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Gareth John Williams

**Temporal Processing Deficits in Children with
Dyslexia and Developmental Coordination
Disorder.**

Doctor of Philosophy

Psychology

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Abstract

This thesis set out to examine whether temporal processing deficits were evident in both children with developmental dyslexia and children with developmental coordination disorder (DCD), and if there were, whether there were similar patterns of deficits in both conditions which suggest evidence of a possible underlying cognitive deficit common to both conditions, as suggested by some researchers (for example, Kaplan, Wilson, Dewey, and Crawford, 1998, and Nicolson, 2000).

A pilot study was carried out to investigate the feasibility of initial tasks that may be used in main studies. The findings from this study suggested automatisisation and temporal processing may be areas to explore further. Consequently, Study One began by investigating the performance of children with dyslexia, DCD and typically developing children on a rapid naming task. The duration of their articulations and non-articulations was measured and the results indicated that the children with dyslexia showed longer and more variable non-articulation durations than the other two groups; the children with DCD had significantly longer articulation durations than the other two groups.

Main Study Two investigated whether there were temporal production deficits in the two special needs groups relative to controls. The findings here suggested a subtle auditory deficit in children with dyslexia, however the children with DCD did not differ significantly from the typically developing group. Main Study Three investigated temporal perception, using a temporal generalisation task. This study found no significant differences between the groups on their performance on the task, but inter-group correlations suggested that the ability to carry out temporal generalisations was associated with different abilities in each group. Finally, Main Study Four, looked at

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temporal order judgements (TOJs) across several modalities by using different types of stimuli: phonological stimuli, tones, shapes, and letters. Here, the children with dyslexia were significantly less accurate than the other two groups in making TOJs with phonological stimuli, but the children with DCD were not significantly different from the controls. All children performed least accurately on the tone condition suggesting that the nature of this condition is generally difficult. The results do not support the hypothesis that there is a general temporal processing deficit in children with dyslexia or children with DCD or that this may be a common deficit between the two conditions. However, the findings were in line with the idea that children with dyslexia have a phonological and / or speech perception deficit, and further work with children who have DCD needs to be conducted to study the heterogeneity of this condition at the cognitive level.

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1. Theoretical Overview

This thesis sets out to investigate:

- a. The nature and scope of any temporal processing deficits in a sample of children with developmental dyslexia.
- b. The nature and scope of any temporal processing deficits in a sample of children with developmental coordination disorder (DCD)
- c. Whether any of the deficits observed in the children with developmental dyslexia are also evident in the children who have developmental coordination disorder.

1.1. Definitions of Dyslexia and Developmental Coordination Disorder.

This first section will discuss definitions of dyslexia followed by those of developmental coordination disorder (DCD). These definitions serve to focus the thesis on what is meant by these two conditions. However, the definitions by themselves are not exhaustive accounts of what constitutes the two conditions. Later sections of this chapter will serve to examine in depth current understanding of developmental dyslexia (hereafter termed dyslexia) and DCD.

Until recently, an 'exclusion' based definition of dyslexia has been widely adopted. For example, in 1968, The World Federation of Neurology (WFN) defined dyslexia as "... a disorder in children who despite conventional classroom experience, fail to attain the language skills of reading, writing, and spelling commensurate with their intellectual

abilities” (World Federation of Neurology, 1968, cited in Nicolson and Fawcett, 2001, p. 160)

However, many have criticised this definition; for example, Snowling (2000) noted that the WFN definition is vague, as it does not define what conventional classroom experience is or exactly what intellectual abilities should be seen as equal to reading and writing. She also notes that it defines dyslexia by what it is not, rather than by identifying the traits that would indicate group membership (so called ‘positive indicators’).

The underlying assumption of the WFN definition is that developmental dyslexia is evidenced by a discrepancy between reading attainment and IQ. This argument had, until recently, dominated the ‘diagnosis’ of dyslexia. The WFN definition suggests that children with dyslexia have a relatively high IQ and low reading and spelling abilities, and implies that children with a low IQ who have low reading and spelling abilities do not have dyslexia, but are classified instead as ‘garden variety’ poor readers (Stanovich, 1996). However research by Siegel (1992) indicated that the underlying phonological deficits of children categorised in this way as either having dyslexia, or being ‘poor’ readers are no different. Stanovich (1996) also noted that similar intervention strategies work well for both groups.

Snowling (2000) has argued that the International Dyslexia Association (IDA) definition is a better attempt at defining dyslexia. It has recently been adopted by the National Institute of Child Health and Human Development in the USA. Since Snowling (2000) it has been slightly amended but has remained similar in style:

“Dyslexia is a specific learning disability that is neurological in origin. It is

characterized by difficulties with accurate and / or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge.” (IDA, *Frequently Asked Questions: What is dyslexia*).

Both definitions, however, do suggest that dyslexia is a condition beyond simple written language difficulties. The IDA notes that it has a neurological basis and the WFN definition argues that dyslexia is more than a reading deficit. As will be detailed later, studies of children and adults with dyslexia have shown that whilst reading and spelling may be some of the more obvious difficulties associated with the condition, deficits are also found in a range of other cognitive processes. Some of the most recent evidence includes: Snowling (2000), who noted that speech problems are often found in children with dyslexia, as is poor handwriting; Nicolson, Fawcett, and Dean (1995) who found that children with dyslexia had difficulties in estimating temporal durations; and Winner et al. (2001) who found that adults with dyslexia had some difficulties in their performance on visual-spatial tasks.

Motor difficulties have also been observed as a characteristic of children with dyslexia. For example, McPhillips, Hepper, and Mulhern (2000) observed residual primary reflexes in children with dyslexia. They focused on a primary reflex in which turning the neck sideways would cause the child's arms to move involuntarily. The reflex, which is inhibited during the first year of typical development, is thought to be

important in developing early visual processing. McPhillips et al. (2000) went further and developed a training system to suppress the reflex. They found that the reading ability of the group who carried out this training improved significantly more than a group who carried out movements that appeared similar to the reflex inhibition movements, and a control group who did not carry out any movements. In a similar vein, Fawcett and Nicolson (1995) assessed children on a range of motor movements. They found that children with dyslexia had deficits in carrying out simple and complex motor tasks compared with typically developing peers. These included moving pegs on a board, and threading beads. This further suggests that dyslexia is more than a reading disorder.

In contrast to dyslexia, less research and attention has been focused on DCD: consequently there are fewer competing definitions and the Diagnostic and Statistical Manual of Mental Disorders-IV (DSM-IV) (APA, 1994) and the Classification of Mental and Behavioural Disorders-10 (ICD-10) (WHO, 1992) have been relied on primarily. According to DSM-IV, a person may have DCD if:

“[there] ...is a marked impairment in the development of motor coordination... If this impairment significantly interferes with academic achievement or activities of daily living... The diagnosis is made if the coordination difficulties are not due to a general medical condition (e.g. cerebral palsy, hemiplegia, or muscular dystrophy) and the criteria are not met for Pervasive Developmental Disorder... If Mental Retardation is present, the motor difficulties are in excess of those usually associated with it...” (APA, 1994, p. 53).

The ICD-10 (WHO, 1992) description of DCD is similar to that provided by the DSM-

IV, although their term for the disorder is different: “Specific developmental disorder of motor function” (SDDMF). It is worth noting that the both are, like the early definitions of developmental dyslexia, exclusionary rather than descriptive of positive indicators. Also, unlike the IDA definition of dyslexia, neither definition provides an indication of what may possibly underlie DCD. ICD-10 also notes three other terms are used for SDDMF: “developmental coordination disorder”, “clumsy child syndrome” and, “developmental dyspraxia”. Portwood (2000) has suggested that “developmental dyspraxia” is a term only to be used for children diagnosed as having coordination difficulties with associated perceptual problems. However, neither DSM-IV, nor ICD-10 make this distinction and, as she provides no evidence to support this distinction, it is unclear from where she derives this characteristic. In contrast, O'Hare and Gorzkowska (1999) reserve the term “praxis” to define gesture and tool use and by implication, dyspraxia is a disability of this. Sugden and Wright (1998) have criticised the ICD-10 inclusion of these extra terms as “... no mention is made of how these terms may relate to each other, if they do at all, or whether they may be used interchangeably.” (p. 8).

Several other issues have been raised with regard to the DSM-IV and ICD-10 definitions. Henderson and Barnett (1998b) raise concerns with regard to the criteria described in the definitions. They note that insufficient research has been carried out to support the claims made by the diagnostic criteria and that there is no clear method of assessing “motor coordination [that] is substantially below that expected given the person’s chronological age” (APA, 1994, p. 53). Whilst diagnostic tools have been produced, they have yet to be as well developed as in other fields and often (as in the Movement ABC, M-ABC, Henderson and Sugden, 1992) involve observation and judgement rather objective analysis.

Henderson and Barnett (1998b) raise concerns with regard to the intelligence-movement discrepancy in DSM-IV. They question whether there are differences between children with low intelligence and high intelligence and poor motor skills. Another question unresolved is the amount of impaired motor coordination that a child needs to have to be diagnosed with DCD and, as noted by Geuze, Jongmans, Schoemaker, and Smits-Engelsman (2001), whether children with DCD who have an impairment across a range of domains (such as fine motor and gross motor) should be considered in the same way as children with deficits in one particular domain. DSM-IV's statement with regard to movement milestones is also difficult to define; life skills such as coordinating a knife and fork are difficult to measure.

“An inability to fasten buttons or put on a sweater may simply be due to the fact that the child is cared for by a minder who does everything for him/her.”

(Henderson and Barnett, 1998, p. 455).

DSM-IV also states that for a child to have DCD the deficit must impair academic or daily life and also not be related to neurological impairment. However, Henderson and Barnett (1998b) take issue with these criteria too. For the former, they note that little guidance is provided as to what constitutes a deficit of this nature; a child who has poor coordination but acceptable literacy skills might not be classified as having DCD even though coordination difficulties put him/her at a disadvantage at physical education. For the latter, Henderson and Barnett note that soft measures of neurological impairment, (such as those used by Fawcett and Nicolson (1999) to study cerebellar deficits) might still not pick up some deficits or find deficits where none are present. Henderson (1987) notes that there is variable evidence that many soft neurological signs relate to actual neurological deficits. Furthermore, deficits that are found might also be dependent on

the choice of measures that the investigator carries out. Finally, they note that what constitutes neurological impairment in the light of new developments in brain scanning is also unclear, "...it is now possible to detect small lesions in the brains of children classified as DCD which would previously have gone undetected." (Henderson and Barnett, 1998, p. 463).

Whereas there are difficulties in the diagnostic criteria there are also difficulties in naming the disorder. This can impact on how comparable the studies are. Henderson and Barnett (1998b) found research reporting coordination difficulties used included a range of terms from "clumsiness" to "perceptuo-motor dysfunction" (p. 451). When Wilson and McKenzie (1998) conducted a meta analysis of DCD studies, they were required to use a wide variety of search terms including "clumsiness, developmental dyspraxia, motor learning disorder, motor dysfunction, motor disability, motor impairment, perceptual-motor disability, motor delay, and developmental coordination disorder" (Wilson and McKenzie, 1998, p. 830) in order to find journal articles (see also Polotajko, 1999 for a similar list of terms). Whereas Wilson and McKenzie (1998) stated that participants in all of the studies were assessed within similar criteria to the DSM-IV definition, a similar review by Geuze et al. (2001) found that was considerable differences in what constitutes DCD amongst DCD papers. Furthermore, few studies adhered to all the criteria as stated in DSM-IV. In terms of resolution to this naming confusion, Miyahara and Register (1998) found that that DCD was the most acceptable name among a large group of questionnaire respondents who attended a convention on motor disorders. DCD was a term with less negative connotations than "clumsy child syndrome" and was more representative of the disorder than "dyspraxia". However, they noted that agreement on a name for the disorder was still open to debate.

Therefore, in line with the DSM-IV and Miyahara and Register (1998), the term that will be used for the remainder of this thesis for children having a specific developmental deficit in motor coordination will be developmental coordination disorder (DCD).

However, in reporting studies that may not have adhered to the criteria of DCD but have used groups with poor motor coordination, the term “children with coordination difficulties” will be used.

Another area that might help inform the nature of DCD are observations by clinicians such as Portwood (2000), Gubbay (1974), and Polotajko (1999). They have suggested that children with DCD tend to have a cluster of difficulties. Portwood (2000) noted that poor coordination can include difficulties in fine motor skills such as handwriting, and doing up buttons, and gross motor skills such as skipping and hopping. A child aged seven years may have great difficulties in physical exercise classes. This may include problems with following instructions given and carrying them out at the right time, catching, tying laces, simple drawings, and writing. The lack of a clear pathway to diagnosis and intervention can allow time for secondary difficulties to become established, Peters, Henderson, and Dookun (2004) noted that children with DCD are only diagnosed “... via a long and torturous route, attracting a range of medical opinions and diagnostic labels.” (p. 469). Portwood (2000) has noted that children with DCD often have such secondary difficulties such as emotional difficulties (possibly arising out of frustration with the world around them) and delays in language skills. These can often result in children with DCD being isolated from their peers because of their difficulties in responsiveness in the playground. Both Polotajko (1999), and Sugden and Wright (1998) provide similar accounts of children with DCD and Gubbay (1974) who carried out a number of case studies notes the case of P.B. which is

representative of these:

“As a small child he had frequent falls and difficulty getting up from the floor. At the age of 8 years his teacher recognised that he was intelligent but commented that he could not do his handwork and was unsuccessful at gymnastics. Inability to play games with other children led to an aloofness and lack of confidence coupled with tenseness and agitation... When examined at the age of 11 years 4 months, he seemed unduly forthright in his manner and lacked insight into his considerable disabilities... He had no idea of how to fold a sheet of notepaper for insertion into an envelope and when asked to salute, touched the back of his head.” (p. 71).

Portwood (2000) describes a number of behavioural indicators that are spread across a range of domains from social to cognitive ability that change throughout the child's development. Assuming that coordination is the prime deficit, Portwood describes how coordination deficits can impact on, for example language deficits. For example, around 18 months of age, an infant with DCD “Listens to nursery rhymes but finds it difficult to make appropriate actions at the right time.” (p.24). Portwood asserts that being unable to carry out such actions leads to children with DCD becoming disinterested in nursery rhymes which impact on a child's ability to develop appropriate language skills. However, empirical evidence suggests that the indicators of DCD are not as consistent across cases as observers might imply. For example, Portwood (2000) notes that social interaction on the playground and physical exercise lessons are often difficult for children with DCD and from the criteria in the DSM-IV and the ICD-10 this would appear to be understandable. Furthermore, Smyth and Anderson (2000) found evidence

to support this, in a playground observation, children with DCD tended to be onlookers to unstructured games and social play or to play alone. However, Smyth and Anderson looked at who played football in the playground and they found some of the children with low scores on standardised coordination tests often played football with typical children. As Smyth and Anderson (2000, p. 410) state, it was not that the children with DCD had a clear cluster of playground difficulties: “Children in the DCD group are more varied in their play than those of the control group.”

Another example is poor handwriting, which is an indicator of DCD according to Portwood (2000). It would be parsimonious to expect handwriting to be poor as it requires the use of complex fine motor skills (Maeland et al., 1992). However, the evidence from various research projects suggests a more variable incidence of poor handwriting. Peters et al. (2004) assessed the referral information of children with DCD who had attended intervention sessions at Great Ormond Street Hospital; 93% of the referrals described handwriting as a problem for these children. Miller, Polatajko, Missiuna, Mandich, and Macnab (2001), in a study looking at interventions, noted that writing improvement was a target treatment for 75% of children with coordination difficulties. However, Maeland (1992) found that nearly half of his sample of children with DCD symptoms did not have poor handwriting. Moreover, Smits Engelsman, Niemeijer, and van Galen (2001) found that of a sample of 12 poor hand-writers, only three had M-ABC scores high enough to be considered to have motor coordination difficulties. Five children with poor handwriting did not show fine motor deficits below the threshold considered problematic. One study to note the heterogeneity of their groups with DCD was Schoemaker et al. (2001). They tested the visual processing abilities of 19 children who had coordination difficulties and who had been referred to

clinicians. They found that the profile of perceptual deficits in one child was not necessarily the same as another. Furthermore, there was little consistency with respect to their motor difficulties.

For standardised tests, there are also remarkable differences in the M-ABC scores found in research papers. In Smyth and Anderson (2000), their nine year old group had a mean M-ABC score around 15 but a standard deviation of 6.51, suggesting a range of severity. Similar findings can be found in Rintala, Pienimaki, Ahonen, Cantell, and Kooistra (1998) where the standard deviations found in their M-ABC range from 6.01 to 8.10. Miller et al. (2001) reported the subscales for each of their nine year old participants. Whereas the mean total M-ABC scores for the DCD group was 18.77 (considered high). The range of scores of subs-kills showed a divergent group of participants in the study. Participants with DCD had Ball Skills ranging between 0 (no impairment) to 10 (high impairment); whereas Balance saw participants with DCD scoring between 0 and 14. Van Dellen and Geuze (1988) also indicated that, in using Test of Motor Impairment (TOMI, the precursor to the M-ABC), while their groups of children with DCD and typical children had different overall TOMI, scores, there was overlap in subskills for Balance and Ball Skills. Where the M-ABC has been compared across other countries, there have been differences in typical children. In Japan, Miyahara et al. (1998) found that a significant minority of children had very low scores in some tests and in Sweden, Rösblad and Gard (1998) found similar scores to those of American children in all but one ball task where the Swedish children had slightly higher scores. Furthermore, even in typical development, O'Hare and Gorzkowska (1999) note that subskills that constitute fine and gross motor coordination independently contribute to overall motor coordination rather than being part of a global

domain.

Therefore, whereas language skills can be seen as a prime factor in dyslexia and reading development; there is not, as yet, a clear understanding of the nature of DCD or motor impairment in general.

Neither the IDA definition of dyslexia, nor the DSM-IV/ICD-10 definition of DCD has fully accounted for the heterogeneity of both conditions or the possibility of comorbidity. Common themes of attentional, language, social, and movement deficits range through Portwood's (2000) descriptions and paints a picture of a child, who by five years of age shows deficits which relate to dyslexia, autistics spectrum disorders, and ADHD.

Macnab, Miller, and Polatajko (2001) raised the possibility that there were subtypes to DCD. They carried out a cluster analysis on 60 children aged between seven and 12 years of age, the children had been assessed on a range of movement and perceptual tasks. They found five distinct clusters in their data: a group characterised by good balance skills, groups with strengths in visual motor, and perceptual motor; then a groups with deficits in motor and visual motor; finally a group with gross motor deficits. However, differences remain in the prevalence of each subtype compared with other studies. Macnab et al (2001) consider this might be due to differences in sampling procedures between this and other studies. Whatever differences might occur in prevalence of subtypes it is becoming clear that this is a feature of DCD and is likely to relate to the heterogeneity discussed earlier in this chapter. Convergent evidence comes from intervention studies, in both the Rintala et al. (1998) and the Miller et al. (2001) intervention studies, most children with DCD showed some improvement, but not all

the children showed uniform improvement. This suggests that some subtypes might benefit from certain interventions more than others.

Visser (2003) conducted a review of subtypes of DCD. It was noted that many studies had participants grouped as DCD who were not necessarily comparable to each other. Often the groups themselves were not homogeneous. One study which appeared to find clear subtypes was Wann, Mon-Williams, and Rushton (1998), who were able to divide their group of children with DCD into two relatively consistent groups that were distinctive from each other with respect to the absence or presence of postural control difficulties.

In summary, the field of DCD requires has considerable development before it can have comparable diagnostic ability with other developmental disorders. For example, researchers such as Henderson and Barnett (1998b) have questioned the standard diagnostic criteria. Whereas observers of children with DCD indicate general patterns to the disorder; where empirical studies have reported individual data there would seem to be substantial heterogeneity. Furthermore, attempts to classify subgroups have yielded variable results.

The range of deficits in both conditions, some of which appear to have little clear relationship with reading and coordination respectively, would suggest that the groups being studied might not be completely homogenous. This has been borne out by some research studies of the two conditions. For example, in dyslexia, Farmer and Klein (1995), note that subgroups of dyslexia have been identified. However, the search for subgroups has been contentious and the distinction between groups is often arbitrary. For example, Wolf and Bowers (1999) identified three types of children with dyslexia,

those with a rapid processing deficit, those with a phonological deficit and a third group of children who had both deficits. However, to some degree which child fell into which category depended on where the cut-off points were set.

In summary, the research into DCD has suffered from a paucity of studies and is only beginning to develop a coherent narrative of the condition. Furthermore, a great deal is still not known about whether all children with coordination difficulties exhibit a unitary underlying deficit. With this in mind, studies of any nature to examine children with coordination difficulties will help to advance the understanding of this area. The subsequent sections of this chapter will look at theories underlying the behavioural characteristics of both conditions and discuss the possibility that both share a similar underlying deficit.

1.2. Phonological awareness

The first of a range of observed deficits in dyslexia is the phonological awareness deficit. This is probably the area that has received the most amount of research attention in relation to theoretical models of reading development and reading disorders. Broadly, it is argued that there is a link between understanding the sounds that make up words in speech (phonological awareness) and written language acquisition. There is a range of sub-lexical sounds that may be important in written language acquisition and are collected under the umbrella term 'phonology'. Primarily, these are syllables, onsets and rimes, and phonemes. In simple terms, syllables are a collection of sounds that can be made with a single 'effort' of the voice (for example, "trumpet" has two syllables "trum" and "pet"), whereas onsets and rimes are subdivisions of a syllable, (for example, the "trum" in "trumpet" can be further subdivided into "tr", the onset, and

“um” the rime. Finally, phonemes are the smallest units of sound that changes a word’s meaning. In English, letters can represent more than one phoneme; therefore although the alphabet has 26 letters, there are around 44 phonemes (Muter, 2002). Convergent evidence for the importance of being aware of such speech sounds for reading development comes from a range of studies across different methodologies. A selection will be examined here, but see Goswami and Bryant (1990), Snowling (2000), and Muter (2002) for further reviews.

There is evidence that being aware of phonological information at an early age has been shown to result in later reading success. For example, Wood and Terrell (1998a) conducted a longitudinal study of reading development, in which thirty children were assessed on their pre-school, pre-literate phonological awareness and were later assessed on their reading and spelling development at the end of each school term for five terms. It was found that the children’s pre-literate rhyme awareness was the single best predictor of both reading and spelling development during this stage of reading acquisition. Other studies, such as Bradley and Bryant (1983) and Maclean, Bryant, and Bradley (1987) have also found evidence in support of the early contribution of phonological awareness, and rhyme awareness in particular, to reading development. However, there has been some debate as to which subcomponents of phonological awareness are most important in reading development. Recently, Hulme et al. (2002) carried out a comprehensive longitudinal study comparing early readers as they became more proficient in reading. They found that phoneme awareness was a strong predictor of the reading proficiency at the end of the study.

One of the earliest studies that pointed to phonological awareness being associated with reading difficulties was carried out by Bradley and Bryant (1978). They tested a

group of 60 children with reading difficulties with an average age of ten years, six months and 30 younger typically developing children, with an average age of six years, ten months who were matched by reading age to the group with reading difficulties (for example, if a nine year old child in the reading difficulties group had a reading age of seven years old, then that child was matched with a seven year old child with a reading age of seven years). The groups were tested on their ability to name the odd word out of four simple words, for example: “car”, “bar”, “far”, “bat”. The researchers found that the children with reading difficulties had significantly more errors in the odd word out task than the reading matched group. In a second experiment, the researchers read words out to the children and asked them to produce rhyming words that were similar to them. Again, the children with reading difficulties were significantly less likely to be able to provide words to rhyme with the test words.

Another example is Katz (1986) who set out to investigate how well children could retrieve phonological information by asking them to rapidly name pictures. Ten poor reading children, 12 average reading children, and 11 good readers, with an average age of eight years, eight months took part in the study. Katz showed the children line drawings and recorded their naming accuracy and reaction times. As the task progressed, the line drawings represented words that became longer and less familiar, for example, simple pictures were “bear” and “square”, whilst later pictures represented “buffalo” and “typewriter”. He found that the poor reading group did show significantly slower and less accurate naming ability than the good and average readers, even when responses to unfamiliar objects were screened out. He argued that this deficit was likely to be due to failure in being able to retrieve the phonological information for the pictures.

It would seem that it is the processing of phonological information at a sublexical level that poses particular problems for children with dyslexia. Frith and Snowling (1983) asked eight participants with dyslexia and ten typically developing children (both groups had an age range of eight to 12 years old) to read real words, such as “coffee” and non-words, such as “molsmit”. The nonwords would require the reader to decode the word phonologically without recourse to other strategies such as by simply recalling the word from a sight vocabulary. Frith and Snowling found that the children with dyslexia did not have problems with reading the real words, but their accuracy at the non-words was significantly below that of the typically developing participants.

Training in phonological awareness can also have a positive impact on children’s reading ability. Vellutino and Scanlon (1987), carried out a longitudinal training study in early readers and veteran readers. Their group of 300 children was divided up into five training groups. The first group were trained in tasks involving phoneme awareness, the second group on whole word acquisition (where readers may have to associate the word “train” with a picture of a train), the third group on a mixture of the tasks for groups one and two whereas the fourth and fifth groups were used as control groups. The two groups which improved the most in reading ability were the first group and the third group, moreover, the third group did not improve significantly over the first group suggesting there was no added benefit to being trained using the whole word acquisition system. Vellutino and Scanlon argue that this is evidence of phoneme to grapheme processing being important in successful reading.

Further research has indicated that phonological awareness deficits are evident even in adults with dyslexia. Pennington, van Orden, Smith, Green, and Haith (1990) conducted four studies to investigate aspects of phonological and phonemic processing in adults

with dyslexia compared with typically developing adults. Their aim was to establish whether the phonological deficit was the prime deficit in dyslexia. They found that of the wide range of linguistic tests they carried out (articulation, verbal memory, picture naming, phoneme awareness, and phoneme perception) the phoneme awareness task, where participants were given a word and they had to remove the first letter and add the syllable “day” at the end was the one that showed the greatest differences between the two groups (for example start with the word “green”, take away the “g”, then add the word day and arrive at “reenday”). They argued that, on balance the findings confirmed that phonological awareness and particularly phoneme awareness is an important underlying deficit in dyslexia.

Recent brain imaging research has also supported the behavioural evidence that phonological processing is problematic in children and adults with dyslexia. Georgiewa et al. (2002) conducted a study with nine children with dyslexia and eight typically developing children, with an average age of around 12 years, six months. The children were tested in an fMRI scanner while they were at rest, while they silently read words, or while they silently read non-words. They found that the typically developing children showed activations in areas previously found to be activated in other fMRI reading studies: one area in particular was the left inferior frontal gyrus. The authors note that this area generally becomes activated when the brain has to process phonological information. In comparison, the children with dyslexia showed activations in other areas of the brain, but they showed much higher activity for the left inferior frontal gyrus than the typically developing children. Georgiewa et al. (2002) noted that previous research has shown that this area often becomes activated when a participant needs to process phonological information. They suggested that the hyperactivation in the group with

dyslexia was due to this area having to do more work, possibly having to compensate for problems in other areas. Therefore, although neurological evidence can support phonological awareness deficits, it is also possible that other areas of the brain might be dysfunctional and so cause the left inferior frontal gyrus to be hyperactive in order to compensate.

In light of research surrounding phonological awareness in reading development, Snowling (2000), amongst others, has put forward the theory that difficulty in processing, encoding, or retrieving phonological representations may be the prime deficit in dyslexia. And the ability to retrieve the phonological code for words has also been shown to be deficient in children with reading difficulties. However this theory is still problematic. First, there are methodological weaknesses in the research into phonological awareness that has been used to support such hypotheses. Second, the phonological deficit hypothesis argues that difficulties are due to problems in storing and accessing phonological representations, whereas there is evidence that children with reading problems may have problems with the perception of speech itself. Finally, it only offers a partial account of the deficits experienced by individuals with dyslexia. It has already been noted that children with dyslexia experience a wide range of symptoms, many of which appear to be unrelated to written language difficulties. By focussing on the phonological difficulties that the children appear to have, it fails to account for the broader syndrome. These issues will now be dealt with in turn.

Many researchers (as noted above) have argued that phonological awareness is important for successful reading development and is a core deficit in children with reading difficulties.

However there is some disagreement as to how comprehensive phonological awareness is as a skill in reading development. Phonological awareness is a broad umbrella term that contains a range of skills such as rhyme awareness, phoneme awareness as so on. Macmillan (2002) reviewed a range of articles supporting rhyme awareness or phoneme awareness as a main causal factor in reading development. She found that stronger methodologies had been employed in the research showing evidence of phoneme awareness as being important in reading development. Recently, a comprehensive review of studies by Castles and Coltheart (2004) has also argued that there are flaws in the underlying assumptions of studies that support the importance of phonological awareness in reading development. For example, they noted problems associated with longitudinal studies. These often do not ensure that participants have no reading skills at the beginning of the assessment period. This could cause there to be developmental patterns across the longitudinal study that are due to these unknown early reading skills rather than skills measured during the longitudinal study. They also noted that the majority of studies looking at phonological awareness assume that this is a unitary construct whereas there is evidence that it is made up of at least the capability to divide words and then blend them back together. They note that further research will be needed in order to develop studies that address these assumptions.

There is compelling evidence that children with dyslexia might have difficulties in speech perception. A speech perception deficit could affect a child's ability to encode accurate phonological representations, consequently affecting their ability to read and spell in line with typically developing children. Furthermore, they would show deficits in tasks requiring phonological skills. Studdert-Kennedy (2002) suggested that there was strong evidence that underlying phonological awareness deficits in dyslexia are due

to speech perception deficits. “Poor speech perception gives rise to both ‘fuzzy’ or ‘underspecified’ lexical (and so phonological) representations and to weak verbal short term memory. These in turn give rise to deficits in syntactic awareness and in comprehension in listening and/or reading.” (p. 6).

A number of studies have provided evidence of this nature. Brady, Shankweiler, and Mann (1983) tested 15 children with reading difficulties, and 15 children with typical reading, aged around eight and a half years old. In the first experiment participants were verbally presented with sets of five monosyllabic words, which either rhymed or did not. They found that the poor readers had significantly more difficulty recalling the non-rhyming strings correctly; furthermore, the poor reading children transposed phonemes in the words significantly more often than the typically reading children. After establishing that children with dyslexia did show confusion as to the order of phonemes, they carried out experiment two.

Their second experiment compared the same two groups on their abilities to perceive a range of high and low frequency words when they were either presented individually with no background noise, or with background noise. They found that with both the high and low frequency words the poor reading children made more errors compared to typical children when the words were presented with a background noise than when there was no background noise. When Brady et al. analysed the errors from the results they found in this task, the poor reading children tended to have difficulties with stop consonants such as /b/ and /d/. Brady et al. then report a final study where they attempt to establish whether the difficulties in speech perception that the poor readers had was limited only to speech, or whether, as has been argued by Tallal (1980), the difficulties are due to a more widespread auditory processing deficit. The children were played

environmental sounds such as a piano playing or a baby crying. Again, in one condition the set of sounds had a background noise added, and in the other, the set did not. In this experiment there were no significant differences between the poor reading group and the typically reading group. They argue that the studies "... further suggest that the difficulty the poor readers manifested in perceiving speech in noise is not the consequence of generally deficient auditory perceptual ability but rather is related specifically to the processing requirements for speech." (Brady et al., p. 363).

While these studies provide evidence of a deficit, McBride-Chang (1996) provided evidence that speech perception is implicated in typical reading development. One hundred and thirty six children aged between eight and ten years old were tested on a range of phonological and reading tasks, a measure of IQ, and several tasks where they were presented with words or nonwords acoustically and were required to indicate which word they had heard out of two visually presented choices. In measure one, the words had their initial phoneme edited so that at one extreme it sounded as "bath" and at the other extreme it sounded like "path", 13 speech sounds were created in between with initial phonemes that sounded like an amalgamation of "bath" and "path". In measure two, a similar procedure was used to create the words "split" and "slit" then 11 word sounds that ranged from the former to the latter. The final measure had 11 consonant-vowel segments which ranged from "ba" to "wa". McBride-Chang then conducted a path analysis to see which fitted one of five models which she had initially proposed. The data best fitted her Indirect Model. In this model, speech perception is important in reading, but its influence is indirect, being mediated by aspects of phonological awareness.

A different approach to assessing speech perception abilities in poor readers was developed by Metsala (1997). She developed a gating task to compare 39 children with reading difficulties and 61 typically developing children, aged between 94.63 months and 136.05 months. The task involved presenting first a small portion of a word as speech, in the first trial 100 ms of the start of a word, and then presenting 50 ms more of the word until the participant was able to identify the word. Metsala developed a word stimulus set based on neighbourhood density; words with a high density had many similar sounding words, whilst words with a sparse density would have few similar sounding words. Metsala found that her children with reading difficulties took significantly longer to identify the words with a sparse neighbourhood density than the typically developing children. Her suggestion was that the children with reading difficulties had problems with identifying the speech sounds earlier, especially where there might be fewer previously stored cues such as similarly sounding words to help. Therefore, firstly, she again established a speech perception deficit, this time using a different type of task to the identification task presented earlier. Secondly, it appeared that similarly sounding words the child knew could be used to help identify the target word.

Wood and Terrell (1998b) compared three groups, each comprising thirty children. Their poor reading group had poor performance on reading and spelling measures (at least 18 months behind their chronological age). A chronological age match group were the same age as the poor reading group but were reading in line with their age, and a reading age matched group who were reading in line with their age but matched to the poor readers by their reading age, were also included as controls. This is a design, as suggested by Bradley and Bryant (1978) to control for whether the poor reading may be

due to failure in reading experience rather than a particular failure in reading ability. The poor readers and chronological age matched readers were around nine years, one month of age, and the reading age matched children were around six years and five months of age. Wood and Terrell tested the children on a range of reading, rhyme awareness, phoneme awareness, vocabulary, and speech perception tasks. Two speech perception tasks were used: one task required the children to repeat sentences which had been time compressed. A second measure assessed their sensitivity to speech rhythm. The children with reading difficulties were significantly worse than their age matched controls on both these measures.

Overall, the evidence suggests that the skills that make up phonological awareness are important in both reading development and reading disorder. Furthermore, that in addition to being aware of how language is put together, being able to perceive speech effectively is also an important aspect of phonological processing. However, one problem is that the phonological representations hypothesis or a speech perception deficit hypothesis only accounts for a small subset of the difficulties experienced by children with dyslexia. For example as noted earlier, the research by McPhillips et al. (2000) found primary reflex deficits in children with dyslexia, and Fawcett and Nicolson (1995) found difficulties in motor movements were prevalent in children with dyslexia. In order to account for the full range of deficits several competing, and in some cases complementary, theories have been developed. In addition, some, such as temporal processing theories, attempt to account for the phonological and speech perception difficulties in terms of a more general information processing deficit. Several of the more prevalent theories will now be discussed: automatization difficulties, temporal processing deficit, and the cerebellar deficit. It is worth bearing in mind that,

as these theories attempt to account for the wider deficits apparent in dyslexia they may also relate to processes involved in movement and so have implications for children with DCD.

1.3. Automatisation

Automatisation is a broad umbrella term for the process of transferring a learnt behaviour to an automated process that does not require conscious attention to produce. In research on dyslexia, the area has been dominated by studies involving rapid automatised naming (RAN), however a few studies have also examined other forms of automatisation and these will be dealt with later. One of the earliest studies to investigate automatisation in children with dyslexia was Denckla and Rudel (1976), who tested 52 children with dyslexia, 48 poor reading children, and 120 typically developing children, between the ages of seven and 12 years old. The RAN task was a chart with five stimuli repeated ten times randomly. The study had four different conditions. These were naming words, numbers, colours, or objects. They found that, whilst all the children were able to name the stimuli when they were presented individually, the typically developing children were able to complete all four stimulus sheets significantly faster than the poor reading group who were, in turn, faster than the group with dyslexia. They also found that the best discriminators of the groups were the number and the letter conditions. However, as they discuss, this may be because there is more of an overt phonological aspect to these conditions.

One question is how RAN relates to phonological awareness and speech perception. Wolf and Bowers (1999) have noted that there was a tendency in the reading research field to see rapid naming as a sub-process of phonological awareness rather than as

making an independent contribution to the range of skills required in effective reading. However, a number of studies have shown evidence that this is not the case. Bowers and Swanson (1991) conducted an analysis using a RAN task that was based on the number and letter tasks conducted by Denckla and Rudel (1976). The participants also completed standardised tests of phonological awareness, comprehension, verbal memory and word reading accuracy. Their test groups were 21 typical readers and 25 poor readers around eight years of age. They found that, in line with Denckla and Rudel (1976), the typical readers were significantly faster than the poor readers in both the numerical task and the letters task. Bowers and Swanson (1991) conducted regression analysis to investigate whether naming speed contributed to the word identification, word attack and reading comprehension. Comprehension was the only baseline measure which naming speed contributed to. A second analysis was carried out to investigate naming speed and its relationship with phonological awareness. They used the odd word out test as one of their measures of phonological awareness, (the test was devised by Bradley and Bryant, 1978, and is described earlier). They found that this and other phonological awareness measures did not correlate with the naming task. Consequently, their study provided initial evidence that RAN is independent of phonological processing.

Meyer, Wood, Hart, and Felton (1998) investigated what sort of contribution rapid naming made to reading development using a longitudinal design. In their first experiment, they carried out a longitudinal study of 154 children aged around five years of age who were subsequently tested at eight, ten, and 13 years of age. The poor reading group consisted of 15 children who were performing poorly at around the age of seven years on a range of word reading tasks, they then selected 17 good readers for

comparison with the poor reading group. This left 122 children who were then grouped as a typical reading group. They found that rapid naming was able to predict significantly word identification at later grades for the poor reading group but not for the other two groups. For the poor reading group the RAN tasks were a better predictor of word identification than nonword reading or phonological segmentation tasks. Their second experiment focused on a larger sample of poor readers. Sixty-four children with dyslexia were tested at around the age of ten years and again at around the age of 13 years. In regression analysis rapid naming accounted for a significant amount of the variance in the reading ability of the sample. Their findings confirmed that rapid naming is a pervasive difficulty that children with reading difficulties experience and it is prevalent throughout their school life. Secondly, as the task has predictive power only for the poor reading children, they suggested that rather than being at the tail end of a normal distribution, these children may have a specific disorder in reading proficiency. The unique role of rapid naming ability in understanding reading difficulties has led researchers to investigate whether it is possible to view dyslexia in terms of three subtypes. Wolf and Bowers (1999) argued that children with dyslexia may be categorised by a single deficit in phonological processing, a single deficit in rapid information processing, or a deficit in both domains (a double-deficit). Hit by both deficits, they argued that the double-deficit children would also be the poorest readers of the three groups. Wolf et al. (2002) carried out a study of 144 children around the age of seven and a half and children around the age of eight and a half with reading difficulties. Their test battery was a range of phonological tests and rapid naming tests. The results allowed them to identify three distinct groups: 19% had only a phonological deficit, 15% had only a rate processing deficit, and 60% had a double-deficit. Some

support also was found by a study by Compton, DeFries, and Olson (2001) of 476 children with an age range of eight to 18 who were already taking part in an ongoing twin study. This study supported the assertion that children who had a double-deficit were worse in reading ability than those children with a single deficit. However, they cautioned that the children's membership of the groups was dependent on somewhat arbitrary divisions rather than clear and specific groups. In summary, the evidence reviewed here does indicate that children with reading difficulties had difficulties that extended beyond a simple phonological awareness deficit.

A recent approach to studying RAN has been to record the acoustic information from a participant while the RAN task is carried out and then analyse the acoustic information for the articulation duration and non-articulation duration. This may provide a more detailed insight into RAN ability than simply analysing global measures of RAN such as total time taken to complete the task. One measure in particular, the non-articulation variability, has been shown to be important in typical reading development.

Neuhaus, Foorman, Francis, and Carlson (2001a) tested 50 Grade One and Grade Two children on RAN tasks of letters, numbers, and objects, based on Denckla and Rudel (1974). They found that the speech and silence durations were not significantly correlated for letters and objects RAN, which suggested that they are based on independent processes. The non-articulation duration was related to reading, but the articulation durations were not. Of note was that the letters RAN was the best predictor of reading ability in the two grade groups.

Cobbold, Passenger, and Terrell (2003) conducted a longitudinal study of 68 children aged four years to four and a half years old at the beginning of the study and between

five and five and a half by the end of the study, the children were tested three times over the year. Their RAN task involved the children naming 20 line drawings as quickly as possible. The participants' responses to the task were recorded digitally and analysed for articulation and non-articulation durations using a computer. The children's reading ability was also measured at the end of the study. They found that the non-articulation durations were highly variable at this early age but articulation durations were not and that there was no relationship between early rapid naming proficiency and later reading ability. They argue this suggests that the role of rapid naming becomes more important as children move from a pre-literate to an early literate stage. In line with Neuhaus et al. (2001a), they also found no relationship between the speech and silence durations, suggesting that they are carried out by separate cognitive processes.

Few studies have, however, looked at the articulation and non-articulation durations in the rapid naming performance of children with dyslexia. Snyder and Downey (1995) tested 15 young children (mean age nine years, four months) and 15 older children (mean age 12 years, seven months) who were average readers with 15 young children (mean age nine years, seven months), and 15 older children (mean age 12 years, eight months) who had reading difficulties. Their rapid naming test required children to first name geometric shapes, then colours, then shapes and colours. Each condition had 36 items, and naming was recorded and later analysed for speech and silence durations by computer. They found that the poor reading children took significantly longer to both name each item and also to pause between items.

Snyder and Downey raised the possibility that the slowness was due to not being able to retrieve the words because of poor vocabulary but when they compared vocabulary proficiency of the two groups, they found that this was not the case. This raises an

interesting question: could the difficulties in the pause time be related to difficulties in reading the next stimulus? If so, why would the children have difficulties with production? Snyder and Downey (1995) suggest that difficulties in processing phonological representations during naming may play a part. In particular, a number of the names used were quite long (e.g. yellow circle) so retrieval of the names and their articulation may have been more complex than if it had been just naming a letter or a single syllable word and would have impacted on articulation duration. Alternatively, physically naming the word may have been a problem. Snyder and Downey (1995) included a baseline measure of articulation and they found that this was able to discriminate between the poor reading and typical reading group. Therefore the difficulties in producing the stimulus name may be related to being able to articulate rapidly rather than due to a phonological process. A criticism of Snyder and Downey is that their methodology differed from that of Denckla and Rudel (1976) therefore it is unclear how much of this task is a task of RAN.

However, Anderson, Podwall, and Jaffee (1984) did carry out an analysis of articulation and non-articulation using a RAN task similar to Denckla and Rudel. They also found that children with dyslexia took longer to start a RAN task, took longer to say each stimulus, and took longer between each stimulus. However, Anderson et al. did not analyse the variability of the non-articulation duration. Subsequent research in typical development, has found that the variability of the non-articulation is an important factor in differentiating young children's performance at RAN and older children's performance (for example, Neuhaus, 2001, and Cobbold et al., 2003).

One of the reasons why few studies carried out articulation and non-articulation duration analysis of RAN is that in order to analyse this sort of information a large

amount of data processing has to take place. The duration of each speech and silence event has to be painstakingly measured from the audio output provided by the participant. In a traditional RAN task, that would yield 100 measures per trial, per participant. Even with the use of digital recording, unless specialised software is used to aid the analysis, this can still be a time consuming process.

There have been no studies of the rapid naming abilities of children with DCD.

However a study that decomposes the overall naming speed into speech duration and silence durations would allow the comparison of the pattern of automatized processing in DCD and dyslexia. As rapid naming is not related to the phonological deficits associated with dyslexia there is a possibility it may be related to a temporal processing ability. RAN requires fluency and regularity of articulation, elements that demand good temporal processing ability.

One study to suggest that deficits in automatization may be more widespread than those evidenced by rapid naming difficulties was carried out by Fawcett and Nicolson (1992). They investigated the automatization of balance, which they considered to be a skill learned very early in life. They argued that if dyslexia is partly due to a deficit in automatization then they should find that this ability still has not transferred to complete automated control. Twenty-seven, 10 – 15 year old children and a group of aged matched typically developing children were first asked to balance on one leg on a small platform with their arms stretched out at either side. They were then asked to do this whilst also counting backwards from 100. The number of steps that they had to count backward in (ones or threes) depended on a screening test. This was to ensure that the task was equally difficult for all the children. They found in just the balancing condition there were no significant differences in the amount of “wobble” that the children

made, but in the dual task condition the children with dyslexia did have difficulty maintaining balance. This was in comparison to the control groups who did not have problems counting backwards and balancing. One problem with this study is that there have been difficulties in replicating the findings. For example, Wimmer, Mayringer, and Landerl (1998) conducted a similar study in Germany and found no differences between children with dyslexia and typically developing children in their abilities to balance and carry out a task concurrently.

If, as Nicolson and Fawcett (1990) have argued, children were not able effectively to transfer some or all of the processes involved in reading to automated processing then it would be more difficult to read efficiently, particularly as texts become more complicated as children grow older. These children would not be able to free up sufficient cognitive capacity in order to carry out other reading processes, so if phoneme-grapheme correspondences were not automated then this would be carried out at the expense of other processes such as blending the phonemes together, or comprehension. Furthermore, the behavioural outcome would be slow and laborious reading. Wolf et al. (2002), amongst others, have argued that successful reading and comprehension requires the ability to process fluently information from text. If these collections of skills are not automated then it may also be the case that other learnt skills would also not be transferred and become automatised. As noted earlier, it is possible that if there is a more general cognitive deficit that is shared between children with dyslexia and children with DCD, as argued by Nicolson (2000). Then being unable to effectively transfer movement skills from learnt to automated would impact on their abilities to carry out tasks which require fast and accurate motor processing.

So far, the two main theories of dyslexia covered - the phonological deficit hypothesis and the automatization deficit hypothesis - have provided an account based on cognitive processes. Both have provided evidence that (a) children with dyslexia have deficits in processing and retrieving phonological representations and that these may be caused by speech processing deficits, and that, (b) children with dyslexia can have a second, independent deficit in the automatization of reading processes. The next two models of dyslexia provide, first, a quasi-neuropsychological model related specifically to temporal processing, and secondly, a model of dyslexia based on cerebellar processing which aims to subsume the known deficits in phonology, automatization, and temporal processing under one theory. These two models will now be reviewed in turn.

1.4. The temporal processing deficit hypothesis

The temporal processing deficit hypothesis aims to account for the deficits found in phonological awareness as part of a more generalised deficit in processing rapid acoustic information. The argument is that before speech perception can occur acoustic information has to be processed. In speech, the acoustic information is presented quickly and is very complex. Failure to process this efficiently may lead downstream to speech perception deficits. As Tallal (1984) argued, there is "... support [for] the hypothesis that phonetic processing deficits themselves may result from inefficiencies or deficiencies of the processing mechanisms essential for processing the rapidly changing acoustic spectra which characterise the ongoing speech stream." (Tallal, 1984, p. 168). Llinas (1993) has gone further to argue that, more than a deficit of acoustic spectra, the deficit may lie in processing time-sensitive information.

Tallal's evidence for such a deficit came from a study she conducted some years earlier.

Tallal (1980) carried out two experiments. Her participant groups were 20 children with reading difficulties and an average age of nine years, seven months; and 12 typically developing children with an average age of eight years, five months. Both groups had similar IQ, and the children with reading difficulties were at least two years behind on their reading. The first task (sequencing) involved judging whether two stimuli were the same or different tones. A second task (same or different), the sequencing test looked at whether children could reproduce the order of the two tones.

In the sequencing test, the children had to copy, by pressing buttons on a panel, the sequence of two tones (one at 100 Hz, and the other at 305 Hz). Initially these were presented with an ISI of 428 ms. After they had completed the practice test, they were asked to copy sequences, but this time the two tones were separated by one of several ISIs between: 8 ms, and 305 ms. The same or different subtest required participants to respond yes if the two tones they heard were the same or no if they were not. Initially, the ISI was 428 ms, but like the sequencing task, the later ISIs ranged from 8 ms to 305 ms. In addition to this, Tallal gave participants various baseline measures, including a task of non-word reading.

Tallal (1980) found that the poor reading group were significantly worse than the typically developing group on the sequencing test at ISIs between 8ms and 305 ms; and on the same-different test, again, particularly on the shorter interstimulus intervals. However, when she looked at the poor reading groups carefully, she found that the difference was only due to a small number of poor reading children, "fifty-five percent of the reading-impaired children's performance was within normal limits on this test while 45% of the reading-impaired subjects made more errors than the worst control" (p. 189). But evidence that temporal order judgements (TOJs) were important in

reading came from a significant positive correlation between performance on the rapid perception test and nonword reading that she found. Tallal argued that the poor reading children may have found analysing the rapid acoustic information difficult. This may then lead to difficulties in analysing speech, which is a rapidly changing set of sounds. This would be the basis for particularly the phonemic awareness deficit found in some children, such as the evidence reviewed earlier. One problem that limits the comparability of the groups is Tallal's use of non age matched groups and is something later studies have controlled for. Tallal (1980), defended the use of differently aged groups reasoning that by the age eight years, children are very adept at TOJs.

Further evidence, however, came from Tallal, Miller, Jenkins, and Merzenich (1997) who conducted a training study to provide evidence that children with dyslexia would benefit from support in low level auditory processing. Their argument was that if the children were trained in acoustic spectrum processing and if this had no effect on their reading development then it was clear that the two were separate processes. If training in acoustic spectrum processing improved their reading ability, it was likely to be an important underlying process deficient in children with dyslexia. Tallal and colleagues worked with seven children, aged between five and nine years of age, with language impairments. These children also had poor abilities at auditory TOJ tasks, completed six weeks of intensive training on auditory temporal processing. This involved completing game like tasks to improve their abilities to discriminate between tones at different ISIs, these games adapted to the child's progress, consequently the task became harder as the child improved. In addition, another game was designed in which speech sounds were digitally altered to emphasize the types of speech information previous research had found the children had difficulties with.

Tallal et al. found that after the training the children improved to almost normal levels during the post test for language comprehension and speech discriminations. A second study with a larger group and compared against a control group found similar results. Dramatic though the results were, caution should be taken in generalising from them. The children had language difficulties rather than being diagnosed specifically with dyslexia. Whereas Tallal et al. (1997) noted that children with language difficulties often have reading difficulties too, it is possible that they do not have the same root cause of reading difficulties as children with dyslexia or children with general reading difficulties. Tallal et al. (1997) is one of the few attempts at a training study. However, based on the temporal processing hypothesis a large number of studies have tried to replicate the findings of Tallal (1980).

Reed (1989) carried out two experiments which replicated and extended Tallal (1980). In experiment one, she compared 20 children with reading difficulties, and 20 typically developing children, both groups were matched for age (with an average age of nine years) and gender. She used a sequencing procedure similar to Tallal (1980), but she used a different range of stimuli. The first was a tone stimulus similar to Tallal's, the second were two consonant-vowel digraphs, and the third were two vowels. The children with reading difficulties did not have problems with the vowel sequence but were significantly less accurate on the tone and consonant vowel conditions, particularly at shorter inter-stimulus intervals. In a second experiment, Reed, tested ten of the children from experiment one who had reading difficulties and ten of the typically developing children. Again the children were matched for age and gender. This time she compared their ability to reproduce a sequence of two visual stimuli (see Figure 2.2, . for a reconstruction) and two vowel stimuli that were masked with white noise, which

would make the vowels more difficult to identify. She found no significant differences between the groups in accuracy in reproducing the visual stimuli, or in reproducing the vowel stimuli with white noise. Furthermore, when she compared the poor reading children's accuracy on the vowels with white noise and their previous performance on vowels with no white noise, she found no significant differences. She argues that her findings confirmed that children with reading difficulties have problems with certain types of complex acoustic information and that it is possibly related to a more general auditory processing ability where complex information has to be processed. Reed suggests two alternative interpretations. One is that the deficit is in processing phonological information in the consonant and vowel information. The second, in line with Tallal (1980) is that the deficit maybe related to the perception of complex and fast paced auditory information.

