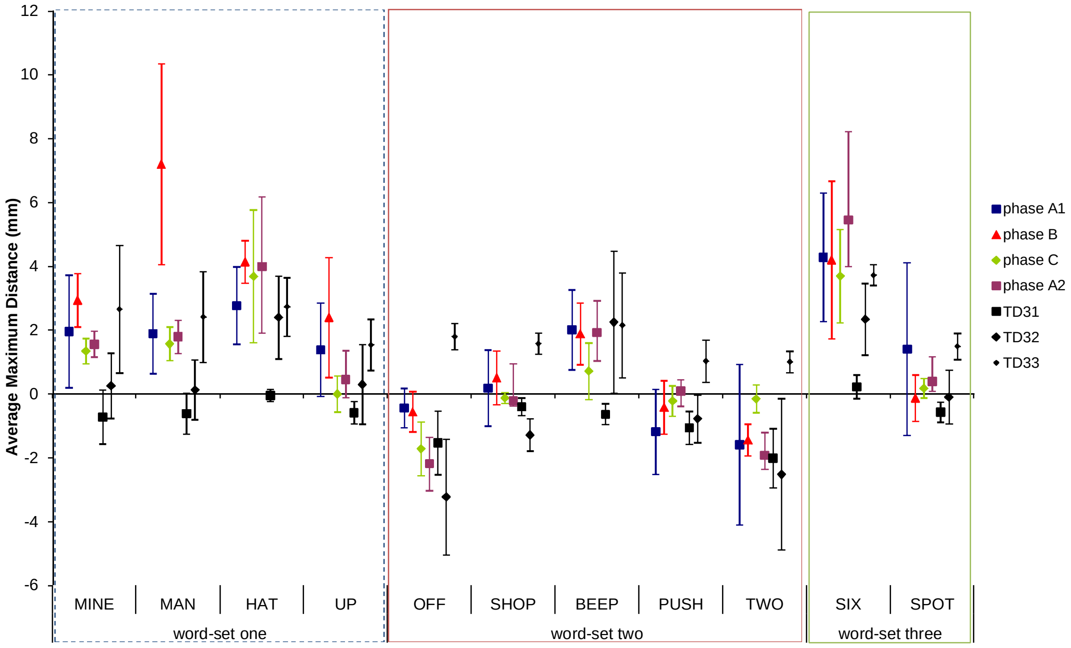


Figure J.4. Average Maximum Lip Rounding and Retraction Distance (LRR) for each word across the study phases for P2 and the TD peers. Error bars represent the standard deviations.

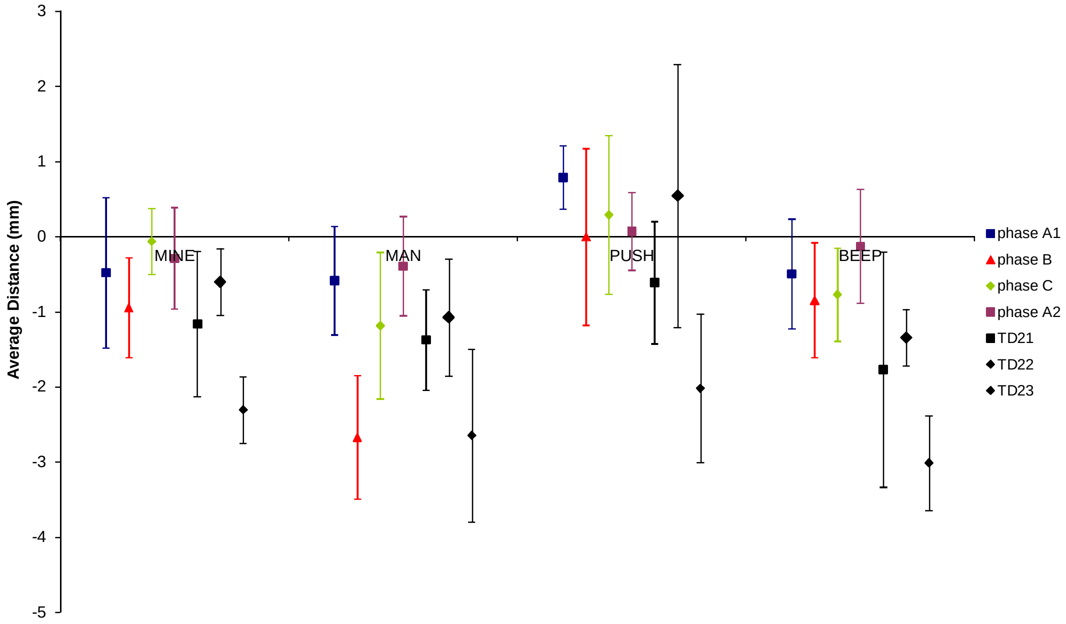


Figure J.5. Average Bilabial Inter-lip Distance (BLC) for all words across the study phases for P2 and the TD peers. Error bars represent the standard deviations.

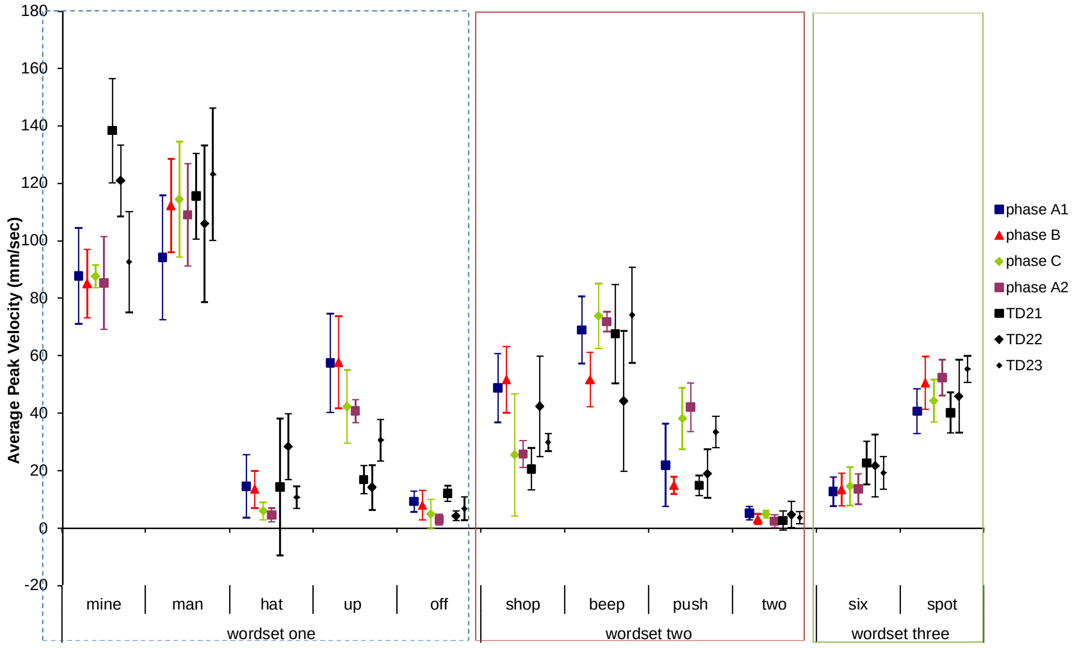


Figure J.6. Average Peak Jaw/Lip Opening Velocity (J/L Vel) for all words across the study phases for P2 and the TD peers. Error bars represent the standard deviations.

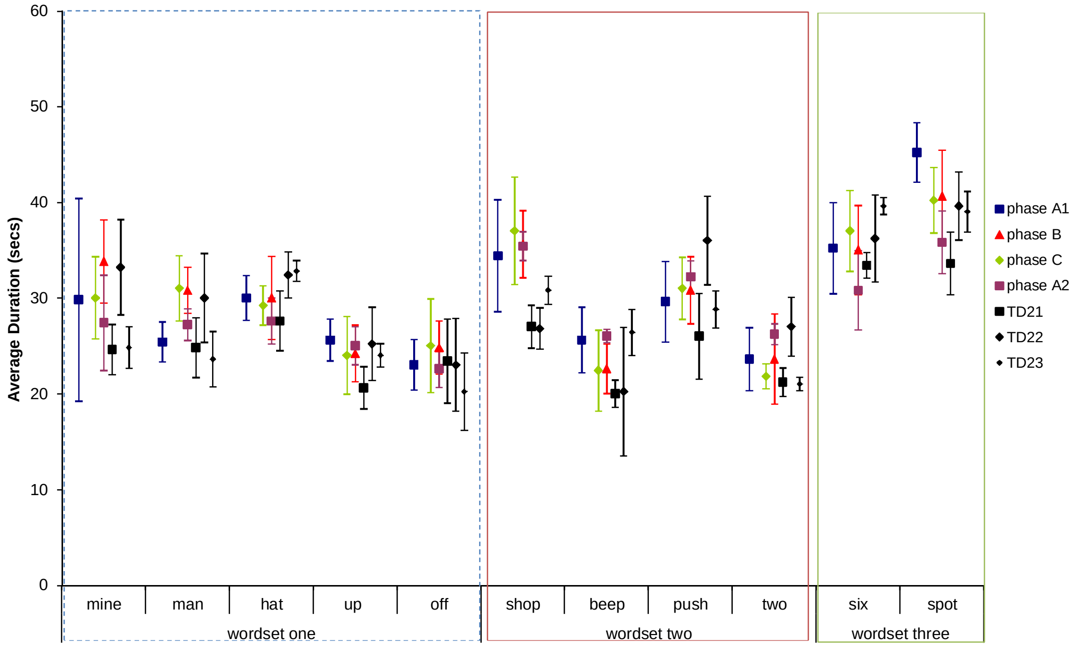


Figure J.7. Average Word Duration (WD) for each of the words across the study phases for P2 and the TD peers. Error bars represent the standard deviations.