Support for Tallal and Reed has come from Farmer and Klein (1995) who conducted a review of studies which assessed temporal processing and found a widespread level of temporal processing deficit in some children which appeared to go beyond deficits associated with just reading. Their findings do support assertions that Tallal has made about temporal processing and dyslexia. Furthermore, the deficits appear not only connected to reading but to more low-level perceptual processing in both visual and auditory domains. More widely, however, they posit a deficit relating to a more centralised temporal process that controls both domains.

Whereas Tallal has focused on low-level auditory deficits, Stein (2001) has argued that it is possible for low-level visual deficits implicated in dyslexia. Abnormal cell development in the magnocellular pathway that delivers fast non-colour visual information from the retina to the visual cortex could cause a less efficient

transmission system and so affect the quality of this information before it reaches phonological processing. Talcott et al. (1998), for example, used two tasks that tap into the magnocellular pathway: random dot kinematograms and flicker fusion. In the former, a participant is presented with a display of dots moving randomly across a screen. However, some of the dots are moving in the same direction and the dependent variable is the number of dots required to move in the same direction before the participant can detect coherent movement. In the latter, participants are required to determine when a screen changes from being a display of one colour to a flickering display. They found that the majority of adults with dyslexia (in comparison to typical adults) had deficits on both tasks. Stein and Talcott (1999) have developed the theory further by arguing that there might be an equivalent magnocellular pathway for auditory systems this would dovetail with the work by Tallal (1980).

However, evidence for the magnocellular theory is equivocal and to date, there is no empirical evidence of a similar auditory pathway. Hayduk, Bruck, and Cavanagh (1996) failed to find magnocellular deficits in their sample of adults and children with dyslexia when they used similar tasks to Talcott et al. (1998). Furthermore, Farrag, Khedr, and Abel-Naser (2002) found parvocellular (a slower pathway complimentary to the magnocellular pathway which transfers fine detail) deficits in their sample of children with dyslexia. Furthermore, Skottun and Parke (1999) have argued that the magnocellular pathway might not play the role in reading argued by Stein (2001). For the purposes of this thesis, the magnocellular theory will be subsumed under the temporal processing theory as it relates to low level processing in dyslexia.

Further concerns come from Farmer and Klein (1995) who added two main caveats to their review. The first being that further research would be required before a clear

case for temporal processing as a cause for dyslexia could be confirmed, and secondly, that a temporal processing deficit may only hold for a subset of children with dyslexia, something that is echoed even by Talcott et al. (1998). Nevertheless, Habib (2000), who reviewed a range of recent literature on dyslexia, has also argued that the temporal processing theory is one of the most compelling of the recent theories into dyslexia that may be able to account for all the deficits that children and adults with dyslexia have. Tallal's (1980) findings have also come under criticism. Few independent researchers have managed to replicate her findings. Those that have, often suggest alternative interpretations. For example, Marshall, Snowling, and Bailey (2001) conducted two studies similar to Tallal (1980). In the first experiment they investigated skills that may be associated with auditory temporal processing. Their sample consisted of 82 typically developing children aged between six years, six months, and 13 years, four months. They found that, when they controlled for age and visual-spatial abilities, the auditory TOJ task correlated well with a range of phonological and reading tests, and therefore did appear to be contributing to reading ability in typical development. In their second experiment, they compared 17 children with dyslexia and 17 typically developing children, aged between eight years, eight months, and 13 years, four months. They found that the children with dyslexia showed significantly poorer auditory temporal judgements. However on closer inspection of this group, they found that only four children with dyslexia were performing very poorly on the task and that this sub-group was affecting the overall group performance. When they compared the group with dyslexia who were poor on TOJs with the group with dyslexia who were typical on the TOJ task they found neither group differed on baseline scores of phonological awareness or reading ability. Even though a subset of the group with dyslexia had

difficulties with the task, it did not appear to have any relationship to their deficits in reading ability. Marshall, et al. observed that during testing this subgroup did appear to be more hyperactive than the other children with dyslexia, suggesting that a further area of study would be attentional demands related to this task.

Mody, Studdert-Kennedy, and Brady (1997) investigated the claim discussed earlier by Tallal (1980) that phonemic awareness was related to TOJ ability. Twenty children with reading difficulties who had been chosen from a larger group because they had poor performance on a /ba/ and /da/ discrimination task were compared to 20 typically developing children. Mody et al. (1997) had done this so that the two groups did not have the overlap in TOJ abilities as the two groups in the Tallal (1980) study had or that there was only a subset of poor performers, as in Marshall et al. (2001). Mody et al. (1997) reasoned that if the children had difficulty with processing the fast changing acoustic spectra of the consonant-vowel digraphs /ba/ and /da/, they would also have difficulty discriminating other consonant-vowel digraphs such as /ba/ and /sa/. Their findings indicated that this was not the case, as both groups were able to discriminate /ba/ and /sa/ as well as other consonant-vowel digraphs. Mody et al. argued that it was more likely that the children with reading difficulties were confusing phonologically similar information rather than the underlying acoustic information itself.

As noted earlier, Farmer and Klein (1995), had argued that children with dyslexia may also have difficulties in both visual and auditory temporal information processing, and so a general deficit. But Reed (1989) had only demonstrated an acoustic deficit. Heim, Freeman, Eulitz, and Elbert (2001) set out to compare abilities on an auditory and a visual TOJ task. They tested 22 children who were diagnosed with dyslexia and 11 typically developing children. The groups were matched on age and nonverbal

behaviour. The auditory task required the children to hear the two versions of the syllables /ba/ and /da/, one with a short formant transition between the consonant and vowel and one with a long formant transition. The participants heard the syllables through headphones and were asked to press a green panel if the two successive syllables were the same or a red panel if they were different. After a practice session, the test trial consisted of 18 presentations at ISIs between eight and 305 ms. The visual task required participants to press a red button when they saw two lights of the same colour or the green button when they saw two lights of a different colour. The two lights were red and green lights, first one light would flash and then the second, then both lights would remain on for two seconds. Heim et al. found a significant difference between the children with dyslexia and the typically developing children in the auditory TOJ task, but closer inspection showed again that a subset of these children were lowering the mean for the entire group. Fourteen of the children with dyslexia completed the task with the same accuracy as the typically developing children. Analyses showed that there were no significant differences in the visual TOJs. When Heim et al. compared the poor performing TOJ dyslexia group with the good performing TOJ dyslexia group, as with Marshall et al. (2001), they found no difference in baseline phonology and spelling deficits.

Finally, another recent study has cast doubt on the generality of TOJs. Bretherton and Holmes (2003) studied temporal processing of tones, speech, and shapes in 42 children with reading difficulties with an average age of ten years, one month. Their children were tested on a range of phonological awareness and reading tests. Their experimental tasks were similar in procedure to those of Tallal (1980) but they only used a repetition task and there were four different conditions. The first was a tone repetition task, the

second was a consonant-vowel task, the third a vowel only task, and the third used the symbols X and O. They went further to divide their poor reading group into one that performed poorly on the tone task and one that was performing to a typical level. They expected to see that the poor tone group would be poorer at the speech tasks if tonal processing underlay speech processing. However, the poor tone perception group showed no significant differences compared with the average tone perception group on the measures of reading, phonological awareness, or the consonant-vowel, vowel only, or symbols TOJ task. Their findings again raise the question of whether the deficits found in tonal processing with some children who have reading difficulties are related to their difficulties in reading.

Few longitudinal studies have been carried out on temporal processing ability; one, however was carried out by Share, Jorm, MacLean, and Matthews (2002). They collected data from several hundred children who were in pre-school, and then followed their progress through years one and two of school. In the pre school and whilst they were beginning readers, Share et al. tested the children on a range of tests known to be important in later reading ability such as phonological awareness and vocabulary. At time two, where the children were around five and a half years of age, they were tested on their reading abilities, and their proficiency at long (428 ms) ISI and short (8 to 305 ms) ISI repetition TOJs. The task itself was very similar to that used by Tallal (1980). In their second set of analysis Share et al. chose children from the group who had reading difficulties in time two. Twenty-five poor reading children were matched with 25 typically reading children. They found that the poor reading children were significantly less accurate on the long ISI TOJ condition, but not the short ISI TOJ condition. A finding which is in contrast to that of Tallal (1980) who found deficits in a short TOJ

ISI only.

Share et al. (2002) then compared groups longitudinally. They chose children who had performed poorly on long ISI and short ISI conditions of the TOJ task, then matched them on age and gender to children whose performance was typical on the two tasks. This yielded 20 children who performed poorly on the long ISI condition, 20 children who performed poorly on the short ISI condition, 20 children who acted as controls for the long ISI group, and 20 children who acted as controls for the short ISI group. They found only one consistent pattern of difficulties; this was in the children with poor performance on the long ISI and was on measures related to vocabulary and comprehension. They conclude that their findings show little support for TOJs underlying phonological awareness deficits in reading development, and reading disorders. Secondly, where there were difficulties they appeared to be related to other difficulties that may not be central to reading.

A collection of studies by Schulte-Körne and colleagues casts further doubt over the claim that low level auditory processing of tones is a problem for children with dyslexia. If the gaps between information presented causes problems in children with dyslexia, then they should also have difficulties in detecting short gaps themselves. Schulte-Körne, Deimel, Bartling, and Remschmidt (1998b) studied the abilities of 15 children with dyslexia and 14 typically developing children with an average age of 12 years old to detect gaps in auditory stimuli. The children were required to detect a small gap between two pure tone, same pitch stimuli. The gap varied between 20ms and 80ms. They found there was no difference in the abilities of the groups to detect the gaps.

In a study published in the same year, Schulte-Körne, Deimel, Bartling, and Remschmidt (1998a) tested the pitch unconscious discrimination of children with dyslexia and typically developing children with an average age of 12 years, six months, using event-related potential sensors. In the task, the participants were instructed to attend to a silent film whilst stimuli were played to them. Event related potential sensors were used to record brain activity. There were two conditions: in the first, the acoustic stimuli were pure tones, either a standard tone or, a tone slightly higher in frequency, non-standard tone; in the other condition, they were played speech segments; either /ba/ or /da/. They were asked to focus their attention on the silent film and not to attend to the auditory stimuli as they would have a questionnaire to complete about the film after it had finished. Schulte-Körne, et al. found that there was no significant difference in activity during the pure tone condition, but with the speech stimuli, the group with dyslexia showed a significantly different pattern of activity to the children with dyslexia. Rather than there being a low level auditory processing difficulty, Schulte-Körne et al. argued that the findings indicated a speech processing deficit.

Schulte-Körne, Deimel, Bartling, and Remschmidt (1999) followed their previous two studies and tested 19 children with dyslexia and 15 typically developing children with an average age of 12 years, six months on a gap detection task, a pitch discrimination task, speech discrimination task, baseline phoneme, and spelling tasks. Their aim was to develop a structural equation model (SEM) of the processing measures. They had two main findings from their study. The study again supported their previous research in that children with dyslexia did not have difficulty with tonal discrimination. The SEM indicated that speech perception was linked to speech discrimination (similar to the indirect model of speech perception as proposed by McBride-Chang, 1996). which in

turn was linked to phoneme awareness and finally to spelling proficiency. But the auditory processing showed no significant associations. Taken together, the studies show strong evidence for speech perception in particular being an underlying deficit in dyslexia, not low level auditory processing.

A concern raised from a number of studies, for example Share et al. (2002), is precisely how temporal are TOJs? Although the durations between two stimuli are manipulated, central to the judgements made are skills in pitch perception: was there a high tone and was there a low tone, or were they both the same pitch? And which one came first? It is possible that temporal processing is in some way required at fast presentations, for example, an efficient system of encoding a time stamp for the two tones could help in making judgements of which came first, but then so could simply assigning them sequentially as first and second. A tantalising piece of convergent evidence that children with dyslexia show temporal processing deficits comes from Nicolson et al. (1995) who used a different paradigm.

Few studies have centred directly on *perceiving* temporal information; rather, judging the order of quickly presented information (TOJ) has become the predominant, albeit controversial investigative method. A study that has examined how well children with dyslexia can perceive differences in the duration of stimuli was carried out by Nicolson et al. (1995). Nine children aged nine, ten children aged 14, and 12 adults aged 18, all with a diagnosis of dyslexia were age matched to three groups of typically developing children and adults. After a practice session, the participants were presented with a pair of auditory stimuli. The first stimulus was 1,200 ms in duration. After an interstimulus interval of 1,000 ms, the second stimulus was presented. This could be one of 11 shorter stimuli, from 400 ms to 1,180 ms, or one of 11 longer stimuli, from 1,220 ms to 2,000

ms. The whole task comprised 22 stimuli presented three times. A second comparison task was also used in which the participants had to judge the loudness of stimuli, this was to ensure that any differences were due to judging duration and not a general auditory deficit. Nicolson et al. found that the three groups of participants with dyslexia scored significantly poorer on judging the durations compared to their control groups. In contrast when the children were also tested on their abilities to discriminate between the volume of different stimuli, there were no differences in this task. They argued that temporal processing deficit may underlie the reading and spelling deficits in dyslexia. Complementary to temporal perception, some studies have also looked at difficulties children with dyslexia have in producing rhythmic sequences. Whereas temporal perception tasks would require participants to make a judgement about sets of durations, temporal production tasks require participants to perceive a duration and carry out an action related to that duration. Wolff, Cohen, and Drake (1984) recruited 20 participants with dyslexia, and 20 age matched control participants; the group with dyslexia had an average age of 12 years, four months and the control group had an average age of 12 years two months. Wolf et al. tested the children on a wide range of timing tasks. However, important to this section of the literature review is the study they conducted into tapping. Participants were required to tap on a tap-plate using the index finger of their preferred hand. This was then recorded, using an audio tape for later analysis using a computer. Participants were asked to listen to a metronome and then synchronise their tapping to the metronome and continue tapping even if the metronome was stopped until the experimenter indicates the end of the trial. Both the synchronisation (tapping with the metronome) and continuation (tapping after the metronome had been stopped) trials lasted 30 seconds and there were two conditions: 652 ms ISI and 330 ms ISI. They

found that at the 652 ms speed, participants with dyslexia were significantly more variable at the one handed tapping compared with controls. In addition, they were shown to speed up during the continuous part of the task at 652 ms, although no differences between the groups were found in the faster condition. Wolff et al. suggested that this difficulty could be related to sequencing difficulties and TOJ processing in children with dyslexia.

A later study by Wolff (2002) looked at another aspect of tapping, namely, anticipation times. He tested 12 children with dyslexia and an age matched control group; the average age for the groups was 13 years, seven months. Participants were asked to listen to the beat and then synchronise with the beat by tapping on a tap-plate. There were two conditions, synchronisation to either 670 ms or 500 ms. He was interested in how much ahead of the metronome beat the children tapped. During the task, this occurred with almost every beat in both groups. He found that, in both conditions the average anticipation time was significantly longer for the children with dyslexia: 130 ms, compared with 41 ms for the typically developing children. Wolff argued that this was further evidence of some sort of temporal processing deficit that had been found in previous studies but that it could underlie a more widespread deficit in sequencing information.

The evidence presented in this section tentatively suggests that there is a low level processing deficit related to temporal processing in children with dyslexia. This field does not have the same level of research activity that the phonological deficit hypothesis for dyslexia has had. Furthermore, many of the findings have been difficult to replicate or have been open to other interpretations. However where research has been carried out, children with dyslexia have been shown to have difficulties in making

judgements of stimuli where the temporal information has been manipulated, and in tasks that require temporal production. The forthcoming section will detail neurological evidence that children with dyslexia may have a temporal processing deficit, and furthermore that the deficit could be related to atypical cerebellar processing. The cerebellar deficit hypothesis may provide a framework to underlie both the phonological deficit hypothesis and the automatization deficit hypothesis. The framework may also provide a possible explanation for underlying processing deficits common to both dyslexia and DCD.

1.5. The cerebellar deficit hypothesis

The cerebellum is part of the hind-brain. It is a structure common to all animals and broadly, its function is related to motor processing, posture, temporal processing, and automatization. Recently, studies have implicated it in a much wider variety of processes (Justus and Ivry, 2001). Llinas (1993) was one of the first to suggest that the cerebellum could be related to difficulties associated with dyslexia. In a review of evidence relating to the temporal processing deficit in dyslexia, he suggested that as there is evidence that the cerebellum is important in temporal processing (see also Braitenberg, 1976) cerebellar dysfunction might impair temporal processing. In parallel, Nicolson and Fawcett (2001), proposed that as the cerebellum is important in automatization, deficits in cerebellar processing may impair the learning of complex skills such as reading. Because of this association between temporal processing and the cerebellum, some of the evidence reviewed for the temporal processing deficits may also support the cerebellar theory.

For example, Nicolson et al. (1995) found that children with dyslexia had less accurate

judgements of tone duration, and Ivry and Keele (1989) found patients with cerebellar damage also showed such deficits. Similarly, Wolff et al. (1984) found more variable synchronisation to a paced stimulus, a finding also shown by Ivry and Keele (1989) in adults with cerebellar damage.

Because of the importance of the cerebellum in a wide variety of abilities, Nicolson and Fawcett (1999) have argued that a likely developmental dysfunction in the cerebellum could account for the phonological, visual, and automaticity problems associated with dyslexia. For example, a deficit in cerebellar function may affect either timing processes during reading, for example in ocular stability, or the processing of auditory information or simply the ability to automatise reading, which would cause substantially more cognitive capacity to be diverted to the task at the expense of other processes. Their support for the theory comes from a number of studies they have carried out to assess how children with dyslexia perform on tasks that have previously shown deficits in patients with cerebellar damage.

Fawcett, Nicolson, and Dean (1996) conducted a study to assess whether soft neurological signs of cerebellar deficits were prevalent in children with dyslexia. They tested a total of 55 children with severe dyslexia and without dyslexia, in an age range from ten years to 18 years old. This group was then divided into three separate age groups: 10 year olds (12 participants with dyslexia, 8 controls), 14 year olds (nine participants with dyslexia, 11 controls), and eighteen year olds (eight participants with dyslexia, seven controls). Using this design it was not only possible to compare chronological age matches but also to compare older children with younger reading age matches. In the analysis they compared the ten-year-old typically developing children

with the 14 year old children with dyslexia and the fourteen year old typically developing children with the eighteen year old children with dyslexia.

Composite scores for three areas of cerebellar function were derived from a range of assessments: maintenance of posture, arm muscle tone and complex movements. These clinical assessments were derived from established tests that had been used to determine whether cerebellar damage had occurred after head trauma. Maintenance of posture included the amount of time participants could balance whilst blindfolded, and the stability of their posture when gently pushed. The arm muscle tone tasks looked at how much muscle movement there might be; they included assessments of: how much muscle movement occurred when the participant's hand was gently shaken, the drop of the hand when it was relaxed and the arm was raised, and the amount of time participants could hold a bottle of water out rigidly. Complex movements associated with cerebellar processing included a task where participants were asked to point repeatedly to a bull's eye using a pen whilst blindfolded; blindfolded finger to finger pointing, moving the hands from being palm down to palm up in a constant rhythm, the amount of time it took to tap a toe ten times and a sequential finger and thumb movement.

Fawcett et al. (1996) found that the children with dyslexia performed significantly worse on all of these tasks compared with their age matched controls. When reading age matched children were used as a comparison group, again the children with dyslexia performed significantly poorer in all the tasks with the exception of arm shaking, muscle tone, and finger to finger touching. Effect sizes were computed and from this the number of children who performed poorly at the task was determined; a child was considered to have performed poorly at one of the tasks if the effect size was minus

one or less. This showed very high incidence rates for the children with dyslexia. For example, poor postural stability was found in 97% of the group with dyslexia but only in 15% of the control group. They argued that these findings indicated that rather than there being a subgroup of children with cerebellar dysfunction in the dyslexic population that this was much more widespread and possibly an underlying cause of dyslexia. In relation to reading, they argue that:

“Even after speech and walking emerge, one might expect that the skills would be less fluent, less “dextrous”. If articulation is less fluent than normal then it takes up more conscious resources, leaving fewer resources to process the ensuing sensory feedback. In particular, the processing of the auditory, phonemic structure of the words spoken may be less complete.” (p. 279).

Evidence from Fawcett et al. (1996) would suggest widespread soft signs of cerebellar dysfunction in children with dyslexia. However, these are tasks which require an element of subjective clinical judgement, even though Fawcett et al. (1996) attempted to minimise this. This was not a double blind study: the experimenters appeared to be aware of which children they were testing had dyslexia and which ones did not and this may have also affected the judgement outcome.

More objective evidence in support of a cerebellar deficit has come from Nicolson et al. (1999) who investigated cerebellar activation in a Positron Emission Tomography (PET) study. They tested six men diagnosed with dyslexia, average age 21 years but who had average reading age of 12.8 years; and six men who were not diagnosed as having dyslexia (21.5 years of age with a reading age of 17 years or higher). Nicolson et al. (1999) designed a simple learning task for the participants. The task required the

participants to learn a sequence of key presses on a four-key pad by trial and error.

There was a pacing tone every three seconds. If a participant correctly identified a key press there was a high tone, an incorrect key press provided a low tone as a response and the participant would try another key.

Participants learned a sequence two hours before the scan until they could repeat it effortlessly. During the scanning, they completed three and a half minutes of key presses using the learned sequence and two minutes of rest. During the final trial the participants completed the key presses whilst responding to a digit span test to assess the automaticity of the key press sequence. They also carried out the key press learning task using a different sequence whilst the participants were being tested in the PET scanner. The results showed that the group with dyslexia showed significantly less right cerebellar activation in both the pre-learned and the learning sequences. It is noteworthy that, although Nicolson et al. (1999) argue for a whole cerebellar dysfunction in their theory of dyslexia, they find a right cerebellar deficit (see Figure 1.1). It is not clear whether the fact that the left lobe of the cerebellum appears to be functioning well in adults with dyslexia is of significance to the theory or not.

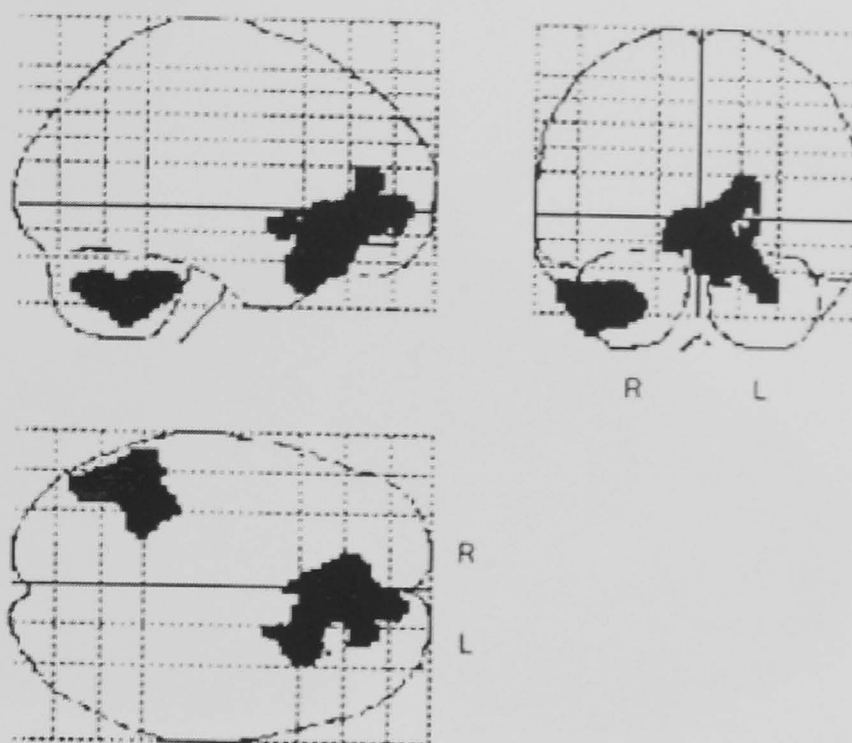


Figure 1.1 Diagram taken from Nicolson et al. (1999) depicting the significant difference in blood flow for the adults with dyslexia compared with the typical adults during the execution of a pre-learned button press sequence.

Of interest to temporal processing theory, they also isolated the cerebellar vermis (see Figure 1.2) in their study and found that the six control participants showed a significant blood flow increase in this region in both the pre-learned and learned conditions of the task compared with at rest, whereas there was no change in the blood flow in the vermis for the six participants with dyslexia. This is an area that has been implicated in temporal processing (Jancke et al., 2000). So this would seem to suggest that in addition to other possible cerebellar deficits, there may be a difference in the ability to process timed motor responses in dyslexia.

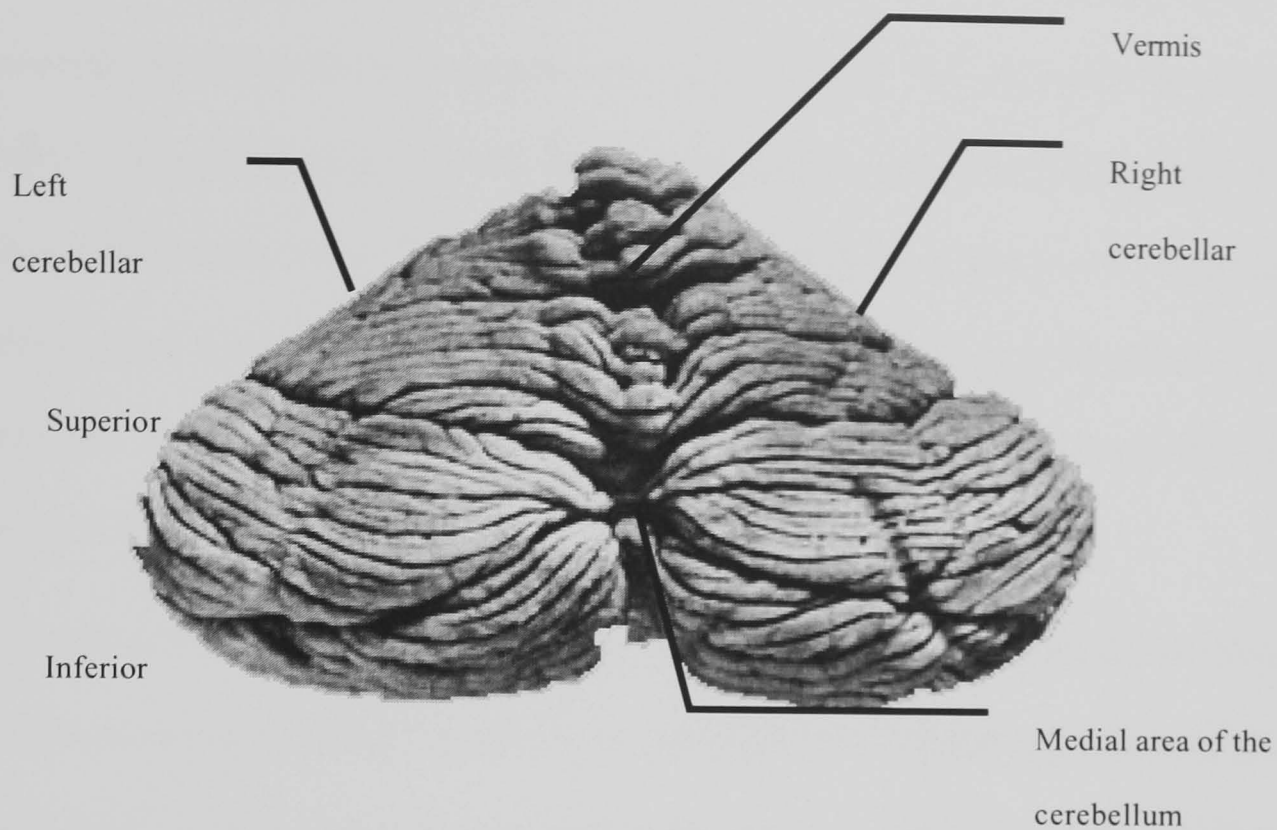


Figure 1.2 Diagram showing a posterior view of the areas of the cerebellum activated during tapping in the study by Jancke et al. (2000). Picture taken from Williams, Gluhbegovic, and Jew (2004).

Some support for the cerebellar hypothesis comes from Rae et al. (2002). They examined asymmetry in the cerebellum using MRI to measure its size and shape with adult males with dyslexia, and typical adult males. They found that the cerebellum was more symmetrical in adult males with dyslexia and furthermore that the more symmetrical the cerebellum was the worse the adults with dyslexia were on measures of nonword reading. This study has does have an advantage over Nicolson et al. (1999) in that it has attempted to directly investigate reading and cerebellar morphology whereas Nicolson et al. (1999) used a keypress task. However, Rae et al. (2002) note other studies have found symmetry in other structures of the brain of adults with dyslexia. One suggestion may be that there is widespread symmetry to structures of the brain in dyslexia, and that the cerebellum is only one aspect of the differences in brain structure

and function compared to typically developing adults. Nicolson et al. (1999), for example, do not elaborate on another area of the brain in their study where there is significantly different blood flow, the prefrontal cortex of the left hemisphere. This was shown to be more active in the control group during the carrying out of the prelearned button press sequence compared with the group with dyslexia (see Figure 1.1). It is possible, therefore, that focussing on the cerebellum in dyslexia may miss out other areas of the brain which could be important.

One of the main criticisms of the cerebellar deficit hypothesis is the lack of direct connections between the cerebellum and reading or reading deficits. Although children with dyslexia have shown signs of soft cerebellar processing difficulties and there is evidence that adults with dyslexia show less cerebellar activity, one major criticism related to the PET study was that the task carried out by the groups was a motor task (i.e. fingers pressing keys) and also a task that involved synchronisation to a pacing stimulus. Given the role of the cerebellum in motor control it is difficult to then disentangle the potential activation due to automaticity or temporal processing from the activation from motor movement. Finally, given the lack of a direct link and convergent evidence between dyslexia and cerebellar function, there is the possibility that the cerebellum is different structurally in adults and children with dyslexia. However, this might not be related to their deficits in reading or as suggested by Rae et al. (2002) that the cerebellum is only part of a more widespread neurological abnormality.

Nevertheless, it is not possible to totally discount the cerebellar theory unless a clear disassociation can be found between cerebellar processes and reading. This has yet to be demonstrated.

So far, this chapter has examined four possible theories that may provide an explanation of dyslexia. The first, the phonological awareness deficit suggests that difficulties in speech sound processing of one form or another are associated with dyslexia. This would be a deficit specific to the complex manipulation of language such as reading and spelling and is not solely associated with dyslexia. The second was the automatization deficit, a more general deficit in the transference of a learnt skill to an automated skill. However, much of the evidence for this has come from language based studies. Also the evidence would suggest that the automatization of reading and spelling processes is relatively independent from any apparent phonological deficit.

The temporal processing deficit hypothesis suggests a more widespread deficit related to the ability to process timing or temporally sensitive information. As such it seeks to encompass both the phonological awareness deficit, assuming that phonological information also has embedded temporal information, and also automatization, as effective timing is a key to many of the automatization tasks. Finally, the cerebellar deficit hypothesis seems to provide an integrative account of dyslexia as a neurological deficit in an area of the brain implicated in numerous basic processes from motor control to temporal processing. An attractive possibility from the latter two hypotheses is that they could serve to account for those deficits that are not reading related but that children with dyslexia are often found to have. They may also provide an account of possible underlying commonalities between dyslexia and DCD. The chapter will now proceed to examine two of the main theories that attempt to explain the deficits related to DCD: visual processing deficit theory, and temporal processing theory.

1.6. The origins of DCD: Vision, and timing

Substantially less research has been carried out into the underlying causes of DCD compared with dyslexia. Consequently, this section will provide an overview of two of the main theories that have been suggested to explain the difficulties associated with this condition: visual and perceptual difficulties, and temporal processing deficits.

1.6.1. *Visual processing deficits*

Visual processing deficits have been put forward as an explanation of the behavioural symptoms of DCD. Whereas coordination difficulties could be due to the actual moving of limbs, evidence, which will be outlined below, has pointed towards visual or perceptual difficulties as underlying DCD. Within this, a link has been put forward in terms of visual-motor integration, a skill which may require temporal processing. This may be a parsimonious explanation of DCD as not being able to perceive effectively apertures in tasks such as threading, and the positions of objects and people in daily life would cause difficulties in coordinating movements.

Some of the most compelling evidence comes from a meta-analysis by Wilson and McKenzie (1998). Their meta-analysis was based on 50 studies that had involved children with DCD. They categorised the studies into those that looked at visual processing, kinaesthetic and cross-modal perception, motor control, general intelligence, and screening for motor difficulties. They found that the largest effect sizes included visual spatial and visual perceptual type tasks. These effect sizes were found even when tasks that did not have a motor component were analysed. They note that one possible explanation is that basic ocular movements might be deficient in these children. However they found that studies that involved ophthalmologic measures such as

vergence control (the ability to co-ordinate both eyes in order to view the same object accurately) did not show a great deal of difference between children with DCD and controls. They argue that the evidence suggests that any deficits were likely to be perceptual in nature rather than due to difficulties in controlling the visual system.

One of the studies included in the Wilson and McKenzie (1998) review was by Hulme, Smart, and Moran (1982). They tested 12 children with coordination difficulties and 12 typically developing children, aged around eleven years old on a specifically perceptual task. The task involved presenting a white line on a black background to the children and then presenting a line that could be adjusted in height next to it. The children were then asked to adjust the height of the second line so that it was the same height as the first line. They found that the children with DCD were significantly less accurate at matching the second line to the first line. In a second experiment, they controlled for the possibility the children with DCD may have problems with ocular stability or controlling saccades. They presented two white lines on a black background for 100 ms. The second line might be longer, the same length, or shorter than the first line. Again, the children with coordination difficulties showed significantly less accurate judgements. Hulme et al. argued that the evidence from the studies indicated that there is likely that visual-perceptual deficits are involved in DCD.

After perceiving information about objects and their position in space there is the need to integrate this with carrying out a motor movement. There is evidence to suggest that whereas there may be basic visual-perceptual deficits in DCD, more than this, DCD may be a disorder of integrating visual information with motor movements. Three studies have recently provided evidence of this.

One of the initial studies was by Parush, Yochman, Cohen, and Gershon (1998). They tested 30 children with coordination difficulties, and 30 typically developing children, aged between four years, ten months old to seven years one month old, on a range of visual perception tasks and visual-motor integration tasks. Parush et al. had two major findings. Firstly in eight out of nine of their measures, the exception being a visual processing task (form constancy), the children with DCD were significantly worse than controls. They then produced composite measures of visual perception ability and visual motor integration and examined correlations between the two measures. They found that there was no significant correlation between these two measures for the typically developing children, but there was a significant correlation for the children with DCD. Their findings indicated that the two processes were separate in typically developing children, but that the two processes were not disassociated in children with DCD, possibly due to an immaturity in their visual system.

Second, support for Parush et al's. study has come from Schoemaker et al. (2001). They investigated whether children with DCD have deficits in visual processing or whether these deficits could be better explained through motor or proprioceptive deficits (proprioception being the ability to monitor limb position in space without visual feedback). A range of tasks were used with a group of 19 children who had DCD and a group of 19 control children. The groups were around eight years, five months of age. Included in their test battery were tests of visual ability with no motor movement (for example being able to match objects on size); and tests of visual ability with a motor component (for example being able to mark dots with a pen in rows of small circles). They found that the children with DCD were poor on two of their four measures of visual processing, but were significantly worse than controls on all four of their tasks of

visual and motor ability.

Further evidence comes from a study by Smyth and Mason (1998). They examined how well children with DCD could aim at a target when using either visual information or proprioceptive information. As this task involves aiming, it could be considered a task which involves a motor component. Forty three children with DCD and 73 age matched typical children, aged between five and eight years old took part in the experiment. The children were seated at a table that had four coloured dots on it. Each dot had a hole in its centre. In the visual condition, the experimenter indicated which dot a pin needed to be placed on, and the child was required to reach under the table and put a pin at a location below the dot. In the proprioceptive with visual conditions, the child had to put one finger on the dot, and another then to put the pin under where the dot should be. In the proprioceptive only condition, the child had to put a finger on the dot, close his or her eyes, and put a pin under where the dot should be. Smyth and Mason found that the children with DCD were significantly less accurate compared to controls under the visual only condition. By implication, proprioceptive information helped improve their performance on the task. This would again suggest that visual and motor integration posed difficulties for children with DCD.

Another explanation for the difficulties experienced by children with DCD is a possible deficit in visual memory. With this in mind, Dwyer and McKenzie (1994) tested 19 children with coordination difficulties, and 19 typically developing children aged between nine and 13 years old. They presented geometric shapes to the children either for them to copy down directly or to draw fifteen seconds after seeing the shapes. They were asked to repeat the word “the” during the delay so they could not verbally rehearse the pattern. They found no impairment in the quality or the speed of the drawings

between the two groups when they were asked to copy them down but the children with DCD had significantly poorer drawings in the delay condition.

It is difficult to account for the results found in Dwyer and McKenzie (1994) in light of Hulme et al. (1982) who controlled for memory load in their task; and Schoemaker et al. (2001) who used some measures which had a low memory load in some of their tasks and still found poor performance in the children with DCD relative to controls. For example, Dwyer and McKenzie (1994) and Schoemaker et al. (2001) both used copying tasks. In the former, the children with DCD had difficulties in copying without a delay, however in the latter, the children with DCD did not have difficulties in copying without a delay, and only performed poorly when a delay was introduced.

However, there is overlap in the types of tests used by Parush et al. (1998), and Schoemaker et al. (2001). Both use similar standardised tasks of visual motor integration. One possibility is that it is the nature of these tasks rather than deficits in DCD performance per se that are indicating deficits, although the convergent evidence from Smyth and Mason (1998) suggested this may be unlikely.

Evidence would seem to indicate that there is a visual deficit related to DCD and furthermore that difficulties in visual and motor integration could account for the coordination deficits that occur in children with DCD. However the evidence is not completely overwhelming, and a second possible theory has recently been proposed, that of temporal processing deficits in DCD. This could also account for possible visual motor integration difficulties, as a process as complex as this would require temporal processing of some sort. This review will now consider the evidence for a temporal processing deficit in DCD.

1.6.2. *Temporal deficits*

An assumption in this thesis is that most complex processes require some form of temporal processing. Temporal processing is the umbrella term for the ability to perceive and make judgements about information that has time-based properties. This may relate to a range of different skills, for example, the ability to perceive durations and compare them to a duration previously stored in order to make judgements about them in tasks such as temporal generalisation; or to anticipate the end of a duration and be able to carry out a process, as in tasks such as tapping. Certain events may have a particular standard duration, for example the time it takes to boil an egg, or for a toaster to make toast. Humans might have an expectation of how long these things take to occur based on previous experiences of that event. Therefore we are able to store a temporal duration in long term memory and then be able to make judgements about it in order to be able to carry out tasks concurrently that may be, for example, ready for the end of that particular duration. Models of temporal processing will be discussed later in the chapter, this section will focus on evidence for temporal processing deficits in children with dyslexia and DCD.

A temporal processing deficit may account for the range of behavioural symptoms associated with dyslexia, from phonological awareness deficits to deficits in automatisations. In addition there is evidence that deficits of this nature may be present in children with dyslexia. Furthermore, neurological studies have implicated the cerebellum in temporal processing and there appear to be some signs of cerebellar deficits in children with dyslexia. With reference to DCD, the production of complex

movements also involves the effective processing of temporal information. By implication, deficits in temporal processing could also be associated with DCD symptoms. This section of the chapter will outline the evidence to support this theory.

Temporal processing and DCD has primarily been investigated by using tapping tasks or duration judgement tasks. Williams, Woollacott, and Ivry (1992) tested 13 typically developing children, and 12 children with coordination difficulties aged between six and 10 years old. Two tasks were carried out: a temporal perception task and a tapping task. The temporal perception task required the children to judge the duration of two auditory stimuli. The difference in the duration of the two stimuli was manipulated until an estimate of the children's ability to judge the durations was established. With the tapping task, the children had to synchronise to a metronome with a 550 ms ISI. After 12 taps the metronome was removed and the participants had to continue tapping. When the participants had completed six of these trials consecutively without the tapping being below 275 ms intertap interval (ITI) or above 875 ms ITI the task ended. They found that, like the patients with cerebellar damage in the study by Ivry and Keele (1989), the children with coordination difficulties had significantly fewer accurate judgements in the perception test, and also significantly more variable tapping.

The findings by Williams et al. (1992) were replicated and extended by Lundy-Ekman, Ivry, Keele, and Woollacott (1991). They compared 14 children with coordination difficulties and neurological signs of cerebellar damage, with 11 children who had coordination difficulties and neurological signs of basal ganglia damage, and 10 typically developing children. They found that the children with cerebellar damage had both significantly more variable tapping and significantly poorer perception of the

duration of sounds.

However, tapping difficulties have not been consistently replicated. In a study using a similar procedure, Geuze and Kalverboer (1994) compared 11 children with coordination difficulties and 12 typically developing children, aged between nine years, four months and ten years, six months on their speed and rhythm at tapping either with one hand or with two hands. They found that whilst with one hand there appeared to be no problem, when the children had to tap twice with one hand, then once with the other hand, the children with DCD had significantly more difficulty than the typically developing children. This measure requires a more overt coordinated movement of both hands and is unlikely to be a pure measure of temporal processing.

The inconsistency of the findings between Williams et al. (1992) and Geuze and Kalverboer (1994) is unlikely to be due to methodology as in unimanual tapping, both used similar procedures. One possible explanation for the differences in results is differences in the ages of the participants. The children in Williams et al. (1992) were around eight years of age, whereas the children with DCD in Geuze and Kalverboer (1994) were around nine and a half years, years of age. It is possible that as children with DCD get older; their proficiency in tasks such as tapping becomes better. Evidence from typically developing children, such as Carlier, Dumont, Beau, and Michel (1993) where older children were found to have faster and less variable un-paced tapping compared to younger children, would suggest this may be case.

A different tapping approach was taken by Piek and Skinner (1999). They compared the abilities of children with coordination difficulties with typically developing children with an average age of around ten years old. Their experiment involved presenting the

children with a sequence of five taps displayed on a computer screen. A dot indicated a soft tap and a square indicated a hard tap. Different conditions varied the position of the tap. They measured the pressure and the duration of both the contact and off-contact durations of the tap. Whilst the actual pressure of the taps did not differ, the duration of the on-contact duration did. The children with DCD had significantly more variable on-contact durations. They argue that processing during the on-contact period is related to “initiating correct muscle activity to release the key.” (Piek and Skinner, 1999, p. 328). So the difficulties that the coordination difficulty group had in tapping may be related to their ability to coordinate effectively muscle bursts. Piek and Skinner suggest this may be due to problems in timing.

However, a problem with using a purely visual tapping task is that it could be classed as a visual-motor integration task itself and children with DCD have been found to have visual motor integration deficits (Parush et al., 1998; Schoemaker et al., 2001). In addition Piek and Skinner’s task required children to remember a visual process and, although at odds with some literature reviewed, remembering visual information was a difficulty found by Dwyer and McKenzie (1994). Therefore, precisely how much Piek and Skinner were assessing temporal processing, and how much they were assessing visual processing impairments is not clear.

As has been noted earlier, one of the prime behavioural characteristics of DCD is coordination difficulties, and one of the confounding factors in tapping tasks is the overt use of motor movement. Both Williams et al. (1992) and Lundy-Ekman et al. (1991) report findings from a separate task involving temporal perception.

As will be detailed later, one of the assessments Ivry and Keele (1989) used to examine

temporal perception in adults with cerebellar damage was a task where the patients had to listen to two tones and judge whether one was longer or shorter in duration than the other. Williams et al. (1992), in addition to the tapping task reported earlier, used this task on their group of children with coordination difficulties, and typically developing children. They found that the children with coordination difficulties had similar patterns of deficits to the cerebellar damage patients in Ivry and Keele (1989). This finding was again, confirmed by Lundy-Ekman et al. (1991). The children with coordination difficulties and soft neurological signs of cerebellar damage showed a temporal perception profile similar to the adults with cerebellar damage in Ivry and Keele (1989), whereas the children with coordination difficulties and soft neurological signs of basal ganglia damage did not.

The evidence, although not clear cut, points to a deficit in temporal processing in DCD. Moreover, evidence from Lundy-Ekman et al. (1991) indicates that at least for some children with coordination difficulties this could be a deficit related to cerebellar processing. However, there are problems with the evidence as it stands in that the paradigms themselves are somewhat limited. In order to establish temporal processing deficit, the researchers have focussed on either temporal production or one form of temporal perception task. This leaves the possibility that the deficits shown in tapping and tone duration judgement are artefacts of the tasks themselves rather than evidence of a genuine deficit. Therefore, further research on a range of tasks with a comparison of modalities would be required to better assess possible temporal deficits in DCD.

The past two sections have focussed on possible cognitive processes that may underlie the deficits in coordination found in DCD. Visual processing and particular visual-motor integration difficulties have been found. However, one possible, if somewhat

tentative, suggestion is that temporal processing deficits are at the root of this. If that is the case, then the already established link between temporal processing and cerebellar processing may also hold. Consequently, both dyslexia and DCD may be related on a temporal processing level. In view of the possible neurological relationship, one further question is whether research has systematically found evidence of commonalities between dyslexia and DCD on a behavioural level. This evidence will be reviewed next.

1.7. Evidence of co-occurrence in dyslexia and DCD.

The theories and their evidence provided so far have suggested that children with dyslexia have deficits in phonological awareness and automatization but that these may be encompassed by a more general deficit in temporal processing, or possibly a cerebellar deficit. Children with DCD have been shown to have visual processing deficits, but again other, more general, deficits may underlie this. Again temporal processing, and therefore by implication, difficulties that appear to be attributable to cerebellar deficit are apparent. The theories therefore lead to a possibility that underlying both the behavioural characteristics of dyslexia and DCD are similar information processing deficits. This final section will review evidence that dyslexia and DCD co-occur.

There is evidence from studies such as Fawcett and Nicolson (1995) that children with dyslexia have been found to have motor deficits and Bradley (1980) noted that children with coordination difficulties often have deficits in reading and particularly spelling. However, two studies have recently been conducted that have looked systematically at the co-occurrence of disorders in children's development: Kaplan et al. (1998) and Kaplan, Wilson, Dewey, and Crawford (2002).

Kaplan et al. (1998) tested 224 children who had been referred to a clinic for children with learning or attention disorders. These children had not been previously assessed for DCD and consequently, one of the aims of the study was to examine to what extent DCD appeared in groups that may instead have been diagnosed as having other learning disorders. In order to compare this clinical group, they also recruited 155 typically developing children. In both groups, the children were between the ages of eight and 17 years old. An extensive set of standardised batteries were employed. These included motor coordination tests; reading, comprehension, and spelling tests; general achievement tests; auditory processing tests; and parental questionnaires. Based on their performance on these tasks relative to the control group, and information from the parental questionnaires, the children who had been referred to the clinic for learning difficulties were divided into those with pure forms of reading difficulties, DCD, and ADHD, those who were comorbid in two of these conditions, and those who were comorbid in all three.

When assessing for comorbidity only those children where the investigators had complete data were used. This resulted in a smaller sample of 115 children. In terms of pure cases, they found 26 children who only had DCD, 19 children with only reading difficulties, and eight children with only ADHD. They had 22 children who were comorbid dyslexia and DCD, seven children comorbid dyslexia and ADHD, and ten children who were comorbid ADHD and DCD. A group of 23 children were found to be comorbid in all three conditions (see Figure 1.3).

In view of their findings, Kaplan et al. (1998) proposed that "... there is growing evidence that it is the nature of the disorders themselves which explains the large degree

of overlap between conditions... When comorbidity is the rule in physical health, a single underlying disorder is usually assumed.” (p. 484).

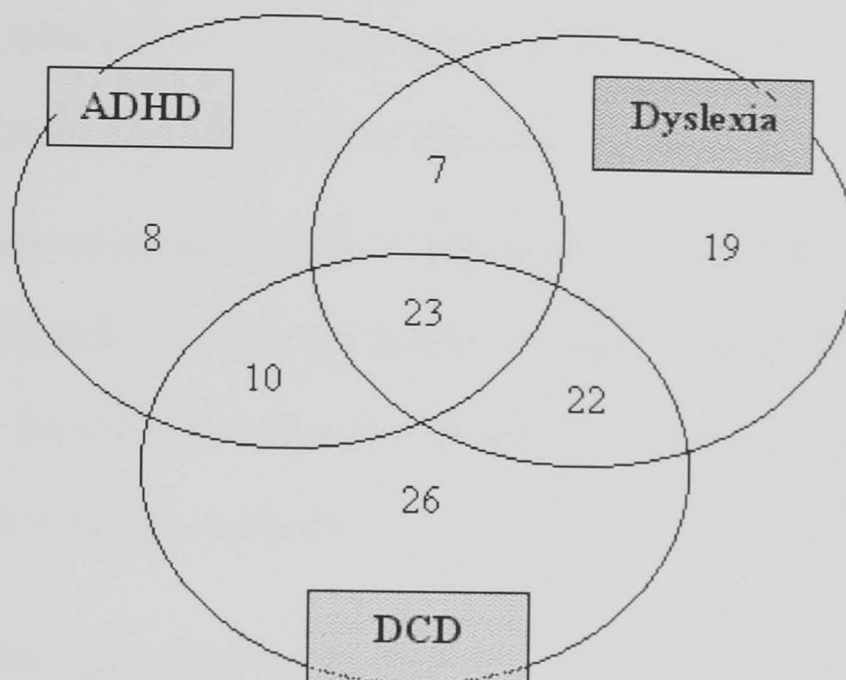


Figure 1.3 Incidence of comorbidity or co-occurrence of developmental disorders in the children assessed by Kaplan et al. (1998, p. 483). The numbers in the circles are the numbers of participants who were assessed as having the disorders

Further support for Kaplan et al. (1998) came from Kaplan et al. (2002). However they question the use of the term ‘comorbidity’, suggesting that the term is often applied to two conditions that may not be related by a common underlying cause. For example if a patient has asthma and measles they are considered comorbid in that the two conditions are present but not connected. However Kaplan et al. (2002) argue that where a connection between two conditions is implied, the term ‘co-occurrence’ should be used instead. They tested 179 children aged between eight years and two months, and sixteen years nine months. The study concentrated on investigating the degree of co-occurrence between reading difficulties, developmental coordination disorder and ADHD. In

addition, if the child met the criteria for either reading difficulties or DCD then they also interviewed the parents of the child about the possibility that the child had other disorders such as oppositional defiant disorder, conduct disorder, depression or anxiety. They found that 48% of their participant group met the criteria for one disorder, 27% for two disorders, and 25% for three or more disorders.

Direct comparisons of dyslexia and DCD will advance the understanding of these two conditions considerably. However, the studies by Kaplan et al. (1998) and Kaplan et al. (2002) highlight the reality that children with specific learning difficulties do not necessarily come in discrete categories.

1.8. Temporal processing

So far, a temporal processing deficit theory has emerged that may be able to account for the range of behavioural deficits in dyslexia and DCD and, furthermore, there is the possibility, outlined above, of commonality between the two conditions. In this section the aim is to review the evidence of a temporal processing mechanism which has been developed to account for temporal processing in typical development. This may provide a framework in which to conceptualise the temporal processing deficits that have been suggested to be evident in dyslexia and DCD.