Appendix K

Descriptive Statistics for the Kinematic Measures of Distance, Jaw/Lip Opening Velocity and Word Duration for P3

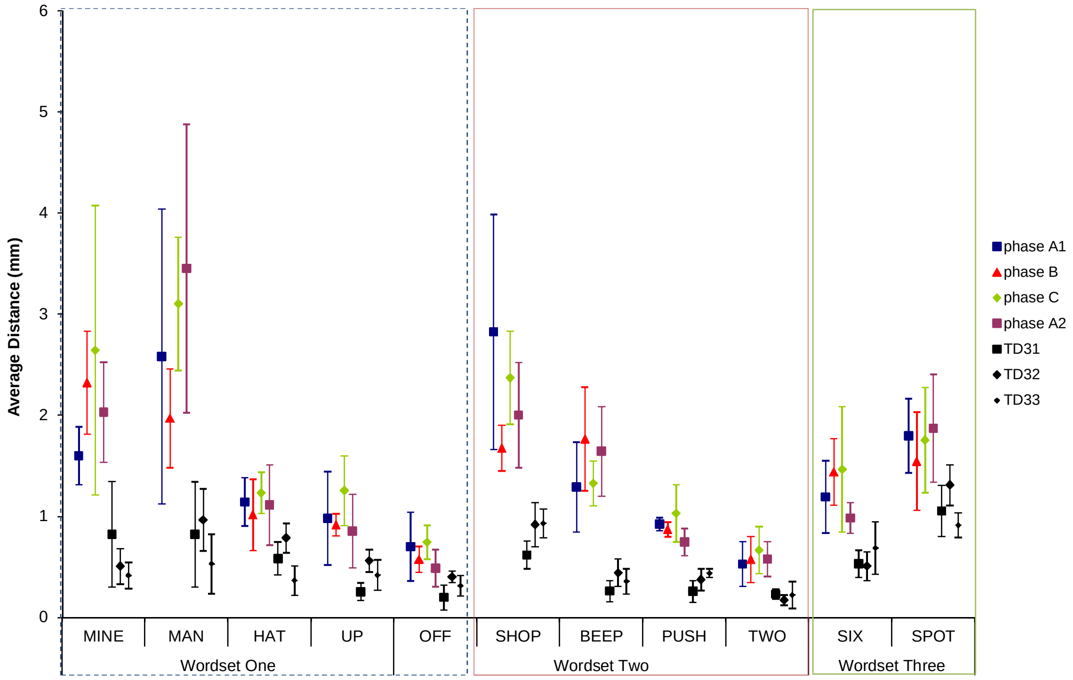


Figure K.1. Average Jaw Path Distance (JPD) for each of the words across the study phases for P3 and the TD peers. Error bars represent the standard deviations.

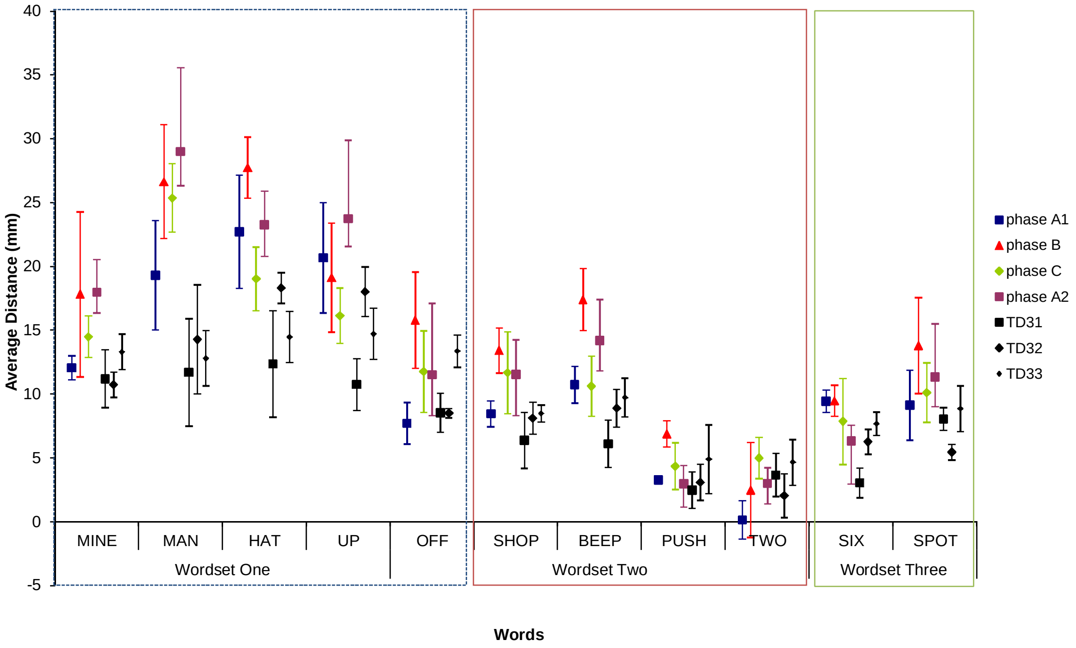


Figure K.2. Average Maximum Jaw Open Distance (JOD) for each of the words across the study phases for P3 and the TD peers. Error bars represent the standard deviations.

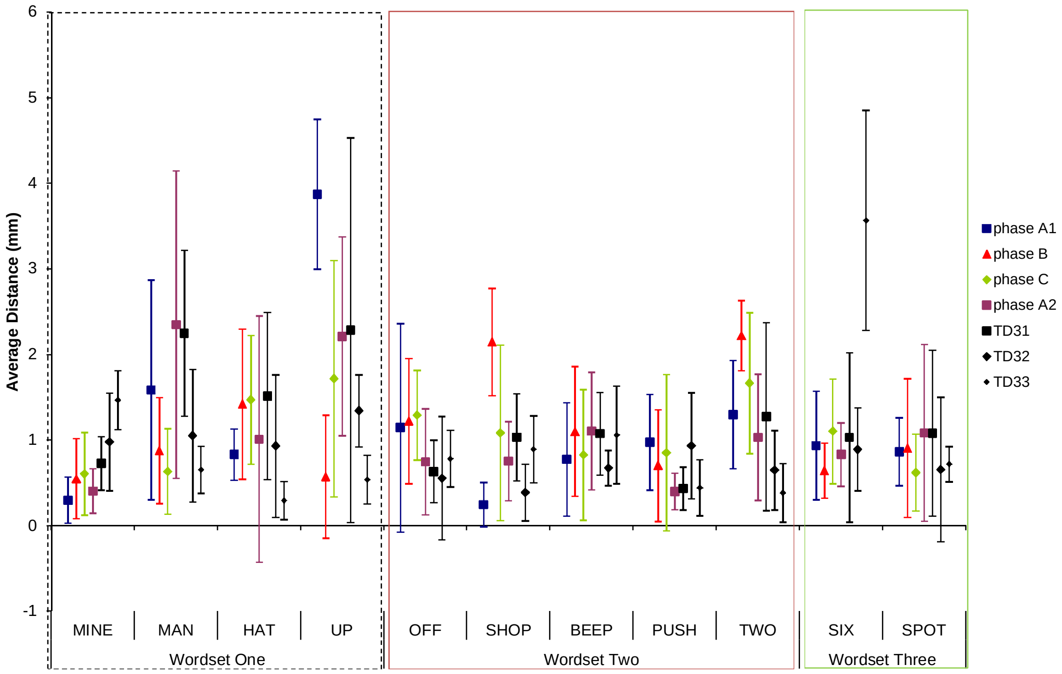


Figure K.3. Average Jaw Lateral Distance from Midline (JLDM) or each of the Words across the study phases for P3 and the TD peers. Error bars represent the standard deviations

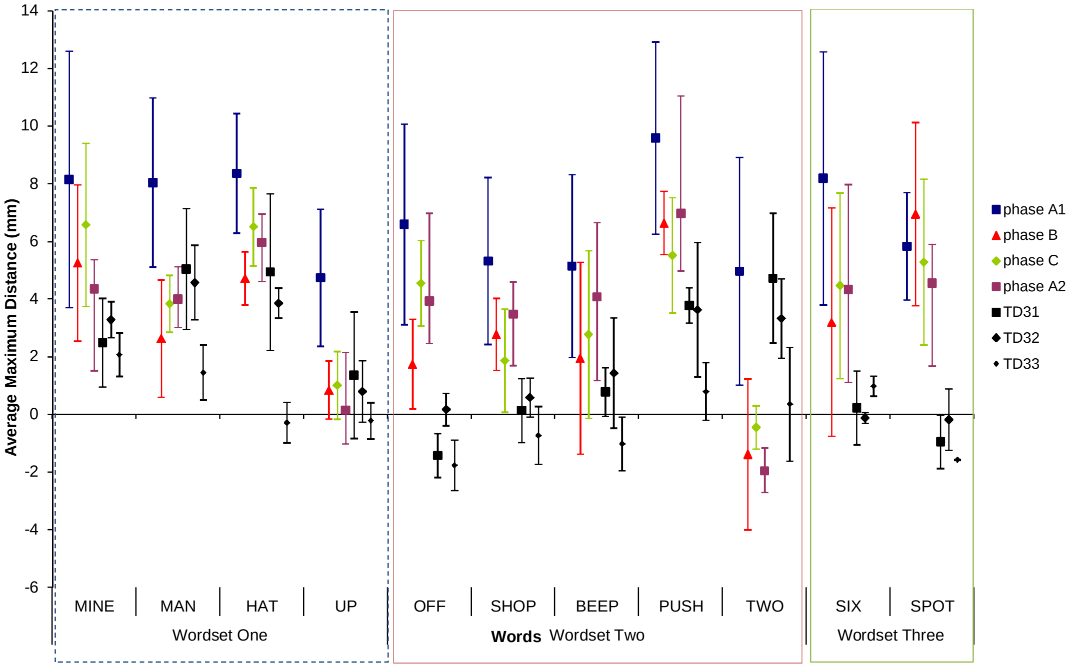


Figure K.4. Average Maximum Lip Rounding and Retraction Distance (LRR) for each word across the study phases for P3 and the TD peers. Error bars represent the standard deviations.

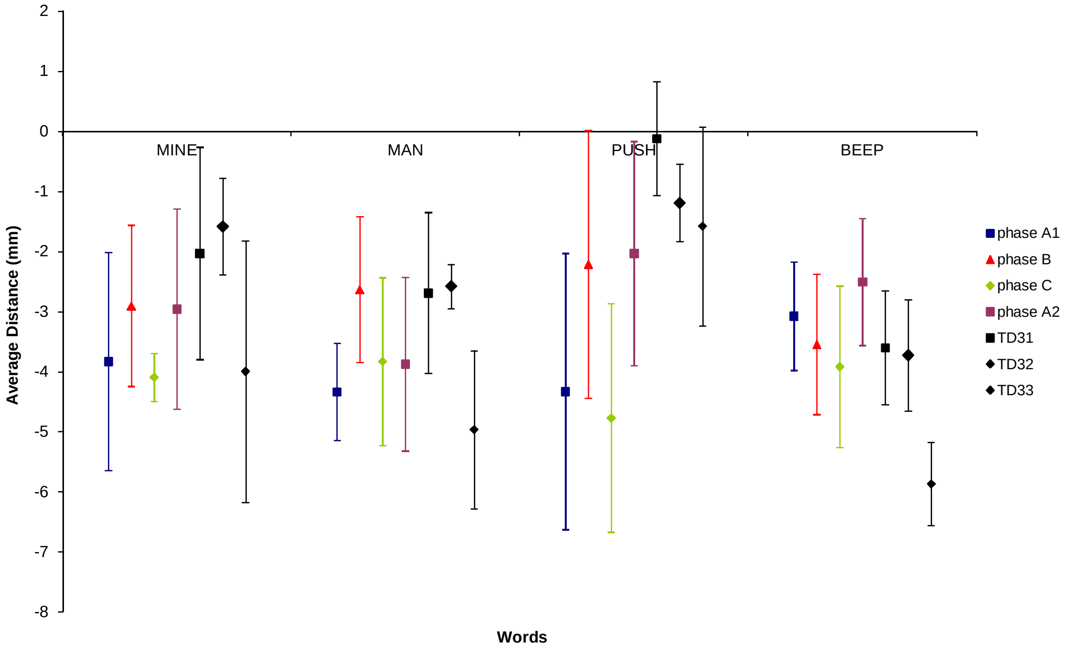


Figure K.5. Average Bilabial Inter-lip Distance (BLC) for all words across the study phases for P3 and the TD peers. Error bars represent the standard deviations.