One of the most prevalent theories related to temporal processing, as argued by Wearden (2001), is *scalar expectancy theory* (SET). Central to this is the existence of a system within the brain that can perceive, store, and make judgements about temporal information. The theory broadly states that pulses are produced and that attention can be shifted to collect these pulses if a temporal duration needs to be recorded. The number of pulses that represent a particular duration can then be stored either in short term

memory or transferred to long term memory in order to be compared with other durations as required. It is hypothesised that this basic timing system could then be used in a wide range of cognitive processes. The key to the relationship between this model and dyslexia and DCD is that such a system may be needed for effective reading and movement. For example, being able to assess the duration of speech segments may make up part of the information processing required for speech perception and having the duration of particular muscle burst stored correctly may be important for the execution of precise and complex movements.

There is evidence that a temporal processing system exists. In a very early study, rats have been shown to have a very precise timing system. Church and Gibbon (1982) reinforced responses made by rats if they were preceded by a standard duration of four seconds, but not to other durations. During the experiment, rats were presented with stimuli of different durations. Church and Gibbon (1982) found that the level of responses declined symmetrically away from the standard duration in that there were an equal number of fewer responses to durations that were shorter or longer than the standard duration. For this, the rats would have to perceive and store the duration and associate that duration with receiving a reward if they pressed the lever. They would then have to be able to perceive, store temporarily and compare with the standard, other durations. Finally some form of judgement is needed in order to decide whether to pull the lever or not. Church and Gibbon (1982) termed this temporal generalisation, the ability to make a generalisable rule about a stimulus duration.

Until Wearden (1991), no analogous study had been carried out with humans. Wearden tested ten adult participants on a task closely modelled on Church and Gibbon (1982). The standard duration for his experiment was 400 ms. After a practice session where

participants were familiarised with the standard duration they carried out the test session where they were presented with auditory stimuli with durations of 100, 200, 300, 500, 600, 700 ms and also the standard stimulus. The reason for keeping the durations below one second was to stop participants counting verbally. Participants had to judge if the stimulus they heard was the same or different to the previously heard standard stimulus. Each response was then followed by feedback, which was equivalent to providing reinforcement in the rat study (however Wearden, 1991, did not report how many trials were conducted). He found that the participants were highly accurate at determining whether the stimulus was the standard but the overall response pattern was different. Rather than the symmetrical pattern found by Church and Gibbon (1982), Wearden (1991) found that the participants tended to confuse the slightly longer duration with the standard significantly more often than they confused the slightly shorter duration with the standard (a 'right asymmetry' of responses). Wearden suggests that this finding is likely to be due to the rules used by the cognitive system in making the judgement, rather than a different process being used altogether. Evidence from this came from a change in the duration stimuli used. He found symmetrical responses when he changed the stimuli durations from a linear distribution to a logarithmic distribution.

Further support came from Wearden (1992) who confirmed the findings with 12 adult participants using a similar experiment to Wearden (1991). During this later study, the non standard stimulus was presented ten times and the standard (400 ms) 24 times. He found that the participants were able to judge the standard correctly 83% of the time. However, again, participants responded positively to a 500 ms standard duration significantly more often than with the 300 ms duration. And again, when the task stimuli was changed to a logarithmic distribution, the judgements became symmetrical.

In a later study, Wearden, Denovan, and Haworth (1997) found similar results with a paradigm that had a linear distribution of durations stimuli over one second. Therefore, for adult humans and rats, there is evidence for a system which can accurately judge temporal durations.

Recently, McCormack, Brown, Maylor, Darby, and Green (1999) have investigated how auditory temporal generalisations may change through the lifespan. Amongst their groups, they tested 26 five year-olds, 32 eight year-olds, 34 ten year-olds, and 26 nineteen year-olds. The task was similar to that designed by Wearden (1992).

McCormack et al. (1999) designed a game where an owl would always make a sound of the same duration; in this case, it was a 500 ms tone. During the task, the participants had to judge whether the sound they heard was the owl's sound or not. The duration of the sounds differed (either, non-standard duration: 125, 250, 375, 750, or 875 ms, or standard duration: 500 ms). First, the participants received a familiarisation session where they were presented with the 500 ms tone five times, then a tone longer and a tone shorter than the standard; and they were informed that these were not the sound the owl made. They then completed a practice session where they were presented with tones of different durations and they received feedback. The test trial consisted of one presentation of each of the non-standard stimuli and two presentations of the standard stimulus. The order of the presentation was randomised. Eight trials were carried out, so that each participant received a total of 64 presentations. In line with Wearden (1991) and Wearden (1992), feedback was given. In this case it was whether the tone the participants had heard was the sound the owl had made or not, and the feedback was given after each response. They found that some of the younger children had difficulties in completing the task, as 10 five-year-olds, and two eight-year-olds were excluded

from the analysis, but those who were able to make judgements showed a different profile of responses to the adult participants.

McCormack et al. (1999) found that the five-year-old children had a tendency to confuse the slightly shorter durations with the standard duration (left asymmetrical bias). This was in contrast to the eight and ten year olds who showed a near symmetrical response and the nineteen-year-old group who, in line with the previous work by Wearden, tended to confuse the slightly longer durations with the standard (a right asymmetrical bias). McCormack et al. argued that there was likely to be a developmental component to successful temporal processing which would require further research to understand it more fully.

The McCormack et al (1999) study was replicated and extended by Droit-Volet, Clément, and Wearden (2001). Whereas McCormack et al. (1999) had studied children as young as five, Droit-Volet et al. (2001) set out to examine temporal generalisation in children as young as three years old. They tested children with an average age of three, five, and eight, years old, with thirty children in each group. The children were then assigned one of two conditions (15 children of each age group). Condition one had a standard of four seconds, condition two had a standard of eight seconds. They used a visual temporal generalisation task in which children were shown a dot on a computer screen. The dot would appear for a particular duration (four or eight seconds), and the children were informed that they were to respond yes only when the circle appeared for that duration. There were three initial findings: first, that there was little difference in the long and short duration conditions; second, that even very young children could make temporal generalisation, evidenced by the finding there were more yes responses to the standard stimulus than to a non-standard stimulus. The third finding was that

by the age of eight, there was a right skew to the responses. whereas at the younger ages, there was a left skew, although the response pattern was flatter overall. Droit-Volet et al. suggested that the findings could be explained by a distortion in the stored standard time in long term memory which, as a child gets older, becomes less distorted. There is an alternative explanation for the pattern of results found by McCormack et al. (1999) and Droit-Volet et al. (2001). It is possible that the temporal generalisation task is quite demanding for young children so that the left bias in five year olds, and possibly the symmetrical pattern of responses in eight and ten year olds might indicate distraction in attention. Gautier and Droit-Volet (2002) argued that, when distracted from the task there could be “a loss of pulses accumulated in the cognitive timer during encoding period: the smaller the number of pulses that are accumulated, the shorter the subjective duration is perceived to be.” (p. 58). Eighteen five-year-olds and fifteen eight-year-olds were tested on two tasks. The non-temporal task required them to name 12 simple line drawings on a computer screen, the pictures were either clear or were made more difficult to name by degrading the quality of the line drawing. The implication being that line drawings that are more difficult would turn attention away from the temporal task and so fewer pulses would be recorded and stored. In the temporal task they were presented with a visual stimulus, a white rectangle, which was displayed for either six or 12 seconds. They then had to reproduce the duration by pressing a button on the computer twice, once for the onset of its appearance and once for the end. Each participant completed five conditions: temporal only, clear picture naming only, degraded picture naming, temporal task and degraded picture naming. temporal task and clear picture naming. In the single task duration estimation, both the five-year-old group and the eight-year old-group estimated the six and 12 second

duration tones to be slightly shorter, however in the dual task both groups estimated the six and 12 second durations to be substantially shorter. Between groups, it was clear that the five-year-old children were estimating the durations to be shorter than the eight year olds in each condition. They argue that the study provides evidence that the cognitive demands that are placed on a child with a dual task are enough to cause this loss of pulses during the switching of attention. Consequently, their comparison duration would be shorter than the previously stored standard duration.

Referring back to McCormack et al. (1999) and Droit-Volet et al. (2001), it is likely that these tasks are much more cognitively demanding than the duration estimation task used by Gautier and Droit-Volet (2002). The McCormack et al. (1999) task included requirements to store a duration signature, a comparison of that memory with a newly presented presentation, and a judgement about whether the two are the same or not, whereas Gautier's simply required the storage and reproduction of a presented stimulus. Therefore the task by McCormack et al. (1999) may also act as a measure of attention, as many of the auditory and visual processing tasks where children with dyslexia show poor attainment could also be related to attention difficulties. If a left bias is found in the results then this may suggest that auditory or visual processing in this type of task may be more related to attentional difficulties rather than phonological, visual or cerebellar difficulties.

A recent research study has, however, provided further evidence of the distortion in memory for the stored temporal duration in young children, as suggested by Droit-Volet et al. (2001). McCormack, Brown, Smith, and Brock (2004) report several studies carried out to establish whether the move from left asymmetry in young children to a right asymmetry in adulthood is due to perception of duration or memory of the

stored duration and whether this left asymmetry is peculiar to temporal processing. In experiment two, rather than training participants in an instruction phase of a standard duration, they presented the standard (in this experiment it was a 500 ms tone), and then the test duration. This allowed the children to compare the two durations rather than having to remember what the standard was, and is similar to the temporal only condition of Gautier and Droit-Volet (2002). Again, the aim here was to reduce the memory demands inherent in the task. The test groups consisted of seventeen children aged six, 18 children aged eight, and 22 undergraduates. With this change of the procedure, the left asymmetry disappeared. In experiment four they carried out an analogous experiment in which the children had to carry out pitch judgement, rather than temporal judgement. The participants (19 children aged six, 25 children aged 10, 15 undergraduates) were presented with a standard pitch of 900Hz, and six non-standard pitches of 600 to 1200 Hz. The resulting pattern was symmetrical for all three age groups. Their findings would suggest that there is the processes involved in temporal duration judgements are different to those of other judgements, such as pitch perception. This study provides evidence to support the suggestion by Droit-Volet et al. (2001) that the long term memory representation of the temporal duration is distorted rather than the perception of the duration.

An interesting difference between Droit-Volet et al. (2001) and McCormack et al. (1999) is that the former used a visual temporal generalisation task, where participants had to attend to a circle on a computer screen whereas the latter had an auditory task where tones were used. Droit-Volet et al. (2001) had a “flatter” profile of responses suggesting their participants were somewhat less accurate at visual temporal generalisation, but that the results were broadly in line with what was expected.

Research that has contrasted visual with auditory temporal processing has found there are qualitative differences in the responses made. Wearden, Edwards, Fakhri, and Percival (1998) directly compared adult performance on a visual temporal generalisation task to that of an auditory temporal generalisation task. When participants were required to carry out visual conditions, as with the children in Droit-Volet et al. (2001), the adults had a less defined profile of responses. They were likely to confuse non-standard durations with the standard more often across the range of non-standard duration rather than at those that were closer to the standard. This was most pronounced in the longer than standard durations rather than the shorter than standard durations. They suggest that, within a model of timing outlined at the beginning of the section, that temporal pulses are, for some reason, running at a faster rate in the visual condition, and that the ability to switch attention to accumulate the pulses is less efficient. However, they concede that further research is required to establish this model.

As discussed earlier in relation to dyslexia and DCD, temporal processing deficits could be related to cerebellar processing deficits. Neurological evidence has indicated that the cerebellum is an area of the brain that is important in temporal processing. In a study of patients with brain damage, Ivry and Keele tested 30 participants with cerebellar damage, 30 with Parkinson's disease, eight with frontal lobe damage, four with peripheral neuropathy, and two with sensory loss, 29 with epilepsy. A group of undergraduates and a group of elderly patients with no neurological damage served as controls. They carried out two temporal tasks. One was a perception task similar to the procedures of Gautier and Droit-Volet (2002), and McCormack et al. (2004) and another was a tapping task. Two control tasks were also employed, a volume perception task, and a pitch perception task. In the temporal perception task, the participants had to

compare the intervals between two successive pairs of tones (each tone was 1000 Hz and 50 ms in duration). The first pair of tones had 400ms interval and this was the standard interval. On half of the trials, the intervals were set to assess the lower perception threshold, in which participants would respond that one of the tones was shorter than the standard 90% of the time. The other half of the trials used intervals to assess the upper threshold of perception, in which the participants would judge the tone to be longer than the standard 90% of the time. Each step was 8 ms and there were steps between 160 ms and 640 ms. The loudness perception task and the pitch perception used a similar method to the temporal perception however varied either the volume or the pitch of the auditory stimulus rather than the duration.

Tapping tasks are another example of a temporal measure. Studies reviewed earlier showed differences in the pattern of tapping between children with dyslexia, children with DCD, and typically developing children. Whereas tapping has a motor component, tapping is also a task that requires participants to make judgements about temporal information and to carry out a process at or near the end of that duration. In the tapping task used by Ivry and Keele (1989), participants were asked to synchronise to a pacing beat set at 550 ms ISI. After 12 taps, the beat was removed and then the participants had to complete 31 self paced taps trying to maintain the ISI from the pacing beat. Each participant completed at least 12 trials.

Ivry and Keele (1989) found that only the group with cerebellar damage showed a deficit in the auditory duration perception task, they also showed higher tapping variability compared with the control groups. As Ivry and Keele (1989) note "It thus appears that only the cerebellar subjects are impaired in the ability to make time-based

perceptual judgements.” (p. 140).

Further support for cerebellar processing being related to temporal processing comes from a repetitive transcranial magnetic stimulation study (rTMS) study conducted by Théoret, Haque, and Alvaro (2001). Slow wave rTMS is a method of temporarily decreasing the cortical activation of a part of the brain targeted by the experimenters. Seven typical adult participants were asked to synchronise tapping to a visual stimulus, a black square presented ten times at an interstimulus interval of 475 ms, on a computer screen. This sequence was repeated 12 times per condition. During the task, participants did not know which areas of the brain, if any, were being stimulated. There were four separate conditions to the task: rTMS stimulation of the motor cortex, a medial cerebellum area, a left lateral cerebellum area (see Figure 1.2), and a placebo condition in which the apparatus was fired away from the participant without his or her knowledge.

Théoret et al. (2001) found the greatest difference in both mean tapping speed and variability was when the cortical excitability of the medial cerebellum was reduced. As disrupting the activity of the motor cortex had not affected tapping variability then it would appear unlikely that motor coordination was the reason for the variability in tapping when the cerebellum was disrupted. One possible interpretation of the findings is that disruption of the cerebellum caused disruption to the processing of temporal information that is important in keeping the variability of tapping to an external stimulus low. A limitation with rTMS is that it is not always clear which areas are being affected, where the coils are being fired at the cerebellum, other structures in the brain may also be disrupted, and so the findings are interpreted with caution in view of the

lack of sophistication in the rTMS procedure.

One study has been carried out to attempt to isolate the neurological structures that are used in tapping and by implication temporal processing. Jäncke, Loose, Lutz, Specht, and Shah (2000) conducted a functional magnetic resonance imaging (fMRI) study of tapping with eight right handed, healthy adult males. They used a constant interstimulus interval of 400 ms but varied the condition between synchronisation to a beat and attempting to maintain the beat after the synchronisation stimulus was removed. In addition, they conducted the study with either an auditory or a visual 'beat'.

The first set of scans was completed with the participants resting. This provided the baseline for the investigation of effect sizes in blood flow to areas of the brain. During the experiment, the synchronisation condition was immediately followed by the continuation condition, which was then followed immediately by another synchronisation condition and so on. In total, there were three synchronisation conditions and three continuation conditions yielding thirty scans in total for each of the condition, this was in addition to thirty scans in the baseline.

Amongst other areas of activation, the cerebellum, particularly the right cerebellum activated for all conditions. Jäncke et al. (2000) compared the effect size for the activity between the baseline, rest period and the tapping conditions. Analysis indicated that the cerebellar vermis was activated for the visual synchronisation and continuation but that the activation was below the baseline for the auditory conditions. The right superior cerebellum was activated across all four conditions, but more so for the visual conditions. The right inferior cerebellum activated for the auditory task but the activation level was below the baseline for the visual tasks.

However the cerebellum is a large structure in the brain and it seems unlikely that is simply devoted to one process; as argued by Justus and Ivry (2001), it is instead implicated in a range of processes. Jäncke et al. (2000) suggest that the right inferior and the right superior cerebellar hold somatosensory maps. These store and process information regarding where parts of the body are in relation to each other using information derived from senses. They found that the visual condition activated the hand representation element of the superior lobe whereas the auditory stimuli activated the hand representation element of the inferior lobe (see Figure 1.2). It is noteworthy that the right lobe of the cerebellum showed activation that was different in the group with dyslexia compared to the typical group in Nicolson et al. (1999). Previous research related to the vermis, however, has shown that it is important “to the production of timed motor responses, particularly when it is complex and/or novel” (Nicolson et al., 1999, p. 64). One of the things noted from the results was that there was more activation in the vermis for the visual condition and they suggest that this was because this condition was more complex for the brain to process.

Within SET, proposed earlier, it is possible that deficits in any of the components, pulse generator, mechanism to attend to the pulses and record them, or the processes to store them in short and long term memory, could cause variability in processing temporal information. This, in turn would affect the efficient cognitive processing in skills such as reading, and complex motor coordination.

This section has presented a theory for temporal processing and the evidence to support it. Furthermore, it has outlined that there may be a developmental pathway to temporal processing, and that different modalities may be handled by the same cognitive process but in different ways. Moreover, the underlying neurological evidence provides an

area of the brain, the cerebellum, which may be implicated in temporal processing.

There are, therefore several links to dyslexia and DCD. The first is that both dyslexia and DCD have theories where deficits in temporal processing may be able to account for the behavioural difficulties both groups exhibit. The second is that temporal processing is likely to be related to cerebellar deficits and there is behavioural evidence of a cerebellar deficit in both dyslexia and DCD.

Finally direct comparisons can be made between the work carried out by Ivry and Keele (1989) and research in dyslexia (Nicolson and Fawcett, 1995; Wolff et al., 1984) and DCD (Williams et al., 1992). Their results indicate two main findings. Firstly, adults with cerebellar damage have temporal processing deficits; their patterns of tapping are more disordered. Secondly, they have less accurate temporal perceptions than typical adults. As outlined earlier, similar findings have been found in children with dyslexia (Wolff et al., 1984, and Nicolson et al., 1995), and DCD (Williams et al., 1992 and Lundy-Ekman et al., 1991).

Frith (1999) proposed a framework for conceptualising dyslexia based on three levels: biological, cognitive, behavioural. One of the models she puts forward is based on encompassing a cerebellar deficit in the biological level with later temporal deficits and then biological indicators. One of the striking things about this is how it fits with the evidence presented in this chapter and furthermore could provide an overall framework in which to compare deficits in both dyslexia and DCD. A modified version of this framework is presented in Figure 1.4

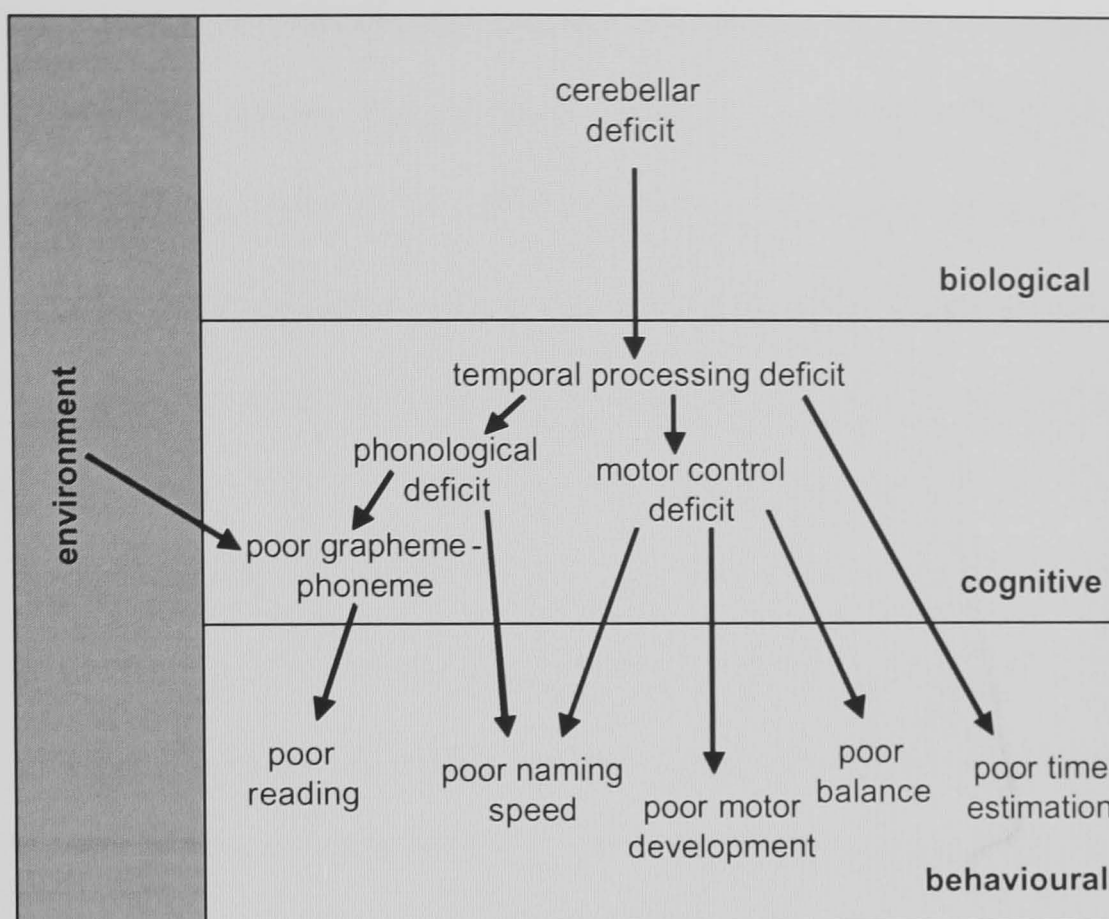


Figure 1.4 An adapted version of the Frith (1999) model of dyslexia as a cerebellar deficit. In view of the evidence in DCD it may also hold for deficits found here too.

1.9. Chapter Summary

This chapter has presented an overview of the current definitions for dyslexia and DCD, and it has presented a general framework for the thesis in terms of temporal processing. The chapter has also provided an overview of the main theories that currently attempt to explain the behavioural deficits associated with dyslexia and DCD. From the evidence presented here, it is clear that there is a fair degree of overlap between dyslexia and DCD on a behavioural level, a cognitive and a neuropsychological level. Research into both groups has suggested that they may have deficits at a temporal processing level. However, the nature of the studies into temporal processing deficit has been different in dyslexia and DCD. Auditory discrimination and rapid processing tasks have dominated the former, whilst temporal perception and production tasks have dominated the latter.

The research points towards the idea that both conditions may be united by a common temporal processing deficit. This is what the thesis will seek to consider. However, first it will be necessary to consider the nature of any temporal processing deficit in each group using the same measures of temporal processing across the two groups. This will enable a clarification of whether there is any evidence of temporal processing difficulties, and what form they take. Therefore, it would be desirable to look at temporal processing across a range of tasks, and across both visual and auditory modalities, as most of the paradigms used appear to focus on the auditory domain. Given the theorised visual deficits in dyslexia and DCD, it would be valuable to assess aspects of visual temporal processing in relation to both conditions. The next chapter will therefore look at temporal processing measures that have been used elsewhere, including studies that have not looked at children, or specific learning difficulties. A discussion of other methodological issues will also be undertaken in that chapter.

Overall, previous research and observations have led to the possibility that temporal processing deficits may be responsible for the difficulties encountered by children with dyslexia, and children with DCD. Although research has been conducted in both conditions in areas related to temporal processing, no study has directly compared both groups on measures of temporal processing. The aim of this thesis will be to test children with dyslexia and DCD on a range of tasks that require temporal processing (see Figure 1.5) in order to attempt to answer the following research questions. First, to investigate the nature and scope of any general temporal processing deficits in a sample of children with developmental dyslexia and in a sample of children with DCD. Finally, whether any of the deficits observed in the children with developmental dyslexia are also evident in the children who have developmental coordination disorder.

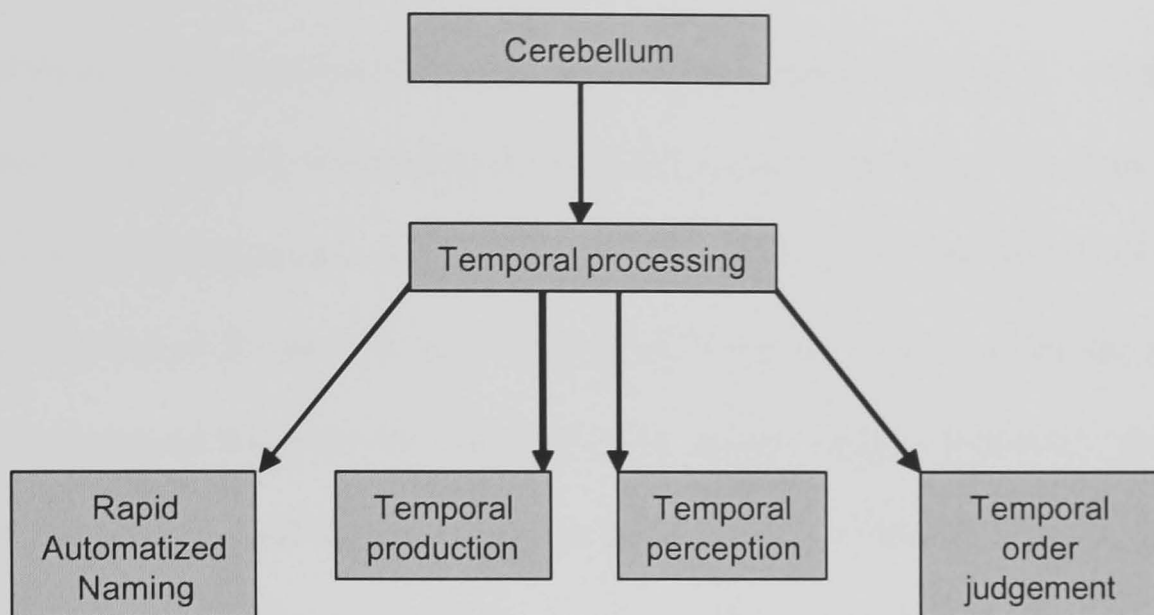


Figure 1.5 Brief diagram of the relationship between temporal processing and the experimental tasks in this thesis.

2. Methodological Chapter

The previous chapter provided an overview of the evidence that supports the idea that there may be a common underlying cause of the cognitive difficulties in observed dyslexia and developmental coordination disorder (DCD). One area that could potentially account for the deficits in reading and complex motor movements noted in both groups would be a possible deficit in temporal processing. Therefore, this chapter will review possible methodologies that could be used to evaluate the temporal processing deficit hypothesis under exploration in this thesis. The aim is to identify tasks that will enable the examination of different aspects of temporal processing. The areas identified as being of particular interest from the preceding literature review are: RAN, temporal production, temporal generalisation, and TOJ.

2.1.1. *Task Specific Evaluation*

2.1.1.1. Rapid Automated Naming (RAN)

As discussed in Chapter One, RAN tasks have been shown to differentiate children with dyslexia from typically developing children, and to differentiate children with dyslexia from poor reading children. The general procedure with respect to RAN tasks has not differed markedly between experiments; however, both the stimuli used and the outcome measures obtained have differed across experiments.

In a typical RAN task, (e.g. Denckla and Rudel (1976)), participants are seated in front of a grid of symbols; these could be letters, numbers, colours, or line drawings of objects. In Denckla and Rudel (1976) this comprised five stimuli repeated ten times in a random order (see Figure 2.1. for an example). The participants are then asked to read

the symbols as fast and as accurately as possible and the dependent variable obtained is the time taken to read all the symbols in the grid. To be successful at RAN the repetitive sequences of action in the task, such as the identification of the stimulus and then the naming of the stimulus, need to be processed quickly and rhythmically. This would require an automated process for each of the stimuli, as suggested by Wolf, Bowers, and Biddle (2000) and temporal processing ability would also be required to regulate these processes, (see Wolf, 1991). However, as Muter (2002) notes, little is known about the underlying cognitive processes required in RAN.

o	a	s	d	p	a	o	s	p	d
s	d	a	p	d	o	a	p	s	o
a	o	s	a	s	d	p	o	d	a
d	s	p	o	d	s	a	s	o	p
s	a	d	p	a	p	o	a	p	s

Figure 2.1 An example of a RAN letter grid similar to that used by Denckla and Rudel (1976).

This version was taken from Anderson et al. (1984).

Whereas the procedure for this type of task tends to be consistent across studies,

different studies have used different stimuli. The earliest studies, such as Denckla and Rudel (1976), used a range of stimuli: colours (red, green, black, blue and yellow), numbers (2, 6, 9, 4, 7), line drawn pictures of objects (comb, key, watch, scissors, umbrella), and letters (p, o, d, a, s). Other studies that have used the same stimulus set include Anderson et al. (1984) and Meyer et al. (1998).

Many of the more recent studies, such as Wolf and Bowers (1999), have focused on the letter and number RAN, as Wolf et al. (2002) noted that these two are often more predictive of later reading ability than the colour and object RAN.

With this in mind, it is noteworthy, that both the Dyslexia Early Screening Test (DEST) (Nicolson and Fawcett, 1996) and the Phonological Assessment Battery (PhAB) (Frederickson, Reason, & Frith, 1997) employ an objects RAN task. The DEST uses 20 line drawings of common objects repeated twice, and the PhAB uses line drawings of a box, a table, a ball, a hat, and a door, repeated ten times. However, the PhAB also includes a number RAN, although this is not presented in a 'grid' format.

Several experimental studies have, however, used slightly different stimuli, and these are summarised in Table 2.1. Bowers and Swanson (1991) and Bowers (1993) used a six stimuli letters and numbers RAN task. In contrast, Compton et al. (2001) used four RAN tasks with six stimuli and slightly different letters, numbers, and colours to those that had been used by Denckla and Rudel (1976). Compton et al. may also have used different line drawings of objects, however the article does not detail what the objects were, only that they were of 'common objects'. Finally, Fawcett and Nicolson (1994) used eight stimulus letter and number RAN tasks, then a six stimulus colour RAN task, and a 12 stimulus line drawing task. Their paper does not provide a rationale for the

divergence from the Denckla and Rudel type of RAN although their findings are roughly comparable to studies that have used smaller stimuli numbers.

One of the few studies that used a set of stimuli substantially different from Denckla and Rudel (1976) is Snyder and Downey (1995). Their measure of RAN involved children reading colours in one condition, simple line drawn shapes in another condition, and finally, line drawn shapes with colours in a third condition. The article, however, did not provide details of what the shapes and colours were. The studies do show that within groups of children with dyslexia, there is some difference in time taken to complete RAN tasks. However, for the aims of the thesis, there appears to be no compelling reason to assess the four main types of stimuli used in RAN, consequently only one stimulus set will be chosen for this study: letters. This is mainly as the only study to compare short form RAN and long form RAN (discussed below) used only a letters and numbers condition. Furthermore, in order to retain a level of comparability to previous studies, the letters stimulus set used by Compton et al. (2001) and Compton, Olson, DeFries, and Pennington (2002) will be used.

Table 2.1 A summary of representative studies with differing RAN stimuli. Children were used as the test population in each of these studies.

Study	Set	Stimuli
Denckla and Rudel (1976)	Letters	a, d, o, p, s
	Numbers	2, 4, 6, 7, 9
	Colours	black, blue, green, red, yellow
	Objects	comb, key, scissors, watch, umbrella
Bowers and Swanson (1991)	Letters	D, K, P, R, S, T
	Numbers	1, 2, 3, 4, 5, 8
Compton et al. (2001) and Compton et al. (2002) (who used only letters and numbers conditions).	Letters	a, b, d, o, p, s
	Numbers	1, 2, 4, 6, 7, 9
	Colours	blue, green, red, yellow
	Objects	Six common objects
Fawcett and Nicolson (1994)	Letters	a, b, c, d, o, s, t, w
	Numbers	1, 2, 3, 4, 5, 6, 7, 8
	Colours	black, blue, green, red, white, yellow.
	Objects	bird, cat, cup, frog, hat, house, leaf, mouse, nose, pig, table, tree
The study in this thesis	Letters	a, b, d, o, p, s

The second issue to consider is how to score a child's ability on the task. The majority of studies (such as, Bowers, 1993, Bowers and Swanson, 1991, Denckla and Rudel, 1976, Fawcett and Nicolson, 1994, Meyer et al., 1998, Wolf and Bowers, 1999, Wolf et al, 2002) have used the time it takes the participant to read the grid of stimuli presented before him or her. Accuracy is not normally measured, as studies such as Anderson et al. (1984) have noted that few participants make errors on the task.

However, recently, Compton et al. (2001) and Compton et al. (2002) have employed a different method of assessing performance on a RAN task. They counted the total number of stimuli read in 15 seconds. This overcame some criticisms of the RAN task to do with duration; for example Fawcett and Nicolson (1994) argued that children with dyslexia often appear to have difficulties with RAN because of fatigue rather than difficulties in automatization.

Fatigue could be a factor in many RAN studies. In Denckla and Rudel (1976), the average time it took a nine year old child with dyslexia to complete the letter RAN task was 50 seconds compared to around 30 seconds for a typically developing child. A possibility is that not only will it take a child with dyslexia longer to complete a RAN task but during that time the effects of fatigue will become cumulative. There is less possibility of this confounding a RAN task which is completed in 15 seconds. A final advantage is that Compton et al. (2002) found that the 15 seconds RAN accounted for more variance in some assessments of reading than the 50 item RAN did.

A more fine-grained method of analysing performance on a RAN task is to record the duration of the articulation of each stimulus and the duration of the non-articulation between each stimulus. Only a handful of studies have carried out such analysis, for example: Anderson et al. (1984), Snyder and Downey (1995), Neuhaus et al. (2001a), and Cobbold et al. (2003). The primary reason for this is that this can be a particularly laborious task unless specialist software can be employed. For example, with a traditional RAN task, a participant would provide 50 articulation and 49 non-articulation durations. If only one presentation of RAN is recorded for each participant, in a group of 30 participants, 1500 articulation, and 1470 non-articulation durations would have to be recorded, collated and then analysed. However, the variability of

non-articulation durations is of particular interest: both Neuhaus et al. (2001a) and Cobbold et al. (2003) have found this to be predictive of later reading ability.

Therefore, an appropriate methodological approach would be to take advantage of the shorter Compton et al. (2003) paradigm but to subject it to a detailed analysis of articulation and non-articulation durations. This would maximise the possibility of detecting any differences between the children with dyslexia, the children with DCD, and the typically developing children.

2.1.1.2. Temporal Production

One element of temporal processing identified as of interest to previous researchers is that of temporal production. One method of assessing temporal production is through the so-called 'tapping' paradigms. In this type of task the participant attempts to synchronise their hand movement to a duration that is either being presented concurrently or has been previously presented.

Broadly, there are four types of tapping task:

- The self paced tapping task
- Synchronisation to a pacing stimulus;
- Synchronisation to a pacing stimulus followed by the continuation of the pace once the stimulus has been removed
- Reproduction of a pacing stimulus that has previously been presented.

A summary of relevant temporal production studies is presented in Table 2.2

Common to most studies is the general nature of the assessment. Typically, a participant

is seated in front of an apparatus that would be able to provide a pacing stimulus. In the most recent experiments, this has been a computer with specialist software. The object to tap to could be a Morse code key, as in Wing and Kristofferson (1973), or in recent studies this is likely to be a mouse button, as in Carlier et al. (1993).

There are some procedural differences for the four types of tapping tasks. In self paced tapping tasks, such as, Carlier et al. (1993), participants are instructed to tap as quickly as possible a certain number of times or for a certain duration. Synchronisation tasks differ in that there is an external pacing stimulus.

One study that concentrated on synchronisation only was conducted by Peters (1989). Participants were presented with a pacing stimulus and were required to synchronise to it as accurately as possible. The study measured the speed and variability of tapping at different ISIs. However, one of the most common procedures is synchronisation to a pacing stimulus followed by the continuation of the pace once the stimulus has been removed. Primarily, this allows two conditions to be studied together. Participants are required to tap in synchrony with a pacing stimulus, after having tapped to a stimulus for some time, the stimulus is removed and participants are required to continue tapping at the same pace without the pacing stimulus. Studies such as Jäncke et al. (2000), and Ivry and Keele (1989) have used this method (see Table 2.2 for an overview of the studies which have used this procedure).

Finally, the reproduction of a pacing stimulus requires participants to observe a rhythm being presented and then reproduce the rhythm. Studies such as Piek and Skinner (1999) used this procedure.

An important question is how much temporal processing is required for these types of

task? It is not clear how much temporal processing would be required to carry out a self-paced tapping task. Although a fast and consistent tapping speed may be indicative of an efficient temporal process, it may also be that the process is more reliant on effective coordination skills. However, the other three types of tapping task are likely to be more strongly dependent on, and therefore indicative of, temporal processing ability. For example Wing and Kristofferson (1973) proposed a well supported model of the variance central timekeeper used during tapping, and Hary and Moore (1987) have modelled the process of anticipation to a stimulus for the synchronisation and continuation procedure.

Synchronising to a stimulus requires a participant to observe the duration between stimuli, store this duration, and then coordinate a motor response in order to produce taps in time with the stimuli. The taps and the inter-stimuli interval would then need to be monitored so that any drift or variation in the taps could be corrected. Evidence from Semjen and Garcia-Colera (1986) suggests that this type of process does occur during tapping. They examined whether the time to prepare for a tapping sequence became longer the more taps that were in the sequence. If all the processing required for a set of taps was cued before the tapping was carried out then it was expected that the time taken between starting the task and initiating the first tap would be longer for long sequences of taps compared with short sequences of taps. Participants were shown the pattern of taps before having to reproduce the pattern. They found that the time taken to initiate the first tap was the same regardless of the length of the tapping pattern, suggesting only some of the information was processed before starting the tapping pattern and the rest was analysed online.

Further evidence of a process out of temporal synchronisation comes from anticipation studies (for example, Wing and Kristofferson, 1973; and Wolff, 2002). Participants tend to anticipate the beat and press the button slightly before the stimulus. This would suggest that tapping does not rely on reacting to the stimulus as it appears but that some kind of temporal process is taking place. Continuing to tap once a stimulus has been removed would also require the duration to be stored. This stored duration would then need to be compared to the duration between taps in order to attempt to, again, correct for variations in the motor process of tapping.

Another element of temporal production tasks is the synchronisation to a stimulus with a constant interstimulus interval (ISI). Peters (1989) suggested that different cognitive processes are likely to be required at different ISIs. Peters (1989) found a rise in variability of tapping at around 300 ms ISI and he suggested that this may be due to a transfer from automatic processes in tapping at short ISIs to a more conscious process of tapping at long ISIs. He also found there was a slow rise in variability of tapping at longer (near 1,000 ms) ISIs. Peters (1989) has suggested that as the ISI becomes longer, attentional factors begin to be important in order to continue to tap effectively. Several studies have used the same ISI. Ivry and Keele (1989), Lundy-Ekman et al. (1991), Williams et al. (1992), and Geuze and Kalverboer (1994) all used the same constant ISI of 550 ms. Both Wing and Kristofferson (1973) and Peters (1989) used around 175 ms as their shortest tapping ISI, however both noted that some participants had difficulty tapping to such a fast beat. This suggests that there is also a limit to how fast synchronisation can be carried out. Being able to carry out analysis on both synchronisation and continuation would allow a more complete investigation of temporal processing. It would be interesting to see, having once stored a temporal

duration using a pacing stimulus, how well the groups are able to generate an internal pacing stimulus. In terms of ISI it would be useful to have three conditions to compare: one on the boundary between conscious and automated tapping, at around 300 ms; one near that of other temporal production studies, around 500 ms, finally, another at a longer duration for comparability with the studies carried out by Wolff (2002), at around 700 ms.

The type of stimulus presented is also important. Pacing stimuli are often presented visually or acoustically. In the case of Jäncke et al. (2000) both modalities were used in separate conditions. The type of stimulus used might have implications as to how well the children with dyslexia and the children with DCD might carry out the tapping. If there is an underlying general temporal processing deficit then it is possible that it will impact on all modalities. However, evidence from Chapter One points towards an auditory processing deficit in dyslexia and a visual processing deficit in DCD. Using only one modality would affect how much can be interpreted in the results. As a result the study in this thesis will compare both visual and auditory temporal production.

Finally, the number of taps needed requires consideration. A summary of the numbers of taps used in studies can be found in Table 2.2. The number of taps needs to be sufficient to allow for statistical analysis, but not too many as to cause detrimental task demands on the participant. In the self paced tapping study by Carlier et al. (1993) participants were only required to carry out 101 taps as quickly as possible with each hand and their measure was how long it took to complete the 101 taps (there was only one session per participant). Peters (1989) only studied synchronisation and, although testing was extensive, in terms of conditions, the least number of synchronisation taps

made by his participants was 21.

Jäncke et al. (2000), who studied brain activation in tapping to a visual or an auditory stimulus, followed by continuation are not clear on how many taps were required. However, an estimate can be derived from the other information that the authors provide: there were thirty scans at rest followed by sufficient taps for 10 fMRI scans for each of the three synchronisation and three continuation periods. In total, therefore, there were 90 scans taken: 30 baseline, 30 synchronisation, and 30 continuation. They also note that it took 30 minutes (1,800 seconds) to complete the experiment per participant. This indicates that it took around 20 seconds to complete a scan (1,800 seconds / 90 scans), and therefore 200 seconds per synchronisation or continuation period (20 seconds * 10 scans). The pacing stimulus was 400 ms and this would suggest that there were around 50 taps per period (20,000 ms scan duration / 400 ms ISI). Across the six periods, this would be 300 taps in total for the auditory condition (synchronisation and continuation), and the 300 for the visual condition (again, synchronisation and continuation). This is assuming that the duration of the stimulus itself is part of the ISI, as in other studies such as Wing and Kristofferson (1973). Similarly, Wolff et al. (1984) do not note how many taps were in each of their synchronisation and continuation conditions, however, again, it is possible to reveal this from the durations that the metronome was used for. The first 30 seconds of the trial required participants to synchronise to a metronome, the metronome was then switched off and the participants were required to continue at the same rhythm for another 30 seconds. At 652 ms ISI, this would be around 46 beats and at 330 ms, and around 92 beats of the metronome for synchronisation. However as Wolff et al. (1984) do not record the actual number of taps each participant carried out, consequently, as some

participants might listen to the metronome before beginning to synchronise to the beat, it is possible that fewer taps were actually recorded.

One consistent feature of prior research has been to have an unequal number of taps in synchronisation and continuation. Wing and Kristofferson (1973) used 24 taps in their synchronisation phase and 31 taps in their continuation phase; whilst, Ivry and Keele (1989), Lundy-Ekman et al. (1991), Williams et al. (1992), and Geuze and Kalverboer (1994) used 12 taps in their synchronisation phase, and 31 taps in their continuation phase. The reason for using an asymmetrical design is unclear, however, and none of the studies indicate a rationale for using 12 taps to synchronise and 31 to continue. Piek and Skinner (1999) used a different procedure. The children saw a visual depiction of five taps then had to reproduce this by tapping. It would appear, however that 12 taps would be the minimum for synchronisation, this is likely to allow the participant sufficient opportunity to become used to the duration of the interstimulus. The continuation phase would then be required to allow sufficient taps to be able to analyse the speed and variability of the tapping. If 12 taps is also sufficient for the analysis of the tapping process then it seems possible that 12 taps would also be sufficient for the analysis of the continuation phase.

Finally, the number of trials and participants appropriate for the study requires some consideration. Carlier et al. (1993) carried out only one trial per hand, but used 100 participants. Peters (1989) conducted at 80 trials per ISI (there were 12 different ISIs), however only 4 participants were recruited for the experiment. Jäncke et al. (2000), who tested eight participants, had six synchronisation and six continuation trials per modality. Wing and Kristofferson (1973) were unclear about the number of trials used but it appears that each participant completed five blocks, each with 11

synchronisation and continuation periods. Wolff et al. (1984), who tested 20 children with reading difficulties and 15 typically developing children, were also unclear about the number of trials, it is possible that only one trial was completed per participant.

Wolff (2002), with 12 children with dyslexia and 12 typically developing children had ten trials per participant.

Ivry and Keele (1989), Lundy-Ekman et al. (1991), and Williams et al. (1992) all recorded 12 successful trials or analysis. Their definition of a successful trial was any trial that did not have a high tapping variability. Piek and Skinner (1999), carried out a block of 20 trials, per participant. The first five were practice trials where verbal feedback was presented, and then the next 15 trials were test trials. Partly related to the number of trials, therefore is how many taps would be collected and averaged in order to gain dependent variable for each participant. Ideally, this appears to be a number of trials more than one, but not too high to cause task demands to cause fatigue. The total number of taps in studies such as Ivry and Keele (1989) were 43, although the authors do not make it clear is an asymmetric balance of taps. It was decided in this study to have an equal number of taps with a pacing stimulus and for continuation to be used. In order to keep the number of taps within that of previous studies, 20 synchronisation taps and 20 continuation taps were used per trial.

Table 2.2 An overview of the number of synchronisation and continuation taps per block and the ISIs used in each of the studies reviewed.

Study	Population	Synch. taps	Self paced taps.	ISI
Wing and Kristofferson (1973)	Adult	12	31	170 ms – 350 ms.
Wolff et al. (1984)	Children	30 sec.	30 sec.	330 ms, 652 ms
Ivry and Keele (1989)	Adults	12	31	550 ms
Peters (1989)	Adults	> 20	N/A	180 ms – 1,000 ms
Lundy-Ekman et al. (1991)	Children	12	31	550 ms
Williams et al. (1992)	Children	12	31	550 ms
Carlier et al. (1993)	Children	N/A	101	N/A
Geuze and Kalverboer (1994)	Children	12	31	560 ms, 1120, ms
Jäncke et al. (2000)	Adults	50	50	400 ms
Wolff (2002)	Children	12	31	500 ms, 670 ms.
Study in thesis	Children	20	20	300 ms, 500 ms, 700 ms.

Finally, the dependent variables to be taken from such a procedure require discussion.

Primarily, the speed and variability of the taps from all the conditions are analysed, as in studies by Ivry and Keele (1989), and Peters (1989). However, an attractive, if time consuming option would be to analyse the on-contact and off-contact durations as Piek and Skinner (1999) did. This would allow for more detail in the analysis, and as noted earlier, both on-contact and off-contact durations are though to tap into different processed.

In view of the studies covered by this section, it appears that it would be important to have sufficient trials to allow enough synchronisation and continuation taps to be recorded for analysis, and that provision should be made to attempt to record both on-

contact and off-contact durations. The pilot study (detailed in Chapter Three) therefore included a measure of self-paced tapping, however, it was the non-significant findings from this study that prompted a more sophisticated method of temporal processing to be carried out in Study Two (Chapter Five). Namely, a synchronisation and continuation paradigm across three different ISIs. As discussed earlier in this section, measures of self-paced tapping might not require as much of an overt temporal processing ability as synchronisation and continuation to a pacing stimulus.

2.1.1.3. Temporal Generalisation

A paradigm that has been used in psychophysics to study temporal perception is temporal generalisation. However, there are some variations in the temporal generalisation methods that have been used. This section aims to examine these in order to design a task that is suitable for use in this thesis.

One of the first studies of temporal generalisation in human participants was Wearden (1992). In this study, he recruited 12 adults. The standard stimulus was a filled tone of 400 ms in duration, and the non-standard stimuli were filled tones between 100 and 700 ms, with 100 ms linear intervals. A trial consisted of the six non-standard tones played in random order, and one presentation of the standard stimulus. There were ten of these trials. After each presentation of a stimulus, participants were required to judge whether the sound heard was the standard stimulus or not. In designing the experiment, Wearden (1992) was required to develop 'human' equivalents of the rat training process, used in the initial studies by Church and Gibbon (1982), which meant including the reinforcement element used in such studies (i.e. the rats were given a food pellet when they pulled the lever to the correct stimulus during the experiment). Wearden's training

procedure was brief but aimed at allowing participants to have a reference for future presentations. The participants were initially presented with the standard duration stimulus five times and this was followed by the onset of the test trials. However, following each stimulus response, participants were informed whether they had heard the standard stimulus or the non-standard stimulus as a means of 'reinforcement'.

An adapted procedure has been developed to test temporal generalisation in groups of children aged five, eight, and ten years old. McCormack et al. (1999) presented participants with a scenario in which they had to judge whether the sound they heard was a sound that a particular owl had made or not. Participants in this experiment were also provided with a longer training session. They were first presented with the standard duration five times and informed that this was the sound the owl made. This was followed by a practice session where they were presented with other durations from the range they would need to judge in the test. Feedback was provided to the participants and then the standard was again presented to them five times before the test trials began. Again, during the task, the participants were informed after each judgement whether the tone duration they heard was the standard or not. The benefit here is that the participants are more experienced with the duration by the time the test trial begins and that there is a context to what could be considered an abstract task. Both elements may help children to be able to provide temporal generalisation judgements. It follows that as long as the instructions could be presented in a non-text format there seems to be no reason that the task could not successfully be employed to test temporal generalisations in children with dyslexia. Care would need to be taken with children with DCD that the input device used to respond to judgements would not cause any motor difficulties, but again, the support and practice in McCormack et al.'s design should help to counter this.

Both Church and Gibbon (1982) and Wearden (1992) study a second stimulus set in this type of temporal generalisation task. Whilst the majority of the studies above used a linear range of tone durations (e.g. a standard tone of 400 ms and non standard tones such as 100 ms, 200 ms, 300 ms in duration, and so on), another possibility is to space the durations in logarithmic steps, for example, a standard tone of 400 ms and non standard tones such as 190 ms, 240 ms, 310 ms, in duration. The two stimuli sets do produce slightly different results. In humans, a linear range results in participants confusing slightly longer stimuli with the standard more often than confusing slightly shorter stimuli, whereas a logarithmic range results in participants having a symmetrical response pattern. However, use of a linear stimulus set would enable a direct comparison with the children in McCormack et al. (1999).

Whereas most temporal generalisation studies have used auditory stimuli, Droit-Volet et al. (2001) used a visual task with a similar procedure to the auditory task. A filled circle was displayed on a screen for the duration stimulus, rather than an auditory tone.

According to Wearden et al. (1998) both auditory and visual temporal information feed into the same timer process, but visual information causes faster pulses to be created and more variability in the storage of these pulses. In view of the possible visual and auditory deficits that children with dyslexia and DCD may have, which were outlined in Chapter One, it would be important to assess both visual and auditory temporal generalisations in both groups.

Finally, therefore, a likely paradigm would be one that could compare both visual and auditory modalities in a task that has previously been successfully used with young children, for example that of McCormack et al. (1999). Consequently two tasks were designed. One was based closely on that of McCormack et al. (1999) in which an

owl made a tone of a standard duration and participants had to judge if tones of other durations were the standard or not. To provide a visual based alternative, a task was devised where a lighthouse made a flash of a standard duration and participants had to judge if subsequent flashes were the lighthouse or not.

2.1.1.4. Temporal Order Judgement

The temporal order judgment task was initially developed by Tallal in the 1970s. The first study using children with reading difficulties was Tallal (1980). The study involved three tasks: two of the tasks, a sequencing test and a rapid perception test, involved participants repeating a sequence of tones presented by the examiner. The third task was a same-different task, which involved the participants responding to whether two tones they had heard were the same or different. The tones were either 100 Hz or 305 Hz; this resulted in possible presentation pairs of 100Hz and 100Hz, 100Hz and 305 Hz, 305 Hz and 100 Hz, or 305 Hz and 305 Hz (or low, low; low, high; high, low; and high, high). In the sequencing test, the two stimuli had an interstimulus interval of 428 ms. In the rapid perception test, and the sequencing test each tone was separated by one of six interstimulus intervals: 8 ms, 15 ms, 30 ms, 60 ms, 150 ms, or 305 ms. There were 24 presentations in the task, four of each interstimulus intervals. Rapid perception involved attempting to reproduce the order of stimuli; sequencing, deciding whether the tones heard was low, low; low, high and so on.

The majority of subsequent studies have followed roughly the same procedure, in part in an attempt to replicate the findings that Tallal found, as noted in Chapter One. Common to all studies are several components, some of which have been modified. These are: the stimuli of the task, the duration of the stimuli and the interstimulus intervals between

stimuli, the number of practice trials and test trials, and finally the dependent variable.

Tonal stimuli have been primarily used in tests of TOJ. Reed (1989), Marshall et al. (2001), Cestnick (2001), and Heiervang, Stevenson, and Hugdal (2002) used stimuli with a frequency and duration identical to Tallal (1980), these being 100Hz and 305Hz in pitch and both having a duration of 75ms. Heiervang et al. (2002) also report findings for 250 ms tones. But there was little difference in the performance of the participants when comparing 75 ms duration tones and 250 ms duration tones.

Several studies have used different frequencies, Bretherton and Holmes (2003) required participants to compare a 250 Hz tone with a 500 Hz tone, whereas, France et al. (2002) used a standard frequency that varied between 480 Hz and 519 Hz. Although they do not note the frequency of the second stimulus, they note that it "...always exceeded that of the standard." (p. 171). That the tones can be clearly differentiated appears to be the implicit justification for the use of these frequencies. Montgomery (2002) and Hanson and Montgomery (2002) had an initial stimulus which was 500 Hz, with a 500 ms duration, then a second tone which was a 2,000 Hz tone with a 1,000 ms duration. Unlike other studies, a response was required as soon as the participant had heard the second longer tone. The first tone acted as a warning signal that the second tone would, after some delay, appear.

Several studies have also used brief speech stimuli. The aim of this variation is primarily to test directly whether there are speech perception deficits over and above the tone processing deficits that Tallal (1980) has argued are an underlying cause for dyslexia. Mody et al. (1997), for example, used consonant vowel digraphs, two of the digraphs: /ba/ and /da/ had a duration of 250 ms, and another two: /sa/ and /fa/ had

durations of 400 ms. Montgomery (2002) used, /ba/ and /da/, each with a 250 ms duration. Hanson and Montgomery (2002) used speech stimuli comprising of /ba/, /da/ and /sa/, all three were 250 ms in duration. Two studies have recently used consonant-vowel syllable stimuli and vowel stimuli. Reed (1989) used vowels /e/ and /æ/, with 250 ms duration; and consonant-vowels: /ba/ and /da/, with 250 ms duration. Bretherton and Holmes (2003), used vowel stimuli (/e/ and /æ/) which were 75 ms in duration, and consonant and vowel syllables (/ba/ and /da/) which were 300 ms in duration alongside tones with different frequencies and visual stimuli.

Few studies have also compared non-auditory temporal order judgments. One notable exception was conducted by Bretherton and Holmes (2003) who, in addition to the tone and speech stimuli noted earlier, also used shapes. Their stimuli were a cross and circle, both were 2.5 cm in height and length, had a duration of 75 ms. Another study was by Reed (1989), experiment two, who used two shapes which are reproduced in Figure 2.2. The shapes were presented for a duration of 83 ms. A comprehensive study of cross modal TOJs was carried out by Laasonen, Sercive, and Virsu (2002) who compared audio to tactile, visual to tactile and audio to visual TOJs. In these experiments, one of the stimuli would be presented in one modality and the other would be presented in a second modality. Participants were then required to indicate which of the two appeared first. Laasonen et al. (2002) began with an ISI of 500 ms and employed an adaptive process to shorten the ISI. Correct responses would shorten the ISI, whereas incorrect responses would lengthen the ISI. The threshold was the point at which 84% of the responses were correct.



Figure 2.2 An example of the two stimuli used by Reed (1989) in her visual TOJ condition.

In terms of ISIs, many studies have, again followed the template provided by Tallal (1980). Tallal, as noted earlier had an ISI of 428 ms during training, and an ISIs of 8 ms, 15 ms, 30 ms, 60 ms, 150 ms, or 305ms in her test. Marshall et al. (2001) used 400 ms for the training sessions and then 10 ms, 50 ms, 100 ms, and 150 ms ISIs during the test phases. Similarly, Heiervang et al. (2002) used 305 ms for training and 8 ms, 15 ms, 16 ms, and 150 ms ISIs during testing. Whilst, Bretherton and Holmes (2003) used a an ISI of 500 ms for training and ISIs of 10 ms, 50 ms, 100 ms, 150 ms, and 300 ms during testing. Cestnick (2001), however, did not state the ISIs used in the study, however, the implication is that they were similar to those of Tallal (1980). Both Montgomery (2002) and Hanson and Montgomery (2002) had substantially longer durations between two tones in their study.

It is likely that two ISIs might be sufficient to compare TOJ ability, a long ISI and a short ISI. The studies reviewed here consistently indicate that as the ISI becomes shorter, children become less accurate at the task, consequently, a condition which is difficult and a condition which is easy could be used rather than the gradient of previous studies. With this in mind, the short ISI duration will be at 10 ms, near the shortest end of the range used by Tallal, and the long ISI will be at 300 ms, near the longer end of Tallal's scale.

Tallal (1980) had several steps to her task which necessitated different trials per task.

Phase one required participants to associate one of the stimuli to a coloured button, and the other stimuli to another coloured button. Once participants were able to complete 20 out of 40 responses correctly, participants were then tested in phase two on their ability to reproduce the sequence of two tones using the buttons, this was done at a constant ISI of 428 ms. There were four demonstration trials, eight trials with feedback, followed by 24 trials where the participants had to make judgements on his or her own. The two main tests then followed these practice session. Phase three required participants to again, reproduce the sequence of tones using button presses, but at much shorter ISIs, as noted earlier, six ISIs were used, and there were 24 trials in total. Phase four required participants to judge whether the two tones they heard were of the same pitch or not, again the six shorter ISIs were used and there was a total of 24 trials.

Of those that have used similar procedures, there have been variations to the method.

Marshall et al. (2001) carried out a similar experiment, but with some changes to the task. Rather than requiring 20 out of 24 responses correct in the first phase, participants were required to complete 12 out of 16 correct responses. It is unclear why Marshall reduced the criteria, although time constraints may have played a part. However, the results of both studies are comparable, suggesting that the 12 out of 16 criteria did not affect the outcome of the later test phases.

Phase two again required 12 / 16; phases three and four had a different ISI range.

consequently 32 trials were carried out in each (2 each of high-high, high-low, low-high, and low-low, at 4 different ISIs). However, Heiervang et al. (2002) had a much shorter training session. Before continuing with the task, participants were required to respond correctly 80% of the time as to whether the tones were the same or different

at an ISI of 305 ms. In their test phase, Heiervang et al. then tested the children on whether they could judge if the tones were the same or different; whether they could reproduce the correct order of the tones; and finally, whether they could discriminate between three, four and five tone patterns.

One assumption is that the large amount of familiarisation used in the initial Tallal (1980) study was partly to overcome the difficult interface used by the task. Two differently coloured buttons were used and therefore a lengthy process of training participants to associate one colour with a particular tone, then the other colour with another tone was required. This study therefore aims to overcome this by providing a clear visual display and a set of practice trials of the task with feedback that participants are required to complete correctly in order to continue to the test trial itself.

Essentially, important elements to consider for the TOJ task are that there are sufficient trials per test condition, that there is the ability to compare across modalities to examine whether there is a deficit in just speech and tone, or whether this extends to visual stimuli too. This may be of particular interest in the children with DCD, as no study to date has examined TOJ in this population, and, as there is evidence of visual deficits in DCD. Consequently four different types of stimuli will be used in the task: /ba/ and /da/ speech segments, high (500 Hz) and low (300 Hz) tones, shapes, and letters, at two different ISIs a 10 ms ISI and a 300 ms ISI.

The chapter so far has discussed the rationale behind the studies carried out in the thesis. The chapter will now turn to a discussion of the children who participated in the studies detailed in this thesis.

2.1.2. *Participants and Schedule of Data Collection*

This section gives details the samples of children who participated in the empirical chapters (Chapters Three to Seven). A group of typically developing children was recruited for the pilot study prior to the collection of data for the main studies. Children with dyslexia, children with DCD, and typically developing children were recruited for the four main experimental studies.

The typically developing children used in the pilot research and in the main experimental studies came from a single mainstream school. The children with dyslexia and the children with DCD came from a different school that specialised in supporting children with statements of special educational needs. The children with dyslexia and DCD were selected for participation in the project by one of the teachers at the school.

The children with dyslexia and the children with DCD had received a Statement of Special Educational Needs (SSEN). An SSEN describes the likely difficulties that a child with special educational needs would encounter. Its prime aim is to describe the provision that should be available to support him or her in school. In addition, it describes how this support should be supervised and any other related information, educational or otherwise, which might be of use. This information can be collected from a range of sources including parents, teachers, and psychologists (DfES, 2001).

The specialist school's instruction methods were based on using small class sizes and standard phonics instruction in reading. Although the teachers at the school were aware of developmental coordination disorder and attempted to make appropriate adjustments for these children's requirements, there were no organised interventions for it. The children with dyslexia, children with DCD, and the typically developing children were

matched as closely as possible for age.

Parental permission for the children to be part of the study was obtained by letter for all the participants and in addition, verbal permission was obtained from each participant at the beginning of the study. It was explained to them that they had the right to withdraw from the project at any time. All the children tested were happy to complete the assessments. Following the sessions there followed a debriefing where the participants had an opportunity to discuss the work they had carried out. The data collection was carried out on the school's premises, under the supervision of school staff. A formal debriefing was also presented to the school, in which the results of each study were presented to members of staff.

Data collection for the pilot study was carried out in one session in May and June, 2001. Details of the participants for this study can be found in the Pilot Study chapter (Chapter Three).

There were two data collection phases for the four main experimental studies of this thesis. The first phase, carried out in late 2001, collected data for the Temporal Production study (Chapter Four) and the Temporal Generalisation study (Chapter Five). An initial sample of 21 typically developing children, 15 children with dyslexia, and 10 children with developmental coordination disorder (DCD) were tested. The children with dyslexia and the typically developing children were age matched with the children who had DCD. This resulted in the exclusion of 11 typically developing children and 5 children with dyslexia from the analysis. The groups used for the final analysis were as follows. Ten typically developing children, with a group mean age of 11 years, five months, who showed no signs of dyslexia or DCD; 10 children with dyslexia, with a

mean age of 11 years, and 10 children with DCD, with a mean age of 11 years, four months, took part in this study. There were seven boys and three girls in the group with dyslexia, nine boys and one girl in the group with DCD, and five boys and five girls in the typically developing group.

Five baseline measures were recorded for this group: chronological age, reading age, threading speed, verbal memory (recall of digits forward), and visual memory. The means and standard deviations can be found in Table 2.3.

The second phase of data collection was carried out in late 2002. During this phase the data collected were used in the RAN Study (Chapter Four), and the TOJ Study (Chapter Seven). Three age-matched groups participated in this study. Unfortunately, a very small number of children with DCD were available at this time, consequently unequal group sizes had to be used. This resulted in thirteen children with dyslexia, (average age of 11 years four months) and seven children with DCD (average age of 11 years five months).

The children with dyslexia and DCD were recruited first and a sample of typically developing children were then chosen as a group who matched the special needs children on age. There was an initial cohort of 23 typically developing children; eight children were excluded as their reading ability was not in line with their chronological age. Therefore, the 15 typically developing children who remained were used to compare to the children with dyslexia and the children with DCD, (average age of 11 years, one month). There were 10 boys and three girls in the group with dyslexia, and five boys and two girls in the group with DCD, there were 11 boys and four girls in the typically developing group. Five baseline measures were taken: Chronological Age,

Reading Age, Spelling, Vocabulary, Verbal Memory: Recall of Digits Backwards.

Details of these can be found in Table 2.4. Baseline measures and materials used in the study are presented below followed by the results of the baseline measures.

2.1.3. Baseline Measures

As many of the same baseline measures were used across the various studies in this thesis, details of their administration are given here rather than repeated in each of the empirical chapters.

2.1.3.1. Block Design

This assessment was used in the pilot study (Chapter Three) only. The Block Design task is part of the Weschler Intelligence Scale for Children IIIR^{UK} (WISC-IIIR^{UK}), Weschler (1992). In the task, participants are presented with a set of blocks. Each block is identical and consists of two white sides, two red sides, and two sides which are half red and half white on these areas the colours are divided diagonally. After a brief practice session, participants are presented with a two dimensional layout which they have to construct with the blocks. Initially four blocks are used and for later trials, nine blocks. Participants are stopped after failure to copy properly the pattern using the blocks or are timed out on two consecutive trials and are scored on whether they were successful and how quickly they completed the trials.

2.1.3.2. Spelling Age

This measure was taken in the RAN study (Chapter Four), and TOJ (Chapter Seven) studies. Spelling age data was provided for the children with dyslexia and with DCD by their school who had just assessed the children's reading and spelling ability prior to

the data collection phase. The decision not to assess the children's spelling ability was taken in consultation with the school, both to limit disruption to the children's lessons, and also to limit the number of assessments that the children had to complete. The children with dyslexia and the children with DCD were assessed using the Vernon test of spelling (Vernon, 1998).

The typically developing children's spelling ages were assessed using the spelling test from the British Ability Scales II (BAS-II) (Elliot et al, 1996). In the BAS-II spelling test, children were provided with a work sheet to write their answers on and the experimenter read aloud a word from the test booklet, as per the standardised instructions. The child then wrote down the word and the experimenter proceeded to the next word on the list. The words become increasing more difficult to spell and there was a cut-off point after a certain number of misspellings. The children were scored on the number of correctly spelt words on the worksheet. The scores converted to spelling ages to enable a comparison with the children with dyslexia and DCD.

2.1.3.3. Threading Speed

This assessment was used in the Pilot study (Chapter Three), the Temporal Production (Chapter Five) study, and the Temporal Generalisation (Chapter Six) study. This task was included to provide a measure of motor coordination and was also used in the pilot study to divide a sample of typically developing children into a fast coordination group and a slow coordination group. It is similar to the task used by Gubbay (1974) and Hulme et al. (1982) who found that threading beads was a good discriminator between children with poor and poor motor coordination. The participants were asked to thread ten large beads (3 cm in diameter, with an 0.8 cm aperture) onto a length of string 92 cm

in length as quickly as possible. The time taken to complete the trial in seconds was recorded. As the task was considered to be a skill that the children were likely to have encountered often in the past, only one trial was completed per participant. Using one trial per participant was also in line with the procedure used by Gubbay (1974).

2.1.3.4. Verbal memory: Recall of Digits Forward

This assessment was used in the Pilot study (Chapter Three), the Temporal Production study (Chapter Five), and the Temporal Generalisation study (Chapter Six). The recall of digits forward task from the WISC-III^{UK}, Weschler (1992), was used. The experimenter read a string of random numbers from the test sheet and the participants had to repeat back the numbers immediately, in the correct order. In the first trial, the string had two numbers, but with each successful repetition the string is increased by one number. Failure on one string terminated the trial and in line with the WISC-III^{UK} manual, there were two trials to this task. The total number of correct responses in both trials was the raw score and this score was used for analysis.

2.1.3.5. Verbal memory: Recall of Digits Backwards

This assessment was used in the RAN (Chapter Four), and TOJ (Chapter Seven) studies. The recall of digits backwards was taken from the WISC-III^{UK}, Weschler (1992). The task is similar to the recall of digits forward except that the participants have to repeat the string of number to the experimenter in reverse order. For example: 8 3 4 1 2 would become 2 1 4 3 8. A point was awarded for each correctly named string of numbers.

2.1.3.6. Visual memory

This assessment was used in the Temporal Production study (Chapter Five), and the Temporal Generalisation study (Chapter Six). Visual memory was assessed using the Recall of Objects subtest from the BAS-II (Elliot et al., 1996). Participants were presented with a sheet of card that showed a grid of 20 pictures. The children were asked to remember as many of the pictures as possible. After a brief period, the card was removed and hidden and the participants were asked to name as many of the pictures as possible within a time limit. Three trials were used in this task, in each, the participant was presented with the pictures, the pictures were then removed and hidden, and the participant was asked to name as many of the pictures as possible. The age equivalent score from this task was used for data analysis.

2.1.3.7. Vocabulary

This assessment was used in the RAN study (Chapter Four), and in the TOJ study (Chapter Seven). This was a test of productive vocabulary taken from the WISC-III^{UK} (Weschler, 1992). Participants were asked to explain what a word meant, for example, to give a definition of a “cow”. As the task progressed the words became increasingly more obscure. Participants were scored on the quality of their answers. Two points are scored if the answer provided a full definition of the word or where two examples of the word’s usage were provided. One point was scored for an incomplete explanation and no points were scored if the participant provided a definition that was incorrect. The task ended after the child had made three consecutive errors and the number of correct responses was recorded as the child’s performance on the task.

2.1.3.8. Reading Age

This assessment was used in all the studies reported in this thesis. As already noted with the spelling age measure, it was agreed that the children with dyslexia and the children with DCD would be tested by their school using the Schonell and Schonell (1970) sub-test of reading ability, and that these would be converted to reading ages to enable a comparison with the typically developing children, who were tested using the BAS II word reading card subtest (Elliot, Smith, and McCulloch, 1996). Both tasks are similar in format and nature. They require participants to read aloud words that were presented on an A4 card. The words at the beginning are high frequency, short length words such as “cat” and are in large font. As the task progresses, the words became less frequent, more irregular, longer and in smaller fonts. Both tests were administered according to standard instructions. All scores were converted to reading ages.

2.1.3.9. Results from baseline measures

The following results are for the first phase of the data collection. The baseline data did not conform to parametric assumptions; consequently, Kruskal-Wallis Non-Parametric analyses were conducted to see if there were any key areas of difference between the groups on these tasks. There were no significant differences between the groups on chronological age, $\chi^2 (2, N = 30) = 0.732, p = .693$, threading speed, $\chi^2 (2, N = 30) = 2.033, p = .362$, verbal memory: recall of digits forward, $\chi^2 (2, N = 30) = 2.288, p = .319$, visual memory, $\chi^2 (2, N = 29) = 0.375, p = .829$.

There was, however, a significant difference for reading age $\chi^2 (2, N = 30) = 10.729, p = .005$. Dunn’s Test of Multiple Comparisons indicated that the children with dyslexia

and the children with DCD had significantly lower reading ages than the typically developing children did.

Table 2.3 Means and standard deviations for the baseline measures for the temporal production and temporal generalisation studies.

Baseline Measure	Typical			Dyslexia			DCD		
	M	SD	N	M	SD	n	M	SD	n
Chronological Age	11; 5	13.04	10	11; 0	8.49	10	11; 4	11.65	10
Reading Age	12; 5	24.03	10	9; 7	19.13	10	9; 8	16.68	10
Threading Speed (seconds)	38.6	7.76	10	35.5	8.73	10	38.8	6.96	10
Verbal Memory Raw	9.4	1.96	10	8.3	2.71	10	8.0	1.76	10
Visual Memory Age	12; 6	42.32	10	11; 11	44.04	10	12; 2	33.28	10

Of note is the non-significant result in the measurement of threading across the three groups. It would have been expected that the children with DCD would be much slower at this task compared with the other two groups. Figure 2.3 shows the threading scores for individual participants. There is a much less spread-out pattern of times compared with the typically developing children and the children with dyslexia, although note the small subgroup of three children who completed the threading task at the 45 to 50 second range. In Chapter One, it had been highlighted that there was evidence of heterogeneity in samples of children reported to have DCD and this may be the case with this group of children.

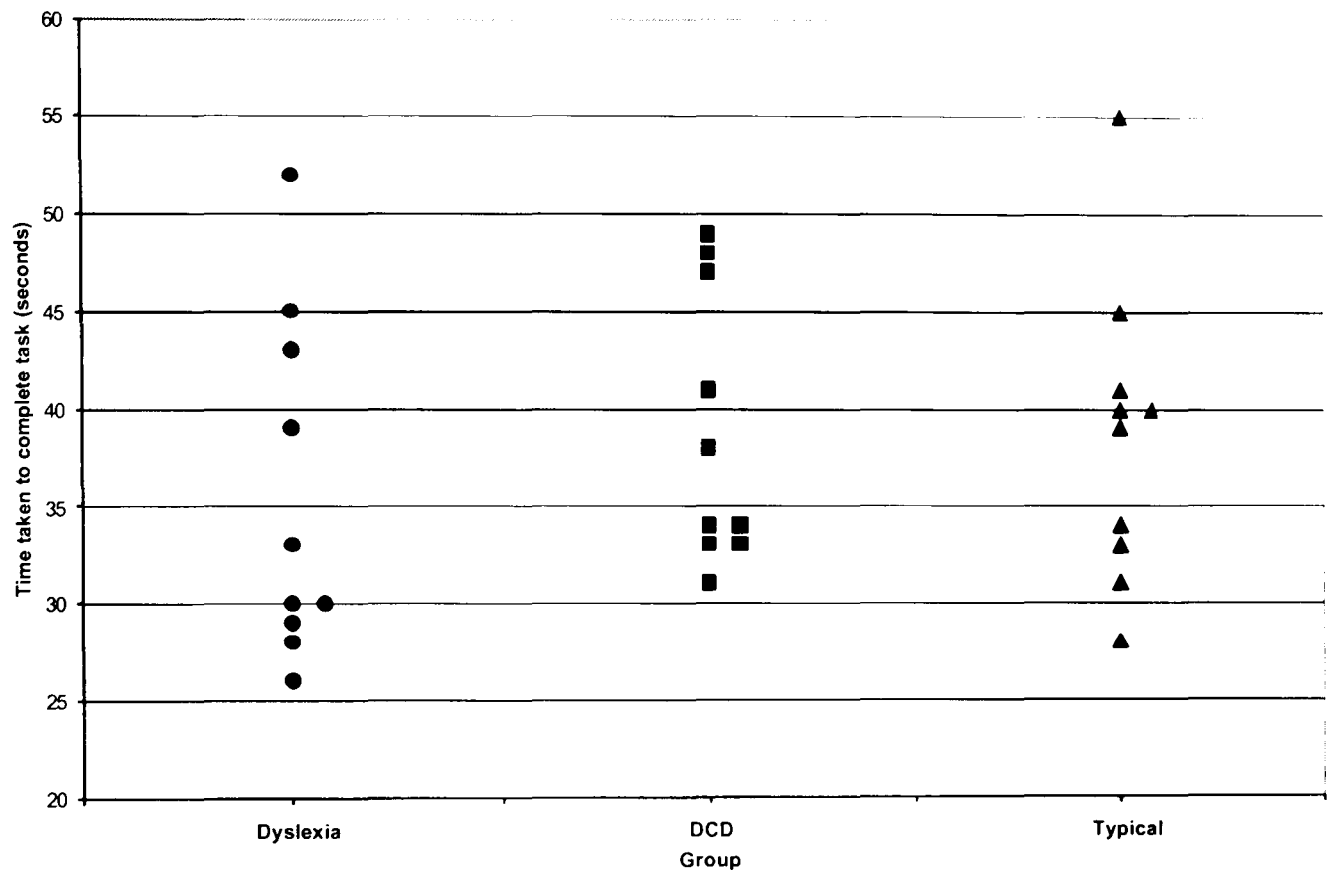


Figure 2.3 Graph showing the individual times per group for the threading task, each dot represents one participant.

In addition, it was expected that the children with dyslexia would show significantly lower verbal memory scores; however, the results were non-significant. This, however, does have a precedent, Bowers and Swanson (1991) had a participant group with reading difficulties whose verbal memory scores did not differ from their typical sample. They used a similar measure to the one used here. However, it was for this reason that recall of digits backwards, which is a more difficult measure of verbal memory, was employed in the second session rather than recall of digits forward.

The following results are for the second phase of the data collection. There was no significant differences between the groups in Chronological Age, $\chi^2(2, N = 35) = 0.204, p = .903$, or Vocabulary, $\chi^2(2, N = 35) = 3.178, p = .204$. There were significant differences for Reading Age, $\chi^2(2, N = 35) = 19.270, p < .0001$, Spelling Age, $\chi^2(2, N$

= 35) = 17.969, $p < .0001$, and Verbal Memory, $\chi^2 (2, N = 35) = 9.339, p = .009$. In all cases where there was a significant difference Dunn's Test of Multiple Comparisons indicated that the children with dyslexia and the children with DCD had significantly lower scores than the typically developing children.

Table 2.4 Means and standard deviations for the baseline measures in RAN and TOJ.

Baseline Measure	Typical			Dyslexia			DCD		
	M	SD	n	M	SD	n	M	SD	n
Chronological Age	11; 1	13.932	15	11; 4	12.653	13	11; 5	11.368	7
Reading Age	13; 11	28.306	15	9; 2	18.090	13	9; 10	21.369	7
Spelling Age	12; 9	25.804	15	8; 8	19.019	13	9; 0	22.401	7
Vocabulary raw score	34.47	7.482	15	31.15	4.598	13	35.29	6.775	7
Verbal Memory raw score*	6.13	1.642	15	4.38	1.044	13	4.71	1.113	7

* In contrast to Table 2.3, the verbal memory score here is for recall of digits backwards.

The profile of baseline measures between the children with dyslexia and DCD is in line with other studies. As little is known about the reading and spelling abilities of children with DCD, it is unclear as to whether it should be expected for them to have poor baseline measures of this nature. As was noted in Chapter One, there is a degree of variability in how assessments of DCD are carried out and the children who participated in this research may have been co-morbid with other disorders. During this phase of the research no assessments of the children's coordination abilities were carried out. This was due to time constraints and concerns for fatigue of the participants and the task demand characteristics of the experimental tasks.

A limitation of both data collection phases is the small size of the groups used. The pilot study aside, the largest comparisons were between the children with dyslexia and typically developing children in two of the studies, where 13 and 15 children were in the groups respectively. However, these group sizes are comparable to other studies. For example, Nicolson et al. (1995) had nine participants in their nine years old group with dyslexia (they report a total of 31 participants with dyslexia aged between nine and eighteen but divide them up into three groups for analysis) and Williams et al. (1992) had 12 participants with coordination difficulties in total. Larger groups would, however have been preferable and so limit what can be interpreted from the findings presented in this thesis. It is noteworthy, however, that in attempting to gain 'statemented' populations to study the pool of available participants was going to be limited. This was an unavoidable aspect of the nature of the field studied.

2.1.4. Computer Equipment

One feature of this thesis is that the data collection for the experimental measures was exclusively carried out using computers. The tasks were presented on a Toshiba Satellite laptop. The computer was configured with an Intel Celeron 500MHz processor, 128MB RAM, and a 35cm Thin Film Transistor screen with a resolution of 1024 x 768 pixels. The operating system was Microsoft Windows Millennium Edition.

2.2. Conclusion

The aim of this chapter was to review the various methodological approaches that could be taken in designing the various measures of RAN, temporal production, temporal perception and TOJ. This discussion highlighted the approaches taken by other

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researchers and rationales for the design of the measures used in this thesis were given. This was followed by an overview of the baseline measures that were used in the five studies and details of the participants and data collection phases were also given. The thesis will now turn to the empirical studies that were carried out in order to study temporal processing abilities.

3. Pilot Study

3.1. Introduction

The introduction suggested that aspects of temporal processing and automatization may be important for both reading and movement. These therefore provide a basis for investigating the possibility of common underlying cognitive deficits in dyslexia and developmental coordination disorder. However, prior to carrying out research on the target populations, the nature of the measures that are likely to be used in the main studies needed to be ascertained and evaluated. Therefore, this pilot study investigated whether groups of typically developing children with different levels of competence in reading and co-ordination can be differentiated by tasks that assess automatization and temporal production ability.

As noted earlier, one possible area of underlying commonality between children with dyslexia and children with DCD may be due to a general inability to transfer learnt processes into automated processes (Nicolson and Fawcett, 2001). Both reading and complex movement are skills that, at first, have to be learnt. However, following a period of practice, it should be possible to carry out reading or complex movements without as many cognitive demands. This would allow other tasks to be carried out concurrently or for the skill to be developed further.

The task of automatization that was used in this pilot study is similar, in some ways, to the task used by Nicolson et al. (1999) who studied adults with dyslexia. These participants were required to learn a sequence of key-presses by trial and error. Even after a large amount of practice, they still showed some difficulties with carrying out the

sequence once it had been learnt. In addition, Nicolson and Fawcett (2000) found that children with dyslexia took longer to learn some choice reaction time tasks than typically developing children. Literature searches did not indicate whether recent studies had shown clear deficits of transferring learnt skills to automated skills in children with DCD. However a difficulty of this nature could cause deficits in motor coordination. As a result, it warrants further investigation.

One measure of automatization that has been systematically used in the reading literature is that of RAN. Studies that have used this measure have found that children with reading difficulties are significantly slower than typically developing children are at naming items (e.g. Denckla and Rudel, 1976; and Wolf and Bowers, 1999), and that performance on this task is, to some extent, independent of any phonological difficulties (as argued by Wolf et al., 2002). As a result, it was decided to also include a measure of rapid naming here to see if it can also discriminate between children who have good and poor coordination skills. It was of particular interest to see whether both this measure and the computer-based measure of automatization would be able to discriminate between the groups, or whether one task might be a better discriminator than the other.

In order to assess temporal processing ability, it was decided to use a temporal production task. Studies of temporal production have been conducted with children with dyslexia and children with DCD. Wolff et al. (1984) and Wolff (2002) found that children with dyslexia had more variable and less accurate tapping patterns than typically developing children did. Lundy-Ekman et al. (1991), Williams et al. (1992) found similar patterns in children with coordination difficulties. Moreover, Piek and Skinner (1999) found that children with DCD held their fingers on a tapping plate for significantly longer than the typically developing children. Consequently, a self-

paced tapping measure was used here, and both number of taps and variability of tapping were assessed.

Finally, the pilot was also intended to assess how well children would work with computer-based assessments. An aim for subsequent studies in the thesis was to carry out the majority of the data collection using computer-based tasks and so this was an opportunity to collect valuable information about how children of the target age range, between eight and 12 years old, worked with computers and interface systems such as mice and keyboards.

The pilot study was therefore designed to address the following research questions:

1. Do measures of RAN, computerised measures of automatization and temporal production differentiate children with different reading abilities?

It is predicted that the children with poor reading ability would show poorer performance on RAN, automatization and temporal production measures than children with good reading ability.

2. Do measures of RAN, and computerised measures of automatization, and temporal production differentiate children with different coordination abilities?

It is predicted that the children with poorer co-ordination ability would show poorer performance in RAN and automatization, and temporal production than children with good co-ordination ability.

3. How comfortable are children using computer based assessments?

This research question will be addressed through informal observations and discussion of the tasks with the children after each assessment session.

3.2. Method

3.2.1. *Participants*

As can be seen from the studies reviewed in Chapters One and Two, a substantial amount of research had previously focussed on children who were between the ages of nine and 11 years. Consequently, children around this age were the main participants for the pilot study and subsequent main studies. However, as this was an initial exploratory study, children with dyslexia and children with DCD were not part of the test group.

There were two reasons for this. As there are small numbers of children with dyslexia and DCD, it is often difficult to recruit participants with dyslexia and DCD, so it was decided, to ensure that there were sufficient children available for the main study, not to use them during the piloting phase. Secondly, it was felt that the research questions at this stage in the thesis could be answered by looking at the normal range of ability on these skills in typically developing children.

Sixty seven children, 30 boys and 37 girls, from one school in Milton Keynes (average age of 10 years, two months) were recruited to the study. Children who were 'typical readers' and children who were 'poor ability readers' were identified based on their ability to complete the word reading task from the BAS-II (Elliot, Smith, and McCulloch, 1996). Participants who were one or more years behind in their reading were classed as poor readers, whereas participants who had reading which was expected for their age were classed as typical readers. This yielded 23 typical readers, and 28 poor ability readers, with the poor ability readers on average two years, six months (30.43 months) behind their chronological age in reading ability. A t-test confirmed that there was a significant difference in reading ability between the two groups, $t(39.004) =$

-11.378, $p < .0001$.

Fast and slow motor coordination groups were identified based on their speed at threading ten beads. For analysis, the 15 fastest performing children (those who took 31 seconds or less to thread the beads) were classed as the ‘fast motor coordination group’, and the 15 slowest performing children (those who took 42 seconds or more to thread the beads) were classed as the ‘slow motor coordination group’. A t-Test confirmed that there was a significant difference between the two groups on their threading ability, $t(19.747) = -12.568, p < .0001$.

As can be seen from Table 3.1, many of the participants from the threading groups are also included in the reading groups and it was possible that this could bias the results. A chi-squared analysis was therefore conducted to investigate whether there was significant association between membership of the reading groups and the membership of the coordination groups. This was found to be non-significant, $\chi^2 = 1.066, p = .302$, suggesting that none of the groups were over-represented in other groups.

Table 3.1 Membership for reading and threading groups.

	Poor ability readers (out of 28)	Typical ability readers (out of 23)	In a threading group but not in a reading group
Slow threading (out of 15)	8	6	1
Fast threading (out of 15)	4	7	4
In a reading group but not in a threading group	16	10	

3.2.2. Materials

Procedures for the baseline measures can be found in the methodology chapter.

Rapid Automated Naming (RAN). The version of the RAN paradigm used here was

similar to that found in the Phonological Assessment Battery by Frederickson et al. (1997). The task consists of a sheet with a grid of 50 line drawings which were representations of five common objects repeated randomly ten times. The objects were “ball”, “box”, “door”, “table” and “hat”. After ensuring that the participants could name the five objects individually, the participants were then presented with the test sheet and asked to name the objects as quickly as possible. The total time to name all the objects indicates the children’s proficiency on this task. For reasons of time constraint, one trial was completed per participant. Whereas Study One used a letters based RAN, for this initial pilot it was decided to use a picture based RAN task for two reasons: (a) as this was an initial exploration of the RAN task it was felt using a standardised RAN task would allow the result to be compared to the data in the assessment battery if needed; (b) it is possible that objects RAN is less abstract in form than letters RAN. Participants need only identify an object and respond to it rather than carry out a reading process in order to name letters.

Computer-Based Automatization Task. The task was designed to assess how quickly a participant could learn to carry out a simple movement sequence. The premise for this task was that Buzzy the Bee needed to collect nectar from flowers as quickly as possible before returning to the beehive. The task required them to click, using a bee shaped icon which they controlled using a mouse, on five flowers that appeared on the screen followed by a beehive (see Figure 3.1). There was an instruction phase during which the task was explained to them. The instructions given were as follows: “Help Buzzy be the fastest nectar collector by clicking on the flowers as fast as you can then click on the beehive to send Buzzy home”. This was followed by a brief familiarisation phase and then the children continued through the 12 test trials. However, participants were not

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informed that the flowers appeared in the same place in each of the trials. Time taken to complete each of the trials was used to indicate the degree of automatization achieved. .

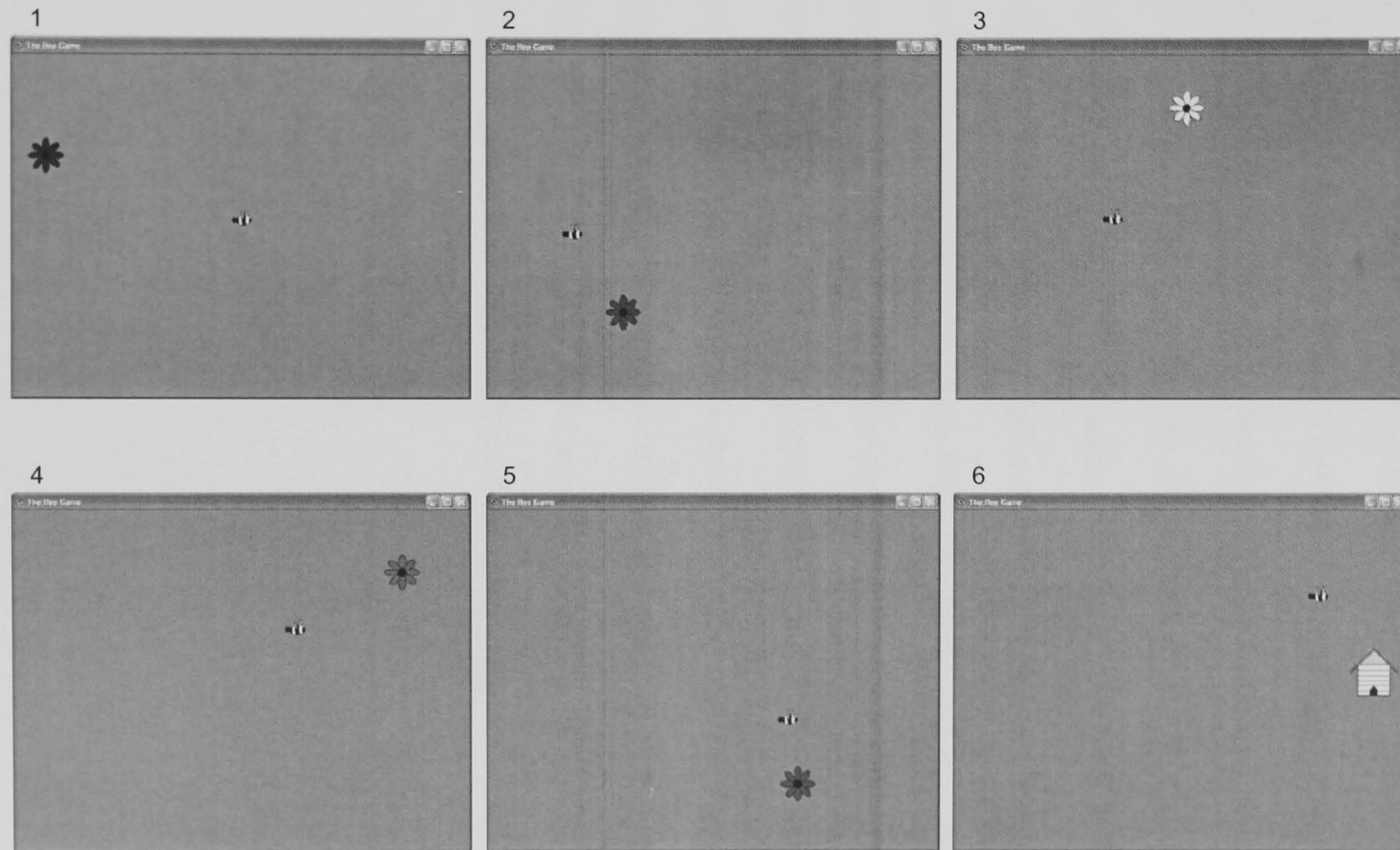


Figure 3.1 Screenshots of the automatization task. Screenshot one represents the first flower the participants had to collect, screenshot six is the beehive.

Experimental Temporal Production Task. This was a task designed to elicit data on fast, self-paced tapping. The premise presented to the children was that there was a racing competition played by mice in a house when humans were not around. The participants were required to help a mouse who was competing. This was accomplished by tapping quickly on the computer mouse, as each tap moved the mouse along the screen (see Figure 3.2 for a screenshot). Participants, tapped the left button on a standard computer mouse. The competition element was designed to keep the participants engaged with the task and to encourage them to tap as quickly as possible. To ensure consistency in motivation across participants, there was no possibility of losing a game: the computer controlled car moved half the distance that the participant's car moved: each tap moved the participant's car 75 pixels ahead, but moved the computer controlled car on 36 pixels ahead. The task comprised one practice trial and five test trials, a format recommended by Snow (1987). The task elicited two dependent variables from the five test trials: the average speed of the participant's tapping and the variability, in standard deviations, of the tapping intervals.

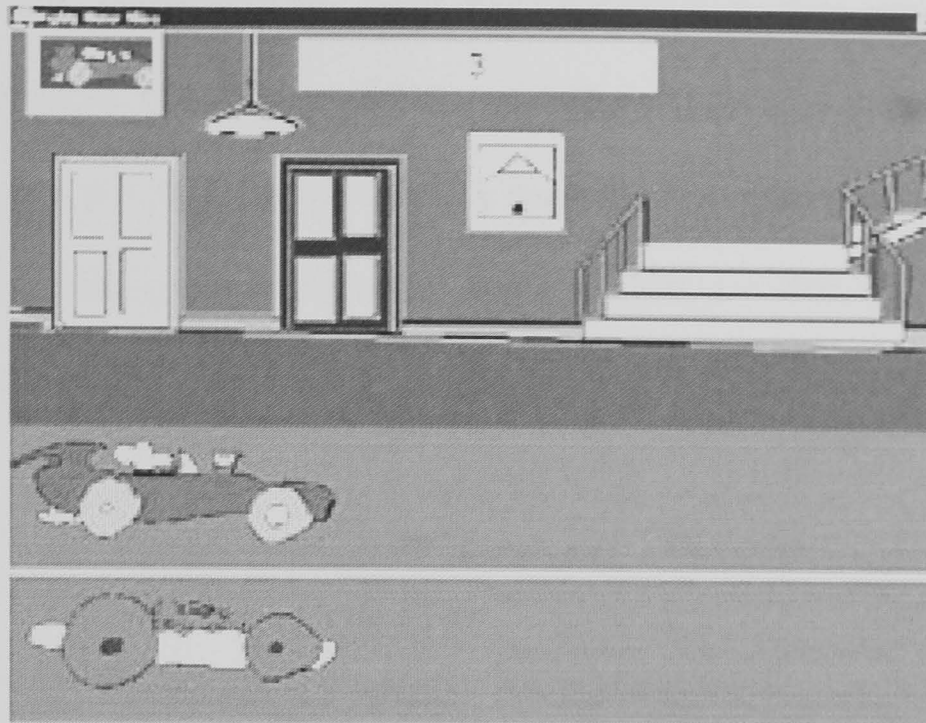


Figure 3.2 Screenshot of the temporal production task. The blue car moved forward as the participant tapped the mouse.

In addition to the experimental measures, baseline measures of block design, verbal memory, threading, vocabulary, and word reading were carried out. Details of the procedures for these baseline measures can be found in Chapter Two.

3.3. Procedure

The tasks were administered individually to each child over two sessions, both lasting around 30 minutes and there was a minimum of three days between each session. Word reading, RAN, block design, vocabulary, and short term memory were presented in the first session. Threading, automatization, and tapping were presented in the second session. Within these sessions, to overcome any order effects, the order of task presentation was randomised.

3.4. Results

Before examining the research questions, the groups were compared on the baseline

measures that were included in this study. The poor ability reading group, had a lower verbal memory score, $t(42.520) = -2.730, p < .005$, and a lower vocabulary score, $t(46.437) = -2.935, p < .005$. The poor ability reading group performed as well as the typical ability reading group on threading, $t(48) = 0.780, p = .440$, and on block design $t(49) = -0.891, p = .383$. Table 3.2 shows the descriptive statistics for the reading groups.

Table 3.2 Means and standard deviations of the reading groups, the significant differences are shown in bold.

	Typical ability reader			Poor ability reader		
	mean	SD	n	mean	SD	n
Age (months)	122.00	3.631	23	122.43	4.402	28
Reading (months)	148.83	19.437	23	92	14.013	28
Block design (raw score)	30.52	9.322	23	28.32	8.309	28
RAN (seconds)	39.74	4.873	23	49	5.975	28
Verbal Memory (raw score)	9.05	1.939	22	7.61	1.729	28
Threading (seconds)	36.59	9.179	23	38.41	9.056	28
Vocabulary (raw score)	25.87	6.601	23	20.50	6.380	28
Automatization (ms)	6486.284	246.783	23	7714.797	481.777	28
Tapping (ms)	112.42	26.87	23	116.059	16.673	28
Tapping variability	100.052	237.559	23	60.190	34.46	28

There were no significant differences between the fast coordination group and the slow coordination group on any baseline measure, with the exception of threading on which group membership was decided (as noted earlier). The coordination group baseline measure inferential statistics were as follows: word reading, $t(28) = 0.180, p = .858$,

RAN, $t(27.795) = -0.951$, $p = .350$, short term memory, $t(27) = 1.658$, $p = .109$,
vocabulary, $t(27.103) = 1.432$, $p = .164$, and block design, $t(26.205) = 1.647$, $p = .112$.

Table 3.3 shows the descriptive statistics for the two coordination groups.

Table 3.3 Means and standard deviations of the threading groups.

	Fast motor coordination			Slow motor coordination		
	mean	SD	n	mean	SD	n
Age (months)	124.20	2.981	15	120.27	3.807	15
Reading age (months)	120.20	22.691	15	118.07	39.847	15
Block design (raw score)	31.93	9.091	15	27.07	6.954	15
RAN (seconds)	42.67	8.006	15	45.33	7.345	15
Verbal Memory (raw score)	8.67	1.718	15	7.64	1.598	14
Threading (seconds)	26.53	2.850	15	48.53	6.151	15
Vocabulary (raw score)	24.53	6.791	15	21.27	5.650	15
Automatization (ms)	6328.446	261.474	15	6899.923	427.789	15
Temporal production (ms)	107.522	20.117	15	116.410	27.033	15
Temporal production variability	56.961	43.606	15	124.784	297.562	15

The first research question considered whether there would be significant differences between the children with different reading abilities on the measures of RAN, automatization, and temporal production.

The outcome measure for the RAN task was the time taken to name all fifty stimuli. An independent samples t-test was conducted to compare the children with poor ability

reading and the children with typical reading. The result indicated that the children with typical reading ability were significantly faster at completing RAN than the poor reading children, $t(49) = 6.096, p < .0001$. The mean durations can be found in Table 3.2.

To investigate whether the typically reading children improved more across trials than the poor ability reading children did on the automatization task, a 2 x 13 (poor reading children, typically reading children x practice trial to trial 12) split-plot ANOVA was conducted. The analysis indicated that there was a significant main effect within the groups across trials, $F(1, 6.619) = 2.694, p = .012$ (Greenhouse Geisser) and there was also a significant main effect between groups, $F(1, 49) = 4.527, p = 0.038$, with the typical ability reader group being faster across trials than the poor ability reading children. There was no interaction between group and trial, $F(1, 6.619) = 0.447, p = .863$ (Greenhouse Geisser). Figure 3.3 shows the performance of the two groups across the trials. It can be seen that the typical ability reading group improved substantially between the practice trial and trial one. Between trials one and five, they remain at roughly the same level of performance. There then follows a more variable pattern from trial six to trial 12. However, throughout the whole time, the typical readers can be seen to be faster than the poor readers.

The poor ability reading group were slower at the beginning, but improved between the practice trial and trial one. They then appeared to have difficulty maintaining a constant duration speed, from trials two to 12, the pattern is of variable durations for each trial.

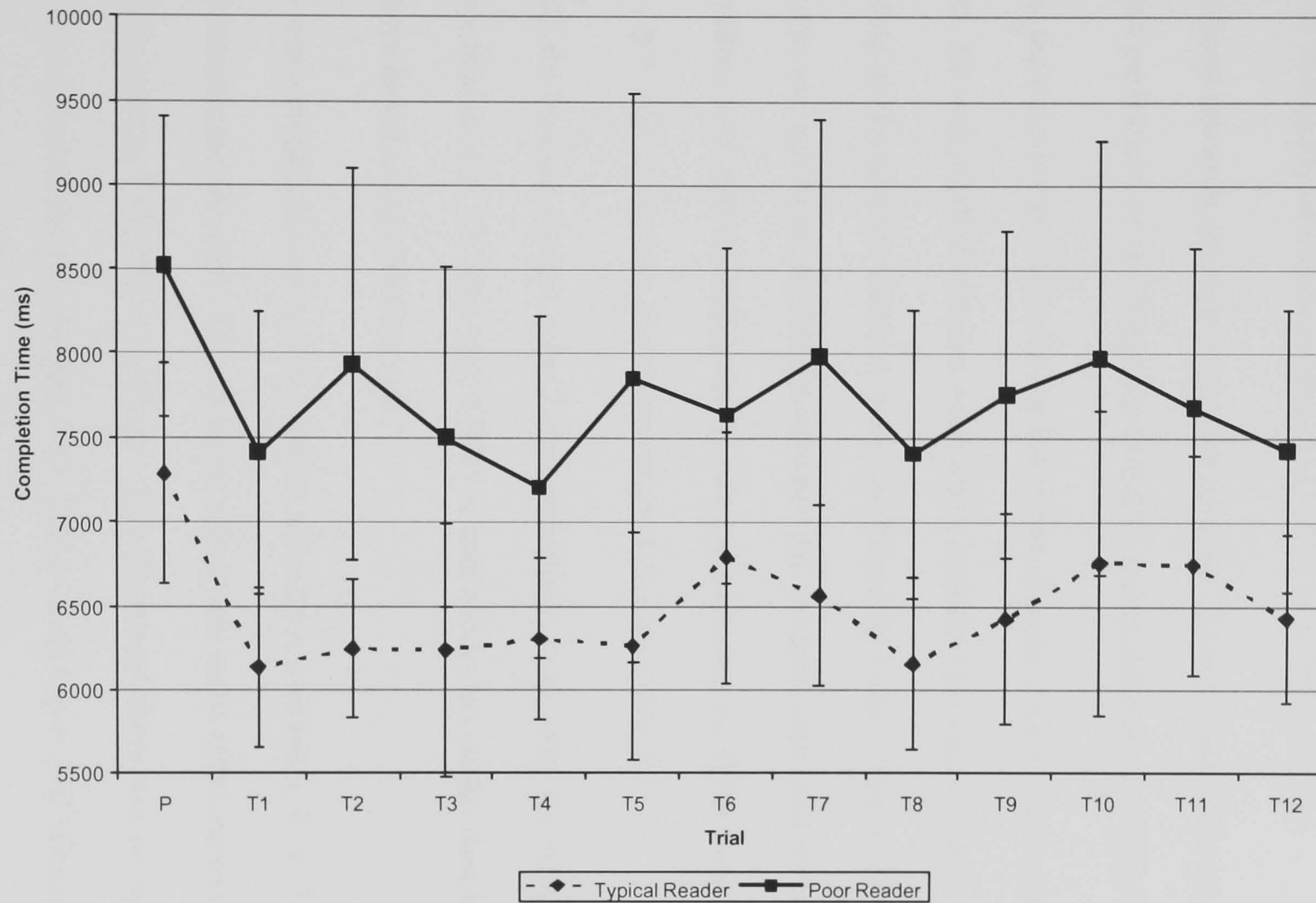


Figure 3.3 Graph comparing the total time to complete the automatization trials for the typically reading group and the poor reading group. The error bars indicate the 95% confidence rates.

The results from the temporal production task indicated that there was no significant difference between the children with poor ability reading ability and children with typical reading ability on either mean duration of button presses, $t(33.574) = 0.554$, $p = .583$, or variability of button presses, $t(21.721) = -0.780$, $p = .444$.

The second research question looked at how the children with different threading abilities performed on the measures of RAN, automatization, and temporal production.

Again, the outcome measure for the RAN task was the time taken to name all fifty stimuli. An independent samples t-test was conducted to compare the children with slow threading ability and the children with fast threading ability. The result indicated that there was no significant difference between the children with slow threading ability and the children with fast threading ability when completing the RAN task, $t(27.795) = 0.951$, $p = .350$. The mean durations can be found in Table 3.3.

As with the reading groups, a 2x12 (fast threading group, slow threading group x practice trial to trial 12) split-plot ANOVA was conducted on the data from the computer-based automatization task.

There was a significant main effect within subjects across trials, $F(1, 7.55) = 2.832$, $p = .006$ (Greenhouse Geisser). There was no significant main effect between the two threading groups, $F(1, 28) = 1.299$, $p = .264$. However, there was no significant interaction between the two factors, $F(1, 7.55) = 0.914$, $p = .502$ (Greenhouse Geisser). Figure 3.4 compares the two groups across the trials. It can be seen from the error bars that there is a large amount of overlap between the two groups. It is also interesting to note that the fast group have a highly erratic profile of trial completion times.