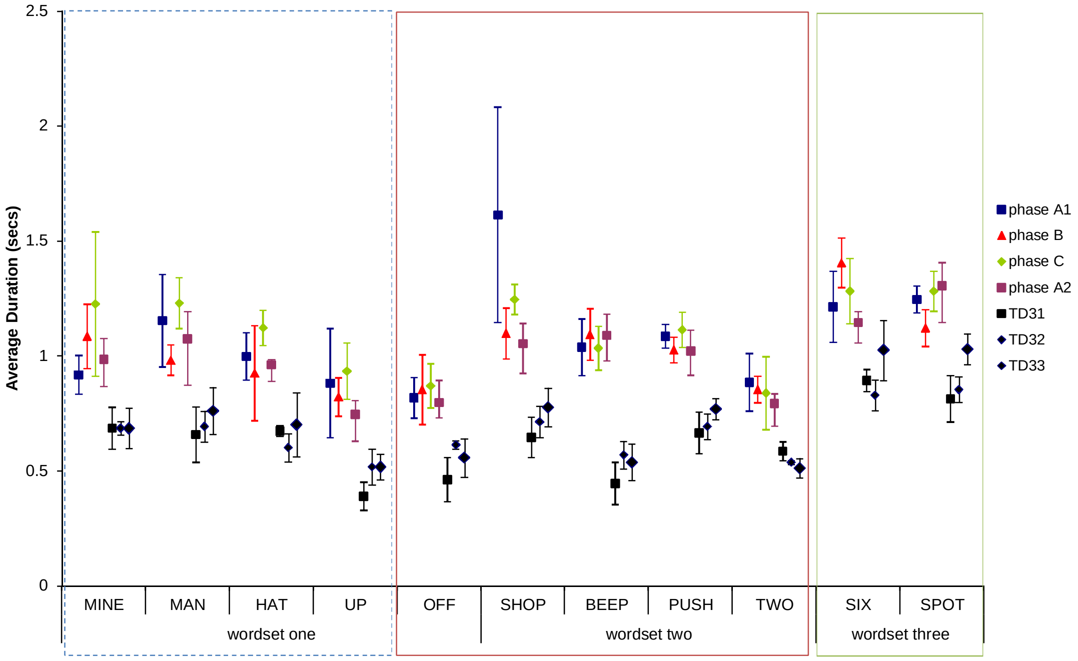


Figure K.6. Average Peak Jaw/Lip Opening Velocity (J/L Vel) for all words across the study phases for P3 and the TD peers. Error bars represent the standard deviations.

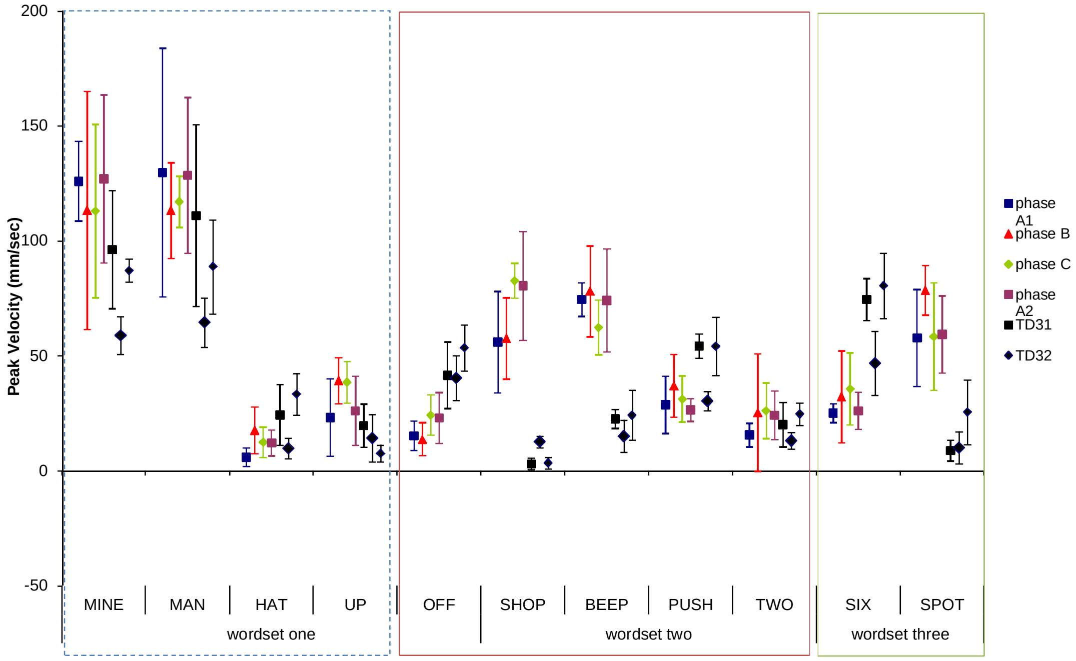


Figure K.7. Average Word Duration (WD) for each of the words across the study phases for P3 and the TD peers. Error bars represent the standard deviations

Appendix L

Descriptive Statistics for the Kinematic Measures of Distance, Jaw/Lip Opening Velocity and Word Duration for P4

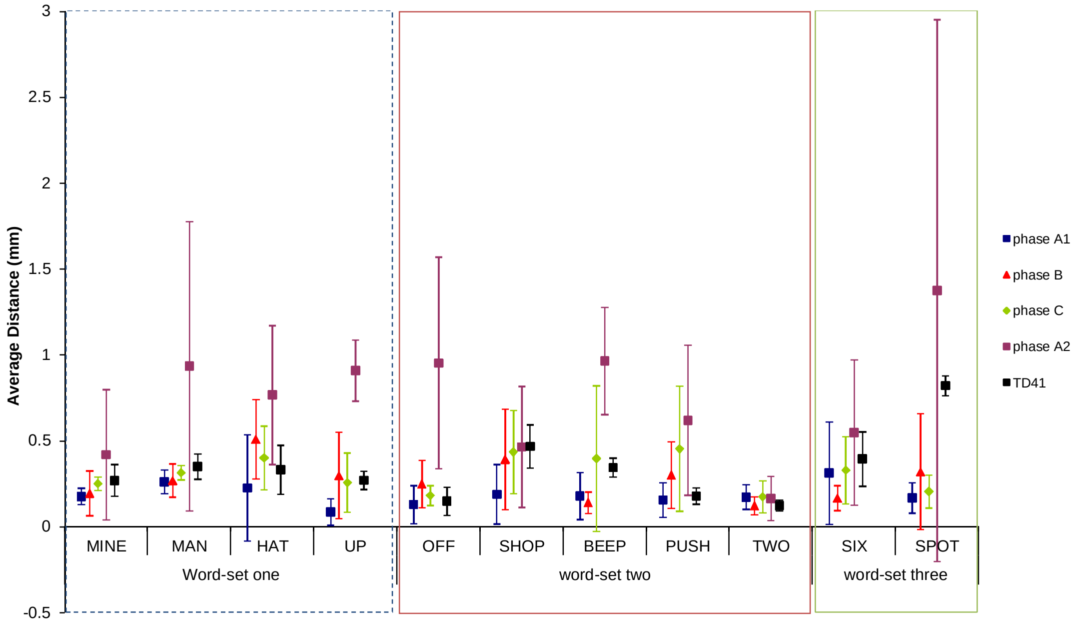


Figure L.1. Average Jaw Path Distance (JPD) for each of the words across the study phases for P4 and the TD peers. Error bars represent the standard deviations.

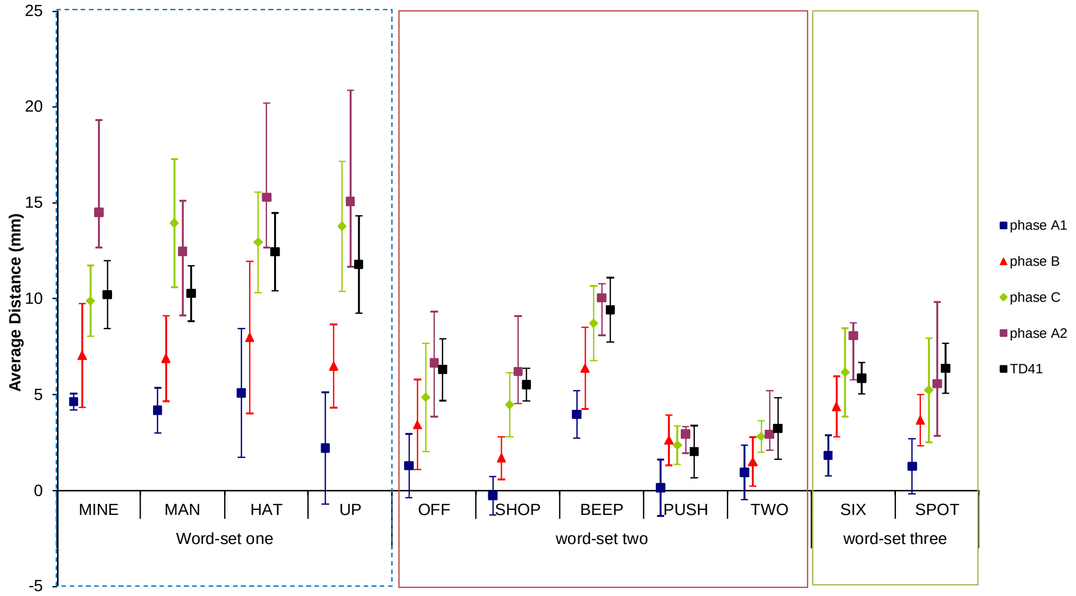


Figure L.2. Average Maximum Jaw Open Distance (JOD) for each of the words across the study phases for P4 and the TD peers. Error bars represent the standard deviations.