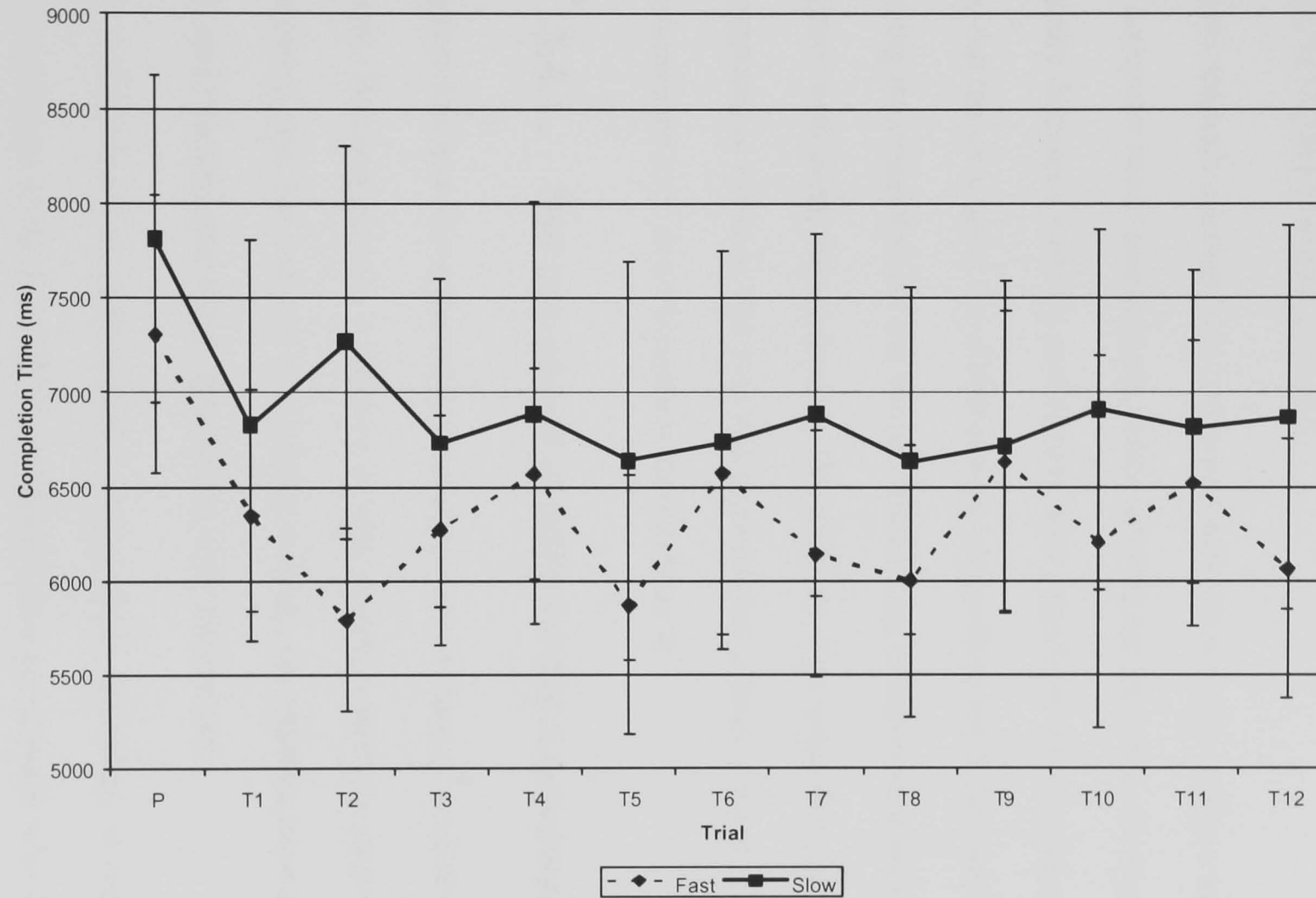


Figure 3.4 Graph comparing the total time to complete the automatization trials for the fast and slow coordination groups. The error bars indicate the 95% confidence rates.

The results from the temporal production task indicated that there were no significant differences between the children with fast coordination and the children with slow coordination in mean speed of tapping, $t(23.966) = -0.999$, $p = .328$, or in variability of tapping, $t(13.531) = -0.844$, $p = .413$.

The third research question was concerned with whether the children were comfortable using computer based assessments. After carrying out the tasks, the experimenter informally discussed with the participants their experience of computers and whilst they carried out the pilot tasks, the children were observed to see if they were comfortable with using the computer and the mouse. None of the children were observed to have any difficulties with using the equipment. The children often noted that they or their parents had computers at home or that they had used them at school. Almost all had at least had a games console such as a Playstation, or Nintendo 64.

3.4.1. *The construct validity of the experimental tasks*

Of interest was how the experimental measures were related to established baseline measures. This may provide a guide as to what common skills the experimental tasks were tapping into. For analysis of construct validity, the children were analysed as one cohort, and Pearson, one tailed, correlations were carried out.

Ability in RAN has been documented as being related to reading, as noted in Chapter One. The findings of the correlations confirmed this; participants who were fast at RAN were also found to have high scores in verbal memory, $-.226$, $p = 0.043$, vocabulary, -0.380 , $p = 0.001$, and reading age, -0.523 , $p < 0.0001$ (Pearson correlations, one tailed).

The automatization task was a task that was considered to involve similar processing to RAN as they both required fast processing of repetitive information. However there

was no significant correlation between the average time that participants completed trials on the automatization task and RAN, $.164, p = .106$.

The automatization task also involved visual spatial processing; consistent with this there was a significant correlation between the block design task and the mean time to complete the task, $-.272, p = .018$. The direction of the correlation indicates that participants who scored highly on block design also completed trials of the automatization task quickly.

It was possible that fast tapping could also be related to RAN. Fast, consistent responses in RAN are related to fast completion times for RAN and so may also reflect in fast, consistent responses in self-paced tapping. However RAN did not significantly correlate with the mean time to tap, $.142, p = .142$, or the variability of the tapping, $-.111, p = .201$.

3.4.2. *Internal reliability of the experimental tasks*

Internal reliability for the 13 trials in the automatization task was assessed using Cronbach Alpha. The result was an alpha of $.968$. Due to the nature of the measures, it was not possible to provide a measure of internal reliability for the tapping task or the RAN task.

3.5. Discussion

There were two main aims to the pilot study; the first was to evaluate areas that may be later studied with children who have dyslexia and DCD; the second was to evaluate whether computerised tests would be a viable method of data collection with children in the target age range.

Based on previous research, two areas of commonality were examined in this study: automatization and temporal processing. Children with different abilities in reading and coordination were compared on tasks of RAN, automatization and temporal production. Differences were found, but not consistently, when comparing children with reading difficulties to children with typical reading; and then children with slow threading ability to children who had typical threading ability. The findings of the two experiments will now be discussed in detail.

In terms of the reading group, the RAN task and the computer-based task of automatisisation differentiated the two groups. The results for RAN are consistent with that of many previous studies in which children with reading difficulties are slower on RAN than typically developing children. However, as noted by Denckla and Rudel (1976) children with dyslexia often have RAN completion times that are slower than children who have reading difficulties but are not considered to have dyslexia. The children who were behind in their reading also had a slower pattern of responses across trials for the computer-based task of automatisisation. There is evidence from Nicolson and Fawcett (2000) that children with dyslexia have difficulty in learning patterns of repetitive responses. There is little or no literature as to whether this difficulty extends to children with general reading difficulties, as the children in this study are considered to have, but the evidence from this pilot study suggests this may be the case. In terms of children with slow threading and fast threading, the pattern was different. The RAN task did not differentiate the children with slow threading compared with fast threading, neither was there a main effect between groups for the computer based task of automatisisation, although the children with slow threading did show a more erratic pattern across trials. There is no direct evidence that children with slow threading might

be slower than children fast threading on measures of RAN so it was not expected that they would be slower on this task, furthermore, the mean reading age for the two groups was similar, suggesting that children with slow threading ability do not tend to be impaired on reading measures. It had been expected that being slow on coordinating beads with thread would lead to being slow in coordinating movements for the computer-based automatization task and although there is some suggestion here (see Figure 3.4 where in some cases the children with slow threading are slower than the fast threading group), it is not consistent pattern.

One possibility is that the skills required to complete RAN and the computer-based automatization task are different and there is evidence of this. In comparing both tasks, despite both RAN and the Automatization task appearing to share similar skills, both require the processing of repetitive information, the automatization task did not correlate significantly with the RAN task. Children who were fast at the RAN task did not show a fast mean completion time for the automatization task. This may suggest that whereas both tasks are in some way relating to skills required for reading, they may not necessarily be tapping into the same processes.

The computer-based task of automatization did, however, correlate with block design. A high score on the block task was associated with a fast automatization completion time. Block design is considered to tap into processes involved in visual-spatial processing, however as it requires participants to manipulate blocks so there is a coordination element to the task. On balance, it appears that the task does not clearly test automatization but may require other skills that are associated with visual spatial processing and reading to successfully carry out. Feedback from the participants suggested that some became uninterested later in the experiment so it could be that

attention also plays a role in successful completion of the task. One possible future avenue would be to directly study RAN in further detail. The global RAN score differentiated the reading groups however an analysis of the components of RAN: articulation and non-articulation, as carried out by Cobbold et al. (2003) on typically developing children, might allow a better understanding of how RAN related to coordination.

Although the self paced tapping yielded no significant differences between any of the groups, this was a very basic measure of rhythm and speed in tapping. A measure that has a more overt temporal processing requirement may elicit better information about possible temporal processing deficits. It is possible that these underlie the future target populations of children with dyslexia and children with DCD. Many studies of tapping that have involved children with dyslexia and children with DCD have looked at how these children are able to synchronise to an external beat, for example from a metronome. Manipulating the external source that the children would synchronise to, then removing it altogether may elicit a better understanding of the abilities in temporal processing that children with dyslexia and children with DCD have.

Finally, the pilot study provided information regarding the development of computer based tasks with children aged between eight and eleven. It also confirmed that children in this age range are conversant with computers to a degree where there would be little or no problems with them carrying out the tasks.

The next chapter will consider one of the measures that were found to discriminate between the groups of children in the pilot study, RAN, and whether children with dyslexia and children with DCD show deficits on a refined version of this task.

4. Study One: Rapid Automated Naming

4.1. Introduction

The theoretical overview (Chapter One) outlined that the aim of this thesis was to investigate the possibility of similar temporal processing deficits being present in children with dyslexia and DCD. With this in mind, one of the outcomes of the pilot study (Chapter Three) was that it took longer for children with poor reading to complete a RAN task compared to typical readers. However this task did not readily discriminate between children with fast and slow motor coordination times.

Much of the focus of RAN research has been on its use as an indicator of fluent phonological processing (for example, Wolf, 2002). However, it is also likely to indicate temporal processing ability. That is, Wolf (1991) has argued that to be successful at RAN a person needs to be both fast and regular at naming. These skills would require an efficient system to process the temporal components in reading and speech production. Research into RAN has focussed on children with dyslexia and there is substantial and consistent evidence (such as Williams et al., 1992) that this group has poor performance on RAN tasks and on other tasks that require temporal processing. However, no study to date has directly examined RAN performance in children with DCD.

Special methodological considerations need to be made regarding how to analyse the results of a RAN task when the intention is to compare two groups of children who may show a deficit on the task. When comparing the children with dyslexia and DCD one possible outcome is that they will both be significantly slower than controls, however it

would be unclear from a global measure, such as total time taken to name 50 items, why this may be the case. It could be due to slowness prior to articulation or slow articulation, furthermore there could be different patterns between the groups. As a result it may be necessary to analyse the articulation and non-articulation durations in the RAN task.

As detailed in the introduction, very few studies have decomposed the overall time to complete the task into both articulation durations and non-articulation durations so there is little research on what cognitive processes might underlie such measures. Cobbold et al. (2003), Neuhaus et al. (2001a), and Neuhaus and Swank (2002) found that as reading developed in typically developing young children, the non-articulation duration became significantly less variable. This suggested that the processes involved in the non-articulation duration are closely linked to reading development. However, Neuhaus et al. (2001a) found that this was only the case with the non-articulation duration of letter and number naming but not object naming. As noted in Chapter Two, this may be because letter and number RAN may involve symbolic decoding. However, another process that is likely to take place during the non-articulation phase is the processing of temporally sensitive information.

Two studies have investigated articulation and non-articulation durations in children with dyslexia and typically developing children. Anderson et al. (1984) tested six children with dyslexia and six typically developing children between the ages of eight and 10 years old on letter, numeral, object, and colour RAN task. They found that the children with dyslexia showed significantly longer articulation and non-articulation durations compared with the typically developing children. They also report higher variability in non-articulation durations in the children with dyslexia, however they

did not subject this dependent variable to statistical analysis (in their letters RAN, the standard deviations were .324 for children with dyslexia, and .248 for typically developing children). The second study was by Snyder and Downey (1995) who compared 30 children with reading difficulties and 30 typically developing children, aged between eight years, six months of age and 13 years, four months of age, on a colour and object naming type RAN task. They only found that the children with dyslexia had a significantly longer articulation duration compared to the typically developing children. However, their task was substantially different to other RAN tasks so it is not clear whether this finding was an artefact of the task they used.

In summary, studies of componential analysis of RAN in typical development suggest that variability in the non-articulation duration is important in development of processes associated with reading. In the literature that has studied dyslexia, there appears to be evidence of a more disordered naming pattern involving longer durations in both articulation and non-articulation, and the possibility of higher variability in non-articulation durations. However, considering the failure of Anderson et al. (1986) to analyse the variability of non-articulations and the non-standard nature of the stimuli in Snyder and Downey (1995) there is still scope to systematically analyse the sub-components of RAN in children with dyslexia compared to typically developing children.

One final element to consider is the format of the RAN task itself. As discussed in the methodology chapter (Chapter Two), until recently, the standard format of the RAN task would be to present a grid of 50 stimuli (five stimuli repeated ten times) and ask participants to read the stimuli out loud as quickly as possible. This has remained the

standard RAN paradigm since Denckla and Rudel (1976). However recently, Compton et al. (2002) have proposed a shorter form of RAN task.

Compton et al. (2002) compared a short form version of a RAN task to the long form, 50 stimulus version of the RAN task. The short form RAN used a grid of six stimuli presented at random in five columns (see Figure 4.1). In one condition they used letters and in another, numbers. Instead of timing the time taken to name all of the items, they counted the number of letters the participant could read in 15 seconds. They tested this short form RAN and compared it to a more standard long form RAN on 130 children with reading difficulties and 177 typically developing children, with an average age of 11 years, six months old. They found that the short form RAN task still significantly differentiated the two groups, with the typically developing group naming more letters than the children with dyslexia. One benefit of this amended version is that the task may be less demanding. As discussed earlier, if a child has difficulty at the beginning of a RAN task then he or she may tire and so later in the task it is not fluent phonology or pure rate processing that is being assessed, but attention and fatigue. Finally, from an administration point of view, an attraction of the short form RAN is that it is quicker to complete.

The basis for most articulation/non-articulation studies, such as those by Anderson et al. (1984), Neuhaus et al. (2001a), and Cobbold et al. (2003) was the long form RAN. Even though Compton et al. (2002) determined that as a global measure the short form RAN is comparable to the long form RAN, no study has yet to analyse articulation non-articulation in short form RAN. The changes in task demands may affect the way children with dyslexia and typically developing children approach the task.

Furthermore, less data is likely to be collected as it is unlikely that children will

complete 50 items in 15 seconds. Therefore, before comparing the children with dyslexia to the children with DCD, it is first important to establish that the short form RAN produces similar patterns of results to the long form RAN. This will require an analysis of the patterns of articulation and non articulation in children with dyslexia and typically developing children. It will then be possible to compare the performance of all three groups.

Consequently, the study aimed to investigate two research questions:

1. Although Compton et al. (2002) established that the alternative RAN task is comparable to the traditional RAN task, no study of articulation and non-articulation durations has been carried out using this modified version of the task. It would be important to establish that this type of task is comparable to those previously used in comparing articulation and non-articulation. Therefore, the first question is: Does the alternative RAN task produce a similar pattern of articulation and non-articulation deficits to RAN tasks used by previous researchers in typically developing children and children with dyslexia?

It is predicted that the children with dyslexia and the typically developing children will have significantly slower naming speed and significantly more variability in articulation and non-articulation relative to typically developing children in the short form RAN (as previous studies have demonstrated with long form RAN).

2. In line with the aims of the thesis, this study aims to investigate whether there are common temporal processing deficits in children with dyslexia and DCD: Do children with DCD show a similar pattern of deficit RAN proficiency to the children with dyslexia?

It is also predicted that the children with dyslexia and the children with DCD will show a similar pattern of articulation and non-articulation deficits (i.e. there will be no significant differences between these groups). This pattern will, however, be different from the one presented by the typically developing children.

4.2. Method

4.2.1. *Participants*

Thirteen children with dyslexia, seven children with DCD, and 15 typically developing children took part in this study. Participant details for this study can be found in the Methodology Chapter (Chapter Two).

4.2.2. *Test Materials and Procedure*

Four baseline measures were recorded in addition to the RAN task, a test of: reading age, spelling age, verbal memory, and vocabulary. Details of these can be found in the Methodological Chapter (Chapter Two). Each participant was tested individually in one 45-minute session. Within this session, the order of the tests was counterbalanced. The experimental task used for this experiment was a modified RAN task. Its method will be detailed below.

Rapid Automated Naming (RAN): The RAN task was based on the task used by Compton et al. (2002). During the first stage of the task, each participant was presented with the letters “a” “b” “d” “o” “p” “s” on a laptop computer screen and asked to name them. If the child could not correctly identify any letter then the task was terminated. If the child could correctly identify the letters then the child proceeded to the second stage.

However, during the study, all the children were able to identify the letters correctly.

In the second stage, the child was presented with a five column by 15 row grid of letters (see Figure 4.1). The letters were, again, “a” “b” “d” “o” “p” “s” and were repeated randomly in the grid. The computer stopped the trial after 15 seconds. Two trials were used; the order of the letters was different in both trials. In addition, the order of the trials was counterbalanced. Participants were asked to name as many letters as quickly as possible and then the task began.

s	d	a	p	o
a	d	p	o	s
o	p	d	p	a
o	a	d	o	p
b	b	a	a	d
p	d	a	s	o
s	p	a	o	d
p	o	d	a	s
p	p	b	p	b
b	d	a	b	p
p	d	d	s	d
d	d	a	p	d
p	a	a	d	p
o	s	o	a	a
s	p	s	s	o

Figure 4.1 An example of the RAN task presented to participants, similar to that of Compton et al. (2002).

The task was presented on a laptop, details of the equipment can be found in the Methodological Chapter (Chapter Two). Each child wore a microphone headset and the

child's verbal responses during the task were recorded digitally by the laptop at a rate of 11250 samples per second for later analysis.

The audio files were carefully analysed by the experimenter to make sure that there were no background sounds that the RAN articulation and non-articulation analysis software might confuse with speech output. Any that were evident were removed by hand using audio editing software.

The audio output was then analysed using software written by the author (See Appendix Two for further details of the software). It was designed to analyse the audio output from the task and record the duration of articulation and non-articulation in milliseconds. The software assessed the volume of the audio file: sound above a certain, user controlled threshold was considered speech and sound below a certain threshold was considered non-articulation. The results from both trials were averaged to yield four scores for each participant:

- The mean duration of articulation phase.
- The variability of the duration of the articulation phase.
- The mean duration of the non-articulation phase.
- The variability of the duration of the articulation phase.

The accuracy of the responses was not analysed as the majority of the previous research (for example, Anderson et al. 1984) in RAN had indicated that participants tended to be near ceiling levels on this task. Secondly, the number of letters named in the 15 second trial period was not analysed. The duration of the articulation and non-articulation was analysed and from this it can be inferred that a child with slow articulation and non-

articulation rates would also have named fewer letters.

Self-corrections appeared very infrequently during the RAN task. Only 7.69 % of the audio files had one hesitation, 1.01 % had more than one. In line with Neuhaus, Carlson, Jeng, Post, and Swank (2001b) self-corrections, along with background noise that the software could confuse with an articulation, was erased and included in the pause duration.

4.3. Results

Two research questions were raised from the previous research into RAN. The first was whether the analysis of articulation duration and non-articulation duration and the alternative RAN would be able to replicate similar findings using the traditional RAN in children with dyslexia and typically developing children, namely that typically developing children would perform better at the task than children with dyslexia. The second was whether the pattern of responses that children with DCD made on the task would be similar or divergent to that of the children with dyslexia. Similar responses to those of the children with dyslexia would possibly point to a similar underlying deficit in temporal processing.

The participants who took part in this study also took part in the TOJ Study, consequently, the baseline measure results for the groups can be found in the Methodological Chapter (Chapter Two). Table 4.1 provides a summary of the means and standard deviations for the baseline measures and the RAN task. As can be seen, the vocabulary scores remain similar across groups, whereas the children with dyslexia and DCD appear to have difficulties with the other baseline measures. In terms of RAN, the children with dyslexia appear to show longer durations and higher variability in the non-

articulation duration, note as well, the slow articulation in the DCD group.

Table 4.1 Means and standard deviations for the baseline measures and RAN

Baseline Measure	Typical			Dyslexia			DCD		
	M	SD	n	M	SD	n	M	SD	n
Chronological Age	11; 1	13.932	15	11; 4	12.653	13	11; 5	11.368	7
Reading Age	13; 11	28.306	15	9; 2	18.090	13	9; 10	21.369	7
Spelling Age	12; 9	25.804	15	8; 8	19.019	13	9; 0	22.401	7
Vocabulary raw score	34.47	7.482	15	31.15	4.598	13	35.29	6.775	7
Verbal Memory raw score*	6.13	1.642	15	4.38	1.044	13	4.71	1.113	7
RAN Articulation Duration	239.352	59.345	14	304.620	76.54	13	333.578	64.698	7
Ran Articulation SD†	84.703	37.188	14	83.109	45.405	13	74.422	28.779	7
RAN Non-articulation Duration	229.038	51.627	14	288.694	69.50	13	231.513	92.413	7
Ran Non-articulation SD†	174.238	49.319	14	257.304	55.740	13	194.144	61.811	7

* The verbal memory score here is for recall of digits backwards.

† The standard deviations here are an indication of the variability of the duration of each articulation or non articulation within the audio segment.

Research question one looked at whether children with dyslexia were slower and more variable in articulation and non-articulation duration compared with typically developing children. The four main variables taken from the RAN task in this study were: mean articulation duration, variability of the articulation duration (standard deviations), the mean non-articulation duration, and the variability of the non-articulation duration (standard deviations).

Shapiro Wilks analysis of the results indicated that the two of the variables did not achieve the assumptions for parametric analysis: mean articulation duration and variability of articulation duration. Mean non-articulation duration and variability of non-articulation duration met the assumptions for parametric analysis. However, in view of the mixture of parametric and non-parametric data, Mann-Whitney U analysis was conducted on all the measures.

The analysis found that the typically developing children had a significantly faster articulation duration than the children with dyslexia, $U = -2.357$, $p = 0.0085$. However, the variability of the articulation durations was not significant between the two groups, $U = -.485$, $p = 0.627$.

The results also indicated that the typically developing children had a significantly shorter non-articulation duration than the children with dyslexia, $U = -2.184$, $p = 0.029$. In addition, the typically developing children had a significantly less variable non-articulation duration than the children with dyslexia, $U = -3.203$, $p = 0.001$.

The results from only comparing the typically developing children and the children with dyslexia indicated that the RAN task, although shorter than the long form RAN task, was able to discriminate effectively between the children with dyslexia and the typically developing children. Furthermore, the pattern of findings is much in line with the previous research by Snyder and Downey (1995) and Anderson et al. (1984).

The second research question asked whether children with DCD would show similar deficits in RAN naming to the children with dyslexia. The four measures used to compare the children with dyslexia and the typically developing children were again tested; as the data did not meet assumptions for parametric analysis and it was not

possible to normalise the data, Kruskal-Wallis analysis was conducted on the scores.

The first measure was the mean duration of the articulation. A significant difference was found, $\chi^2 (2, N = 34) = 9.627, p = .008$. Dunn's Multiple Comparisons Test showed that the DCD group had significantly longer articulations than the group with dyslexia and the typically developing group at the task.

The second measure to examine was the variability of the articulation durations. No significant difference was found between the groups, $\chi^2 (2, N = 34) = 0.851, p = .653$.

The third measure from the RAN task was the mean non-articulation duration for the three groups. The result indicated a significant difference across the groups in the average duration of the non-articulation phase, $\chi^2 (2, N = 34) = 6.095, p = .0475$.

Although Dunn's Multiple Comparison's Test did not indicate a significant difference between the three groups, the pattern appeared to be that the children with dyslexia were markedly slower than the other two groups in their non-articulation durations.

The final measure from the RAN task was the variability of the non-articulation durations, Neuhaus and Swank (2002) and Cobbold et al. (2003) had shown that this measure was related to reading development, children with little variability in their non-articulation durations also had good reading proficiency. The results showed that there was a significant difference in the variability of the non-articulation durations between the groups $\chi^2 (2, N = 34) = 10.826, p = .0045$. Dunn's Multiple Comparison's Test indicated that the significant difference was between the children with dyslexia and the typically developing children.

4.4. Discussion

The study described here investigated the possibility that similar underlying temporal deficits related to RAN could be found in children with dyslexia and children with DCD. Three groups of children: children with dyslexia, DCD, and typically developing children completed a RAN task which had been developed by Compton et al. (2002). Measures of the participants' articulation and non-articulation durations were recorded digitally and later analysed. The research questions will now be discussed in order.

The first research question was related to whether the alternative RAN task developed by Compton et al. (2002) could find a similar pattern of articulation and non-articulation deficits to the traditional RAN task used by previous researchers. The task devised by Compton was shorter and yet appeared to provide comparable results to longer RAN tasks. One possibility, however, was that it might affect the nature of the task at the level of articulation and non-articulation. Previous research, such as Anderson et al. (1984) had found that children with dyslexia had significantly longer articulation and non-articulation durations than typically developing children. Snyder and Downey (1995) had only found significantly longer articulation durations. Of particular interest is the non-articulation duration as research by Neuhaus and Swank (2002) and Cobbold et al. (2003). They recorded participants completing letter-naming RAN and divided this into articulation and non-articulation durations. They found that the variability of the non-articulation durations was related to reading proficiency. The findings from this study show that despite being shorter than the traditional RAN type task, the alternative RAN task reveals children with dyslexia as exhibiting the same type of deficits as in previous RAN articulation and non-articulation analysis studies have done. Here, the

children with dyslexia had both significantly longer articulations and non-articulations than the typically developing children. Consequently this study provides further evidence that the greater amount of time taken, or the fewer stimuli named, by children with dyslexia is a consequence of longer durations in both components.

The second research question was: do children with DCD show a similar pattern of RAN deficit the children with dyslexia? Central to this thesis is an investigation of possible underlying temporal processes that may be common to dyslexia and DCD.

Fast and regular naming (or subcomponents thereof, such as fluent, or 'automatic' phonological processing) is likely to require effective temporal processing.

Furthermore, similar patterns of RAN performance in children with dyslexia and children with DCD may indicate similar underlying deficits. However, the results indicated that this was not the case. This study found that the children with dyslexia had slower non-articulation durations and more variable non-articulation durations than the typically developing children. However, contrary to expectations, the children with DCD showed a different pattern of performance. They showed significantly slower articulation compared with both the typically developing children and the children with dyslexia. However, their pattern of responses was similar to the typically developing children in non-articulation.

One possible interpretation of this finding in DCD is that the difficulty in effective coordination also extends to difficulty in coordination of muscles used in articulation.

As noted by Sugden and Wright (1998), children with DCD often have some form of articulatory deficit along with a coordination deficit.

The consequence of this would be that the children with DCD are slower at naming the

items. An alternative interpretation of the articulation deficit is that both articulation and non-articulation durations require some form of temporal processing. For example, in children with DCD, Piek and Skinner (1999) have argued that in order to coordinate movements effectively, the correct timing is needed when recruiting muscles to move joints. This may also be the case for oral muscles important in articulation.

A large number of studies have looked at global measures of RAN. However, the intensive nature of comparing articulation and non-articulation in children with dyslexia and typically developing children has meant few studies have been carried out. Those that have, primarily, Anderson et al. (1984) and Snyder and Downey (1995) have used very small groups. This study tested 14 typically developing children and 13 children with dyslexia and had a larger test population than both: and moreover, this is the first study to date to examine the ability of children with DCD on measures of RAN. The results indicated a specific pattern to DCD RAN responses that could be elaborated by future studies, for example patterns of fMRI activation to various RAN tasks.

In terms of limitations, however, the numbers of participants used was still relatively small in statistical terms, and reflects the difficulty in obtaining large numbers of children with DCD in particular. However, the findings were consistent with convergent findings from other studies of dyslexia and DCD, as noted earlier. A broader limitation is that there is still speculation about precisely what cognitive processes the articulation and non-articulation durations in RAN are indicative of. Although here it has been used as an indirect measure of temporal processing, there are a number of other skills that are required in order to successfully complete a RAN task, for example verbal fluency, or fast analysing of the orthographic information relating to the stimuli. Further research

needs to be carried out to explore this.

In summary, Study One, was designed to examine possible underlying temporal processing deficits in children with dyslexia and DCD using a short form RAN task. However, the results did not support the possibility that this was the case. Both the children with dyslexia and the children with DCD showed different patterns of ability relative to the typically developing children but there was no evidence of a similar processing deficit. However, RAN itself is not a direct measure of temporal processing. Study Two aims to address this by examining a more overt measure of temporal processing: temporal production.

5. Study Two: Temporal Production

5.1. Introduction

The pilot study (Chapter Three) included a basic measure of self-paced tapping. The results suggested that the four groups in that study (the poor ability readers, typically reading children, children with slow motor movements, and children with fast motor movements) did not differ greatly on their speed of tapping. One possibility is that self-paced tapping requires less reliance on temporal processes compared with other types of tapping tasks such as those with synchronisation to a stimulus. The theory proposed by Wearden (1991) suggests that for temporal processing to occur there would need to be a comparison between a previously stored duration and a newly presented duration. For temporal production, the stored duration might come from the experience of the interval between beats. This could then be compared whilst tapping with the duration between taps.

Previous research, such as Wolff (2002) who studied tapping ability in children with dyslexia and Geuze and Kalverboer (1994) who studied children with DCD, suggests that differences in tapping patterns may be evident between children with DCD, dyslexia and typically developing children. A more detailed analysis of tapping and a direct comparison of children with dyslexia and children with DCD is required for a better understanding of the nature of the two disorders. The introduction will now detail some of the evidence to support divergent patterns of tapping in children with dyslexia and DCD.

As outlined in Chapter One, a temporal processing deficit could affect both reading and

coordination. Farmer and Klein (1995) have suggested that there is evidence of both visual and auditory temporal processing deficits in children with dyslexia. Studies involving children with dyslexia, for example Nicolson et al. (1995) and Wolff (2002), have found evidence that would suggest a temporal processing deficit. Furthermore, studies such as Williams et al. (1992), Geuze and Kalverboer (1994), and Piek and Skinner (1999) have found evidence of what appears to be a temporal processing deficit in individuals with DCD. Research by Ivry and Keele (1989), Jäncke et al. (2000), and Théoret et al. (2001) has found that temporal processing may be related to cerebellar processing and there is evidence by Nicolson et al. (1999) and Lundy-Ekman et al. (1991) that some children with dyslexia and with DCD have signs of abnormal cerebellar processing.

Tapping studies of children who have dyslexia or DCD have shown differences in the patterns of tapping in these two groups relative to those of typically developing children. For example, Wolff et al. (1984) tested children with dyslexia and typically developing children on tapping speed and regularity. The children were required to synchronise to a metronome at either 652 ms or 330 ms ISI and then continue with the same rhythm when the metronome was turned off. Their measures of dominant hand finger-tapping indicated that in both synchronisation and continuation, the children with dyslexia showed significantly more variable tapping than the typically developing children. Recently, Wolff (2002) conducted a study into tapping comparing children with dyslexia and typically developing children in a study similar to Wolff et al. (1984), but here he concentrated on the point at which participants anticipated the metronome beat (where the tapping plate is pressed slightly before the metronome beat). They found that the children with dyslexia had a significantly longer anticipation duration

than the typically developing children. It is possible that this is due to the children with dyslexia not being as effective at synchronising the tap with the beat; this could be caused by an underlying temporal processing deficit.

Children with DCD have been studied by Williams et al. (1992) who compared the performance to that of typically developing children. They were required to synchronise to a 550 ms tone for 12 taps and then continue at the same rhythm without the tone for a further 31 taps. Williams et al. found that children with coordination difficulties were more variable at tapping. In support, Piek and Skinner (1999) also found that children with DCD had a different pattern of tapping to typically developing children. They asked children with DCD and typically developing children to copy a tapping sequence. Piek and Skinner then analysed how long the participants had held down the tapping plate (on-contact duration) and how long they had their fingers released from the tapping plate (off-contact duration). The mean on-contact duration of the children with DCD was significantly longer than the mean on-contact duration of the typically developing children. Piek and Skinner went further and, based on previous findings by Piek, Glencross, Barrett, and Love (1993), argued that there are separate processes involved in on-contact and off-contact durations. The on-contact durations are indicative of processes important in coordinating muscles to release the finger from the tapping plate, whereas off-contact durations are related to aspects of planning the next tap and processing temporal elements of the tap. However, they concede that the outcome measure may not clearly measure each process. For example, a deficit in off-contact processes could affect subsequent on-contact processes and so would look like a deficit in on-contact processes when it is actually a deficit in off-contact processes.

However, differences in the way the temporal production studies were carried out makes it impossible to compare directly the abilities of children with dyslexia and children with DCD. For example, Wolff (2002) used synchronisation to an auditory stimulus, whereas Piek and Skinner (1999) devised a task where participants had to copy a pattern of taps presented visually using flashing icons. This would need to be addressed in subsequent studies.

This section has so far provided an overview of the previous studies in dyslexia and DCD with tapping and has established that a deficit may exist and there is a possibility that it is specific to particular processes; however, there is a lack of directly comparable studies of the two conditions. Furthermore, there are other design considerations to take into account that could be useful in the investigation of possible temporal deficits in dyslexia and DCD and whether both conditions may share similar underlying deficits.

The present study has been based on several previous studies of tapping, as discussed in the methodology chapter (Chapter Two). This study incorporates several features of prior research to provide a detailed investigation of the patterns of tapping in children with dyslexia and children with DCD. Broadly, tapping studies include these four main features: different interstimulus intervals; auditory and visual conditions; a synchronisation and continuation procedure for the tapping task, and the analysis of on-contact and off-contact durations. Studies where these elements have been taken into consideration will now be detailed in turn.

Peters (1989) examined whether there were differences in the variability of synchronising to a stimulus at different interstimulus intervals (ISIs). His shortest interval was 180 ms, and his longest was 1000 ms. He found that, rather than the

participants responding consistently over the different ISIs, there was high variability at 180 ms ISI, a sharp drop in variability at 210 ms ISI, then a sharp increase in variability of tapping around the 300 ms ISI. The tapping then became less variable over the longer ISIs. Peters argued that the sharp increase was due to a transition between automated tapping processes, and more conscious control of the tapping. However, most studies have focussed on the conscious control area of tapping, primarily around 500 ms ISI (for example Williams et al.,1992). Consequently, three interstimulus intervals are proposed. One, near a possible boundary between conscious tapping and automated tapping, at 300 ms. One near the ISI other studies have used, at 500 ms; and another longer ISI: 700 ms.

Another component of the methodology is whether to use a visual or auditory stimulus. Jäncke et al. (2000) carried out an fMRI study of tapping. In the task, participants were asked to synchronise to a stimulus and after a pre-set number of taps, the stimulus was removed. Participants then had to continue tapping at the same pace. Jäncke et al. also compared synchronising and continuing to tap to a visual stimulus and to an auditory stimulus. They found that different cortical areas were responsible for processing synchronisation and continuation of the stimulus. In addition, it appeared to be harder to synchronise to an auditory stimulus compared with a visual stimulus. Given the auditory differences noted in children with dyslexia, it would be useful to compare directly performance on these modality dependence issues here.

A final component of the study is the analysis of on-contact and off-contact durations. This will allow a more fine-grained analysis than mere speed and regularity measures allow. Two recent studies have investigated on-contact and off-contact durations in tapping: Pick et al. (1993) with typically developing adults and, as noted earlier,

Piek and Skinner (1999) with children who had DCD. In both, their methods differed from Peters (1989) and Jäncke et al. (2000) in that they asked participants to copy a sequence of taps which had been presented visually. In addition, the analysis was restricted to only five taps. However, from their study, Piek et al. (1993) argued that the on-contact and off-contact duration required different cognitive processes, with on-contact related to the process of releasing the finger from the tapping plate, whilst off-contact was related to organisation of the next tap in the sequence.

This study will compare children with dyslexia and DCD with typically developing children on measures of temporal production and it will comprise synchronisation and continuation conditions, the use of several interstimulus intervals, the use of both visual and auditory stimuli, and the analysis of on-contact and off-contact duration.

The aim of the study is to investigate whether there are differences in the patterns of tapping in typically developing children, children with dyslexia, and children with DCD under a number of conditions. In particular, it would be expected that if the children with dyslexia and the children with DCD had underlying general temporal processing deficits (as proposed by researchers such as Wolff, 2002 and Williams et al., 1992) then they would be modality independent and a persistent deficit in performance would be observable across all the stimulus conditions.

Consequently, the research questions are as follows:

1. Do children with dyslexia show a deficit in tapping performance relative to an age matched control group?
2. Do children with DCD show a deficit in tapping performance relative to an age matched control group?

3. If both groups show evidence of deficit, are the children with dyslexia and the children with DCD significantly different in their performance on the tapping tasks?

Based on the previous research, and in line with the temporal processing framework of this thesis, it is predicted that a pattern of tapping in the children with dyslexia and DCD will be different from that of the typically developing children. The pattern displayed by the children with dyslexia and DCD will be characterised by higher off-contact variability in both the visual and auditory modalities, suggesting a general temporal processing deficit.

5.2. Method

5.2.1. *Participants*

For details of the participants in this study, see the Participants section of Chapter Two. The means and standard deviations for their performance on the baseline and experimental tasks are summarised in Table 5.1.

Table 5.1 Means and standard deviations for the baseline measures for the temporal production and temporal generalisation studies.

Baseline Measure	Typical			Dyslexia			DCD		
	M	SD	n	M	SD	n	M	SD	n
Chronological Age	11; 5	13.04	10	11; 0	8.49	10	11; 4	11.65	10
Reading Age	12; 5	24.03	10	9; 7	19.13	10	9; 8	16.68	10
Threading Speed (seconds)	38.6	7.76	10	35.5	8.73	10	38.8	6.96	10
Verbal Memory Raw	9.4	1.96	10	8.3	2.71	10	8.0	1.76	10
Visual Memory Age	12; 6	42.32	10	11; 11	44.04	10	12; 2	33.28	10

5.2.2. Test Materials and Procedures

Several baseline measures of ability were conducted to establish profiles for the three groups: reading age, threading speed, verbal memory, and visual memory. Details of the procedures for these tasks can be found in the Baseline Measures section of Chapter 2.

The experimental tapping task. Participants were initially asked about their hand preference and tapped with their preferred hand throughout the task. If the experimenter felt that there was any uncertainty in handedness, participants were to be administered the Annett (1970) hand preference questionnaire; however, none of the children in the study had difficulty in identifying their hand preference.

Participants faced a computer screen with their dominant hand resting on a tapping plate. The distance of the screen and audio levels were adjusted to ensure that they were at comfortable levels for the participant. The tapping plate was a custom designed micro-switch which was connected to the mouse input port of the computer.

The tapping was completed under several conditions: there was one familiarisation trial

for each of the conditions, and eight test trials of each condition. A total of 54 trials were completed, six familiarisation trials and 48 test trials. The familiarisation trials were not used in the data analysis. The order of the familiarisation trials and the test trials was randomised for each participant. There was also a minimum of a five second break between each trial.

Participants were asked to synchronise their tapping to the pulse of either the auditory or visual stimulus presented (synchronisation phase). They were told that after a number of taps, the stimulus would be removed and that they were required to continue tapping at the same pace until the trial ended (continuation phase). Each trial consisted of a stimulus being presented for 20 taps, the stimulus being removed and the trial ending after the participant had completed a further 20 taps. The auditory stimulus was a tone with a frequency of 300 Hz.

There were three different interstimulus intervals and two different external stimuli. The interstimulus intervals were 300 ms, 500 ms, and 700 ms. The visual stimulus was a black dot on a white background, 100 pixels in diameter. Both stimuli were presented for 50 ms in duration, as in Wing and Kristofferson (1973), and this formed part of the interstimulus interval (for example, the 300ms interstimulus interval consisted of 50 ms stimulus and then 250ms of silence).

The computer recorded the time (in milliseconds) every time the participant pressed the button and each time the participant released the button. The computer then computed the duration the button was pressed (on-contact duration) and duration the button was released (off-contact duration).

After the trial had been completed, the computer calculated the tapping speed by using

the average on-contact and off-contact duration. The tapping regularity was measured by calculating the standard deviations of the on-contact and off-contact durations for both the synchronisation part of the trial and the non-synchronisation part of the trial. See Figure 5.1 for a diagram of the presentation of the stimulus and the tapping analysis. In view of the large number of conditions in the stimuli, Table 5.2 provides a summary of the analyses.

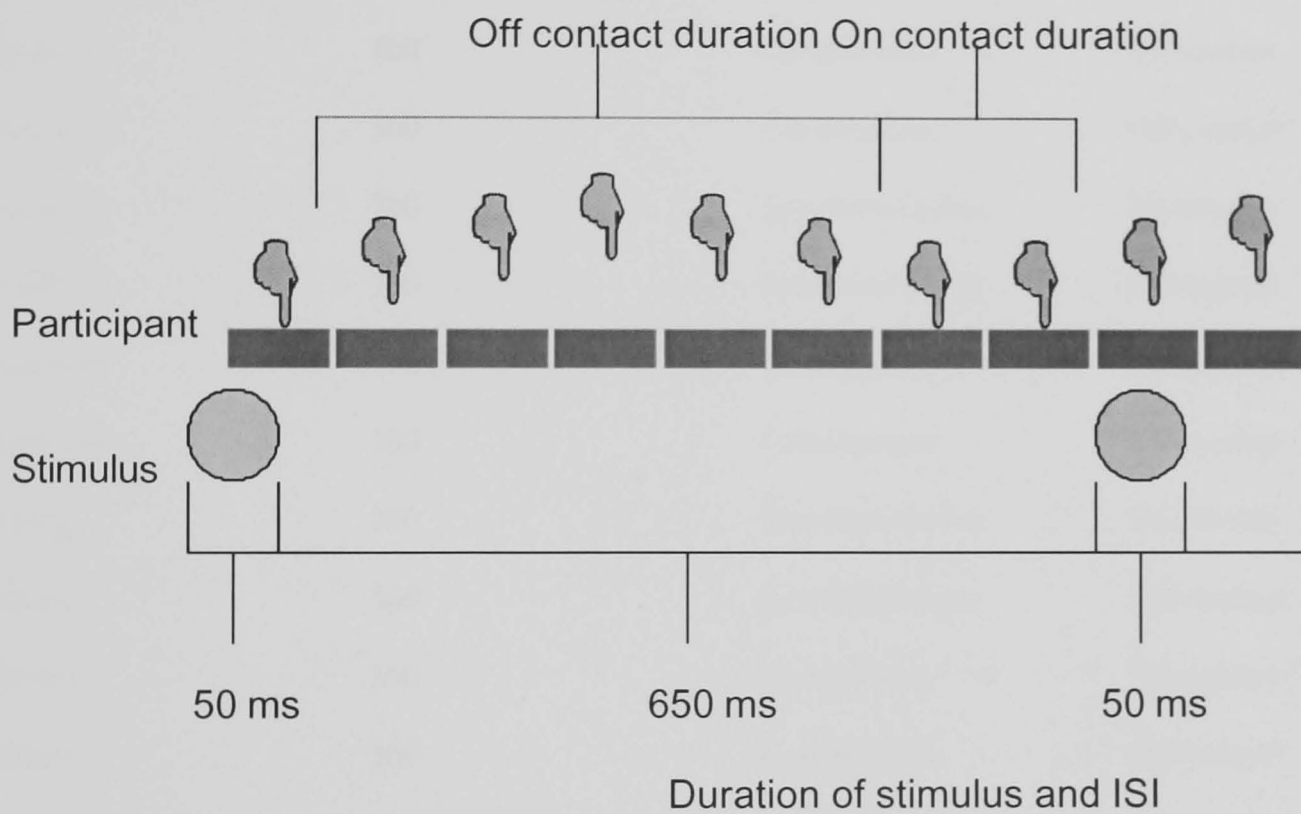


Figure 5.1 Diagram depicting part of the stimulus of a 700ms visual finger tapping trial.

Table 5.2 Summary of conditions in the tapping task

Modality	ISI	Phase	Contact
Auditory	300	Synchronisation	On-contact
Auditory	300	Synchronisation	Off-contact
Auditory	300	Continuation	On-contact
Auditory	300	Continuation	Off-contact
Auditory	500	Synchronisation	On-contact
Auditory	500	Synchronisation	Off-contact
Auditory	500	Continuation	On-contact
Auditory	500	Continuation	Off-contact
Auditory	700	Synchronisation	On-contact
Auditory	700	Synchronisation	Off-contact
Auditory	700	Continuation	On-contact
Auditory	700	Continuation	Off-contact
Visual	300	Synchronisation	On-contact
Visual	300	Synchronisation	Off-contact
Visual	300	Continuation	On-contact
Visual	300	Continuation	Off-contact
Visual	500	Synchronisation	On-contact
Visual	500	Synchronisation	Off-contact
Visual	500	Continuation	On-contact
Visual	500	Continuation	Off-contact
Visual	700	Synchronisation	On-contact
Visual	700	Synchronisation	Off-contact
Visual	700	Continuation	On-contact
Visual	700	Continuation	Off-contact

From each condition, two dependent measures were taken: the average speed of the tapping and the variability (in standard deviations) of the tapping.

5.3. Results

Shapiro-Wilks analysis was carried out on the data and indicated that some of the measures did not meet the assumptions for parametric analysis. Furthermore, it was not possible to normalise the data. Kruskal-Wallis analysis was used to compare the children with dyslexia, the children with DCD, and the typically developing children for each measure summarised in Table 5.2 at the end of this chapter.

Research question one looked at whether children with dyslexia showed deficit in tapping performance relative to the typically developing group. The Kruskal-Wallis analysis with post-hoc Dunn's Test of Multiple Comparisons ($p < 0.05$) indicated that on several measures the children with dyslexia performed poorly compared with the typically developing children. The children with dyslexia had significantly faster on-contact durations whilst synchronising to an auditory stimulus at 700 ms, $\chi^2(2) = 7.930$, $p = 0.045$; and significantly slower off-contact durations whilst synchronising to an auditory stimulus at 300 ms, $\chi^2(2) = 6.070$, $p = 0.048$; 500ms, $\chi^2(2) = 7.200$, $p = 0.026$; and 700ms, $\chi^2(2) = 7.930$, $p = 0.019$. The means, standard deviations, and Kruskal-Wallis analyses for all measures can be found in Table 5.3. Figure 5.2 and Figure 5.3 depict the differences in a graphical format.

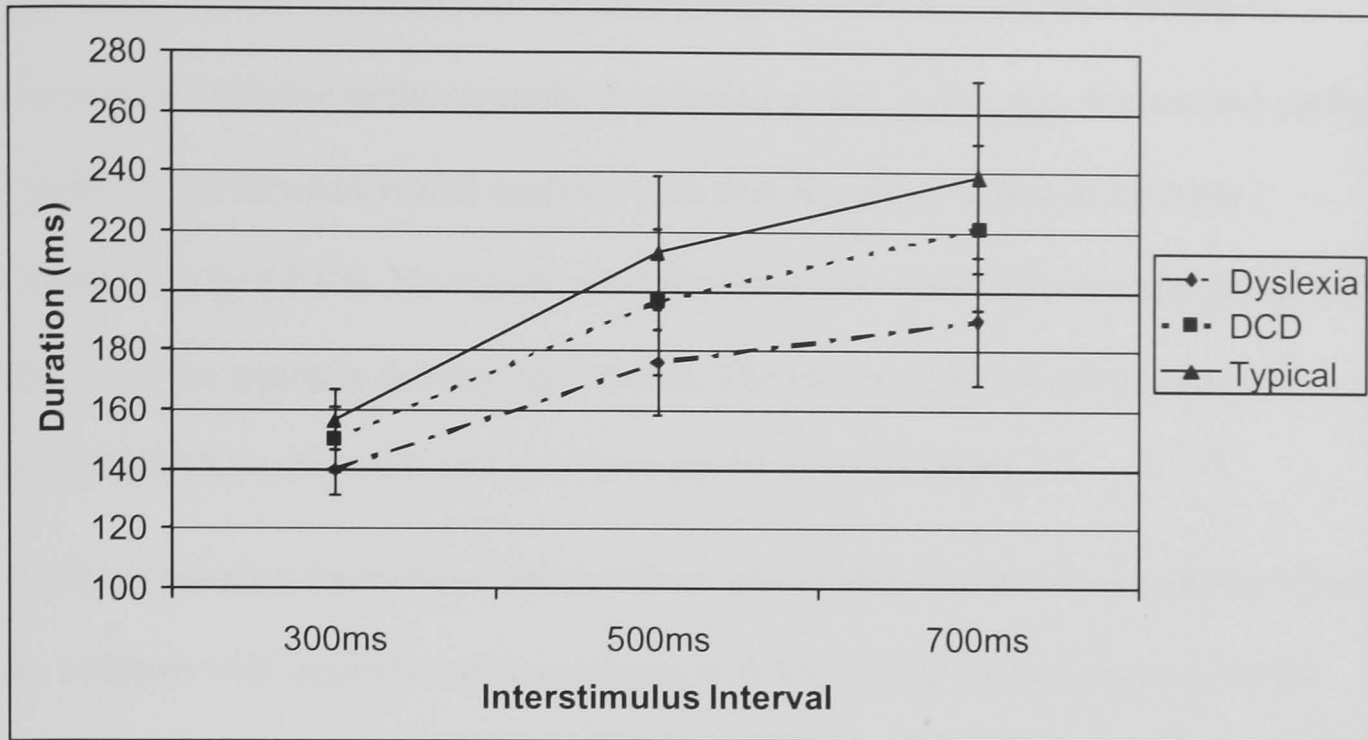


Figure 5.2 Mean on-contact duration in auditory synchronisation tapping. The error bars indicate the 95% confidence intervals. As can be seen, differences are beginning to appear by the 700 ms duration, particularly between the children with dyslexia and the typically developing group.

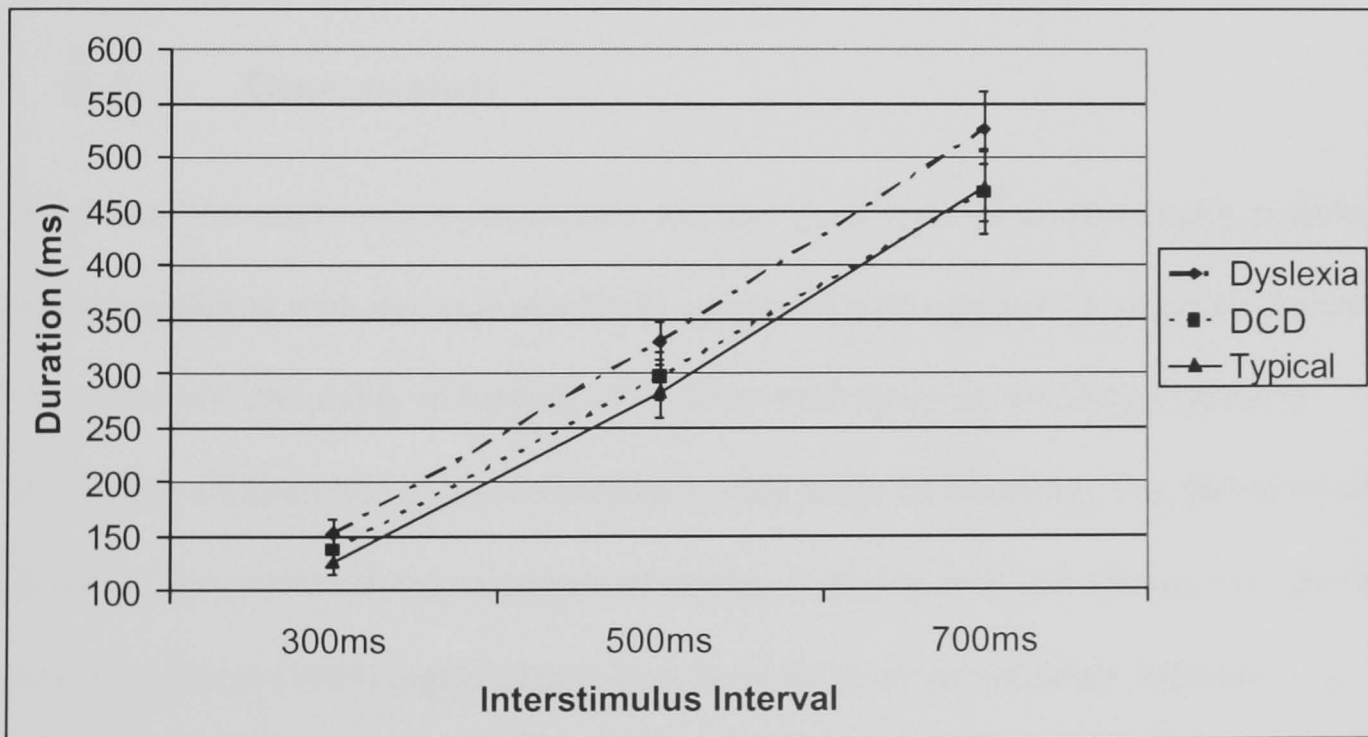


Figure 5.3 Mean off-contact duration in auditory synchronisation tapping. The error bars indicate the 95% confidence intervals. Throughout the three ISIs the children with dyslexia tend to have longer durations in the off-contact phase. This is particularly pronounced by the 700 ms ISI.

Research question two looked at whether children with DCD showed deficits in performance relative to the typically developing group. Again, this was carried out by looking at the Kruskal-Wallis analysis with post-hoc Dunn's Test of Multiple Comparison ($p < 0.05$). No significant differences were found between the group with DCD and the typically developing children. The means, standard deviations, and Kruskal-Wallis analyses for all measures can be found in Table 5.3.

Research question three asked whether there was evidence of a common deficit between the children with dyslexia and the children with DCD. The analysis carried out for research question one and research question two indicated that there were no common deficits between the children with dyslexia and the children with DCD relative to the typically developing children. The means, standard deviations, and Kruskal-Wallis analyses for all measures can be found in Table 5.3.

5.4. Discussion

The aim of this study was to investigate whether there were common tapping patterns between children with dyslexia and DCD compared with typically developing children. The speed and variability in tapping of children with dyslexia, DCD and typically developing children was compared across a wide range of durations. The durations were chosen as they were related to aspects of tapping found in previous studies, 300 ms was chosen as Peters (1989) argued that it was likely to be at the boundary between conscious and automated tapping; 500 ms is near the tapping speed used in studies by Williams et al. (1992); 700 ms was near one of the longest ISIs used in previous studies, that of Wolff et al. (1984). The discussion will now cover the research questions and consider the strengths and weaknesses of the study.

Research question one looked at whether the children with dyslexia showed differences in tapping patterns relative to the typically developing children. The results indicated that the children with dyslexia had significantly shorter on-contact durations at 700 ms ISI compared with typically developing children and significantly longer off-contact durations in the auditory condition compared to the typically developing children across all three ISIs (300 ms, 500 ms, and 700 ms). Research question two asked a similar question of the children with DCD. However the pattern was different for this group. The children with DCD did not show any significant differences compared with the typically developing children in either the on-contact or off-contact durations. Therefore in response to research question three, there is no evidence that the different pattern observed in the children with dyslexia is common to both the children with dyslexia and the children with DCD.

One possible explanation for the distinct pattern of results in children with dyslexia comes from the studies by Piek et al. (1993), and Piek and Skinner (1999). They argued that distinct processes are carried out during the on-contact and off-contact phases. That on-contact durations relate to coordinating the raising of the finger from the tapping plate and that off-contact are related to planning and executing the forthcoming tap. A disruption in temporal processing may cause a longer off-contact duration as this is the phase of the tap where these processes are likely to be carried out. The significantly shorter on-contact duration found at 700 ms provides support for Wolff (2002).

Children with dyslexia were shown to press the tapping button for a substantial duration in anticipation of a metronome. In this study, if anticipation occurred it would occur during the on-contact phase and therefore the short on-contact phase may be where participants have pressed the button down well ahead of the stimulus and raised it

shortly after the stimulus. Wolff argued that this may be due to an underlying auditory temporal processing deficit where the children with dyslexia had to anticipate the tap with more space between the tap and the stimulus in order to experience the two occurring simultaneously. The findings in this study would suggest that this deficit occurs at some ISIs but not at others. Furthermore, the differences found were only for the auditory stimulus conditions which suggests that this is a domain specific deficit rather than a more generalised deficit. Therefore, the findings would not suggest support for the position presented by researchers such as Farmer and Klein (1995) who argued for a generalised temporal processing deficit and which has been outlined earlier.

The results suggested that there was little difference in tapping performance between the typically developing children and the children with DCD. Other studies have also found this, for example, Geuze and Kalverboer (1994) found no significant difference between their group of children with DCD and typically developing children on measures of unimanual tapping. But whereas Geuze and Kalverboer (1994) had looked at global measures of tapping; this study had decomposed the taps into on-contact and off-contact durations. A previous study by Piek and Skinner (1999) had found differences in tapping for children with DCD when doing this. However, the study by Piek and Skinner (1999) had used possibly a more demanding task than synchronisation and continuation: children were required to attend to a visually presented tap pattern and then reproduce it. There are two possible reasons for the differences in this study and Piek and Skinner's. The procedure used in this study had fewer processing steps and it may be that the children with DCD were able to carry out the task in line with the typically developing children for that reason. Alternatively, the use of a visual presentation in Piek and Skinner may have inadvertently assessed visual memory

difficulties that previous researchers have shown are characteristic of children with DCD (for example, Wilson and McKenzie, 1998) rather than temporal processing.

The strengths of the study described here are as follows, ; the breadth of conditions used; the analysis of on-contact and off-contact durations; the direct comparison of children with dyslexia and children with DCD. This study extends the work of previous studies through the breadth of conditions used, the different modalities in which tapping was carried out, and the analysis of on-contact and off-contact durations, and the direct comparison of children with dyslexia and children with DCD. None of these elements has been looked at in a single study before. For example, many studies, such as Wolff et al. (1984), and Wolff (2002) have focussed on an auditory modality but in order to consider a more general deficit other areas have to be taken into account. In addition many studies only examine tapping as a global measure, such as mean tapping speed or regularity. However, here it was possible to study the two main elements in tapping: the duration the finger is held in contact with the tapping plate, and the duration, the finger is released from the tapping plate.

There are five possible limitations to this study. The first is that the familiarisation phase was not sufficient to provide the participants with enough practice in order to be more consistent in their tapping. This may particularly be the case with the visual stimuli which, as noted by Jäncke et al. (2000), and may have been more difficult for all participants. The study had a one trial per condition familiarisation phase. However two of the most analogous studies, Wolff (2002) for dyslexia and Williams et al. (1992) in DCD, both have similar procedures. Wolff (2002) does not report the amount of practice participants had of the task but it appears to be limited, and he noted during the methodology section that participants' tapping speed was verbally corrected, if

necessary, during practice. Williams et al. (1992) does not report a practice session being carried out; however during the experiment, trials where the participants' tapping intervals were outside a set range were discarded. One of the main problems with this type of procedure is that it potentially discards actual variation in behaviour of tapping which may be important in understanding the temporal production abilities of the children with dyslexia and the children with DCD.

Another limitation is that the study reported here was based on too few trials: eight per condition. In contrast Williams et al. (1992), who tested children with DCD and typically developing children, analysed eighteen trials in total. Wolff (2002) does not report the number of trials for synchronisation: however, a similar task within the study was carried out ten times. However in Williams et al. (1992), the total number of synchronisation taps used in the analysis was 216 per participant ($12 \text{ taps} * 18 \text{ trials} = 216$), which compares well with the number analysed in this study: 160 per participant ($20 \text{ taps} * 8 \text{ trials} = 160$). Although it is clear that the number of continuation taps is much higher in Williams et al. (1992) compared with this study (558 vs. 160 taps). This may partly explain why they found a higher variability in the results of their tapping when comparing the children with DCD and typically developing children, a finding not replicated here. The main reason for limiting the number of trials was attentional factors; the task is arduous, as participants are required to repetitively tap over a large number of conditions. Even with the frequent breaks designed in this study, the task was laborious for the children to carry out.

The small number of participants in this study, 30 in total, is a possible limitation. The small groups were primarily a consequence of constraints on time and resources, however steps were taken to match the groups for age in order to improve the

comparability. Small size groups are not the exception in studies of this nature. In Williams et al. (1992), 12 children with coordination difficulties took part, and 13 typically developing children; similarly in Wolff (2002), where 12 children with dyslexia and 12 typically developing children took part. However, in view of the small size of the groups in this study, it is possible that this affected the power of the statistical analysis to detect differences.

Another concern is the number of non-parametric analyses carried out (56 Kruskal Wallis analyses to compare across conditions). This can increase the likelihood of a type one error. However, the pattern of significant differences in this study is clustered around the off-contact auditory durations rather than being spread across the data. This might suggest that a significant difference where one is not present is not the case, nevertheless caution should be taken in generalising this data and further research is recommended.

Finally, as noted in the introduction, Piek and Skinner (1999) suggested that a deficit in on-contact duration could show up as a deficit in off-contact durations and vice versa. This may imply that the significantly longer duration in the children with dyslexia may be due to the processes in off-contact duration or could be a response to deficits in on-contact durations. However, the finding at 700 ms, where both on-contact and off-contact durations were slower would suggest that the tapping processes in general were less efficient. A more detailed analysis of durations, possibly of anticipation to the stimulus, may help elicit a more detailed understanding of tapping in the two groups with special needs.

There are several potential future directions for this research. The findings from the

auditory tapping conditions had suggested two possible hypotheses as to why there was a longer on-contact duration in children with dyslexia. Further research into anticipation times in tapping to auditory stimuli could provide a fuller understanding of auditory temporal processing in dyslexia. It is possible that the task was not complex enough to show deficits in the children with DCD, consequently controlled studies into more complex patterns and also the use of bimanual tapping, as in Geuze and Kalverboer (1994) which may elicit a better understanding of deficits in tapping in children with DCD but there is a question over whether bimanual tapping is a coordination task more than a temporal processing task. Finally, this study focussed on the production of temporally sensitive information. However further research into how children process temporal information and its relationship to reading and movement may elicit a better understanding of the nature of the deficits in dyslexia and DCD. Main Study Three (Chapter Six) will investigate the role of temporal generalisation in children with dyslexia, DCD, and typically developing children.

In summary, a study of temporal production ability of children with dyslexia, DCD, and typically developing children was conducted. The findings suggest that children with dyslexia have different temporal production abilities compared with children with DCD and typically developing children. The children with dyslexia were significantly slower when required to tap to an auditory pacing stimulus but were performing typically when required to tap to a visual pacing stimulus. This finding suggests that whilst children with dyslexia may not share similar underlying deficits with children who have DCD, the deficit they may have is specifically related to auditory temporal production.

Table 5.3 Means and standard deviations per group and Kruskal Wallis analysis summary for each of the conditions in the temporal production task.

Condition	Dyslexia			DCD			Typical			Kruskal Wallis		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	χ^2	df	p
Speed												
Auditory Condition												
300ms Interstimulus Intervals												
Off-contact duration whilst synchronised to an external stimulus	152.709	22.970	10	138.454	24.873	10	126.394	18.179	10	6.070	2	0.048
On-contact duration whilst synchronised to an external stimulus	139.866	13.949	10	149.947	17.791	10	156.500	16.829	10	4.328	2	0.115
Off-contact duration following synchronisation to an external stimulus	157.096	29.199	10	141.385	30.280	10	134.661	23.712	10	2.934	2	0.231
On-contact duration following synchronisation to an external stimulus	146.325	18.410	10	156.858	20.685	10	156.229	18.835	10	1.559	2	0.459
500ms Interstimulus Intervals												
Off-contact duration whilst synchronised to an external stimulus	329.794	27.786	10	297.081	36.022	10	283.069	40.574	10	7.280	2	0.026
On-contact duration whilst synchronised to an external stimulus	176.004	28.893	10	196.520	39.716	10	213.046	41.473	10	2.991	2	0.224
Off-contact duration following synchronisation to an external stimulus	307.920	26.223	10	285.878	56.101	10	268.114	48.400	10	3.074	2	0.215
On-contact duration following synchronisation to an external stimulus	185.122	33.875	10	210.465	47.692	10	216.067	39.646	10	2.557	2	0.278
700ms Interstimulus Intervals												

Table 5.3 Means and standard deviations per group and Kruskal Wallis analysis summary for each of the conditions in the temporal production task. Continued.

Condition	Dyslexia			DCD			Typical			Kruskal Wallis		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	χ^2	df	p
Off-contact duration whilst synchronised to an external stimulus	526.338	54.059	10	467.981	62.108	10	471.985	51.533	10	7.930	2	0.019
On-contact duration whilst synchronised to an external stimulus	190.280	34.696	10	221.438	45.166	10	238.548	51.338	10	6.225	2	0.045
Off-contact duration following synchronisation to an external stimulus	444.055	42.719	10	416.589	65.856	10	409.593	78.814	10	0.751	2	0.687
On-contact duration following synchronisation to an external stimulus	201.356	42.816	10	240.922	53.064	10	245.991	61.771	10	3.610	2	0.164
Visual Condition												
300ms Interstimulus Interval												
Off-contact duration whilst synchronised to an external stimulus	170.934	41.965	10	158.157	35.279	10	148.282	32.251	10	1.621	2	0.445
On-contact duration whilst synchronised to an external stimulus	160.229	27.466	10	151.500	27.911	10	161.817	23.553	10	1.706	2	0.426
Off-contact duration following synchronisation to an external stimulus	164.473	39.155	10	160.487	47.531	10	140.988	24.041	10	1.610	2	0.447
On-contact duration following synchronisation to an external stimulus	159.416	20.571	10	160.039	29.422	10	165.892	28.688	10	0.983	2	0.612
500ms Interstimulus Interval												
Off-contact duration whilst synchronised to an external stimulus	303.871	39.901	10	285.514	47.581	10	271.013	43.848	10	2.712	2	0.258
On-contact duration whilst synchronised to an external stimulus	174.478	23.150	10	188.944	34.755	10	202.327	33.213	10	3.843	2	0.146

Table 5.3 Means and standard deviations per group and Kruskal Wallis analysis summary for each of the conditions in the temporal production task. Continued.

Condition	Dyslexia			DCD			Typical			Kruskal Wallis		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	χ^2	df	p
Off-contact duration following synchronisation to an external stimulus	290.801	40.534	10	268.928	54.698	10	253.430	49.616	10	2.810	2	0.245
On-contact duration following synchronisation to an external stimulus	184.120	30.547	10	202.549	40.482	10	218.661	36.483	10	3.757	2	0.153
700ms Interstimulus Interval												
Off-contact duration whilst synchronised to an external stimulus	447.851	85.080	10	413.540	79.155	10	425.937	85.067	10	1.241	2	0.538
On-contact duration whilst synchronised to an external stimulus	190.099	29.274	10	200.477	34.602	10	223.314	43.406	10	4.119	2	0.128
Off-contact duration following synchronisation to an external stimulus	402.191	77.707	10	373.238	78.386	10	386.808	81.868	10	0.622	2	0.733
On-contact duration following synchronisation to an external stimulus	207.008	43.274	10	212.380	37.860	10	237.909	49.868	10	3.053	2	0.217
Regularity (in standard deviations)												
Auditory Condition												
300ms Interstimulus Interval												
Off-contact duration whilst synchronised to an external stimulus	49.380	18.924	10	37.652	16.546	10	49.805	41.093	10	1.463	2	0.481
On-contact duration whilst synchronised to an external stimulus	36.174	15.381	10	37.690	19.899	10	61.241	51.243	10	1.517	2	0.468
Off-contact duration following synchronisation to an external stimulus	67.204	63.762	10	51.462	28.104	10	60.866	53.339	10	0.885	2	0.642

Table 5.3 Means and standard deviations per group and Kruskal Wallis analysis summary for each of the conditions in the temporal production task. Continued.

Condition	Dyslexia			DCD			Typical			Kruskal Wallis		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	χ^2	df	p
On-contact duration following synchronisation to an external stimulus	34.579	17.799	10	41.118	23.082	10	57.783	45.969	10	0.705	2	0.703
500ms Interstimulus Interval												
Off-contact duration whilst synchronised to an external stimulus	73.210	26.660	10	66.702	22.763	10	105.493	108.016	10	0.797	2	0.671
On-contact duration whilst synchronised to an external stimulus	41.204	14.581	10	44.894	13.074	10	77.007	68.539	10	0.452	2	0.798
Off-contact duration following synchronisation to an external stimulus	63.042	20.463	10	82.206	58.384	10	102.288	106.565	10	0.705	2	0.703
On-contact duration following synchronisation to an external stimulus	42.247	19.053	10	42.699	16.765	10	66.817	68.242	10	0.173	2	0.917
700ms Interstimulus Interval												
Off-contact duration whilst synchronised to an external stimulus	115.609	66.106	10	105.030	23.802	10	171.645	186.279	10	0.472	2	0.790
On-contact duration whilst synchronised to an external stimulus	49.234	21.749	10	57.256	27.760	10	83.112	70.488	10	0.560	2	0.756
Off-contact duration following synchronisation to an external stimulus	82.697	31.499	10	100.736	37.510	10	145.843	149.203	10	1.355	2	0.508
On-contact duration following synchronisation to an external stimulus	41.857	21.999	10	52.784	21.768	10	78.135	74.760	10	2.403	2	0.301
Visual Condition												
300ms Interstimulus Interval												

Table 5.3 Means and standard deviations per group and Kruskal Wallis analysis summary for each of the conditions in the temporal production task. Continued.

Condition	Dyslexia			DCD			Typical			Kruskal Wallis		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	χ^2	df	p
Off-contact duration whilst synchronised to an external stimulus	56.708	26.042	10	54.093	14.654	10	68.838	60.134	10	1.494	2	0.474
On-contact duration whilst synchronised to an external stimulus	53.186	37.337	10	46.000	15.050	10	60.314	50.170	10	0.134	2	0.935
Off-contact duration following synchronisation to an external stimulus	56.689	34.809	10	67.303	40.786	10	65.785	52.191	10	0.668	2	0.716
On-contact duration following synchronisation to an external stimulus	38.262	18.961	10	53.427	21.352	10	65.886	51.354	10	2.666	2	0.264
500ms Interstimulus Interval												
Off-contact duration whilst synchronised to an external stimulus	70.743	41.029	10	74.773	43.036	10	102.857	102.397	10	0.054	2	0.973
On-contact duration whilst synchronised to an external stimulus	34.224	12.827	10	42.311	25.294	10	63.805	57.386	10	1.551	2	0.460
Off-contact duration following synchronisation to an external stimulus	61.860	31.201	10	65.375	23.960	10	93.287	93.764	10	0.519	2	0.772
On-contact duration following synchronisation to an external stimulus	45.489	37.397	10	52.234	29.914	10	78.597	60.140	10	3.657	2	0.161
700ms Interstimulus Interval												
Off-contact duration whilst synchronised to an external stimulus	102.373	37.311	10	111.101	69.439	10	165.991	156.328	10	1.179	2	0.555
On-contact duration whilst synchronised to an external stimulus	41.740	12.242	10	42.676	11.429	10	80.068	67.334	10	0.498	2	0.780
Off-contact duration following synchronisation to an external stimulus	85.169	45.792	10	88.554	29.625	10	136.298	134.543	10	0.668	2	0.716

Table 5.3 Means and standard deviations per group and Kruskal Wallis analysis summary for each of the conditions in the temporal production task. Continued.

Condition	Dyslexia			DCD			Typical			Kruskal Wallis		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	χ^2	df	p
On-contact duration following synchronisation to an external stimulus	43.552	17.754	10	47.550	18.719	10	72.831	76.624	10	0.519	2	0.772

6. Study Three: Temporal Generalisation

6.1. Introduction

The previous two studies focussed on skills related to automatization and temporal production. This study examined a different element of temporal processing: namely, how children with dyslexia, DCD, and typically developing children differ in their ability to *perceive* temporal information. To do this, the study in this chapter used a temporal generalisation paradigm, which has provided evidence for the temporal processing theory proposed by, amongst others, Wearden (1992) and was outlined in Chapter One.

The only study published to date that has examined temporal perception in dyslexia was conducted by Nicolson et al. (1995). They aimed to investigate the possibility that dyslexia was not only related to phonological processing deficits. A previous study by Ivry and Keele (1989) had assessed temporal processing in adult patients with cerebellar damage. Their participants heard two auditory stimuli of either a similar or a different duration and had to judge whether they were of the same duration. They found that the patients who had cerebellar damage performed poorly on this type of task compared with typical adults. In order to rule out the possibility of general auditory problems, the participants were also asked to judge relative differences in the volume of two auditory stimuli. They found that the patients with cerebellar damage had no difficulties with this task. In their study, Nicolson et al. (1995) found that children with dyslexia showed similar response patterns to the adults with cerebellar damage on a similar temporal perception task to that used in Ivry & Keele (1989).

Williams et al. (1992) also carried out a similar experiment using the Ivry and Keele (1989) temporal perception task with children with DCD. They also found that these children were less accurate in their auditory duration perception than typically developing children. Taken together, the results of Nicolson et al. (1995) and Williams et al. (1992) suggest that both children with dyslexia and children with DCD may have a common deficit in auditory temporal perception, relative to typically developing controls. However, visual temporal perception has yet to be investigated in either group. Moreover, both groups have yet to be compared to each other in a single study.

Despite researchers of both dyslexia and DCD proposing that auditory temporal perception may be a deficit in both conditions, no study to date has used the temporal generalisation paradigm to assess this in dyslexia or DCD. However this is a paradigm that has generated evidence for theories of temporal processing in typically developing adults and children, as noted in Chapter One, and provides an alternative method for assessing temporal perception ability. By using this paradigm, not only will it be possible for this study to investigate how robust the deficits observed previously by Nicolson et al. (1995) and Williams et al. (1992) are, but it will be possible to directly relate these results to those found in studies of typical adults and children.

Temporal generalisation requires participants to learn a particular stimulus duration and then to compare this to a newly presented duration which may be the same or different. A judgement must then be made as to whether the comparison duration is the same as the standard duration or not. It therefore serves as a perception task similar to that used by Nicolson et al. (1995) and Williams et al. (1992), but has an additional temporal memory component, making the task more demanding. For example, Wearden (1992) played participants an auditory stimulus of a particular duration and told them that this

was the 'standard' duration. During the experiment, they were asked to judge whether subsequent durations they heard were the same or different to the standard. Through this method Wearden (1992) established that adults could make accurate auditory temporal generalisations, albeit with a tendency to confuse slightly longer stimuli with the standard where the stimuli were distanced in a linear fashion, (for example auditory durations of 100 ms, 200 ms, 300 ms, 400 ms, 500 ms, 600 ms, and 700 ms were used, and the 400 ms stimulus was the standard). This finding has been robustly replicated since Wearden's study.

However, the focus of this study is on children and McCormack et al. (1999) conducted the one of the few developmental studies of typical temporal generalisation to date. They found that children aged five confused shorter durations with the standard more often than the longer durations, whereas children aged nine were found to show a symmetrical pattern of responses (see Figure 6.1). This has raised two possible interpretations. Firstly, that the pattern is due to the attentional demands of the task (Gautier and Droit-Volet, 2002). Secondly, that it is due to a degraded representation of the standard duration (McCormack et al, 2004)

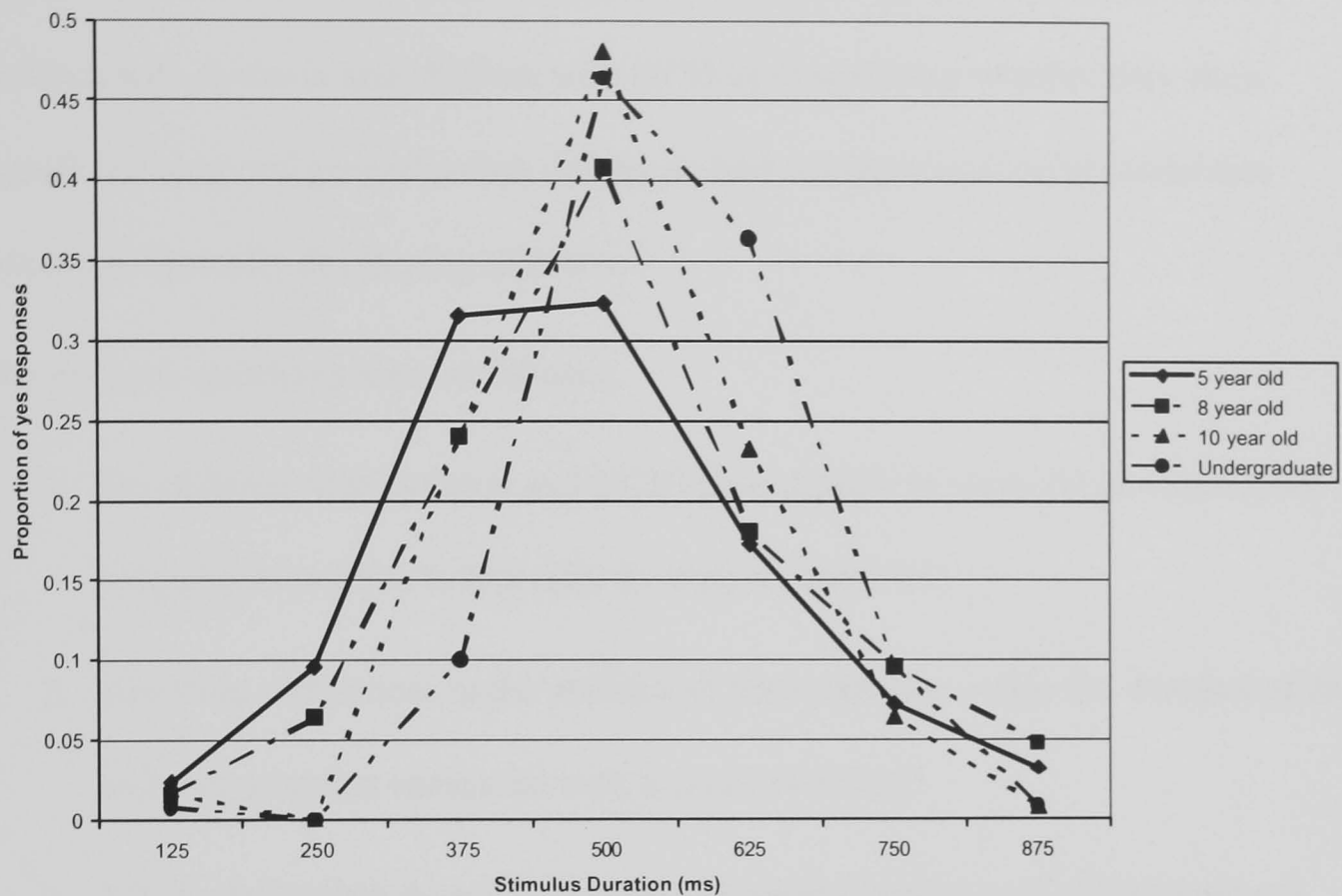


Figure 6.1 A reproduction of the yes response graph from Mc Cormack et al. (1999). However it is of note that this data were transformed; see the discussion section of this chapter for how the scores were transformed.

In addition to using a standardised procedure, the nature of the stimulus presentation needed to be considered. The theoretical overview indicated that children with DCD may have visual processing deficits, and the children with dyslexia may have auditory processing deficits, and there is evidence from studies of typical adults that even their responses to tones and lights can be different. However, the model proposed by Wearden et al. (1998) suggests that temporal processing under visual conditions and under auditory conditions is handled by the same cognitive system. If there was an underlying deficit in temporal processing it should, according to this theory, be expected to affect both visual and auditory conditions equally and not simply performance in the visual condition for children with DCD and performance in the auditory condition for the children with dyslexia. Consequently, this study will compare both modalities.

The study aims to extend current research into temporal generalisation ability in children with dyslexia and children with DCD by considering whether they show significant temporal generalisation deficits in both auditory and visual modalities relative to typically developing children.

The research questions were as follows:

1. Do children with dyslexia and DCD show deficits in temporal generalisation judgements relative to typically developing children?
2. Are there differences in the abilities of the children to judge the duration of an auditory stimulus compared with a visual stimulus?
3. What relationship do auditory temporal generalisations and visual temporal generalisations have to baseline measures of reading, motor coordination, and memory?

It was predicted that, based on Ivry and Keele (1989), Williams et al. (1992), and Nicolson et al. (1995), children with dyslexia and children with DCD would perform significantly worse than the typical developing children on the auditory temporal generalisation task and on the visual temporal generalisation task. Secondly, it was predicted, based on Jäncke et al. (2000), that the visual task would be significantly more difficult to complete than the auditory task for all the children.

Finally, it was predicted that there would be significant correlations between auditory temporal generalisation and reading and visual temporal generalisation and threading as there may be a relationship between auditory processing in reading, as argued by Reed (1989), and visual processing in threading, as implied by the findings of Wilson and McKenzie (1998).

6.2. Method

6.2.1. *Participants*

Details of the participants can be found in the Methodological Chapter (Chapter Two) and are summarised in Table 6.1.

6.2.2. *Test Materials and Procedure*

The order that the tasks were presented in within a session was counterbalanced to ensure that no order effects would confound the results. The Auditory Temporal Generalisation task and the Visual Temporal Generalisation task were presented using software written by the author. Details of the equipment used can be found in the Methodological Chapter (Chapter Two).

Baseline measures of word reading age, visual memory age, verbal memory, and threading speed were taken. Details of the procedures for these tasks can be found in the Methodological Chapter (Chapter Two) and a summary of the descriptive statistics can be found in Table 6.1

Table 6.1 Means and standard deviations for the measures used in the temporal generalisation study.

Baseline Measure	Typical			Dyslexia			DCD		
	M	SD	n	M	SD	n	M	SD	n
Chronological Age	11; 5	13.04	10	11; 0	8.49	10	11; 4	11.65	10
Reading Age	12; 5	24.03	10	9; 7	19.13	10	9; 8	16.68	10
Threading Speed (seconds)	38.6	7.76	10	35.5	8.73	10	38.8	6.96	10
Verbal Memory Raw	9.4	1.96	10	8.3	2.71	10	8.0	1.76	10
Visual Memory Age	12; 6	42.32	10	11; 11	44.04	10	12; 2	33.28	10
Aud. Temp. Gen. Proficiency	.48	.241	10	.409	.197	10	.483	.549	10
Vis. Temp. Gen. Proficiency	.27	.166	10	.24	.123	10	.212	.07	10

Auditory temporal generalisation. The procedure used here was as close as possible to that used by McCormack et al. (1999). The standard duration was a filled 500ms tone and the non standard durations were filled tones of 125 ms, 250 ms, 375 ms, 625 ms, 750ms, and 875ms. In line with McCormack et al. (1999), the task consisted of eight trials. Each trial consisted of one presentation of each of the non standard stimuli and two presentations of the standard stimulus. The stimuli were randomised within the trials.

Participants first completed the instruction section of the task. A transcription of the instructions can be found in Appendix One. The computer informed the participants that an owl made the following sound. The standard tone was then played five times. During the instruction section, a picture of the owl was displayed on the computer. Next the picture in Figure 6.2 was displayed; the computer played the 750 ms tone and informed participants the owl did not make this sound. The crossed out owl was briefly

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highlighted. The 500 ms tone was then played and participants were informed that this was the sound the owl made. The owl with a tick was briefly highlighted. Finally, a 250 ms tone was played and participants were informed that this was not the sound the owl made. Again, the crossed out owl was briefly highlighted.

The instruction section was followed by a familiarisation section in which the participants had to judge if the tone was the sound the owl made. One presentation of each of these durations was used: 125 ms, 375 ms, 500 ms, 625 ms, and 875 ms.

Feedback was provided after each response. The feedback informed participants whether the tone they had heard was the standard or not. Before proceeding to the test trials, participants were presented with the standard duration a further five times.

Whereas no overt assessment was carried out to indicate whether the children had learnt the standard by the end of the familiarisation phase, this procedure was in line with McCormack et al. 1999. The level of accuracy at determining the standard during the experimental section of the task was above chance, which might suggest that the children had learnt the standard stimulus. After each response during the test trials, the computer informed the participant whether the sound they had just heard was the sound the owl made. During the task, the computer recorded the responses of the participants and whether they were correct or incorrect.

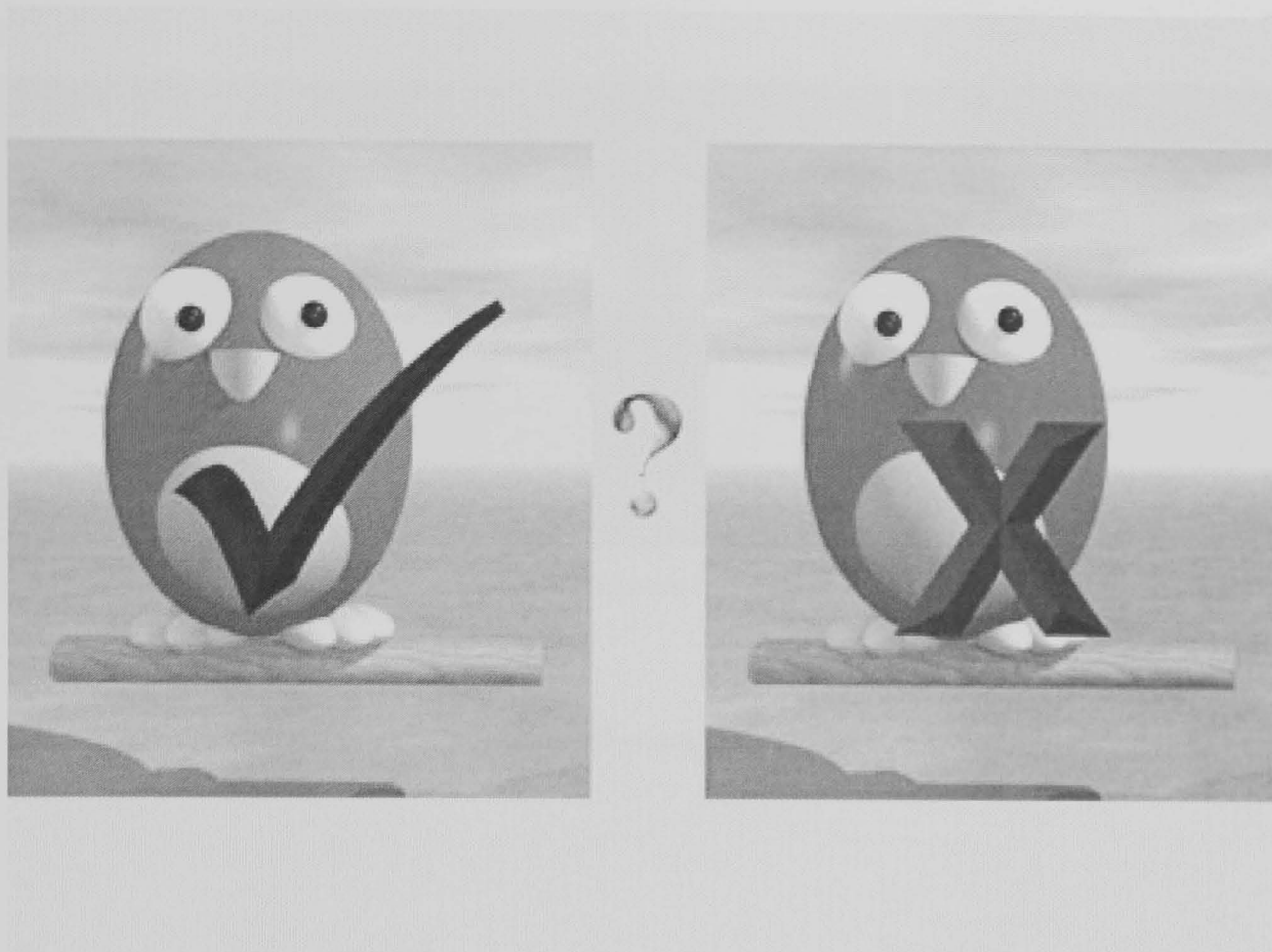


Figure 6.2 A screenshot of the auditory temporal generalisation task.

Visual temporal generalisation. The procedure for this task was identical to the auditory temporal generalisation task. The only difference was that the owl sound was replaced by flashes of light from a lighthouse (see Figure 6.3 for a screenshot of the task). These lasted different durations and the durations were identical to those in the auditory task.

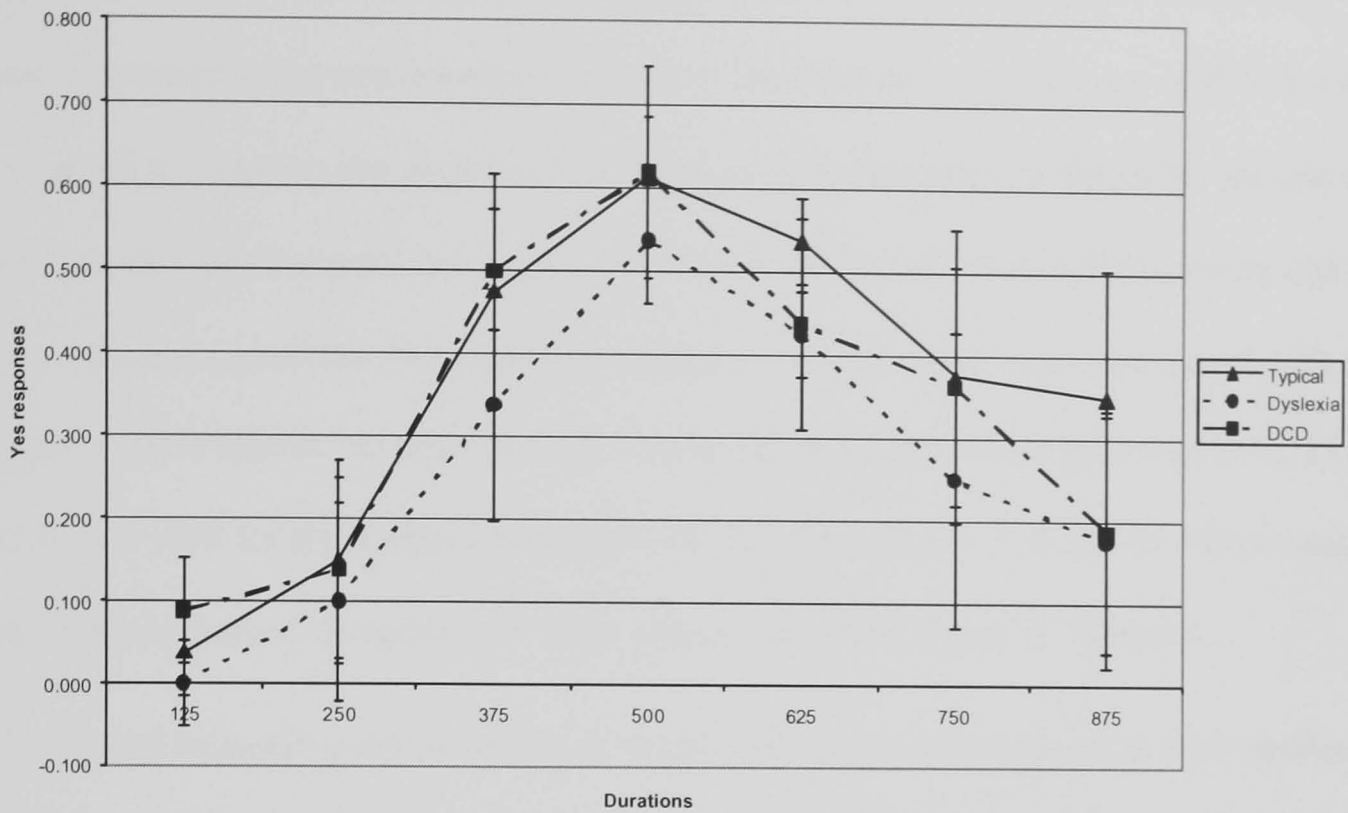


Figure 6.4 The auditory temporal generalisation pattern of the three groups. The error bars indicate 95% confidence intervals.

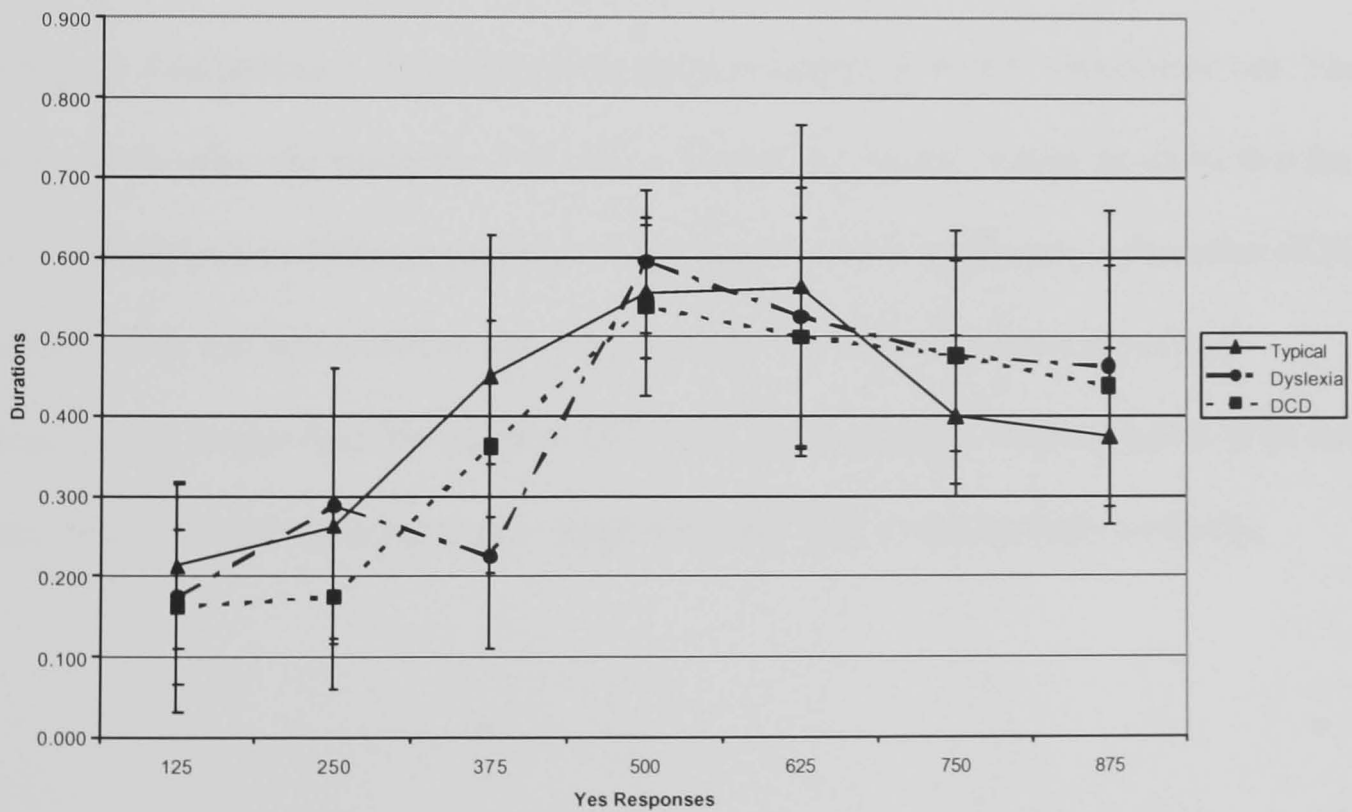


Figure 6.5 The visual temporal generalisation of the three groups. The error bars indicate 95% confidence intervals.

To provide a measure of general proficiency on the task for the three groups, the procedure used by McCormack et al. (1999) was carried out. For each participant, the

'yes' responses to the *standard stimulus* ('hits') were divided by the total number of 'yes' responses to the *non-standard stimulus* ('false alarms'). A one-way ANOVA was computed to examine any significant differences in performance between the groups on both the auditory temporal processing task and on the visual temporal processing task. This measure represents the number of correct responses to the target compared with the number "false alarms" to other stimuli. The results were both nonsignificant: $F(2, 27) = 0.130, p = .879$ for the auditory task and $F(2, 28) = 0.527, p = .598$ for the visual task. Means and standard deviations for these responses can be found in Table 6.1.

The second research question looked at whether there were differences in how children performed in the auditory condition compared with their performance in the visual condition. In view of the result that there were no significant differences between the groups in their performance on the tasks, this analysis was taken for the group as a whole. A 7 (duration) x 2 (modality) repeated measures ANOVA was carried out. There was a main effect for modality, $F(1, 29) = 12.505, p = 0.001$, which confirms that the two modalities had different profiles. See Figure 6.6 for a graphical presentation of the results and it can be seen from the graph that there is a particular divergence in responses at longer than the standard ISIs (625 ms or greater). There appears to be more confusion with the standard in the visual modality than in the auditory modality.

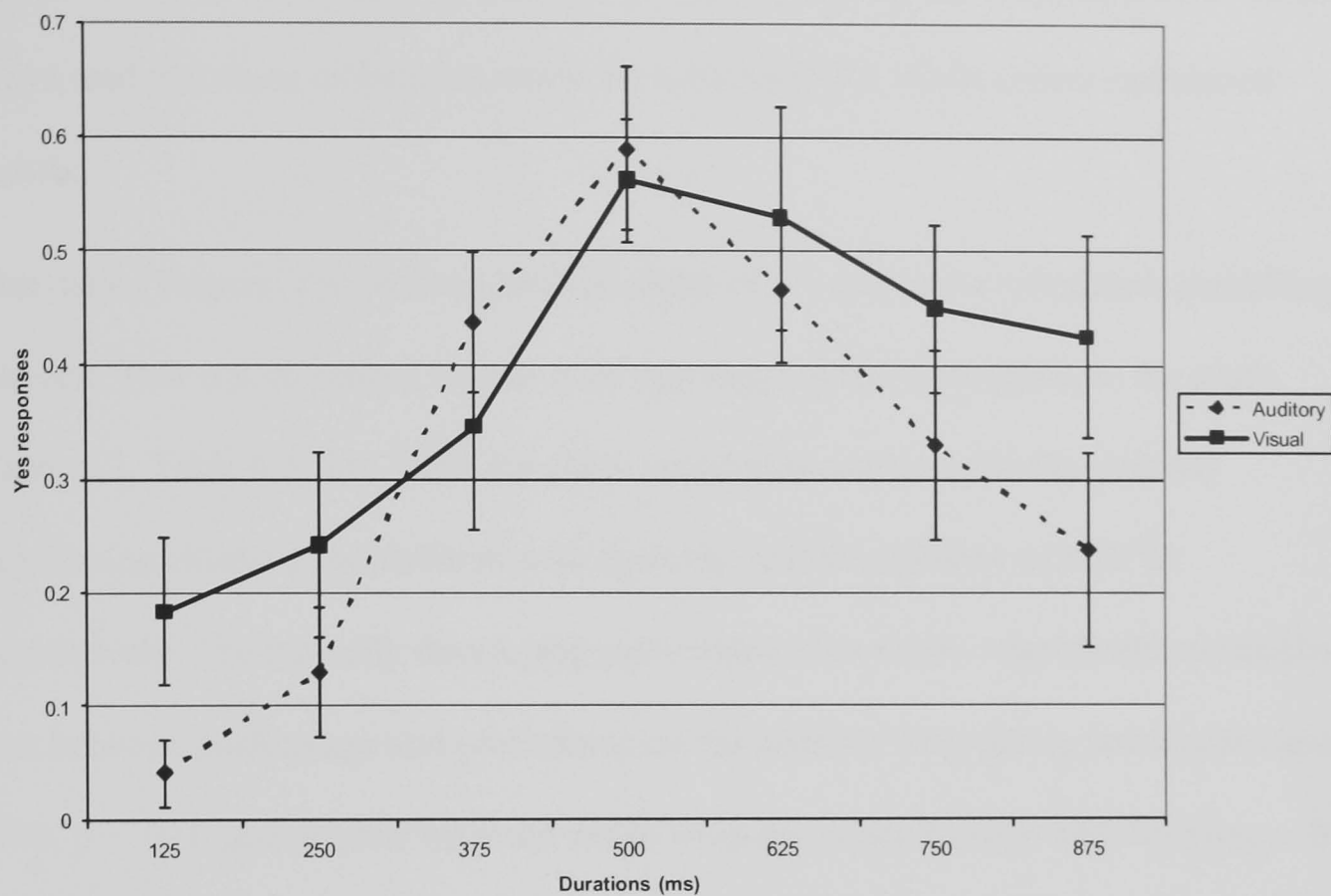


Figure 6.6 Comparison of the auditory temporal generalisation and the visual temporal generalisation responses across durations. The error bars are the 95% confidence intervals.

Finally, a t-test was carried out comparing the whole group's proficiency in the auditory temporal generalisation task with their proficiency on the visual temporal generalisation task. The results indicated that participants scored significantly higher on the auditory temporal generalisation task than on the visual temporal generalisation task, $t(29) = 3.130, p = 0.004$.

The third research question looked at whether the groups showed a similar relationship between the temporal generalisation tasks and the baseline measures of reading, threading and memory. In order to investigate further the relationship between the baseline measures of reading and threading and the auditory and visual temporal generalisation tasks, correlation coefficients were calculated. The decision was made to analyse the groups individually rather than collapsing the three participant groups into

one, as it was possible that the different groups might be processing the task in different ways, and that these differences would be concealed in a whole cohort correlation matrix.

One-tailed Pearson correlations, with an alpha of $p < 0.05$ were calculated, partialling out age. This was to control for the wide age range of the participants in the study.

Table 6.2, Table 6.3, and Table 6.4 show correlation matrixes for the typically developing children, the children with dyslexia, and the children with DCD respectively. The typically developing participants showed two significant correlations, one between reading age and proficiency on the auditory temporal generalisation task, $.740, p = .011$, and another between visual temporal generalisation and threading, $-.683, p = .031$. The participants with DCD showed a significant correlation between reading and the auditory temporal generalisation task, $.861, p = 0.001$ and also a significant correlation between threading and visual temporal generalisation, $.756, p = .009$. The pattern of significant correlations for this group appears the same as that of the typically developing children, but it is noteworthy that the direction of the threading and visual temporal generalisation correlation is opposite to that observed in the typically developing children. By comparison, the participants with dyslexia showed a significant correlation between reading and the *visual* temporal generalisation task, $.733, p = .012$.