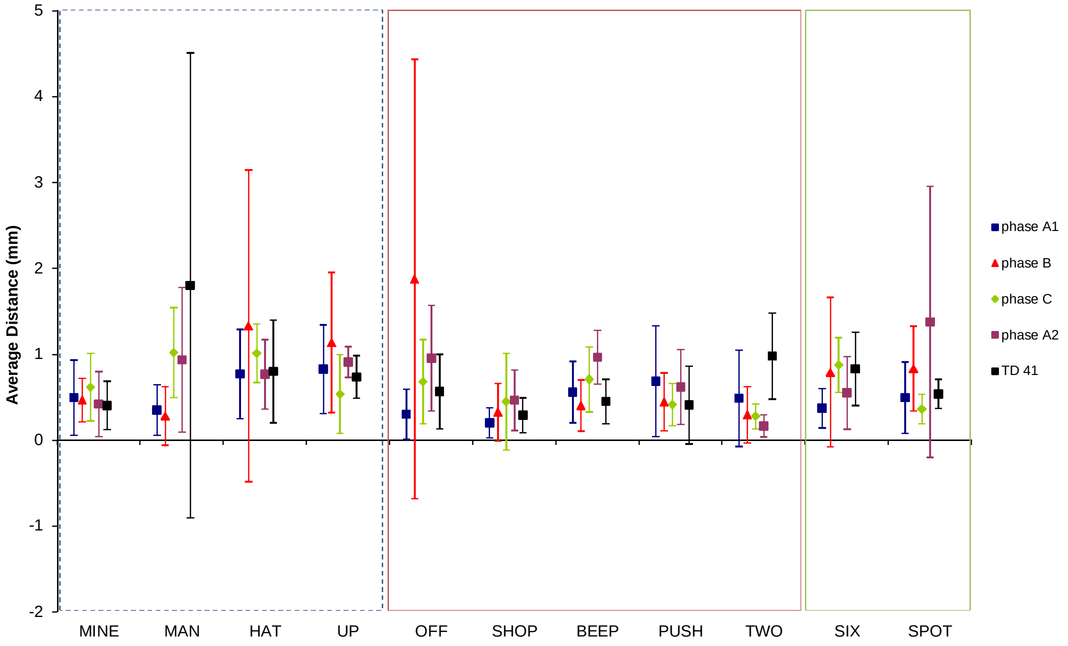


Figure L.3. Average Jaw Lateral Distance from Midline (JLDM) or each of the Words across the study phases for P4 and the TD peers. Error bars represent the standard deviations.

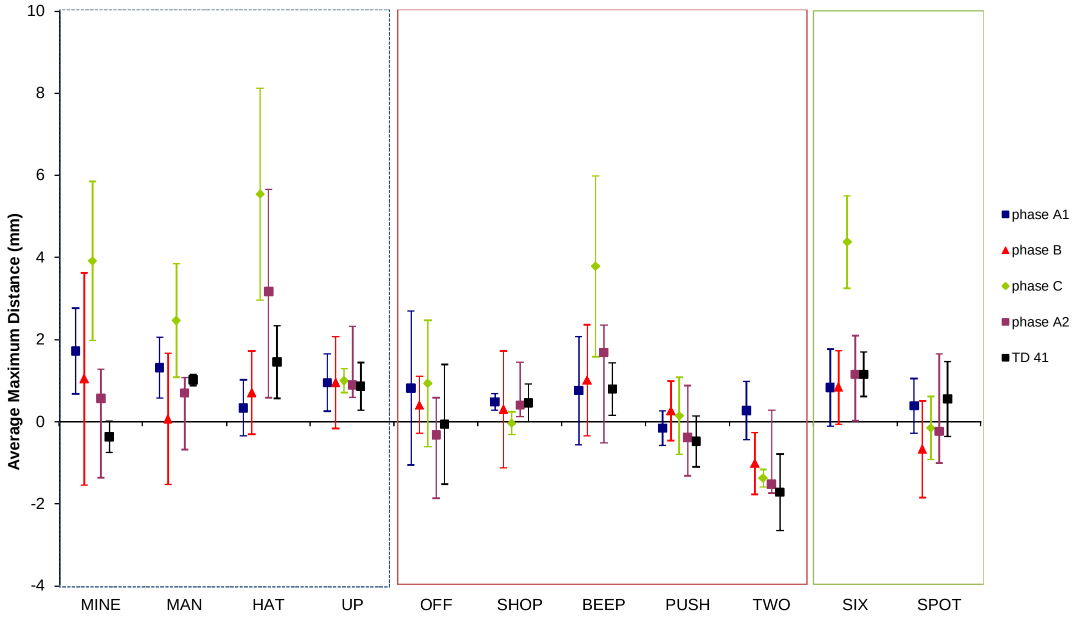


Figure L.4. Average Maximum Lip Rounding and Retraction Distance (LRR) for each word across the study phases for P4 and the TD peers. Error bars represent the standard deviations.

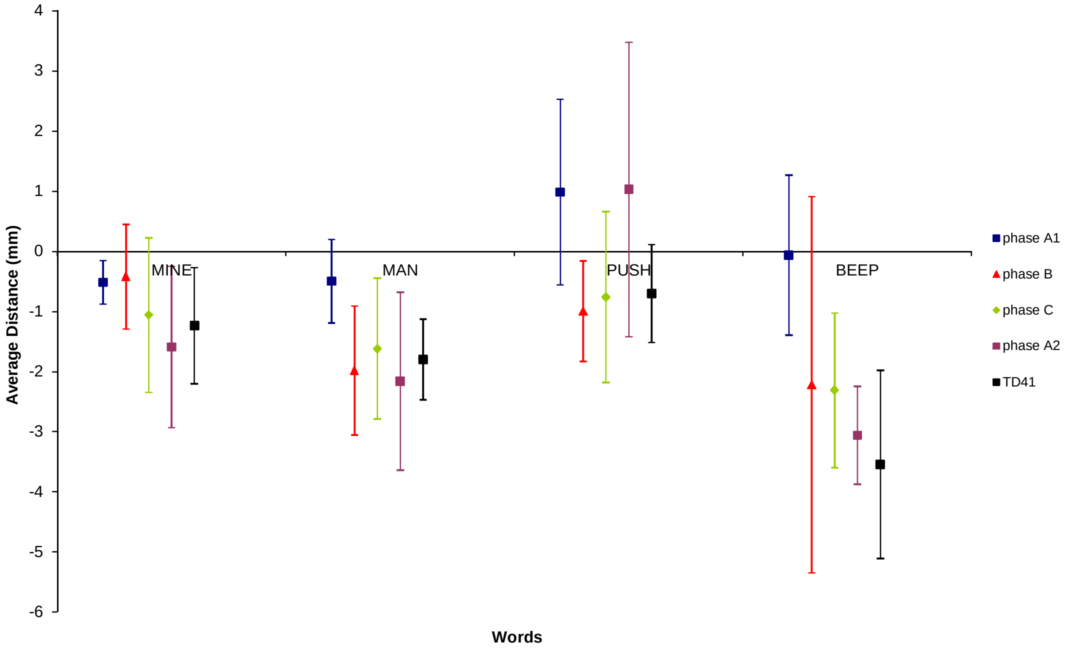


Figure L.5. Average Bilabial Inter-lip Distance (BLC) for all words across the study phases for P4 and the TD peers. Error bars represent the standard deviations.

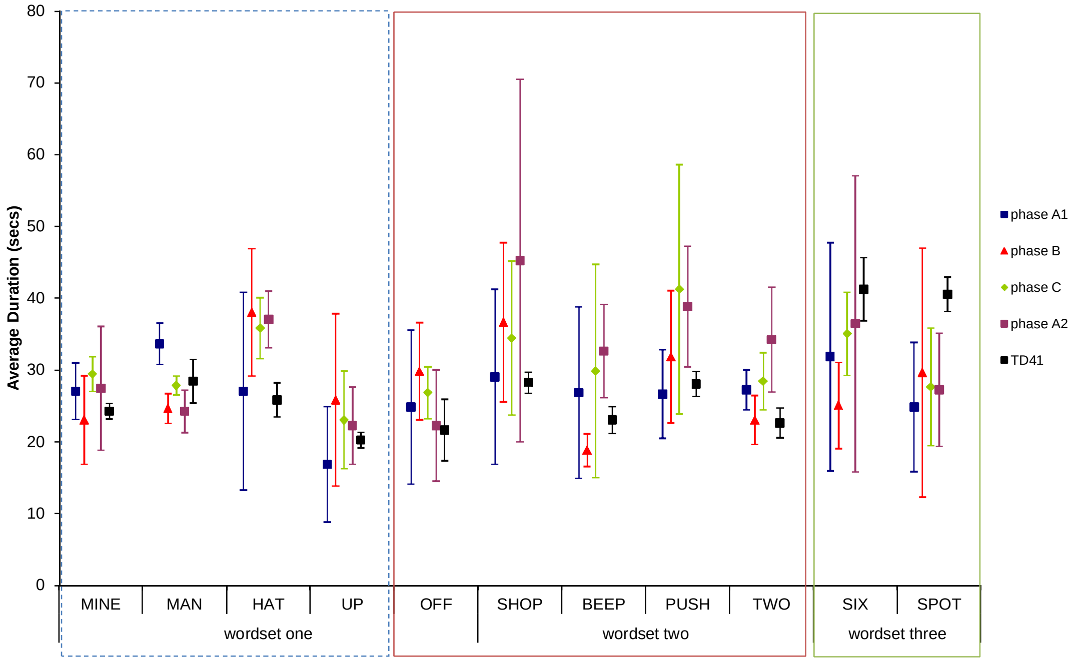


Figure L.6. Average Peak Jaw/Lip Opening Velocity (J/L Vel) for all words across the study phases for P4 and the TD peers. Error bars represent the standard deviations.