Table 6.2 Correlation matrix for the *typically developing group*, one tailed, results controlled for age.

Test	1	2	3	4	5	6
Participants (n = 6)						
1. Auditory Temporal Generalisation	-	0.0763 p = .429	0.779 p = .011	-0.3145 p = .224	0.2748 p = .255	0.0471 p = .456
2. Visual Temporal Generalisation			0.2015 p = .316	-0.6828 p = .031	0.246 p = .279	0.2744 p = .255
3. Reading Age				-0.1212 p = .387	0.5553 p = .077	0.0727 p = .432
4. Threading speed					0.1023 p = .405	-0.4816 p = .113
5. Verbal Memory raw score						-0.2516 p = .274
6. Visual Memory Age						-

Table 6.3 Correlation matrix for the *group with dyslexia*, one tailed, controlling for age.

Test	1	2	3	4	5	6
Participants (n = 7)						
1. Auditory Temporal Generalisation	-	-0.1476 p = .352	-0.0743 p = .425	-0.3472 p = .180	-0.5085 p = .081	-0.1606 p = .340
2. Visual Temporal Generalisation			0.7332 p = .012	0.4253 p = .127	-0.2554 p = .254	-0.142 p = .358
3. Reading Age				0.205 p = .298	-0.0239 p = .476	-0.2762 p = .236
4. Threading speed					0.2355 p = .271	0.4536 p = .110
5. Verbal Memory raw score						0.1025 p = .397
6. Visual Memory Age						-

Table 6.4 Correlation matrix for the group with DCD, one tailed, results controlled for age.

Test	1	2	3	4	5	6
Participants (n = 7)						
1. Auditory Temporal Generalisation	-	-0.1741 p = .327	0.8609 p = .001	-0.043 p = .456	0.0907 p = .408	0.0416 p = .458
2. Visual Temporal Generalisation			0.0805 p = .418	0.7559 p = .009	-0.0934 p = .406	0.5542 p = .061
3. Reading Age				0.3011 p = .216	-0.2787 p = .234	0.298 p = .218
4. Threading speed					-0.4113 p = .136	0.5969 p = .045
5. Verbal Memory raw score						-0.1572 p = .343
6. Visual Memory Age						-

In examining Figure 6.4 there appeared to be a tendency for the children with dyslexia to show a more conservative approach to their judgements in temporal processing. It can be seen that the graph shows fewer 'yes' responses across almost all the data points for the experiment. In order to investigate the participants' sensitivity to the detection of the standard duration compared with the non-standard durations, signal detection analysis was used (Green and Swets, 1966). In this case, signal detection analysis was carried out to see whether the children had a tendency to respond with a 'miss', (where a standard duration was heard but judged non-standard), or a false alarm, (where the non-standard duration was judged to be a the standard duration). The analysis results in a measure of sensitivity to a stimulus relative to noise: d-prime. The results did not indicate that any of the groups were more conservative at detecting either the visual or the auditory signal relative to the noise. In addition, where possible bias was found it was in the same direction across all the groups Figure 6.5 provides a summary of the d-prime scores (d') for each of the groups. A one way ANOVA was calculated comparing

the three groups d' prime scores for the auditory temporal generalisation task, the result was non-significant, $F(2, 27) = 1.658, p = .209$, as was the ANOVA comparing the d' prime scores for the three groups in the visual temporal generalization task: $F(2, 27) = 0.144, p = .867$.

Table 6.5 Means and standard deviations for the d' in the temporal generalisation study.

	Typical			Dyslexia			DCD		
	M	SD	n	M	SD	n	M	SD	n
Aud. Temp. Gen. d'	-.595	1.504	10	.310	1.448	10	.483	1.305	10
Vis. Temp. Gen. d'	.190	1.214	10	.293	1.204	10	0	1.297	10

6.3.1. Internal Reliability of the Experimental Measures

Cronbach Alpha was calculated for the two tasks, no previous study has run internal reliability measures for this task and furthermore it was not possible to use the proficiency scores per trial as a measure for Cronbach alpha. This was as in some cases a child may have made no 'hits' and a number of 'false alarms' which results in a divide-by-zero error for that cell. As there were several of these there were too few participants able to be analysed. Consequently, each task (auditory and visual) resulted in two Cronbach alpha scores. One for the number of 'yes' responses a participant made to a non-standard stimulus. The other for the number of 'yes' responses made to a standard stimulus. The participants were used as one group, consequently, $n = 30$. Furthermore, this is possibly the first study to report Cronbach alphas for temporal generalisation type tasks.

For the auditory task: 'yes' to a standard stimulus ('hits') yielded a Cronbach alpha of .730, in comparison, 'yes' to a non-standard stimulus ('false alarms') yielded a Cronbach alpha of .816. For the visual task: responses to the standard stimulus ('hits') yielded a Cronbach alpha of .403 and 'yes to a non-standard stimulus ('false alarms') yielded a Cronbach alpha of .839. On the whole, the results can be considered to have a strong internal reliability, the only measure of concern is the 'hits' to visual stimuli. One area of concern is the low alpha value for the visual task responses to the standard stimuli. The children did appear to have difficulty with this condition. In particular, it is possible that this response required guesswork rather than judgement. This is likely to affect the generalisability of the findings.

6.4. Discussion

The aim of this study was to examine temporal generalisation ability, and to consider whether children with dyslexia and DCD share a deficit in this ability relative to typically developing children. The study had three research questions, which will now be dealt with in turn, followed by a discussion of the strengths and limitations of the study and recommendations for future research.

The first research question centred on whether children with dyslexia and children with DCD show a deficit in temporal generalisation judgements relative to typically developing children. Evidence from Nicolson et al. (1995) who studied children with dyslexia and from Williams et al. (1992) who studied children with DCD underpinned the suggestion that a temporal perception deficit might underlie both conditions. Similarly if these temporal perception deficits were part of a general deficit in temporal

processing proposed by Farmer and Klein (1995), then the groups would show deficits in both visual and auditory temporal generalisations.

The results indicated that this was not the case. There were no significant differences between the groups on either the profiles of temporal generalisation performance or on a proficiency score derived from correct responses and incorrect responses.

One possible explanation for this result is the difference in the age of the children in this study compared with those used in previous studies of temporal perception. Nicolson et al. (1995) had a group of participants who were younger than some of the children in this study (average age of nine years) and they noted that the level of acuity to temporal information does appear to improve with age. Williams et al. (1992) used a group with a wide age range of six to 10 years old. They also noted that the older children in this group were better than the young children. In addition, in typical development, temporal generalisation ability becomes more accurate with age, as shown by McCormack et al. (1999), Droit-Volet et al. (2001), and McCormack et al. (2004). In particular, it should be noted that the number of correct responses to the standard that was observed in this study on the measure of auditory temporal generalisation is roughly comparable to that of the undergraduate group in McCormack et al. (1999). It is therefore possible that after a certain age that the level of acuity in temporal perception is similar for all children and a temporal generalisation study involving younger children may have shown greater differences.

Another possibility is that the task demands for this task were different to those for the task used in the Nicolson et al. (1995) and Williams et al. (1992) studies. It has been argued by McCormack et al. (2004) that the task used here would be more difficult than the tasks used in the previous studies which involved children with dyslexia and

children with DCD. In these experiments, they presented their standard and then a comparison tone at each trial. In the study reported here, children were presented with a tone but were not presented with a clear comparison tone before each test tone. Instead, they were provided with feedback after each trial. The children were therefore required to store the duration of the tone in memory and compare it against the presented stimulus over a longer period of time than would have been required in the previous two studies. However if there had been a heavy memory load on this task, significant correlations would have been expected between temporal generalisation scores and the memory measures. None of the groups showed such a correlation.

With reference to the tasks used by Nicolson et al. (1995) and Williams et al. (1992) it may be possible for children to become confused as to which are the two comparison tones. They are presented with two tones, asked to respond and are then presented with another two tones. A lapse of attention could cause participants to be confused as to whether they are making judgements about the new set of tones, or the last tone from the previous presentation and the new tones. In this study of temporal generalisation, there was a clear end to each presentation in that feedback was given. In addition there were eight presentations to a block, leaving a clear demarcation between each block. It is possible, therefore, that Nicolson et al. (1995) and Williams et al. (1992) were testing some form of auditory attention or auditory memory rather than temporal processing ability.

The second research question looked at whether there were differences in the abilities of the children to judge the duration of stimuli in the auditory condition compared to the visual condition. Few studies have been conducted on comparing auditory and visual temporal generalisations; consequently this study provided an opportunity to compare

proficiency in the two modalities. A study by Jäncke et al. (2000) which compared auditory with visual tapping noted that there were differences in cortical activations between the two conditions. More closely related to temporal generalisation, Wearden et al. (1998) carried out a task similar to the temporal generalisation task described in this study. Using a sample of undergraduate students, they found that participants had more difficulties with visual judgements than auditory judgements. Their findings broadly indicated that the participants had more difficulty judging durations that were longer than the standard compared with durations shorter than the standard in the visual condition. This is a pattern reproduced in this study (see Figure 6.6). One possible explanation for the observed differences in the profiles of auditory and visual temporal generalisation is that there are two separate processes for auditory and visual temporal generalisation. Wearden et al. (1998) had suggested that both are based on the same central timer and pulse counter that counts duration but that it is affected by the different modalities in different ways. The pulses are slower in speed for visual stimuli than for auditory stimuli and, in addition, the threshold that shifts attention to counting the pulses is more variable for visual stimuli than for auditory stimuli. This suggestion could account for the findings seen here and in the earlier studies.

The third research question was concerned with whether the baseline scores in reading and threading were associated with auditory temporal generalisation and visual temporal generalisation? Although there were no differences found between groups, it was possible that there might be different patterns of association between the baseline and experimental tasks for each group that could be indicative of different cognitive approaches to the tasks.

As discussed in the introduction, auditory processing is considered to be important in reading (Snowling, 2000) whilst it is likely that threading would require elements of visual-spatial processing, and visual-motor integration (Parush et al., 1998). For the typically developing children, there was a significant correlation between auditory temporal generalisation proficiency and reading, and a significant correlation for visual temporal generalisation proficiency and threading. In both cases the direction was in terms of improvement through association, i.e. participants with high auditory temporal generalisation proficiency scores also had high reading ages, and children with high visual temporal generalisation proficiency scores had fast threading speeds. In contrast, the children with dyslexia showed only a significant correlation between visual temporal generalisation proficiency and reading and here, the children with a high visual temporal generalisation proficiency score had the higher reading ability within this group. The children with DCD showed a different profile: as with the typically developing children there was a significant positive association between auditory temporal generalisation proficiency and reading, however children with DCD who had a high visual temporal generalisation proficiency score had the slowest threading scores.

The typical profile of correlations would suggest that there are common processes in auditory temporal generalisation and reading. However there was no correlation for typically developing children in visual temporal generalisation proficiency and reading, this would suggest less reliance on the visual features of words when reading for children in this age group. This would be in line with the argument that auditory processes are more critical than visual processes are in reading, as detailed in Chapter One. Auditory temporal perception might be associated with the development of phonological representations in reading development, a position argued by Tallal

(1984). However, phonological awareness was not assessed in this study, so this requires further investigation, and the direction of such an association requires particular attention. It would also seem reasonable to suggest that children who have good visual temporal perception may also exhibit better hand eye-coordination as measured by a task like threading.

In the group of children with dyslexia, the correlation between reading ability and *visual* temporal generalisation proficiency is intriguing. That is, the children in this group who were more adept at the visual task were at the higher end of the reading ability for this group. For example, one child with dyslexia had a high visual temporal generalisation proficiency (but a low auditory temporal generalisation proficiency score) and had a word reading age nine months ahead of his chronological age. It may be that a substantial subset of these children have poorer auditory temporal perception and weaker phonological representations. As a result they may come to rely more on their visual skills to become skilled readers. The participants with dyslexia also showed no significant correlation between threading and either the visual temporal generalisation proficiency or threading and the auditory temporal generalisation proficiency task. However their threading ability was comparable to that of the typically developing children. It is possible that there are other strategies in threading that do not require a reliance on visual temporal awareness and these may have been employed by the children with dyslexia. However, how visual temporal perception might contribute to skilled reading is not immediately clear. One possibility is that children with dyslexia might be more reliant on the visual features of words to compensate for deficiencies in phonological awareness. Van der Leij and Van Daal (1999) found that children with dyslexia were more reliant on some forms of orthographic information when decoding

non-words. However, this strategy is still likely to be a disadvantage as children with dyslexia have fewer skills at their disposal when encountering unfamiliar words and non-words.

Finally, the children with DCD showed a strong significant positive correlation for auditory temporal generalisation proficiency and reading, which is consistent with the pattern observed in the typically developing children. However, the positive correlation observed in this group between visual temporal generalisation proficiency and threading speed suggests that there is some form of visual difficulty. That is, the children who scored highly on the visual temporal generalisation task, had the *slowest* speeds of threading for their group – the opposite of what was found to be the case for the typically developing children. Parush et al. (1998) suggested that children with DCD there may have an immaturity in the integration system between motor processing and perception. This would cause these systems to be less separate than they would be in typically developing children. The implication would be that the visual and motor processing systems would be more prone to interference. This could explain the results that the children with DCD exhibit in this study. They may have been the children with DCD who had the greatest interference between visual and motor systems.

Strengths and limitations of the study will now be considered. A strength of the study is that it was based on a task that has been extensively used in prior research.

Consequently, there was an existing literature relating to adults and typically developing children that had established this as a temporal perception task. This study extends the current research into temporal generalisation and, more widely, temporal processing.

The findings suggest that temporal generalisation ability may be implicated in reading and coordination tasks, but this would require further investigation. What this study has

shown is that children with dyslexia and children with DCD of this age group do not differ significantly with respect to temporal generalisation. It would seem, therefore, that any deficits in temporal perception that are apparent at a younger age may be recoverable during the course of childhood development, although the ability to apply these skills appropriately to reading and coordination tasks may be more limited than is apparent in typically developing children.

An unusual feature of previous temporal generalisation studies is that feedback is provided throughout the task. The use of feedback was in line with much of the research using temporal generalisations (e.g. Wearden, 1991, McCormack et al. 1999, and Droit-Volet, et al., 2001) no paper provides an explanation as to why this procedure might be employed but might date back to Church and Gibbon (1982) whose temporal generalisation tasks with rats included a reinforcement schedule for responses to standard stimuli. The feedback is, therefore, included in this study to allow comparability with previous studies. One possible implication is that participants could continue to learn which duration is the 'standard' and which ones are not throughout the task. However, as yet, there is no empirical research comparing reinforcement and non-reinforcement temporal generalisation tasks.

Another area of further research prompted by the results of this study is to examine the TOJ abilities of the three groups, as this would take the assessment of temporal information processing beyond purely responses to a stimulus and also require participants to process the nature of those stimuli. In addition, the possibility of visual processing difficulties in children with DCD suggests that comparing performance on a visual form of this task to the more standard auditory version of the paradigm may also

elicit further information about the nature of some of the difficulties experienced by children with DCD.

In summary, Study Three was designed to look at auditory and visual temporal generalisations (temporal perception). The main area of investigation was whether common temporal perception deficits could be found between children with dyslexia and children with DCD. However the study found that there were no group differences on the task. Evidence was found that the processes required in visual and auditory processing of temporal generalisations may also be associated with other processes such as reading and threading and that the patterns of association were different for the children with dyslexia, children with DCD, and typically developing children.

7. Study Four: Temporal Order Judgement

7.1. Introduction

The main aim of this thesis was to investigate the idea that children with dyslexia and children with DCD may ‘share’ a similar profile of temporal processing deficits. The study in Chapter Six explored the possibility that there might be an underlying temporal generalisation deficit in both dyslexia and DCD. That study, in line with the previous chapters, found little evidence of a shared deficit. The study outlined in this chapter aimed to extend these findings by looking at the ability of children with dyslexia and DCD to process rapid sequential information through the use of a TOJ paradigm.

Much of the research into TOJ ability, as discussed in Chapter One, has been conducted on children with a specific language impairment or dyslexia, (for example, Tallal, 1980, and Farmer and Klein, 1995). However, studies such as Williams et al. (1992) and Piek and Skinner (1999), using different paradigms, have found evidence of other temporal processing deficits in children with DCD. In contrast, the studies so far in this thesis have not found clear evidence of a temporal processing deficit. However, it is possible that the behavioural characteristics of DCD could be linked to difficulties in rapidly processing sequential information and that a deficit may be apparent on a TOJ task.

One of the earliest studies of TOJ was conducted by Tallal (1980). She tested 20 children with dyslexia (average age: nine years, seven months) and 20 typically developing children (average age: eight years, six months). She further divided these participant groups in half. Ten children with dyslexia and ten typically developing children carried out a sequencing task, whilst the other half completed a same/different task.

In the sequencing test the children had to copy a sequence of two tones by pressing buttons on a panel. Initially these tones were separated by an ISI of 428 ms. After the children had completed the practice test, they were asked to reproduce the tone sequences that they heard, but this time the two tones were separated by one of several ISIs: 8 ms, 15 ms, 30 ms, 60 ms, 150 ms, or 305 ms. The same / different subtest followed the same procedure, but required participants to respond, by pressing buttons, 'yes' if the two tones they heard were the same or 'no' if they were not. In addition to this, Tallal gave participants various baseline measures, including a task of non-word reading.

Tallal found that all the children were able to complete the sequencing and the same/different task when the ISI was 428 ms. But as the ISI became shorter the performance of both groups became worse. Between groups analysis indicated that the group with dyslexia were significantly less accurate at the task than the typically developing children. However, on closer inspection of the dyslexia group, she found that although some children were performing very inaccurately at the task, many were performing in line with the typically developing children. It was clear that the proficiency of both groups overlapped greatly. Tallal also found a strong significant positive correlation between non-word reading and the sequencing task. She argued that children who were poor at pure tone auditory perception were also poor at the types of skills required to complete the non-word reading task successfully, such as phonemic awareness. Tallal (1984) went further and argued that failure to process rapidly changing acoustic information was a central underlying deficit in dyslexia. Support for this has come from a training study by Tallal et al. (1997) who found that training children in processing acoustic information resulted in improved reading performance.

However, since Tallal (1980) many studies have had difficulty replicating her findings. For example, Marshall et al. (2001) were able to partly replicate the findings but the poor reading group's inaccurate performance on this task was, again, only attributable to a small number of poor readers. When these readers were studied in detail, they appeared to be no better or worse on measures of phonological awareness and reading than the poor readers who did well on the TOJ task. Bretherton and Holmes (2003) took a different approach and compared children's performance on tonal TOJ, speech segment TOJ, and their rapid perception of shapes. If the deficit had been as widespread as argued by Tallal (1984) then they would have expected deficits in both tonal, speech, and possibly shape TOJs. However, they only found deficits when speech segment stimuli were used, which may suggest a deficit of a specific phonological nature rather than one of processing rapidly changing information. Further evidence that speech perception difficulties may be a more salient deficit than TOJ is has come from Mody et al. (1997).

Nevertheless, the possibility that difficulties in processing rapidly changing information across a range of modalities is implicated in both reading and movement difficulties has yet to be systematically studied. In particular, this study will consider three aspects that have so far been neglected by research in this area. First, the majority of studies have focussed on accuracy and consequently the role of reaction time has not been fully explored. Second, few studies have used stimuli other than tones or phonemes to study TOJ; consequently this study aims to assess performance on both visual and acoustic stimuli. Finally, no study has yet directly assessed the TOJ ability of children with DCD.

In view of the overall aim of the thesis, to examine possible underlying common processes in dyslexia and DCD, the previous research has therefore led to five research questions.

1. Do children with dyslexia and DCD have a deficit in accuracy scores on a TOJ task compared with typically developing children?
2. Do children with dyslexia and DCD have slower reaction times on a TOJ task compared with typically developing children?

It is predicted that children with dyslexia and DCD will show less accurate and slower responses on a TOJ task relative to the performance of typically developing children.

3. Are the children's accuracy responses and reaction times affected by stimulus type?

In line with Bretherton & Holmes (2003) and Mody et al (1997), it is predicted that there will be significant differences in accuracy of response, and in reaction time, across the various stimulus conditions of the TOJ task.

4. Do the TOJ tasks correlate with the baseline measures for the typically developing children, children with dyslexia, and the children with DCD?

It will be recalled that Tallal (1980) found a significant correlation between performance on the TOJ task and non-word reading ability. As a result, it is expected that there will be a significant association between TOJ performance and the baseline measures within each of the three participant groups, such that as proficiency on the baseline measures increases, accuracy scores on the TOJ task will also increase and reaction time scores will decrease.

7.2. Method

7.2.1. *Participants*

The participants who took part in this study were those from the second data collection phase. Details of these participants can be found in Chapter Two. A summary of the descriptive measures for this group can be found in Table 7.1.

7.2.2. *Test Materials*

Four baseline measures were recorded in addition to the TOJ task: reading age, spelling age, verbal memory, and vocabulary. Details of the procedures for these measures can be found in the Methodology Chapter. Each participant was tested individually in one 45 minute session. Within this session, the order of the tests was counterbalanced.

Specifications used for the laptop can also be found in the Methodology Chapter. The auditory stimuli were presented using earphones at a volume that was comfortable for the participants. A Kensington Trackball Pro roller-ball mouse was used to interface with the computer. Software for the TOJ program was written by the author.

The temporal order judgement task: This task consisted of two phases: the familiarisation phase followed by test phase. The familiarisation phase consisted of two of the four possible stimulus pairs that would be encountered in the test phase.

Participants were required to identify the correct sequence of stimuli in both pairs. The practice stimuli were presented with a 300 ms ISI. A single trial consisted of the first stimulus being presented, followed by the interstimulus interval, then the second stimulus being presented. The participant then had to respond by clicking on the buttons that became active on the left and the right of the screen which were labelled with

symbols to describe the stimuli he or she had just seen (see Figure 7.1 for a screenshot sequence). The computer provided feedback as to whether the response was correct or incorrect and verbal feedback and support was provided if the child appeared to be having particular difficulties. All of the children completed the familiarisation phase and could not proceed to the test phase until the stimuli sequences were successfully completed in the familiarisation phase.

In the test phase, each condition consisted of eight blocks of trials. Each block consisted of one presentation of the stimulus pair with a short ISI (10 ms), and one with the long ISI (300 ms). Within a block, the order of the presentations was randomised. The software recorded two dependent measures from each response: reaction time and accuracy. No feedback was given during the test trials.

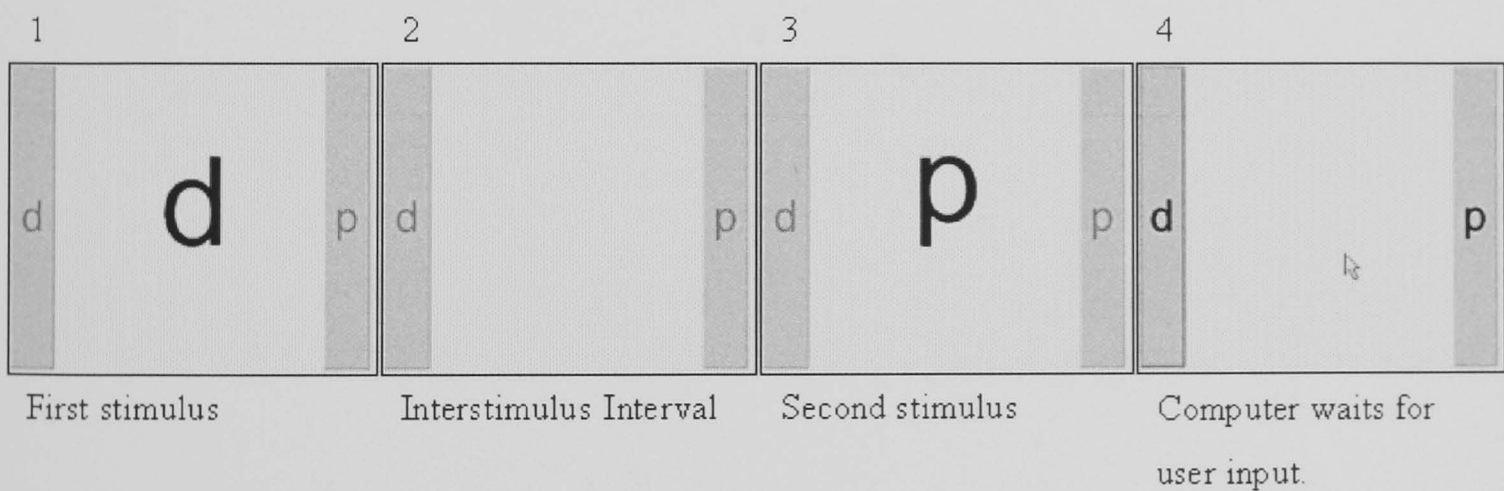


Figure 7.1 Stimulus presentations for the letters condition of the TOJ task.

There were four different stimulus pair conditions: letters, shapes, tones, and speech. The letter pairs were the letters “d” and “p” which displayed in Arial font at 72 point size. The shapes were a circle and an octagon; the circle was 5 cm in diameter and the octagon was a similar size. In the tones condition, the two tones used were high, at 500 Hz, and low, at 300 Hz. The speech stimuli were the speech segments “ba” and “da”.

They were recorded digitally using a male voice and altered to ensure that the formant transition in both was similar and that the two speech segments were of equivalent duration. The “b” and “d” sounds were around 40 ms in duration; the “a” sound was around 210ms in duration. Each condition yielded four separate stimulus pairs, for example in the letter condition, the pairs were “dd”, “dp”, “pd”, and “pp”. All the stimuli were presented for 250 ms in duration. At the beginning of each new test item the cursor was reset to the centre of the screen

7.3. Results

A summary of the descriptive statistics for both the baseline measures and the experimental measures can be found in Table 7.1.

Table 7.1 Means and Standard Deviations of the three groups across all the measures.

	Typical			Dyslexia			DCD		
	M	SD	n	M	SD	n	M	SD	n
Baseline Measures									
Age (in months)	133.400	13.932	15	136.462	12.653	13	137.286	11.368	7
Verbal Memory Raw Score	6.133	1.642	15	4.385	1.044	13	4.714	1.113	7
Vocabulary Raw Score	34.467	7.482	15	31.154	4.598	13	35.286	6.775	7
Reading age (in months)	167.400	28.306	15	110.385	18.090	13	117.857	21.396	7
Spelling age (in months)	152.600	25.804	15	104.462	19.016	13	108.143	22.401	7
Phonology Condition									
Phonology accuracy short ISI	0.867	0.068	15	0.766	0.122	12	0.862	0.065	7
Phonology accuracy long ISI	0.898	0.100	15	0.810	0.108	12	0.884	0.053	7
Phonology reaction time short ISI	1815.165	327.697	15	1971.919	439.259	12	2161.045	514.986	7
Phonology reaction time long ISI	1764.096	314.207	15	2077.609	425.755	12	2054.964	478.191	7
Shape Condition									
Shape accuracy short ISI	0.910	0.060	15	0.895	0.064	11	0.897	0.080	7
Shape accuracy long ISI	0.933	0.042	15	0.906	0.079	11	0.906	0.068	7

Table 7.1 Means and Standard Deviations of the three groups across all the measures. Continued.

	Typical			Dyslexia			DCD		
	M	SD	n	M	SD	n	M	SD	n
Shape reaction time short ISI	1735.102	343.139	15	1771.690	411.670	11	2174.071	571.954	7
Shape reaction time long ISI	1829.327	338.207	15	1731.696	308.091	11	2193.393	578.924	7
Tone Condition									
Tone accuracy short ISI	0.702	0.290	15	0.659	0.249	13	0.629	0.260	7
Tone accuracy long ISI	0.763	0.298	15	0.733	0.286	13	0.714	0.314	7
Tone reaction time short ISI	2106.725	366.509	15	2177.947	395.427	13	2663.344	973.905	7
Tone reaction time long ISI	2066.975	366.945	15	2294.227	346.573	13	2459.299	908.573	7
Letters Condition									
Letters accuracy short ISI	0.935	0.058	15	0.870	0.093	13	0.938	0.057	7
Letters accuracy long ISI	0.915	0.087	15	0.882	0.090	13	0.915	0.088	7
Letters reaction time short ISI	1745.675	293.399	15	1826.726	369.740	13	2014.250	597.413	7
Letters reaction time long ISI	1869.647	346.883	15	1937.587	333.568	13	2291.946	902.185	7

The first research question was: ‘Do children with dyslexia and DCD have a deficit in accuracy scores on a TOJ task compared to typically developing children?’ There were eight conditions in total (phonological, sounds, letters, and shapes, each with two ISIs: long and short). Analysis using Shapiro Wilks indicated that the data did not meet the assumptions for parametric data, consequently, analysis was carried out using Kruskal Wallis. Significant differences were found in two of the eight measures: the accuracy of the phonological TOJs for short ISI, $\chi^2 = 6.705$, $df = 2$, $p = 0.035$, and long ISI, $\chi^2 = 7.355$, $df = 2$, $p = 0.025$. Dunn’s Multiple Comparisons Test indicated that in both cases, the children with dyslexia were less accurate than the typically developing children, indicating a deficit in performance. However, the performance of the children with DCD was not significantly different to the other two groups with respect to accuracy of responses. Furthermore, the three groups did not differ significantly in their accuracy scores on any of the other measures (see Table 7.2 for the details of the Kruskal Wallis results of all the accuracy measures and Figure 7.2. for a bar chart of the results).

Table 7.2 Kruskal Wallis analysis of the accuracy data of the TOJ task.

	χ^2	df	p =
Phonology accuracy short ISI	6.705	2	0.035
Phonology accuracy long ISI	7.355	2	0.025
Shape accuracy short ISI	0.519	2	0.772
Shape accuracy long ISI	0.949	2	0.622
Tone accuracy short ISI	0.886	2	0.642
Tone accuracy long ISI	0.282	2	0.869
Letters accuracy short ISI	4.845	2	0.089
Letters accuracy long ISI	1.769	2	0.413

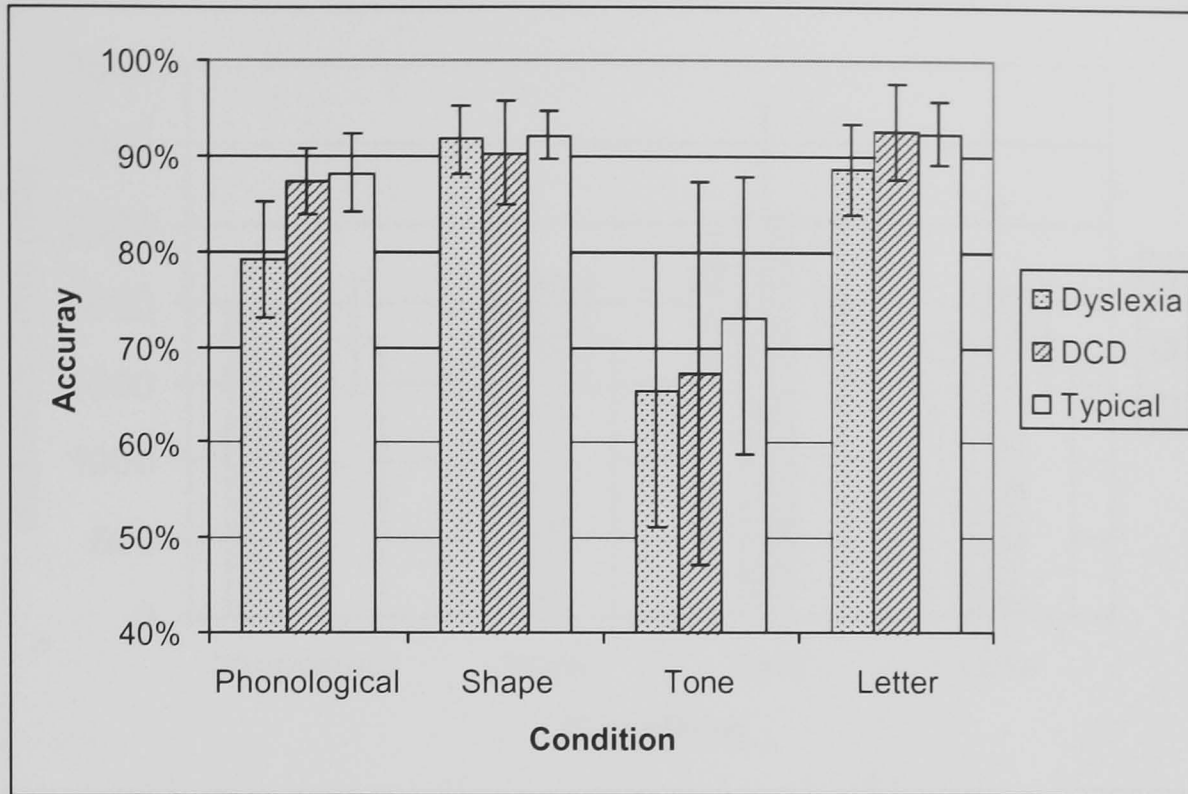


Figure 7.2 Comparison of the accuracy of the children with dyslexia, DCD, and typically developing children across the four conditions. The bars represent a composite of the long and short ISI conditions and the error bars are for 95% confidence levels.

The second research question centred on whether there were any significant differences between the three groups on reaction time measures. Analysis using Shapiro-Wilks indicated that the speech measures violated the assumptions of parametric analysis. Consequently all the reaction time measures were analysed using Kruskal Wallis. The results indicated no significant differences across the groups for any of the conditions (see Table 7.3 for the detail of the results of this analysis and Figure 7.3 for a bar chart of the results). Overall, the results suggest that the three groups were able to respond to the task at comparable speeds.

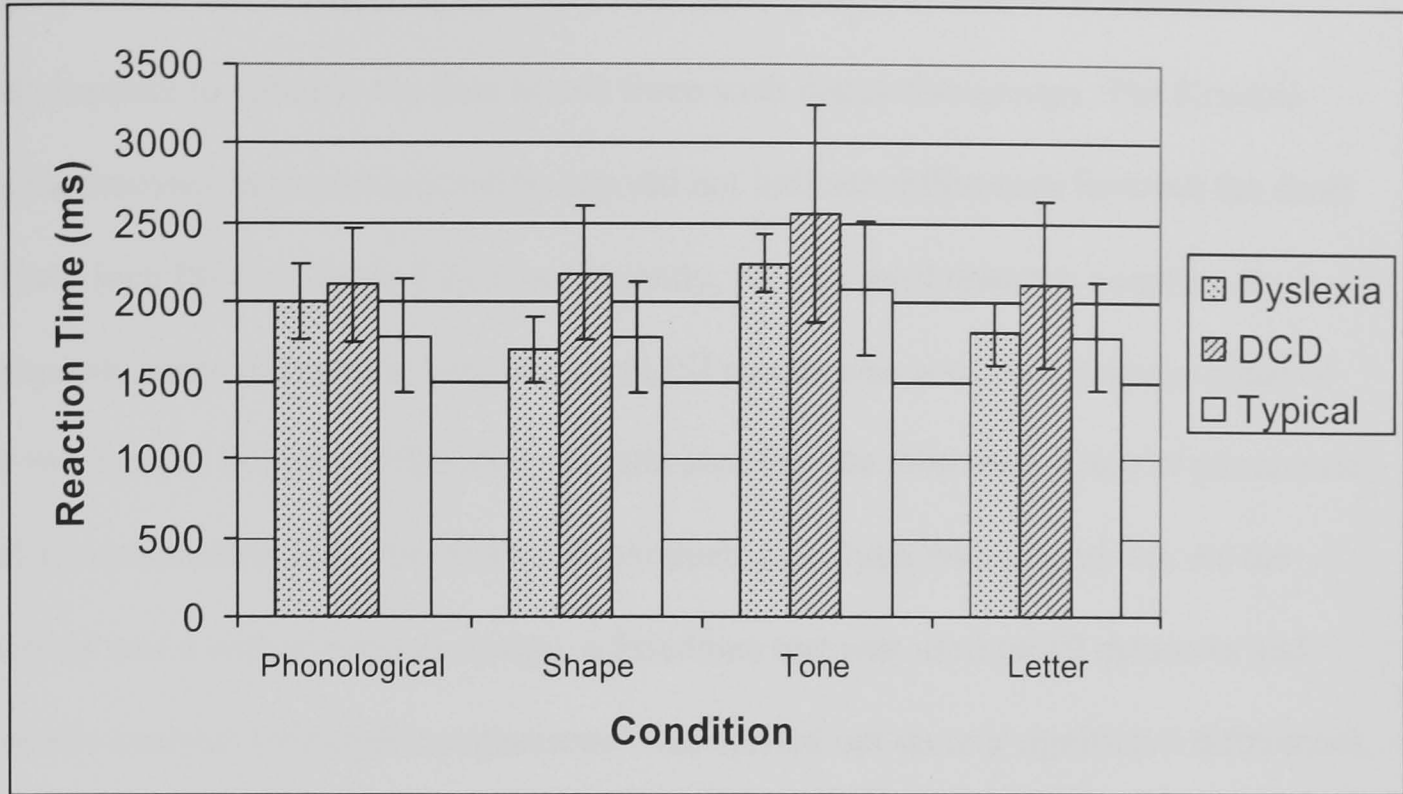


Figure 7.3 Comparison of the reaction times of the children with dyslexia, DCD, and typically developing children across the four conditions. The bars represent a composite of the long and short ISI conditions and the error bars are for 95% confidence levels.

Table 7.3 Between Groups Analysis of the Reaction Time Measures of the TOJ Task

Kruskal Wallis	χ^2	df	p =
Speech short ISI	2.914	2	.233
Speech long ISI	3.645	2	.162
Shape short ISI	3.459	2	.177
Shape long ISI	3.846	2	.146
Tone short ISI	1.455	2	.483
Tone long ISI	2.279	2	.320
Letters short ISI	0.875	2	.646
Letters long ISI	1.948	2	.378

The third research question asked whether there were significant differences in accuracy and reaction time scores across the phonological, tone, shape, and letter TOJ conditions.

This question was considered for each of the three groups in turn, as it would be inappropriate to collapse the data across three such distinctive groups. The Kruskal-Wallis analyses in research question one did not indicate differences between the short ISI and long ISI (see Table 7.2). Consequently, for this third research question, a composite score of both the long and short ISI results was used by taking the mean of the two results. Shapiro Wilks analysis indicated that the data were a mix of parametric and non-parametric data, therefore non-parametric analysis was carried out. As the analysis was a within subjects design, a Friedman test was used on all measures and post hoc analysis (Multiple comparisons) was carried out on any significant differences.

There was a significant difference for each of the three groups and the results were as follows. There was a significant difference between conditions for the typically developing children, $\chi^2 = 10.756$, $df = 3$, $p = 0.013$. Multiple comparisons analysis indicated that their accuracy for the tone condition was significantly lower than it was in the letter condition. A significant difference between conditions was found for the children with dyslexia, $\chi^2 = 12.818$, $df = 3$, $p = 0.005$. Multiple comparisons found that the children with dyslexia were also significantly less accurate at the tone condition compared to the letter condition.

Finally, there was a significant difference for the children with DCD, $\chi^2 = 6.705$, $df = 2$, $p = 0.002$. Multiple comparisons analyses indicated two differences, one where the children were significantly less accurate at the tone condition compared with the shape condition, and another where they were less accurate at the tone condition compared with the letter condition (as was found to be the case in the other two groups). The differences are illustrated in Figure 7.2.

In terms of reaction times, the children's results followed a similar pattern to the accuracy scores across the conditions, in that the tone condition appeared to be the most difficult one to respond quickly to. For example, there was a significant difference between conditions for typically developing children, $\chi^2 = 13.560$, $df = 3$, $p = 0.004$, and tests of multiple comparisons found that the children showed a significantly slower reaction time in the tone condition compared with the phonological stimuli condition and a significantly longer reaction time in the tone condition compared with the shape condition. The children with dyslexia also showed a significant difference in their reaction times across conditions of the task, $\chi^2 = 16.440$, $df = 3$, $p = 0.001$. Here the multiple comparisons test indicated that the children had significantly slower reaction times for the tone condition compared with the shape condition. No significant differences in reaction times were found for the children with DCD, $\chi^2 = 2.486$, $df = 3$, $p = 0.478$. The differences are illustrated in Figure 7.3.

Research question four was concerned with whether the experimental measures correlated with the baseline measures for the three groups. As the data were non-parametric, one tailed Spearman's Rho correlations were used. For the experimental measures the composite scores were again used, as in research question three.

For the typically developing children, there were no significant correlations between baseline measures and the TOJ *accuracy* measures, possibly an artefact of the high accuracy rates. However, there were significant correlations between the baseline measures and the TOJ *reaction time* measures. The phonological TOJ reaction time correlated with age, -0.459 , $p = .043$, verbal memory -0.455 , $p = .044$, vocabulary -0.770 , $p < .0001$, reading age -0.500 , $p = .029$, and spelling age -0.445 , $p = .048$. As age correlated with many of the measures, it was partialled out of the (one tailed) correlations. When

this was done, only one significant correlation remained: verbal memory, $-.744$, $p = .001$. The tone TOJ reaction times for this group correlated with age, $-.513$, $p = .012$.

Reaction times from the 'shape' condition correlated with vocabulary, $-.514$, $p = 0.025$,

and the reaction times from the 'letter' condition correlated with age, $-.482$, $p = 0.034$.

Table 7.4 shows the correlation matrix for the accuracy scores, whilst Table 7.5 shows the correlation matrix for the reaction times of the typically developing children.

Table 7.4 Correlation matrix for TOJ accuracy and baseline measures in typically developing children.

Test	6. Phon. accuracy	7. Tone accuracy	8. Shape accuracy	9. Letters accuracy
Participants (n = 15)				
1. Age - Months	$-.240$ $p = .194$	$.151$ $p = .295$	$-.295$ $p = .143$	$-.057$ $p = .420$
2. Recall Digits Backwards	$-.020$ $p = .472$	$.172$ $p = .269$	$.092$ $p = .373$	$-.254$ $p = .180$
3. Vocabulary	$.114$ $p = .343$	$.373$ $p = .085$	$-.086$ $p = .381$	$.210$ $p = .227$
4. Reading age	$-.101$ $p = .359$	$.066$ $p = .407$	$-.160$ $p = .285$	$.035$ $p = .451$
5. Spelling age	$-.033$ $p = .454$	$-.167$ $p = .276$	$-.209$ $p = .228$	$-.098$ $p = .364$
6. Phonology accuracy		$.189$ $p = .250$	$.395$ $p = .072$	$.515$ $p = .025$
7. Tone accuracy			$-.133$ $p = .318$	$.313$ $p = .128$
8. Shape accuracy				$.632$ $p = .006$
9. Letters accuracy				-

Table 7.5 Correlation matrix for TOJ reaction times and baseline measures in *typically developing children*.

Test	6. Phon. accuracy	7. Tone accuracy	8. Shape accuracy	9. Letters accuracy
Participants (n = 15)				
1. Age - Months	-.240 p = .194	.151 p = .295	-.295 p = .143	-.057 p = .420
2. Recall Digits Backwards	-.020 p = .472	.172 p = .269	.092 p = .373	-.254 p = .180
3. Vocabulary	.114 p = .343	.373 p = .085	-.086 p = .381	.210 p = .227
4. Reading age	-.101 p = .359	.066 p = .407	-.160 p = .285	.035 p = .451
5. Spelling age	-.033 p = .454	-.167 p = .276	-.209 p = .228	-.098 p = .364
6. Phonology accuracy		.189 p = .250	.395 p = .072	.515 p = .025
7. Tone accuracy			-.133 p = .318	.313 p = .128
8. Shape accuracy				.632 p = .006
9. Letters accuracy				- -

For the children with dyslexia, phonological TOJ reaction times correlated positively with vocabulary, $.572, p = .026$. This was a direction contrary to that of the typically developing children, in that here, the children with high vocabulary scores had slow phonological TOJ reaction times. In addition, the letters condition reaction time scores correlated with vocabulary, and again, children with high vocabulary scores had the slower reaction times, $.479, p = .049$. Even though letters condition reaction time scores also correlated with age, $-.506, p = .039$, the correlation between vocabulary TOJ reaction time and phonology TOJ reaction time remained once age had been controlled for, $.704, p = .008$. Age was also a correlate for tone condition reaction times, $-.697, p = .009$, and shape condition reaction times, $-.534, p = 0.030$. In all these cases, older

children had faster TOJ reaction times. Table 7.6 shows the correlation matrix for accuracy, whilst Table 7.7 shows the correlation matrix for reaction time for the children with dyslexia.

Table 7.6 Correlation matrix for accuracy and baseline measures in *children with dyslexia*.

Test	6. Phon. accuracy	7. Tone accuracy	8. Shape accuracy	9. Letters accuracy
Participants (n = 13)				
1. Age - Months	-.011 p = .487	.107 p = .364	.110 p = .373	-.014 p = .482
2. Recall Digits Backwards	.092 p = .388	-.289 p = .169	-.403 p = .109	-.165 p = .295
3. Vocabulary	-.167 p = .302	.391 p = .093	.111 p = .373	-.257 p = .198
4. Reading age	-.347 p = .134	.330 p = .135	.069 p = .420	.152 p = .310
5. Spelling age	-.161 p = .308	.371 p = .106	.002 p = .497	.015 p = .480
6. Phonology accuracy		.301 p = .171	.677 p = .016	-.317 p = .158
7. Tone accuracy			.376 p = .127	-.461 p = .057
8. Shape accuracy				.014 p = .484
9. Letters accuracy				- -

There were two significant correlations between the baseline measures and the TOJ measures for the children with DCD. Age correlated with phonological reaction times, -.714, $p = .036$, and tone condition reaction times, -.786, $p = .018$. Table 7.7 shows the correlation matrix for accuracy, whilst Table 7.8 shows the correlation matrix for reaction time for the children with DCD.

Table 7.7 Correlation matrix for accuracy and baseline measures in *children with DCD*.

Test	6. Phon. accuracy	7. Tone accuracy	8. Shape accuracy	9. Letters accuracy
Participants (n = 7)				
1. Age - Months	.541 p = .105	-.127 p = .393	.179 p = .351	.000 p = .500
2. Recall Digits Backwards	.315 p = .246	-.122 p = .398	.147 p = .377	.305 p = .253
3. Vocabulary	.432 p = .166	.018 p = .485	.214 p = .322	.037 p = .469
4. Reading age	.306 p = .252	-.436 p = .164	-.393 p = .192	-.334 p = .232
5. Spelling age	-.018 p = .485	-.473 p = .142	-.500 p = .127	-.408 p = .182
6. Phonology accuracy		.257 p = .289	.487 p = .134	.430 p = .168
7. Tone accuracy			.691 p = .043	.811 p = .013
8. Shape accuracy				.741 p = .028
9. Letters accuracy				- -

Table 7.8 Correlation matrix for reaction times and baseline measures in *children with DCD*.

Test	6. Phon. RT	7. Tone RT.	8. Shape RT	9. Letter RT
Participants (n = 7)				
1. Age - Months	-.714 p = .036	-.786 p = .018	-.286 p = .267	-.071 p = .440
2. Recall Digits Backwards	-.110 p = .407	-.055 p = .453	.092 p = .422	-.092 p = .422
3. Vocabulary	-.143 p = .380	-.393 p = .192	.179 p = .351	.429 p = .169
4. Reading age	-.393 p = .192	-.143 p = .380	-.536 p = .108	.071 p = .440
5. Spelling age	-.429 p = .169	-.107 p = .410	-.571 p = .090	-.250 p = .294
6. Phonology reaction time		.929 p = .001	.750 p = .026	.357 p = .216
7. Tone reaction time			.536 p = .108	.286 p = .267
8. Shape reaction time				.214 p = .322
9. Letters reaction time				- -

This study did not find significant difference in tone TOJ accuracy between groups, however the children were less accurate at tone TOJ compared to other conditions.

Previous research has examined whether some children in particular experience tone TOJs difficulties and whether this is related to baseline measures. For example, Marshall et al. (2001) observed that the significant difference between children with dyslexia and typically developing children in her tonal condition was due to a small subgroup of children with dyslexia who performed poorly at the task. However, these children did not differ from their cohort when compared to other baseline measures. A similar analysis here might allow new insights into how the baseline measures might relate to TOJ accuracy. For the first step, individual children were compared by group, Figure 7.4 shows a scatter plot of this data.

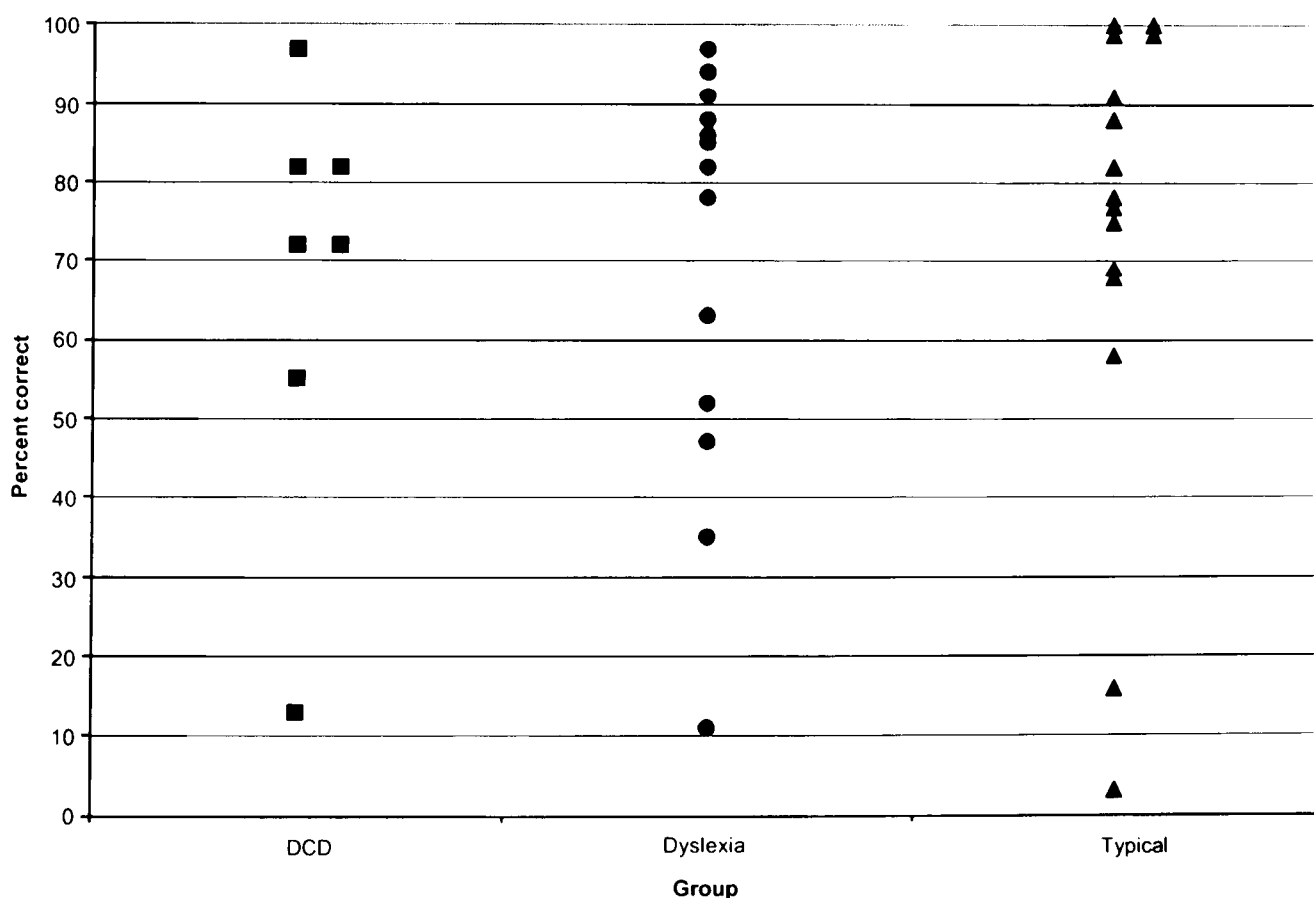


Figure 7.4 Scatter plot depicting individual participant's accuracy scores for the tone TOJ task. Note two typical participants and one participant in each of the special needs groups scored below chance (25% accuracy).