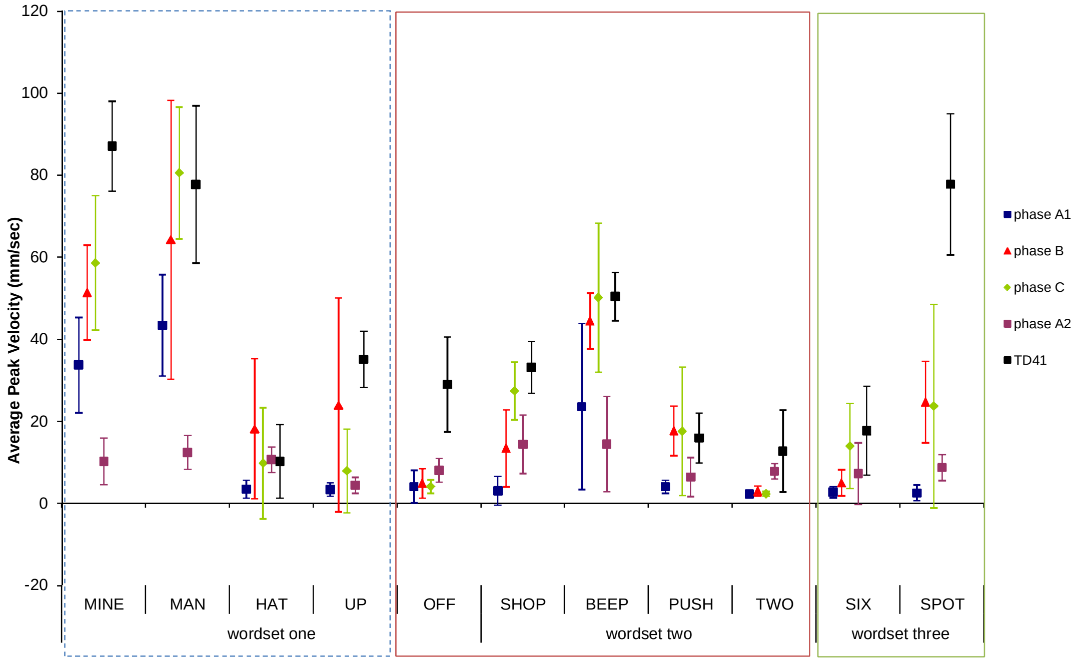


Figure L.7. Average Word Duration (WD) for each of the words across the study phases for P4 and the TD peers. Error bars represent the standard deviations.

Appendix M

Descriptive Statistics for the Kinematic Measures of Distance, Jaw/Lip Opening Velocity and Word Duration for P5

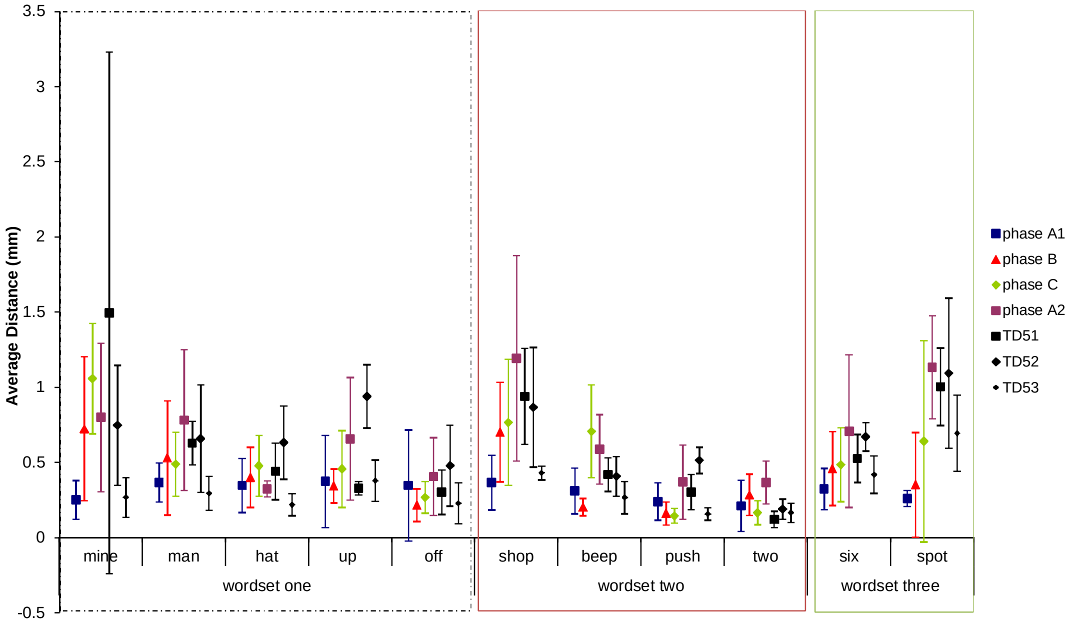


Figure M.1. Average Jaw Path Distance (JPD) for each of the words across the study phases for P5 and the TD peers. Error bars represent the standard deviations.

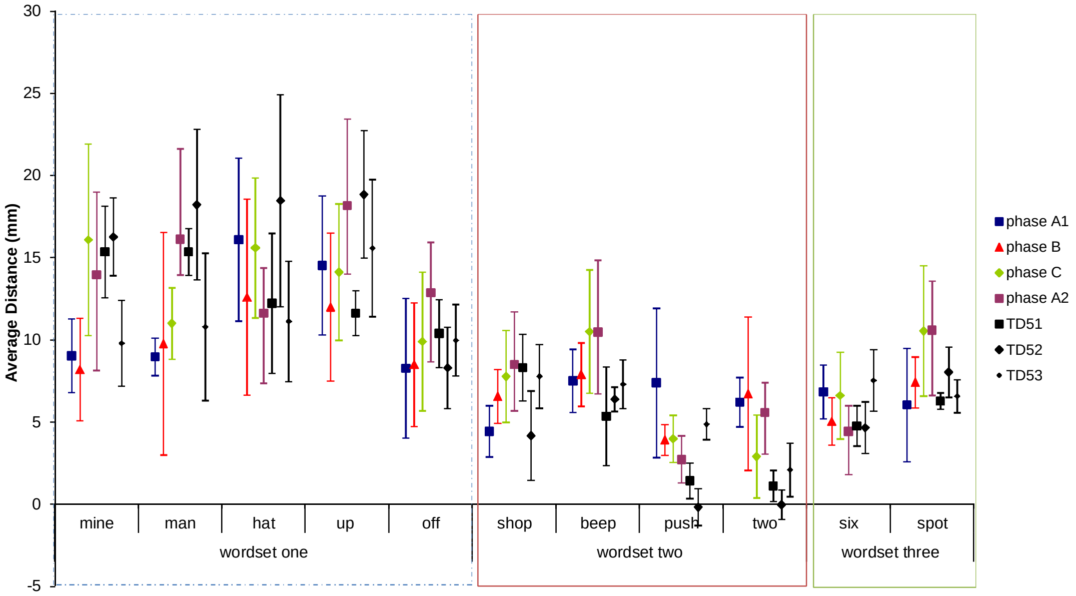


Figure M.2. Average Maximum Jaw Open Distance (JOD) for each of the words across the study phases for P5 and the TD peers. Error bars represent the standard deviations.

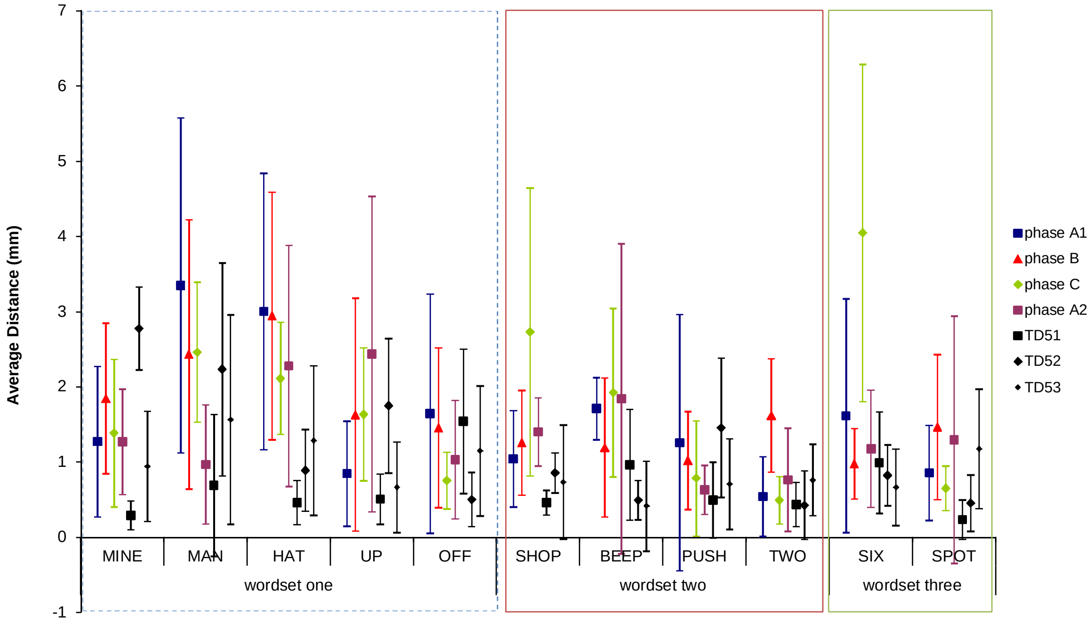


Figure M.3. Average Jaw Lateral Distance from Midline (JLDM) or each of the Words across the study phases for P5 and the TD peers. Error bars represent the standard deviations.

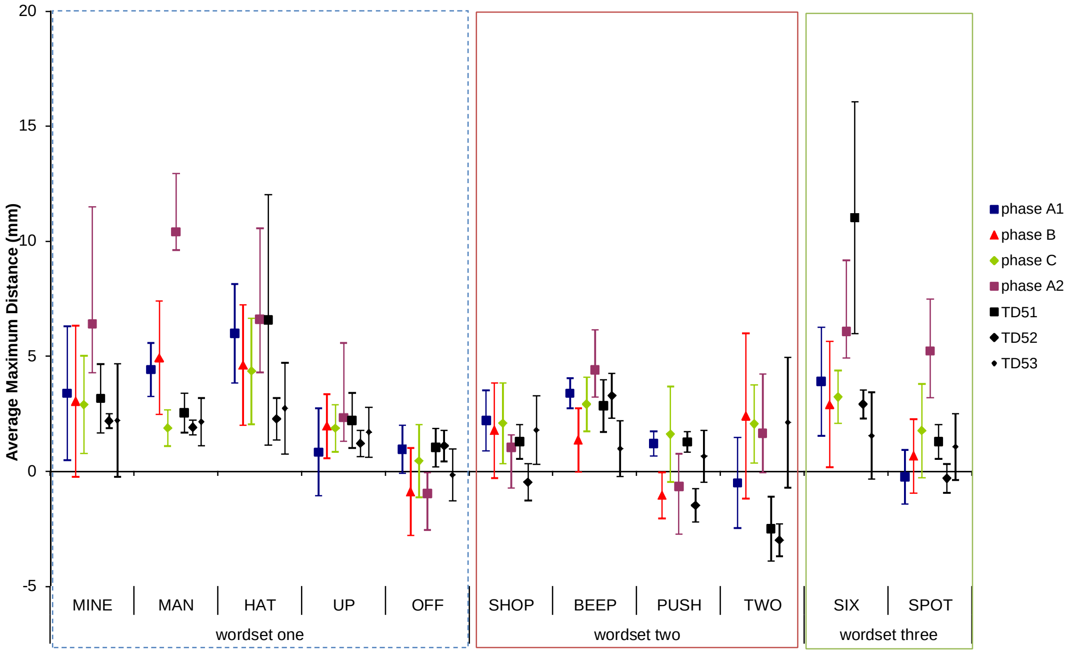


Figure M.4. Average Maximum Lip Rounding and Retraction Distance (LRR) for each word across the study phases for P5 and the TD peers. Error bars represent the standard deviations.

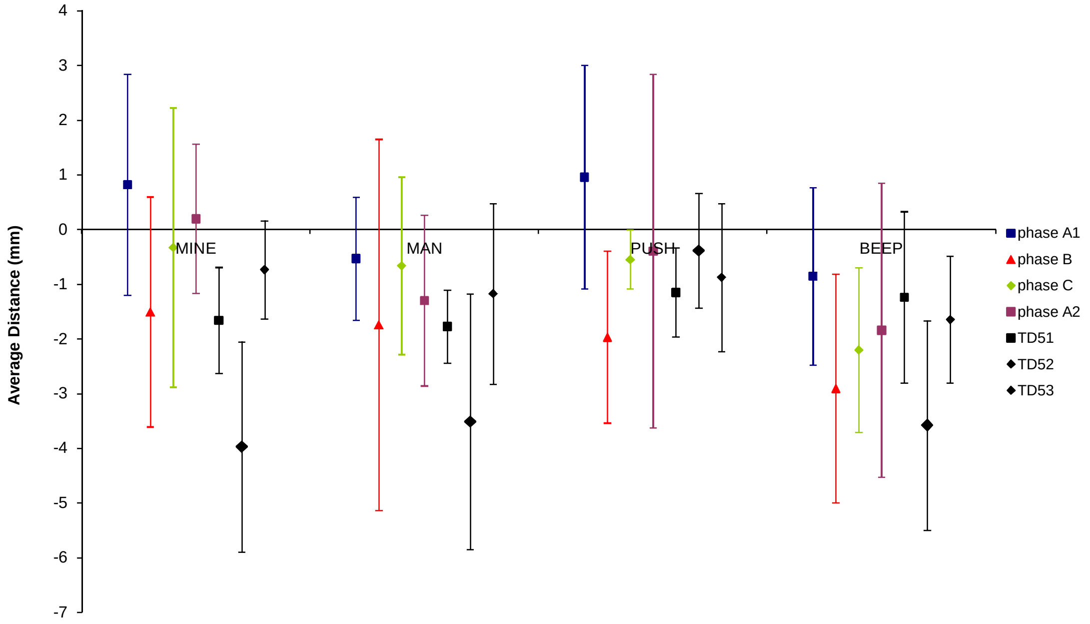


Figure M.5. Average Bilabial Inter-lip Distance (BLC) for all words across the study phases for P5 and the TD peers. Error bars represent the standard deviations.

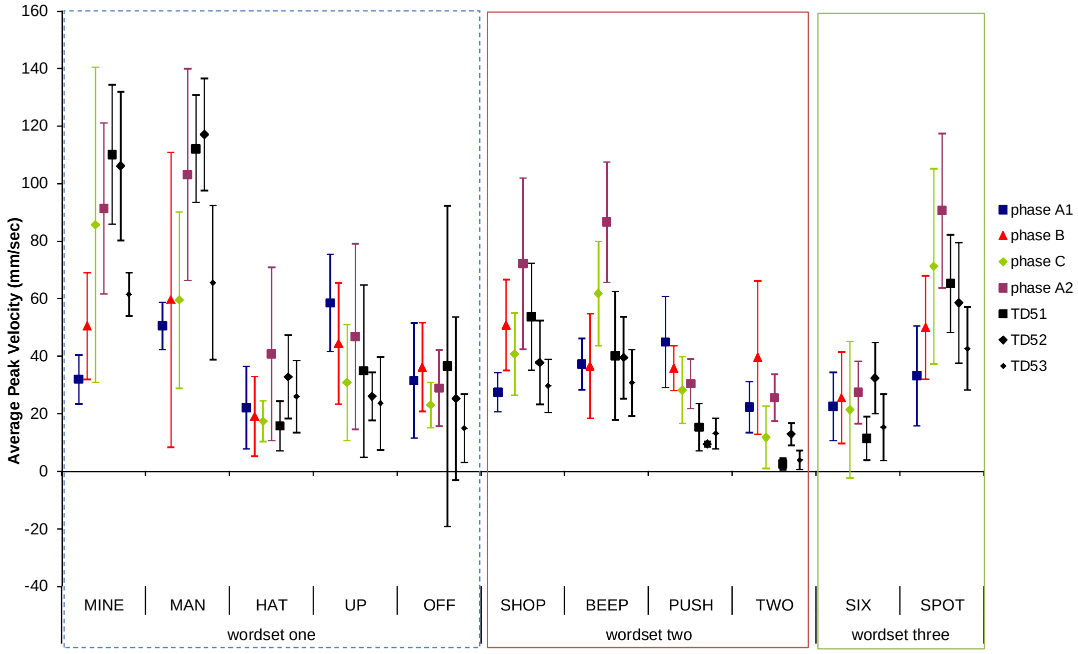


Figure M.6. Average Peak Jaw/Lip Opening Velocity (J/L Vel) for all words across the study phases for P5 and the TD peers. Error bars represent the standard deviations.

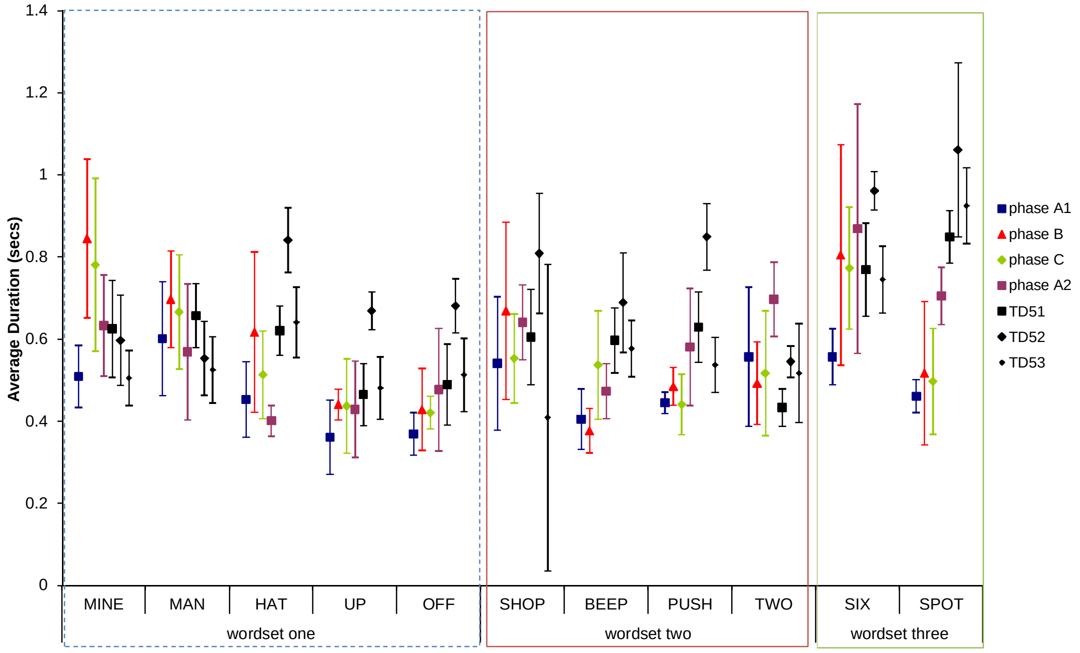


Figure M.7. Average Word Duration (WD) for each of the words across the study phases for P5 and the TD peers. Error bars represent the standard deviations.

Appendix N

Descriptive Statistics for the Kinematic Measures of Distance, Jaw/Lip Opening Velocity and Word Duration for P6

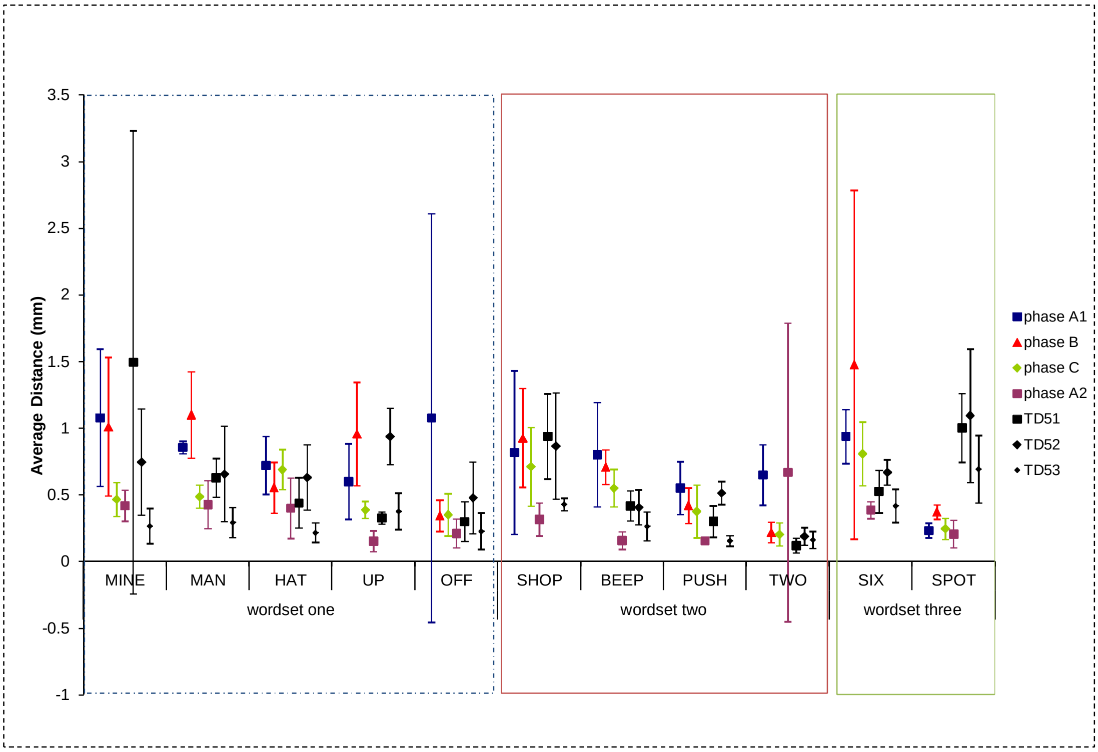


Figure N.1. Average Jaw Path Distance (JPD) for each of the words across the study phases for P6 and the TD peers. Error bars represent the standard deviations.

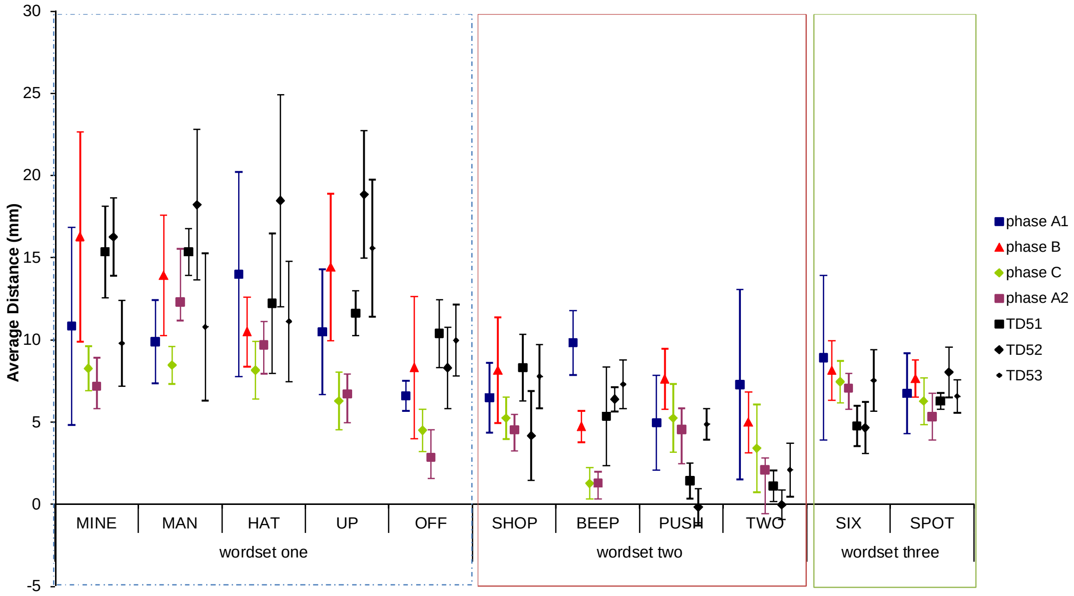


Figure N.2. Average Maximum Jaw Open Distance (JOD) for each of the words across the study phases for P6 and the TD peers. Error bars represent the standard deviations.

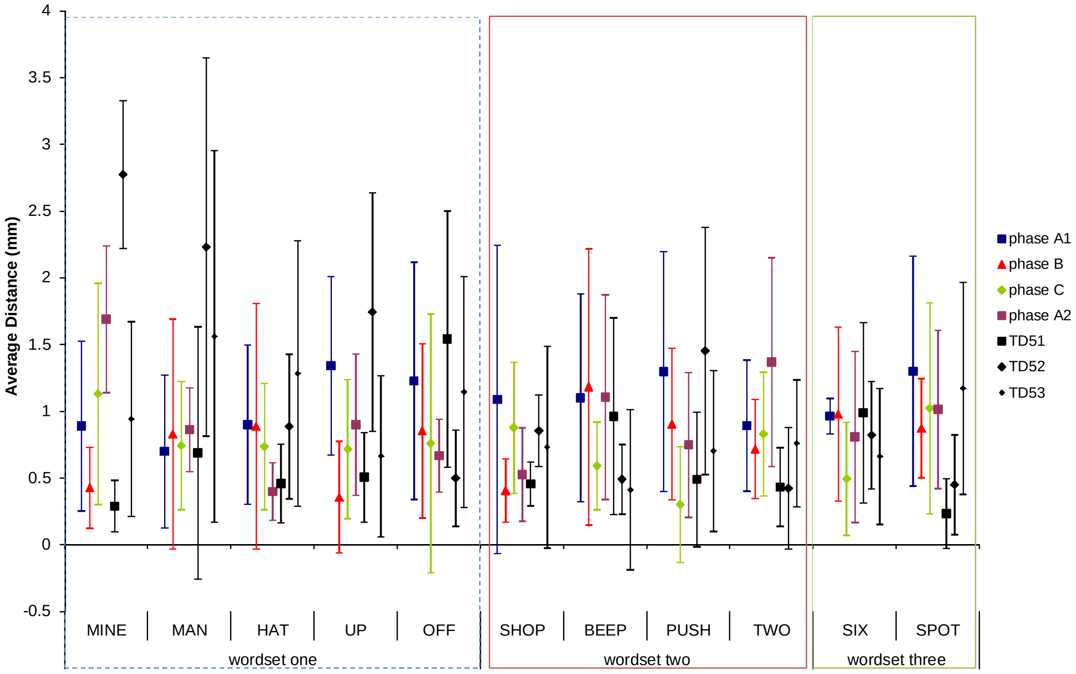


Figure N.3. Average Jaw Lateral Distance from Midline (JLDM) or each of the Words across the study phases for P6 and the TD peers. Error bars represent the standard deviations.

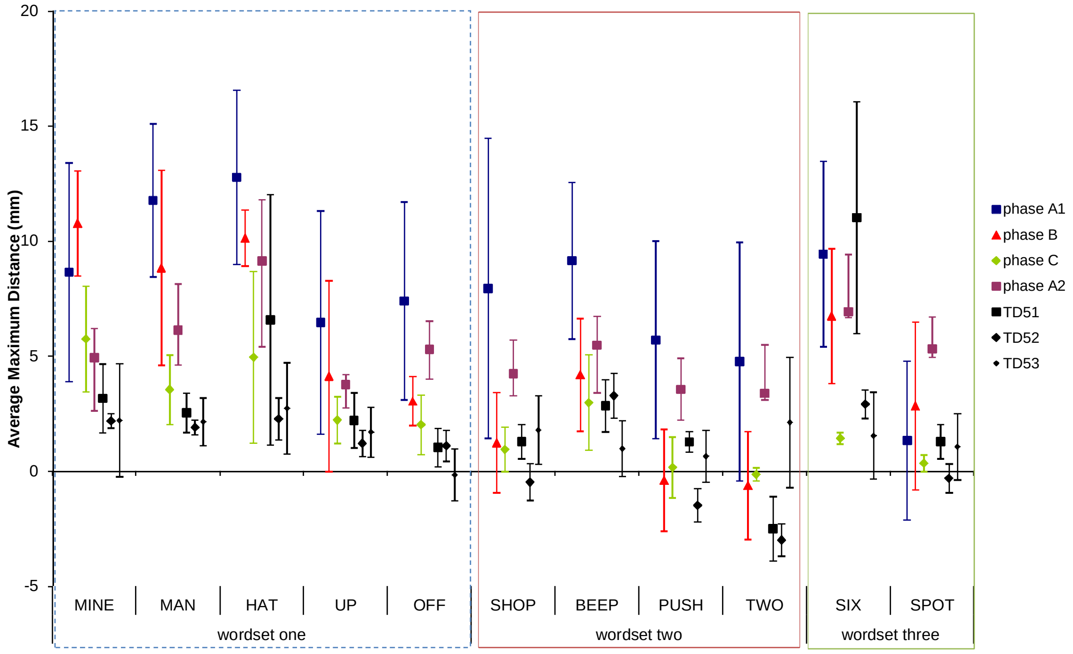


Figure N.4. Average Maximum Lip Rounding and Retraction Distance (LRR) for each word across the study phases for P6 and the TD peers. Error bars represent the standard deviations.

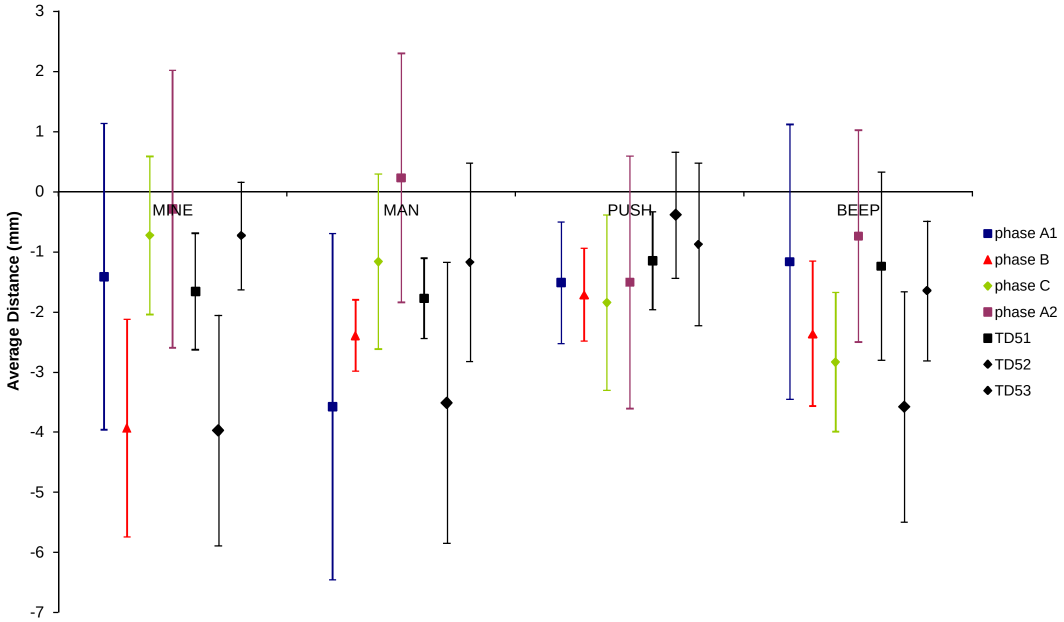


Figure N.5. Average Bilabial Inter-lip Distance (BLC) for all words across the study phases for P6 and the TD peers. Error bars represent the standard deviations.

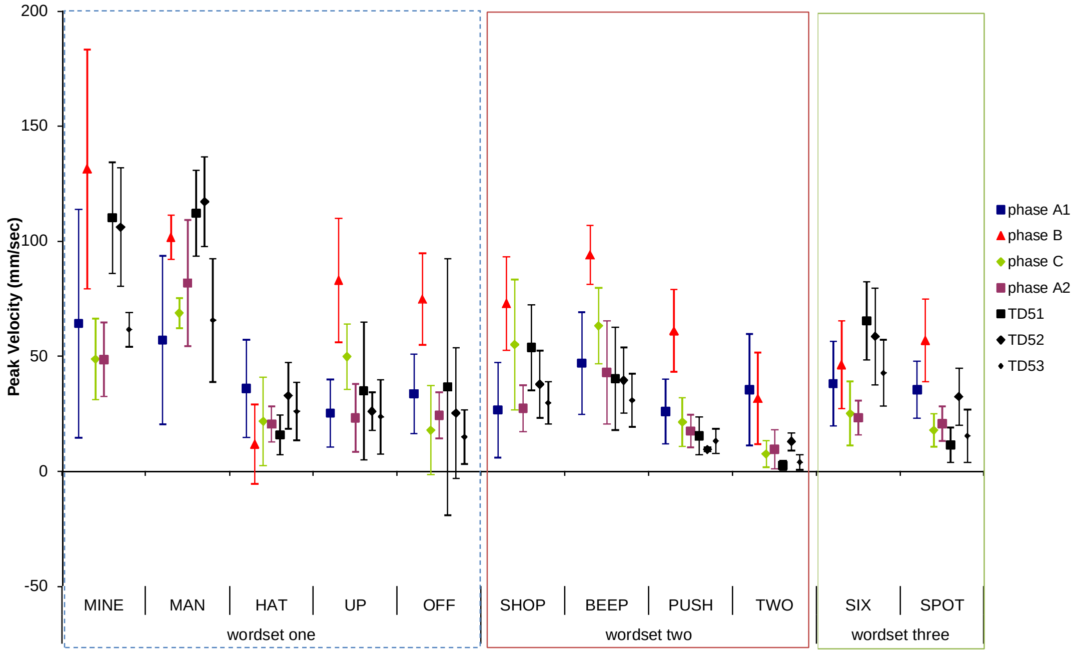


Figure N.6. Average Peak Jaw/Lip Opening Velocity (J/L Vel) for all words across the study phases for P6 and the TD peers. Error bars represent the standard deviations.

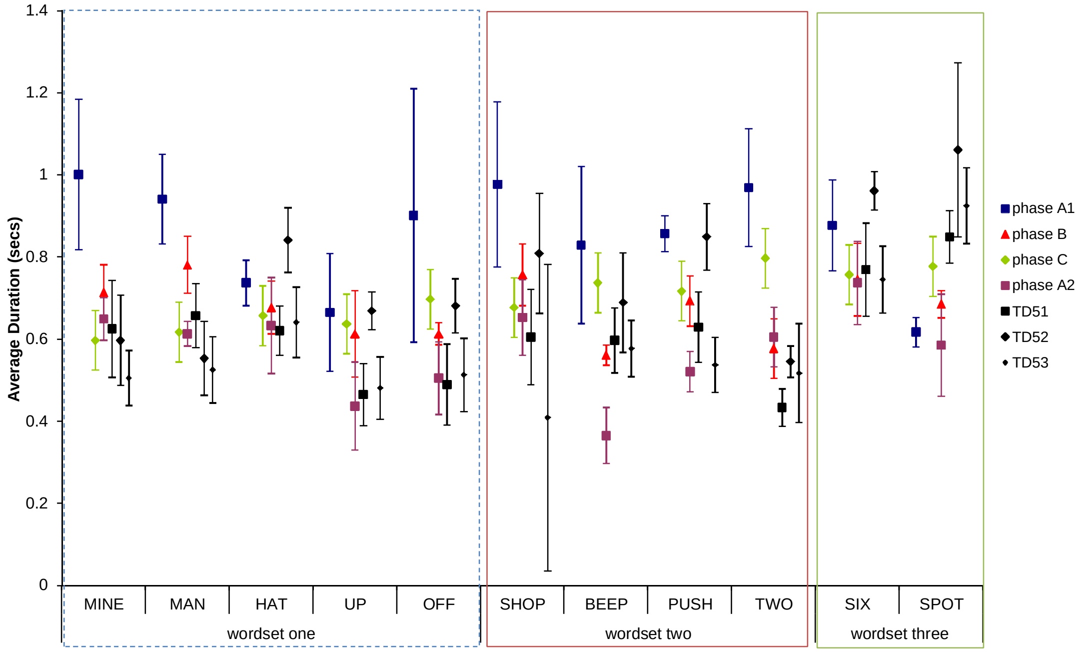


Figure N.7. Average Word Duration (WD) for each of the words across the study phases for P6 and the TD peers. Error bars represent the standard deviations.

Appendix O

Copyright Release PROMPT Institute

19th March, 2012

Ms Deborah Hayden
Executive Director
The Prompt Institute
4001 Office Court Drive, Suite 305
Sante Fe, New Mexico 87507 USA

Dear Ms Hayden,

It is my understanding that you/your organisation hold copyrights in the following materials:

1. The PROMPT conceptual framework;
2. The Motor Speech Hierarchy;
3. The Systems Analysis Observation; and
4. Illustration of the Facial PROMPTS (page 40)

as illustrated in the PROMPT Introduction to Technique Manual (2003).

I would like to reproduce an extract of this work in a doctoral thesis which I am currently undertaking at Curtin University of Technology in Perth, Western Australia. The subject of my research is the evaluation of the effectiveness of PROMPT in children with cerebral palsy. I am carrying out this research in my own right and have no association with any commercial organisation or sponsor.

The specific materials that I would like to use for the purposes of the thesis are the four illustrations listed above.

Once completed, the thesis will be made available in hard-copy form in the Curtin Library and in digital form on the Internet via the Australasian Digital Thesis Program. The material will be provided strictly for educational purposes and on a non-commercial basis. Further information on the ADT program can be found at http://adt.caul.edu.au.

I would be most grateful for your consent to the copying and communication of the work as proposed. If you are willing to grant this consent, please complete and sign the attached approval slip and return it to me at the address shown.

Full acknowledgement of the ownership of the copyright and the source of the material will be provided with the material. I would be willing to use a specific form of acknowledgement that you may require and to communicate any conditions relating to its use.

If you are not the copyright owner of the material in question, I would be grateful for any information you can provide as to who is likely to hold the copyright.

I look forward to hearing from you and thank you in advance for your consideration of my request.

Yours sincerely,

Roslyn Ward

PERMISSION TO USE COPYRIGHT MATERIAL AS SPECIFIED BELOW:

1. The PROMPT conceptual framework;
2. The Motor Speech Hierarchy;
3. The Systems Analysis Observation; and
4. Illustration of the Facial PROMPTS (page 40)

as detailed in the PROMPT Introduction to Technique Manual (2003).

I hereby give permission for **Roslyn Ward** to include the above-mentioned material(s) in her higher degree thesis for the Curtin University of Technology, and to communicate this material via the Australasian Digital Thesis Program. This permission is granted on a non-exclusive basis and for an indefinite period.

I confirm that I am the copyright owner of the specified material.

Permission to use this material is subject to the following conditions: [Delete if not applicable]

Signed:

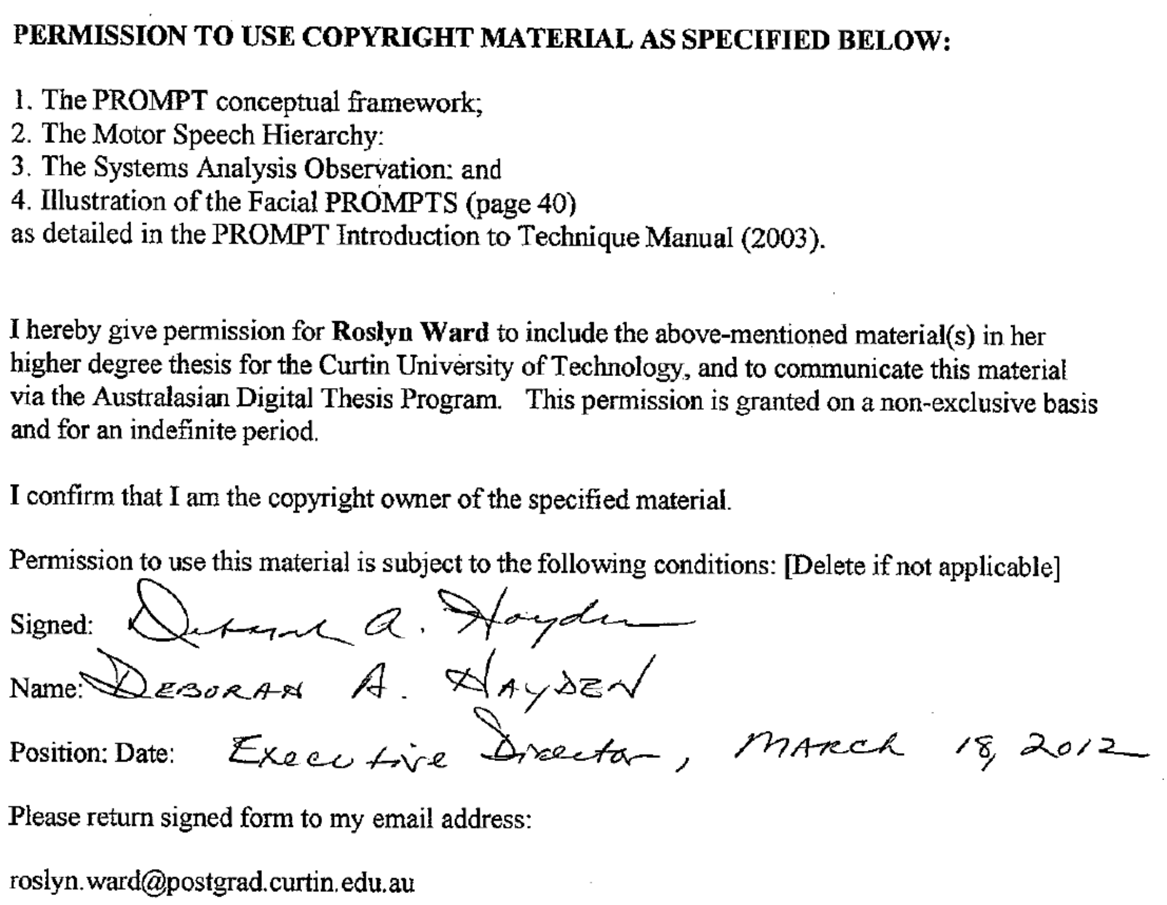
Name:

Position:

Date:

Please return signed form to my email address:

roslyn.ward@postgrad.curtin.edu.au



PERMISSION TO USE COPYRIGHT MATERIAL AS SPECIFIED BELOW:

1. The PROMPT conceptual framework;
2. The Motor Speech Hierarchy:
3. The Systems Analysis Observation: and
4. Illustration of the Facial PROMPTS (page 40)

as detailed in the PROMPT Introduction to Technique Manual (2003).

I hereby give permission for **Roslyn Ward** to include the above-mentioned material(s) in her higher degree thesis for the Curtin University of Technology, and to communicate this material via the Australasian Digital Thesis Program. This permission is granted on a non-exclusive basis and for an indefinite period.

I confirm that I am the copyright owner of the specified material.

Permission to use this material is subject to the following conditions: [Delete if not applicable]

Signed: Deborah A. Hayden

Name: DEBORAH A. HAYDEN

Position: Date: Executive Director, MARCH 18, 2012

Please return signed form to my email address:

roslyn.ward@postgrad.curtin.edu.au