Four participants, two typically developing children, and one child each in the group with dyslexia and the group with DCD performed below chance for tone TOJ, chance being 25% as there was a 1 in 4 chance of responding correctly by guessing (high-high, high-low, low-high, or low-low). As it was only a very small number of participants per group, it was decided not to carry out statistical analysis but to compare the participants against the baseline measures of their own groups. For this, the mean scores for the cohort were re-calculated without the participant(s) who performed inaccurately and bar graphs were produced. The results for each group can be seen in Figure 7.5 for typically developing children, Figure 7.6 for children with dyslexia, and Figure 7.7 for children with DCD.

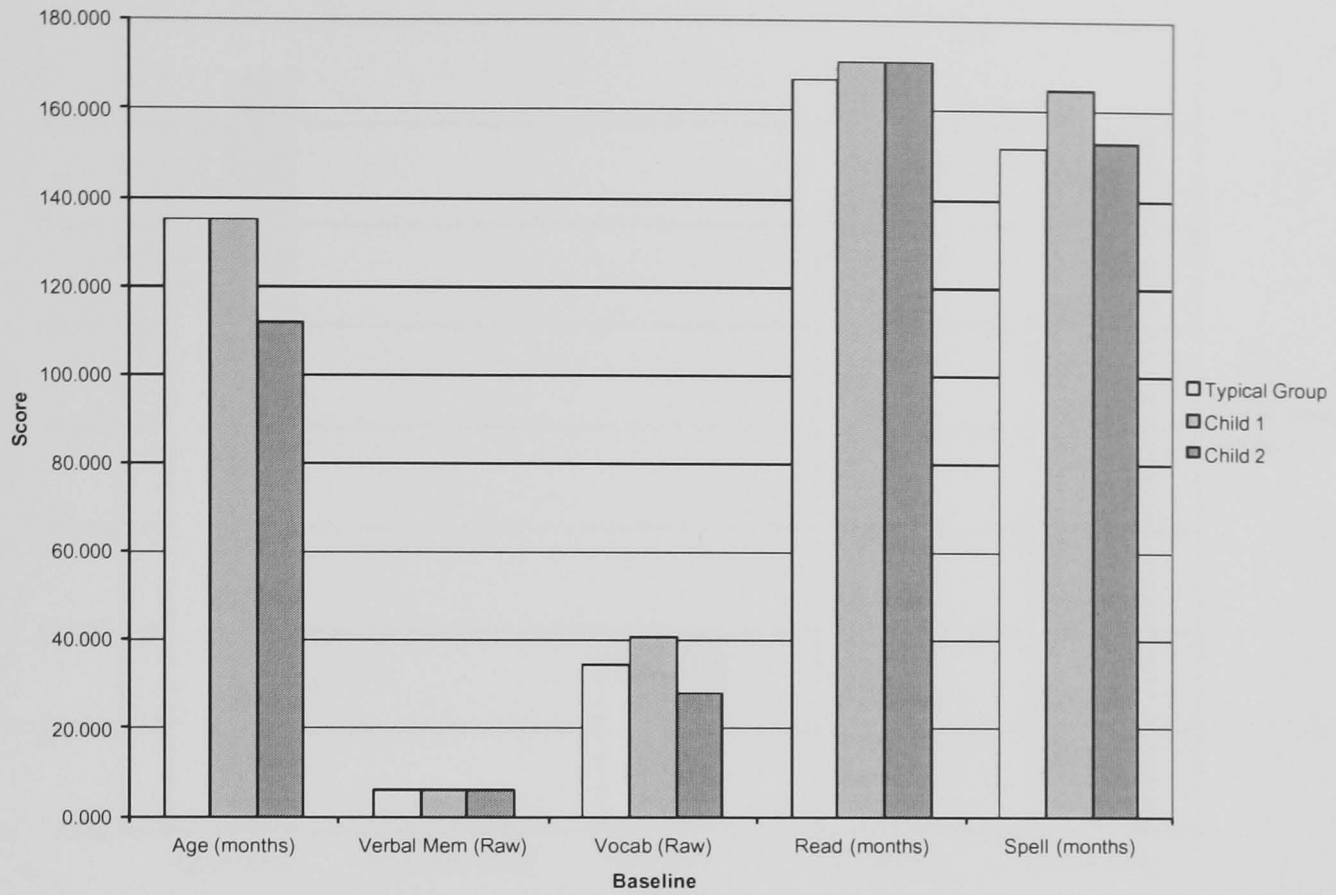


Figure 7.5 Bar graph comparing the two typically developing children who had poor accuracy scores on the Tone TOJ task with their group on baseline measures.

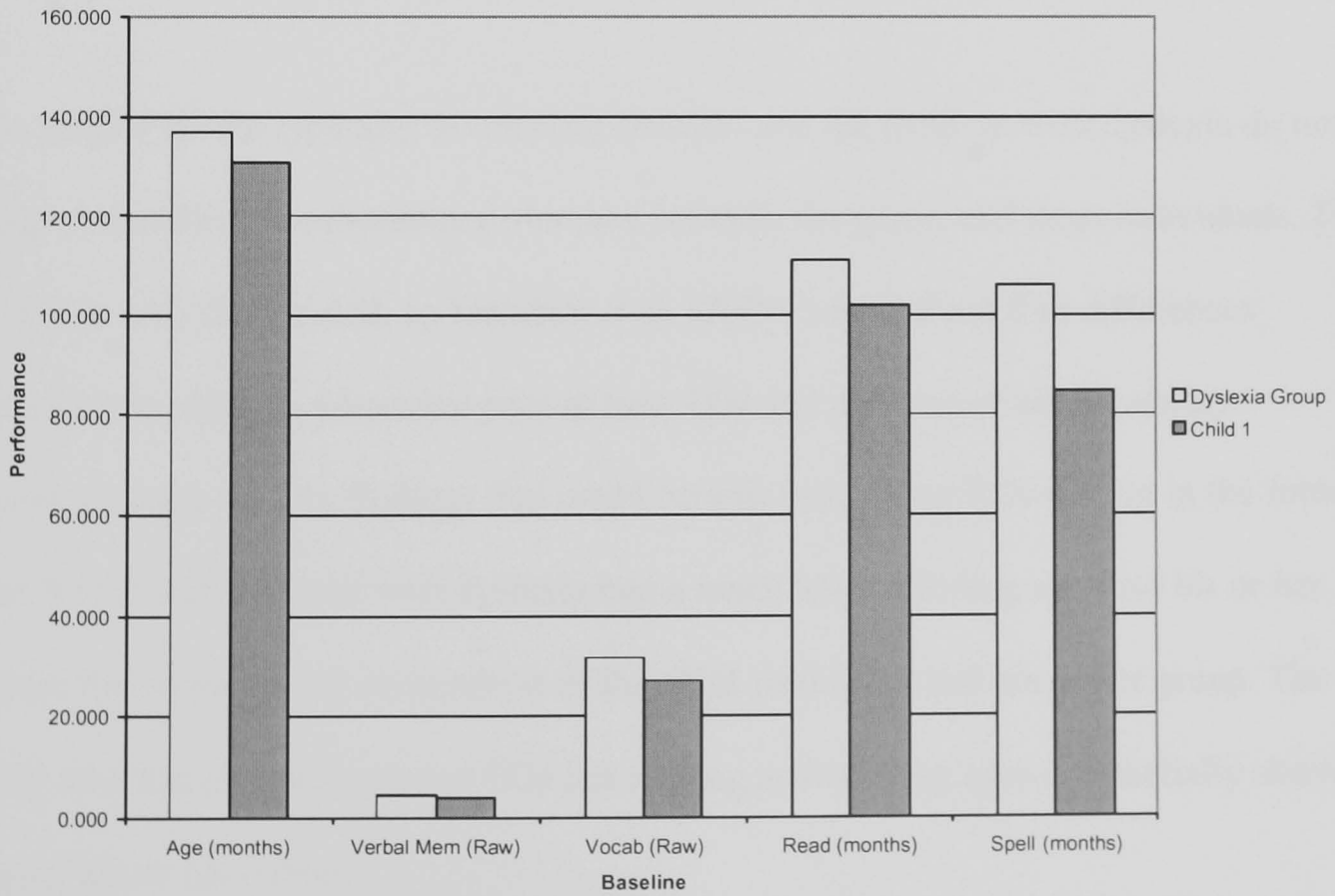


Figure 7.6 Bar graph comparing the child with dyslexia who had a poor accuracy score on the tone TOJ task with the rest of the group on baseline measures.

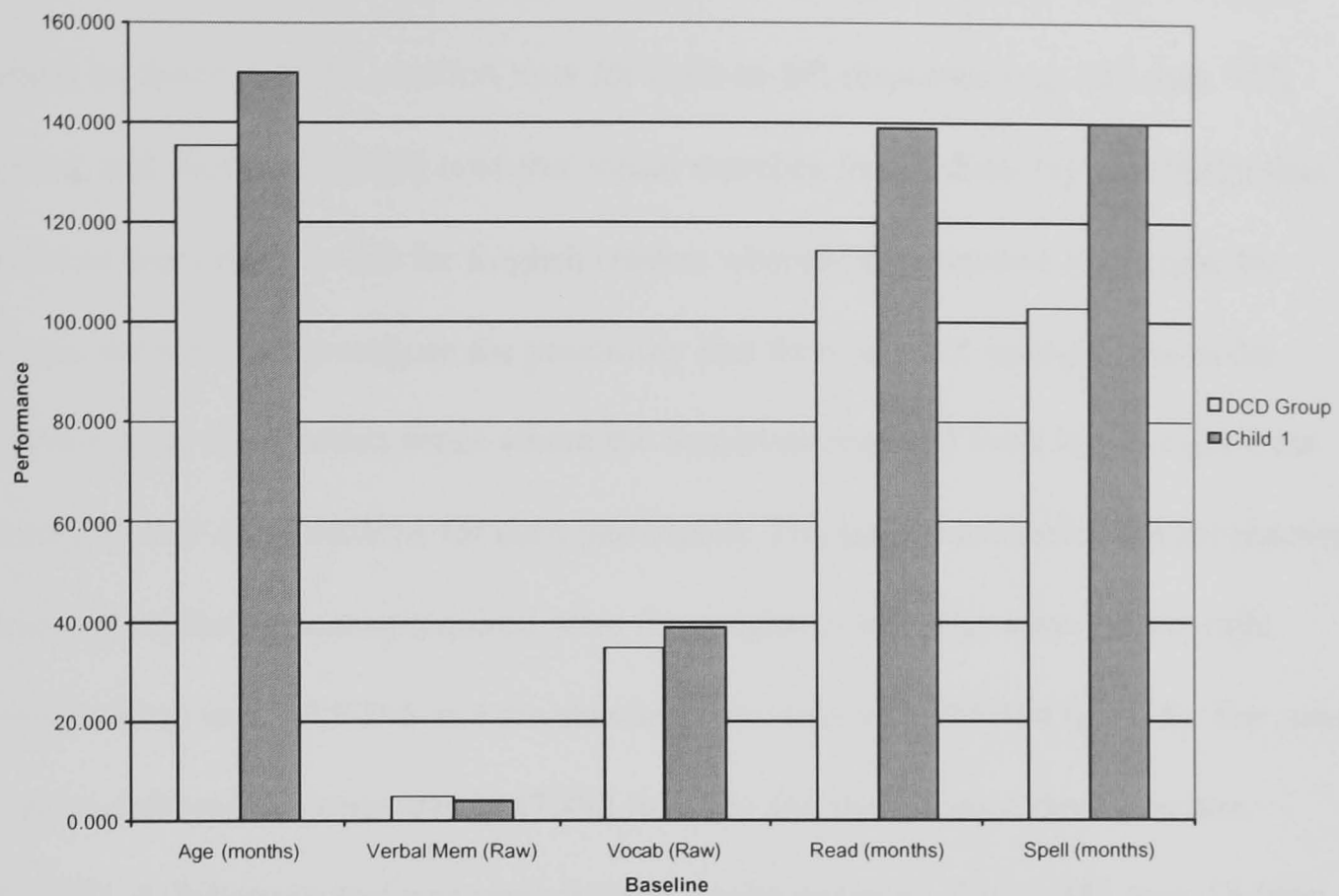


Figure 7.7 Bar graph comparing the child with DCD who had a poor accuracy score for the tone TOJ with the remaining children with DCD.

The graphs for the typically developing children and the children with dyslexia do not suggest that there is substantial difference between the group and these individuals. This is in line with studies such as Marshall et al. (2001) who did not find differences between the children who were poor at tone TOJ and children of similar ability. However there are two findings that could benefit from being followed up in the future. The first is that the child with dyslexia had a much lower spelling age than his or her group; the second is the comparison of the child with DCD and his or her group. The child who had poor accuracy at TOJ has reading and spelling ages substantially above that of his or her cohort.

There is a possibility that the reaction time for left-to-right responses (e.g. d then p) would be faster than the reaction time for right-to-left responses (e.g. “p” then “d”). Spalek and Hammad (2005) note that visual searches from left-to-right are faster than searches from right-to-left for English readers whereas the converse is the case for Arabic readers. To investigate the possibility that there is a left-to-right bias in the responses, all the reaction times where the responses required were left-to-right were averaged over all conditions for each participant. The same was carried out for reaction times where the responses required were from right-to-left. The mean left-to-right reaction time was 1809.598 and the standard deviation was 393.364 ($n = 38$). The mean right-to-left reaction time was 1847.492 ($n = 38$) and the standard deviation was 299.482. A Wilcoxon test was used and the results indicated $Z = -1.341$, $p = .18$ (two tailed). Therefore, there was no significant difference between the left to right responses compared to the right to left responses.

7.3.1. *Internal reliability of the experimental measures.*

Cronbach’s Alpha was calculated across the eight trials on the accuracy and reaction time measures for the four conditions in the TOJ task. They are summarised in Table 7.9. It can be seen that the majority of the alpha values are within acceptable limits.

Table 7.9 Cronbach Alpha scores for the TOJ task

Measure	N	Cronbach Alpha
Phonology Accuracy	35	.933
Shape Accuracy	33	.603
Tone Accuracy	35	.968
Letters Accuracy	35	.791
Phonology Reaction Times	34	.896
Shape Reaction Times	33	.909
Tone Reaction Times	35	.888
Letters Reaction Times	35	.922

In summary it can be seen that, once again, there appears to be no common pattern of deficit between the children with dyslexia and the children with DCD. While the children with dyslexia do show some areas of deficit in accuracy of response on the TOJ task with respect to phonological stimuli, there were no deficits in either accuracy or reaction time for the children with DCD. All the children appeared to find the tone based stimuli the most difficult to make temporal judgements about. These differences and the patterns of correlations found between the baseline and experimental measures for each group will now be discussed.

7.4. Discussion

The study was designed to investigate an aspect of temporal processing which may show common underlying deficits in children with dyslexia and children with DCD. The auditory TOJ task had previously been used to support the theory by Tallal (1980) that children with dyslexia have general difficulties with quickly changing auditory information. In their review of research into temporal processing, Farmer and Klein

(1995) argued that this deficit may be more widespread, encompassing other modalities such as visual processing. However, some studies have had difficulty in replicating Tallal's results, such as Bretherton and Holmes (2003). Others have offered alternative interpretations, such as Mody et al. (1997), who argued that the observed deficits in children with dyslexia may be more related to speech processing deficits rather than a more generalised auditory processing deficit.

To examine a wide range of TOJs, participants carried out TOJs in four different conditions: /ba/ and /da/ speech discrimination, high and low tone discrimination, "p" and "d" letter discrimination, and circle and octagon shapes discrimination. To extend the range of measures further, in addition to accuracy scores, carefully controlled reaction time scores were also recorded. Four research questions were posed in the introduction. They will be discussed below.

The first research question looked at whether children with dyslexia and DCD had similar patterns of accuracy in TOJs to each other and exhibited a deficit relative to typically developing children. The results indicated that the children with dyslexia and DCD did not share a common deficit in TOJs across any of the modalities. The children with DCD did not differ significantly compared with the typically developing children. However there were differences between the children with dyslexia compared to the typically developing children. These differences indicated that the children with dyslexia were significantly less accurate than the typically developing children in both the short ISI and long ISI in the phonological condition. The results do not support the assertion that dyslexia and DCD are related by a similar temporal processing deficit. Neither do the results support the claim by Tallal (1980) that children with dyslexia will show some difficulties in tone discrimination.

However, the results do provide support to research such as Mody et al. (1997) who found that children with dyslexia had accuracy deficits in their ability to discriminate between “ba” and “da”, but not other consonant-vowel digraphs. Therefore, in line with Mody et al. (1997) a parsimonious explanation for the poor accuracy of the children with dyslexia would be some deficit in speech perception. This is likely to be in their ability to differentiate “b” and “d” sounds. However, as there were no significant differences between the children with dyslexia and the typically developing children in the tone condition; a tonal deficit does not appear to underlie the phonological processing deficit. An alternative explanation for this result is that there may have been some visual confusion between the labels “ba” and “da” on the left and right of the computer screen that were used as ‘buttons’ during the task. However, the familiarisation phase of the task should have gone some way to ensure that the participants were not encountering any difficulties with the graphical interface and the location of the buttons. Moreover, a brief comparison of the results of this study suggest that this is unlikely. Even though the participants with dyslexia were significantly less accurate at the task than the typically developing children were, their accuracy was still very high, with an average of 77% correct in the 10 ms ISI condition, and 81% correct in the 300 ms ISI condition. This is comparable to Reed (1989) who carried out a long associate-button-to-stimulus session before the experiment. In her phonological test condition, the children with dyslexia were around 67% accurate at 10 ms and 80% accurate at 305 ms.

The second research question considered whether there were significant differences in the children’s reaction times on the TOJ task. The results indicated no significant differences between the three groups across any of the conditions suggesting that the

children with dyslexia and the children with DCD were able to achieve their generally high accuracy in performance on the task without additional processing time that might be indicative of temporal processing difficulties.

Whereas research questions one and two made comparisons across the three groups, research question four was concerned with a within-groups investigation of whether the profiles of accuracy and reaction times scores differed across the various conditions of the task. The results indicated similar patterns of differences for the three groups with respect to accuracy. That is, the children with dyslexia, the children with DCD and the typically developing children all found the tone condition of the task more difficult than the letters condition of the task but that accuracy levels were still high. The accuracy in the letter condition was near ceiling level for all groups whereas the accuracy to tone was significantly poorer. The children with DCD also showed a significant difference in accuracy scores between the tone and shape conditions of the TOJ task, with performance on the tone condition, once again, the poorest.

The analysis of the reaction time data was somewhat different. This time, both the typically developing children and the children with dyslexia showed significantly slower responses to the tone stimuli compared with the shape stimuli; however, the typically developing children also showed significantly slower reaction times on the phonological stimuli condition compared with the tone condition. The children with DCD, in contrast, showed no significant differences in reaction times across the conditions.

The results from research question three indicated there is a near-consistent pattern indicating that all the children found the tone condition of the TOJ task more difficult than other conditions, conversely, the letter judgement condition appeared to be the

easiest. It appears that processing tones is particularly difficult for the children in this study, and this was borne out by observations of the children during the testing phase of the study. This is a finding that is also shown in the results of other studies, for example both the children with reading difficulties and the typically developing children in Reed (1989) show more errors on the tone task than on the phonological task. Furthermore, this difference is consistent throughout the ISIs Reed used. Similar findings can also be found in Bretherton and Holmes (2003). On an observational level, in some cases, during the practice phase, children across each of the groups required additional verbal support. Often it appeared that they had difficulties in distinguishing the two tones or being able to decide which one was higher in frequency. Some children hummed tones after they were presented to help them to remember the sequence. One possible explanation for these difficulties is that tone differentiation is more abstract or that participants have less experience with it. Participants are often required to differentiate speech, letters, and shapes, but not necessarily tones. Another possibility is that it is more difficult to encode the tones, and then be able to recall them. However, there was no significant association between verbal memory and tone accuracy scores that might suggest that a memory score might facilitate performance in this condition. Therefore, it is possible that the difficulties may lie with the perception of the tones, not their retrieval. This would be an avenue of further research.

The fourth research question looked at intra-group correlations. In the typically developing children it was found that there were significant correlations between age, verbal memory, vocabulary, reading age, spelling age, and the reaction time to the phonological stimuli. Vocabulary correlated significantly with the sound TOJ reaction time. As expected, these were negative correlations: as proficiency at the baseline

measures goes up, the participants were faster at responding to the stimuli. It was clear, however, that much of the proficiency in performance could be explained by maturational processes, as the significant correlations disappeared when age was controlled for. The only exception was verbal memory being associated with the phonological condition of the TOJ task. However, this raises a question with regard to Tallal (1980)'s assertion that children are comparable in TOJ ability after the age of eight years. This may be the case for accuracy scores, but the reaction time correlations indicate that there is still development in TOJ proficiency even after this age. However, a salient finding from the results is that an effective verbal memory strategy can be beneficial in completing the phonological condition of the TOJ task. Furthermore, there is evidence that children with dyslexia have difficulties in effectively storing and processing verbal information (see Palmer, 2000, Oakhill and Kyle, 2000; and also the recall of digits backwards baseline results in this study).

The children with dyslexia showed a significant correlation between reaction time on the phonological condition of the TOJ task and vocabulary. There was also a significant association between reaction time on the letters condition of the TOJ task and vocabulary. However, the direction of these correlations was the opposite of that observed for the typically developing children. For the children with dyslexia, as vocabulary proficiency increased, the reaction times became slower. It is possible that there is some sort of interference between having a large vocabulary and the ability to respond quickly to these conditions for this group of children. Perhaps these children have to inhibit the activation of whole words in their vocabulary when they see or hear orthographic or phonological information (as was the case in these two conditions). There is evidence that might suggest a difficulty of this nature: Caney and Martin

(2003) found that children with dyslexia tended to confuse non-words with real words. This was particularly the case where the non-words were regular words and phonologically similar to real words. One possibility is that a large vocabulary would be more likely to trigger a word based association and this would then have to be suppressed and so it would take longer to respond to the judgement. Finally, there was a different pattern of correlations for children with DCD. Here, age correlated with both phonology and tones. Again suggesting that there is a maturational element to TOJ for this group, it is noteworthy that this is in contrast to the way TOJ is related to dyslexia. Of the results, it was found that the tone task was more difficult than other conditions, and it is noteworthy that there were individuals in each group who had very low accuracy scores on the tone TOJ. It would be difficult to draw any generalisable conclusions from individual participants, but in typical development and dyslexia, this did not appear to be related to the baseline measures, except possibly spelling in dyslexia. In DCD, the child with below chance accuracy at the TOJ task had substantially higher reading and spelling ages than the other children with DCD. This could be an area of future research; analysis involving larger groups might suggest a subgroup within DCD relating to TOJ ability.

There are two main strengths of this study. The first is the range of conditions that have been investigated. Few studies have simultaneously compared phonological, tone, letter, and shape stimuli simultaneously on a TOJ task, and none have looked at these measures with respect to children with DCD. The second is the use of a controlled measure of reaction time. Previous studies have compared accuracy across groups; however, as evidenced by this study, the accuracy rates for TOJ can be very high. The

addition of reaction time has provided another dimension to the ability profiles of the groups.

There were two possible weaknesses to this study. In line with the other studies in this thesis, difficulties in recruiting participants meant that there were small groups of children for dyslexia, and DCD. However it is worth noting that the numbers of participants in the typical and dyslexia groups are higher than that of Tallal (1980). The small groups may have been the reason that the results did not conform to the assumptions inherent in parametric analysis and, as a conservative measure, non-parametric analyses were carried out on the data. Although, there is likely to have been some loss of power, those differences that were found are likely to be indicative of strong differences between the groups. A second weakness may be the relatively brief familiarisation phase that the participants completed. Both Tallal (1980) and Mody et al. (1997) carried out extensive “association” phases where participants associated one unlabeled button with one stimulus and another with the other stimulus. Participants in Tallal (1980) were required to respond correctly beyond a threshold before beginning the test phase of the task (20/24 correct responses). They were required to associate one tone with a coloured button and another tone with another coloured button. However, the rationale behind using such a short training session in this study was that the experiment was computer based and the buttons were clearly labelled. More importantly, it was imperative to limit the fatigue factor in the study, as the earlier studies in this thesis found that the children with dyslexia and those with DCD were especially prone to fatigue during extended task procedures. The short training procedure does not appear to have adversely affected the result, as it can be seen that Tallal had around 30% accuracy in her short tone ISI condition and even though there

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was a shorter training session in this study, the group with dyslexia here had, on average, a 66% accuracy rate.

In summary, the results again suggest that there is no apparent underlying similarity between dyslexia and DCD with respect to their temporal processing ability. It is suggested that the proposed speech perception deficit in dyslexia might explain the deficit found in this study. No real deficit was observed in the children with DCD. All the children had difficulty with the tone stimuli used in the task. However, the correlations did point towards vocabulary having a disruptive effect to response times for children with dyslexia, a finding that would be important to investigate in future research.

8. General Discussion

This thesis set out to examine the nature and scope of any temporal processing deficits in children with dyslexia and children with developmental coordination disorder (DCD). A second aim was to investigate whether the pattern of any temporal processing deficits found in children with dyslexia was similar to the pattern of any difficulties found in children with DCD.

Difficulties in being able to process temporal information effectively may affect a wide range of skills including those often found deficient in dyslexia, such as reading, and in DCD, such as coordination. Furthermore, there is evidence from observational data and research studies, such as Kaplan et al. (1998), and Kaplan et al. (2002), that children with dyslexia and children with DCD show similar behavioural difficulties. It is possible that these difficulties may be due to a common deficit in temporal processing ability.

Temporal processing difficulties have been found in children with dyslexia by Tallal (1980) in her study of TOJ abilities, Nicolson and Fawcett (1994) in their study of general motor ability, Nicolson et al. (1995) in their study of auditory temporal judgements, and Wolff (2002) in his study of temporal production. Furthermore, reviews of research into dyslexia, such as Llinas (1993), Farmer and Klein (1995), and Habib (2000), have suggested that the pattern of behavioural deficits in dyslexia may be explained by temporal processing deficits.

In children with DCD, studies such as Williams et al.'s (1992) study of auditory temporal judgements and temporal production and Piek and Skinner's (1999) study of temporal production have also found some temporal processing deficits relative to

typically developing children. Furthermore, Ivry and Keele (1989) found that temporal information processing may be related to cerebellar processing, and many studies have found cerebellar processing deficits in children with dyslexia, (e.g. Fawcett, Nicolson, and Maclagan (2001); Nicolson et al. (1999), and in children with DCD (e.g. Lundy-Ekman et al., 1991; Piek and Skinner, 1999; and Williams, et al., 1992).

As a broad theoretical basis to the importance of temporal processing in cognition, this thesis draws on SET developed by Wearden (2001). This theory proposes the existence of a central 'timer': a set of components in the brain which are able to process temporal information from a number of modalities. The components comprised a pacemaker for producing pulses, a process for collecting these pulses for a particular duration, then a method for storing these either in short-term memory or long-term memory. Finally, there is a judgement process for comparing these stored durations with newly presented durations. The temporal information analysed by such a system would be involved in a wide variety of complex abilities such as both reading and movement.

This thesis consisted of four studies that were designed to examine four specific types of temporal information processing. These were RAN, temporal production, temporal generalisation, and TOJ. However, almost all previous studies of temporal processing assessed participants' performance with respect to only one sensory modality (typically either visual or auditory processing). Few studies have taken into account the possibility that the two modalities may have different task demands that would be useful to compare directly. If the theory argued by Wearden (2001) is considered viable, that there is a central timer which accepts inputs from visual and auditory modalities in different ways, then there are several possible outcomes to a finding that there is a poor performance on a single modality temporal processing task. For example, an

interpretation of a study that only uses auditory stimuli could be that any apparent deficit in performance is attributed to a deficit in a central timer, alternatively, the central timer could be working properly and there is a deficit in the transmission of the auditory information to the central timer. For example, Nicolson et al. (1995) found that children with dyslexia have less accurate judgements of auditory temporal information, and Tallal (1980) found children with dyslexia have poor auditory TOJs. Both have discussed (for example, Tallal, 1984) how the deficits they found could be part of a general deficit that may transcend auditory processing. However, both studies only examined children's abilities when presented with acoustic information rather than systematically studying a range of modalities. Furthermore, the lack of support for cross-modal TOJ deficits in studies such as Bretherton and Holmes (2003) would suggest that the narrative of temporal processing is more complicated than considered by researchers such as Tallal (1980) and Tallal (1984).

Similarly, Piek and Skinner (1999) found temporal production deficits in children with DCD; however, the tapping pattern to be copied was presented visually. Studies such as Wilson and McKenzie (1998) have found visual processing deficits in children with DCD, and one particular area of deficit appears to be visual-motor integration (e.g. Parush et al, 1998). The Piek and Skinner (1999) task would therefore appear to include heavy reliance on this system and the observed deficit could be independent of a temporal processing deficit. Therefore, throughout the studies presented in this thesis the aim was, where possible, to consider a balance of modalities which would be better placed to support interpretations based on a central timer common to, at least, visual and auditory processes (for example, Wearden et al., 1998; and Wearden, 2001).

In order to determine that there was a temporal processing deficit that was common to both the children with dyslexia and the children with DCD, two criteria would need to be met:

- The children with dyslexia and the children with DCD would need to have less accurate or slower responses compared with typically developing children in at least some of the tasks with a temporal processing element (i.e. demonstrate a deficit in temporal processing ability).
- The children with dyslexia and the children with DCD would have to show deficits on the same conditions of the same tasks.

The four main studies in this thesis will now be discussed.

8.1. Contribution of this thesis

This section aims to detail the unique contribution of this thesis to psychology, and more specifically, to the fields of developmental dyslexia, DCD, and temporal processing. Each of the four main studies will be considered in turn.

The first study of the thesis examined whether children with dyslexia and children with DCD differed on measures of RAN compared to typically developing children. It was argued that temporal processing was likely to be a process implicit in RAN, in order to process the sequential information of the task fluidly. RAN tasks had been tested extensively on children with dyslexia (for example, Denckla and Rudel, 1976, Fawcett and Nicolson, 1994, and Compton, DeFries, and Olson, 2001). However, nothing was known about the performance of children with DCD on this task. Furthermore, this study extended the field of RAN research by using a new variant of RAN devised by Compton et al. (2002) which was shorter and had been shown to be equivalent to longer

forms of RAN, but measuring the articulation and non-articulation durations of the children's responses during this version of task. Consequently, two research questions were developed.

The first research question examined whether the new version of the RAN task showed similar patterns of articulation and non-articulation durations as had been previously observed in children with dyslexia in the few previous studies that had assessed this, but using the longer version of RAN. Whilst it was clear from previous research that children with dyslexia are less proficient at this task (Compton et al., 2001), little research had been carried out into the sub-component processes of RAN. The study found that the pattern of articulation and non-articulation durations demonstrated by children with dyslexia, relative to those of typically developing children, were as had been found by previous studies that had used the longer version of the RAN task. That is, the children with dyslexia had significantly slower articulation and non-articulation durations, and significantly more variable non-articulation durations, compared to the typically developing children. This was a pattern similar to that found by Anderson et al., 1984 and by Snyder and Downey, 1995 and in line with studies of typical development such as Neuhaus et al. (2001a), and Cobbold et al. (2003). This was an important point to establish, as it suggests that any results found using this paradigm could be due to the nature of the groups under consideration rather than the result of some aspect of the new task that was inconsistent with the version of the paradigm used previously by other researchers.

The second research question of this study was concerned with whether children with dyslexia and children with DCD showed patterns of RAN performance which were similar to each other, but that were different to those demonstrated by typically

developing children. No study to date had looked at rapid naming in children with DCD even though the task incorporates many of the elements that are thought to be deficient in children with DCD such as processing of sequential information and automatisisation (see Chapter One). As a result it was important to establish whether this group of children had a deficit on this measure, and if they did, whether it was of the same severity as that demonstrated by the children with dyslexia. The results indicated that the children with dyslexia had significantly slower and more variable non-articulation durations than typically developing children. The children with DCD however had significantly slower articulation durations than both the children with dyslexia and the typically developing children. One possible interpretation of this result was that articulation difficulties were salient in children with DCD when having to name items under pressure. However, it can be seen that although both the children with dyslexia and the children with DCD presented a deficit in RAN performance, there was no similarity in the nature of those deficits.

The second study was designed to investigate whether there might be a temporal production (tapping) deficit in children with dyslexia and in children with DCD compared with the typically developing children. It would be expected that if there was a common underlying deficit in a central timer in both groups of children, both the children with dyslexia and the children with DCD would show either a more variable or slower tapping profile compared with the typically developing children. This study went further than similar previous studies (such as Wolff, 2002) by decomposing each tap produced by the children into the duration the finger was held on the tapping plate and the duration the finger was raised from the tapping plate. Piek and Skinner (1999) had argued that these measures were indicative of separate cognitive processes: the time the

finger was held up was believed to be related to motor action processes, such as temporal and organisational processing, whilst the time the finger was held down was related to timing the finger release. The children carried out the tapping task, first by synchronising to a stimulus, and then continuing the same pace after the stimulus had been removed. There were both visual and auditory stimuli in the task.

Research question one of this second study was concerned with comparing the children with dyslexia and the typically developing children on the measures of tapping.

Whereas studies such as Wolff (2002) had examined auditory temporal production in children with dyslexia, little research had been carried out to directly assess how widespread a possible deficit in temporal production might be for this group of children. The results from this study indicated a slowness in off-contact tapping duration whilst synchronising to an *auditory* stimulus. The pattern was similar across all three inter-stimulus intervals (300 ms, 500 ms, and 700 ms). They were also significantly slower at on-contact durations during the 700 ms duration and this suggests a specific deficit in auditory temporal production rather than a general, cross modal one.

Research question two investigated whether the children with DCD had a different pattern of tapping compared with the typically developing children. Again, no previous study had assessed the range of tapping variables that this study considered. The results indicated that there were no significant differences in performance on any of the conditions for this group of children relative to the typically developing children. This suggests that children with DCD do not have a deficit in temporal production ability, and therefore there was no evidence to support research question three, which was concerned with whether children with dyslexia and children with DCD shared a similar pattern of temporal production deficits. However, this study is significant as no prior

study had directly compared the tapping proficiency of children with dyslexia to that of children with DCD.

Whereas the second study had looked at temporal production, the third study looked at temporal perception using a temporal generalisation paradigm (e.g. Droit-Volet et al., 2001; Wearden, 1992). Participants were required to determine whether an auditory or visually presented stimulus was the same duration as a stimulus that had been presented earlier in the instruction phase of the experiment as the standard stimulus. This was similar to a study by Nicolson et al. (1995) and Williams et al. (1992) which had found that children with dyslexia had difficulties in judging whether two tones were of the same duration. Whereas Nicolson et al. and Williams et al. asked participants to compare two stimuli presented in quick succession, this study required participants to do more as they were asked to make a judgement on a stimulus they had to learn prior to the test trials. By implication the Wearden task therefore is more difficult and was intended to magnify highlights difficulties that children with dyslexia (and children with DCD) might have in more broadly in temporal representation (memory for durations) and in temporal perception. The study in this thesis was the first study to compare the temporal generalisation of both children with dyslexia and children with DCD. The addition of the visual condition also allowed the study to compare the children's performance in both modalities.

The first research question for this third study looked at whether children with dyslexia and children with DCD had different profiles of temporal generalisation ability to those of typically developing children. The results indicated that all three groups completed the task to the same level of accuracy, suggesting that there was no apparent deficit in temporal generalisation in either the group with dyslexia or the group with DCD. A

second question looked at whether the children were equally accurate in both the auditory and visual stimulus conditions of the task. As noted by Wearden et al. (1998) there is a difference between the way auditory and visual temporal stimuli are processed. The use of similar tasks, one with visual and the other with auditory stimuli provided the opportunity to compare directly the ability of children to process these stimuli; an assessment that has not been carried out in previous research. The findings confirmed that there was a difference in performance on this task across modalities. The visual condition showed less accuracy, particularly at durations longer-than-the-standard compared with the auditory task.

The third research question looked at the relationship between auditory temporal generalisations, visual temporal generalisations and baseline measures. Within the aims of the thesis, to examine the possibility of shared underlying deficits in dyslexia and DCD, inter-group correlations provided a way of assessing whether the same skills were correlated with each other in all three groups. The results indicated that, for the typically developing children, there were correlations between auditory temporal generalisation and reading age, and between visual temporal generalisations and threading speed. In contrast, the children with dyslexia showed a significant correlation between reading age and the visual temporal generalisation task; whilst the children with DCD had a significant correlation between auditory temporal generalisations and reading age, and another between visual temporal generalisations and threading speed, although the direction of this correlation was in the opposite direction to that found in the typically developing sample of children. Again, these correlations suggest that different processes are associated with good performance on the temporal generalisation task in each of the three groups of children studied.

The final study looked at the established paradigm of TOJ and aimed to extend previous research. That is, Tallal (1980) had found children with reading difficulties had poor accuracy at reproducing the order of high and low tone sequences and that this may be related to phonemic processing. However, few studies have been able to replicate this finding; notably, Bretherton and Holmes (2003) who were unable to replicate Tallal's (1980) findings on tone but found differences in consonant-vowel discrimination; and Mody et al. (1997), who compared children's abilities to judge consonant-vowel digraphs and argued that speech perception may be an underlying cause of dyslexic children's poor performance on the TOJ task. This study aimed to cover a more complete range of stimuli and also to add reaction time to the range of measures obtained from this paradigm. This thesis therefore looked at four types of judgement: phonological /ba/ and /da/ judgements, a high and low pure tone judgements, "p" and "d" letter judgements, and circle and octagon shape judgements. There were also two different inter-stimulus intervals used: a short (10 ms ISI), and a long (305 ms ISI).

This final study examined four research questions. The first looked at whether there were differences in the accuracy of TOJs between the groups. Studies in the past, for example Reed (1989), Laasonen et al. (2002) and Bretherton and Holmes (2003) had looked at TOJs across a range of modalities. However, this was the first study to do this *and* compare the performance of children with dyslexia to that of children with DCD. The results showed that the children with dyslexia had significantly worse accuracy compared with the typically developing children in the phonological stimuli condition, regardless of the inter-stimulus interval. There were no significant differences in accuracy between the groups in any other condition. This suggested that while the children with dyslexia might have a very specific deficit in temporal order judgment.

Although an alternative explanation might be a specific deficit in being able to process the “ba” and “da” speech sounds of the task. The children with DCD showed no evidence of the temporal order judgment deficit.

The second research question looked at whether there were differences in the reaction times of TOJs across the three groups. Whereas a number of studies, such as those noted above, assessed accuracy, very few studies have measured reaction time. The added dimension of reaction time is important as the accuracy of TOJs is often near ceiling level, a feature that can be seen in the results of this study too. The prediction here would be that children with poor TOJs would also be slower at responding to the stimuli. However, there were no significant differences between the groups on reaction time on any condition. This, once again, is consistent with the suggestion that children with dyslexia and the children with DCD do not have a deficit in temporal order judgment in the way previously suggested by Tallal (1984) and others.

Research question three compared accuracy and reaction time across the various conditions of the TOJ task. Although the process of making a temporal order judgment was similar across the conditions, different stimulus conditions may have been more difficult for some participant groups compared with others. From the previous literature it is not clear if all TOJ stimuli are equal or whether some pose more problems for participants than others. For this reason the conditions were compared with each other. The typically developing group were significantly less accurate at the tone condition compared with the letters conditions. They also had significantly slower reaction times in the tone condition compared with the phonological condition, and the tone condition compared with the shape condition. The pattern was different for the children with dyslexia. Here the results showed that they had less accurate judgements for the tone

condition compared with the letters condition; but only significantly slower tone compared with shape TOJs. Finally, the children with DCD had significantly less accurate tone judgements compared with shape and letter TOJs. Their reaction times were not significantly different across conditions. Beyond abilities between groups, there appeared to be different skills required for processing each of the stimuli, with some being easier to judge than others. It is possible that there is something in the nature of tonal processing, independent of TOJ that means children have difficulties in this condition.

Research question four looked at inter-group correlations for the study. The question was whether the baseline measures are associated with the same conditions for each of the groups. Tallal (1980) showed that TOJ proficiency was positively correlated with non-word reading. In a similar vein, these correlations aimed to examine associations between baseline abilities and TOJ ability. The patterns were different for each group. While a number of significant correlations were found for typically developing children, no correlations were found between baseline measures and accuracy on the TOJ tasks. However, it is here that reaction time became a useful alternative measure. For the phonological stimuli condition, a number of measures were affected by age. When this was partialled out, verbal memory alone was found to correlate with accuracy of performance on phonological TOJs. A very different pattern was found for the children with dyslexia. Vocabulary alone correlated with phonological TOJ reaction times and this remained even when age was controlled for. However, the direction of this association was surprising, as it suggested that children with high vocabulary had slower reaction times in the phonological stimuli condition and slower reaction times in the letter stimuli condition. For the children with DCD it was found that older children

had faster reaction times in the phonological stimuli condition and in the tone stimuli condition. It would seem from these results that a larger vocabulary amongst children with dyslexia interferes with the ability to respond quickly in a judgement-based paradigm like this one.

Overall, the evidence from studies one, two, three, and four does not indicate that there is a common underlying temporal processing deficit in dyslexia and DCD. The findings from this thesis, whilst not entirely rejecting the findings by Kaplan et al. (1998), Kaplan et al. (2002), and arguments by Nicolson (2000) that children with dyslexia and children with DCD may have a common underlying deficit, do not strengthen it.

Temporal processing is an area of cognition that is clearly required for both effective movement and reading. Consequently, deficits in temporal processing could still result in deficits in reading and coordination. The studies in this thesis did find that children with dyslexia and DCD had some difficulties in carrying out some forms of temporal processing task. However, in every case, there were alternative explanations for those results rather than that of a general, common temporal processing deficit, and there was little evidence of shared patterns of difficulties.

In terms of scalar expectancy theory, the studies confirm that typically developing children are able to make temporal judgements and that these conform to previous studies in children, such as McCormack et al. (1999) and Droit-Volet et al. (2001).

Furthermore, comparisons of auditory and visual modalities indicated that visual temporal processing (primarily temporal production and generalisations) is more difficult compared to auditory processing. Although there is evidence of this in adults, for example, Wearden et al. (1998), little research has previously been carried out into

how children accomplish temporal processing; consequently the studies here have helped to develop this field as well.

At the end of the theoretical overview (Chapter One), a diagram by Frith (1999) was presented which sought to conceptualise a potential temporal processing deficit in dyslexia. This was also presented as a possible model for a temporal processing deficit in DCD (Figure 8.1). At a biological level, it was suggested that a cerebellar deficit could affect cognitive processes related to temporal processing, and also aspects of phonological awareness and motor coordination, ultimately presenting as behavioural indicators common to both dyslexia and DCD, and in particular, reading and spelling deficits in the former, and coordination deficits in the latter. This thesis did not assess cerebellar processing so cannot comment directly on the biological element of this proposed model. However, at the cognitive level, a temporal processing deficit appears unlikely to account for the findings here. The sections below will detail the theoretical implications for the two disorders that have been the focus of the thesis.

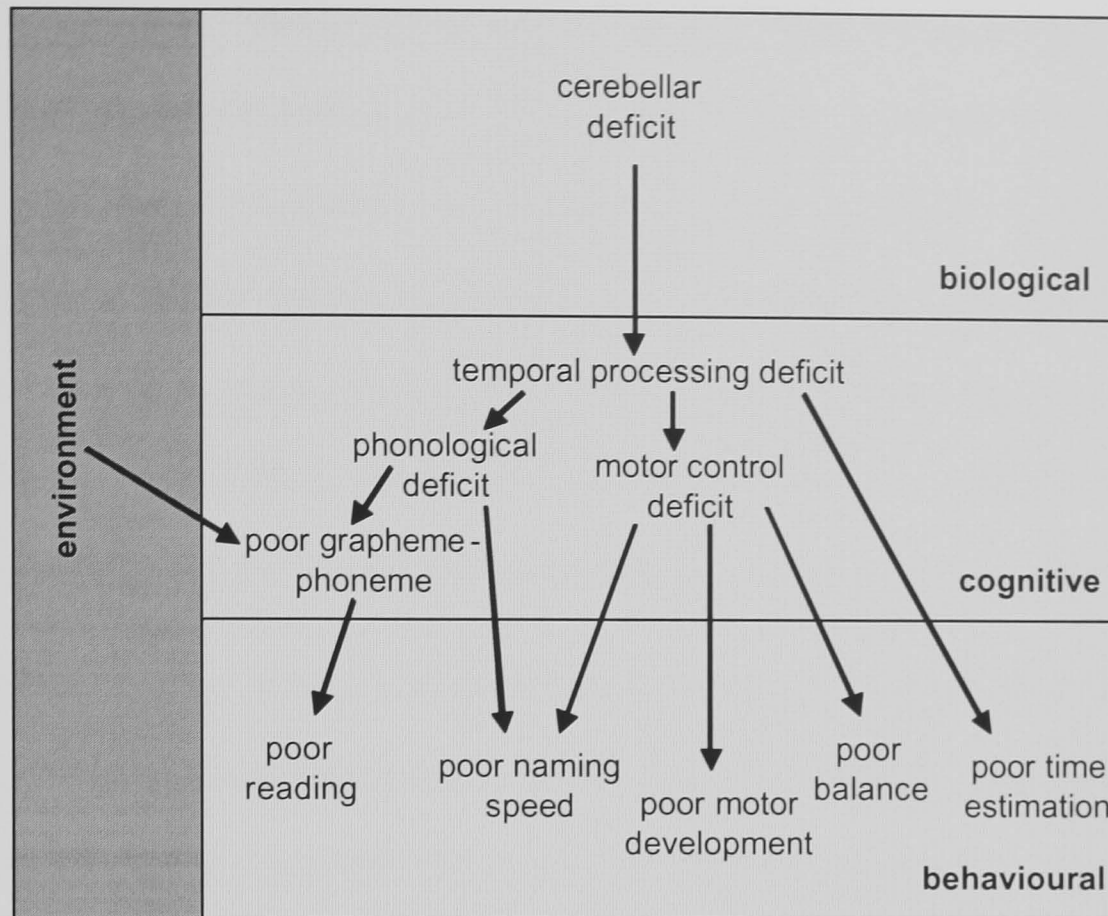


Figure 8.1 A version of the Frith (1999) model of dyslexia as a cerebellar deficit. In view of the evidence in DCD it may also hold for deficits found here too. In Frith's original diagram, "temporal processing deficit" was referred to as a "timing/sequence deficit" and "Poor time estimation" was subsumed under "motor control deficit". In view of the studies discussed in the introduction chapter, the diagram now shows a temporal processing having a direct impact on poor time estimation.

Tallal (1980) and Tallal et al. (1997) argued that the deficit in dyslexia could be due to a general auditory temporal processing deficit. Moreover, Farmer and Klein (1995) and Habib (2000) have suggested that this deficit could extend beyond auditory processing. The attraction of such a deficit is that it offers a parsimonious explanation of specific learning difficulties like dyslexia: many of the skills required in reading, such as phonemic processing, and reading fluency, may be reliant on the ability to process temporally sensitive information effectively. The evidence from the studies in this thesis cast doubt on the generality of this deficit in children with dyslexia. Even though there was evidence of an auditory processing deficit in the temporal production study (a

correlation between reading age and visual temporal generalisation ability in the temporal generalisation study) and evidence of difficulties in making TOJs in the phonological stimuli condition of the TOJ study; there was no evidence of a more general deficit in other conditions of the task (e.g. the pure tone condition of the TOJ task or any of the temporal generalisation tasks). Moreover, in the TOJ study the typically developing children, who had reading and spelling ages commensurate with their chronological ages, had serious difficulties with the pure tone condition.

Neurologically, it has been hypothesised that temporal processing is related to activities carried out by the cerebellum and Ivry and Keele (1989) found that patients with cerebellar damage showed difficulties in both temporal perception and temporal production. Amongst other studies, cerebellar processing for temporal tasks has been shown in typical participants by Jäncke et al. (2000), using an fMRI study of tapping, and by Théoret et al. (2001) using rTMS and tapping. Furthermore, atypical cerebellar development has been implicated in dyslexia. The argument, put forward by Nicolson and Fawcett (2001), is that as the cerebellum is important in converting learnt skills into automated skills and as reading is a complex skill then anyone with a cerebellar processing deficit would have serious difficulties in acquiring reading effectively. In addition, this deficit in cerebellar processing would appear in other cerebellar-based tasks. Fawcett et al. (1996) and Fawcett and Nicolson (1999) found children with dyslexia to have difficulties in carrying out various tasks thought to require cerebellar processing and Nicolson et al. (1999) found differences in cerebellar activation in adults with dyslexia compared with typical adults in a PET study.

But with a cerebellar processing deficit, highly variable tapping would have been expected in Study One: Ivry and Keele (1989) found this with their patients who had

cerebellar damage, Théoret et al. (2001) found this when they disrupted cerebellar processing whilst participants were tapping and as Jäncke et al. (2000) found cerebellar processing in both visual and auditory processing, deficits would be expected in both visual and auditory tasks. This was not found to be the case.

Auditory perception tasks carried out by Ivry and Keele (1989) also found that patients with cerebellar damage had difficulties with temporal perception. When Nicolson et al. (1995) found similar temporal perception difficulties with children who had dyslexia, a cerebellar deficit was one of their proposed explanations of their findings. However, Study Three did not find evidence of a temporal perception deficit.

Four possible theories were described in Chapter One that could account for some or all of the behavioural characteristics observed in developmental dyslexia. These were deficits in phonological representations, speech perception, temporal processing, and automatization. The baseline measures throughout the thesis indicated that the children with dyslexia had difficulties in reading, spelling, and recall of digits backwards. Some of these tasks require phonological awareness but as no explicit analysis of phonological awareness was undertaken, it might be difficult to say definitely that that was the underlying deficit for this group.

To take all four studies, the children with dyslexia showed a specific pattern of deficits in RAN and they were significantly less accurate at judging the consonant-vowel segments in the TOJ task. For the temporal generalisation task, the results are less clear-cut. The children with dyslexia were substantially behind the typically developing children in reading but they did not show clear temporal processing deficits as would have been expected from studies such as Nicolson et al. (1995). They did show a significant correlation with visual processing and reading and no significant correlation

between auditory processing and reading (as was seen in the typical children). One possibility is that the visual task taps into some form of visual processing that the children with dyslexia use to compensate for poor phonological processing when reading. Van der Leij and Van Daal (1999) have shown that word visual-feature compensation in reading is something that children with dyslexia can carry out.

The results are broadly consistent with what would be expected of a group of children with dyslexia in terms of a phonological deficit and rate-processing deficit with concomitant speech processing difficulties. Where required to manipulate speech-based information, they were less accurate and some of the analysis suggested that they were more reliant on visual processes than on auditory ones. In terms of the framework offered by Frith (1999), the evidence may suggest an adapted version of the one she presents in her paper. Although Frith's original diagram (see Figure 8.2) had rapid naming subsumed under phonological processing, there is no evidence from this study to discount Wolf et al. (2002) suggestion that rapid naming is a deficit that is independent of phonological awareness. It is beyond the scope of this thesis to directly relate to neurological causes as these were not examined in the studies, however, as noted in Chapter One, there is a likelihood that the deficits found in dyslexia have a neurological cause, and one possibility is a deficit involving structures of the left hemisphere. There is evidence of this from studies such as Georgiewa et al. (2002).

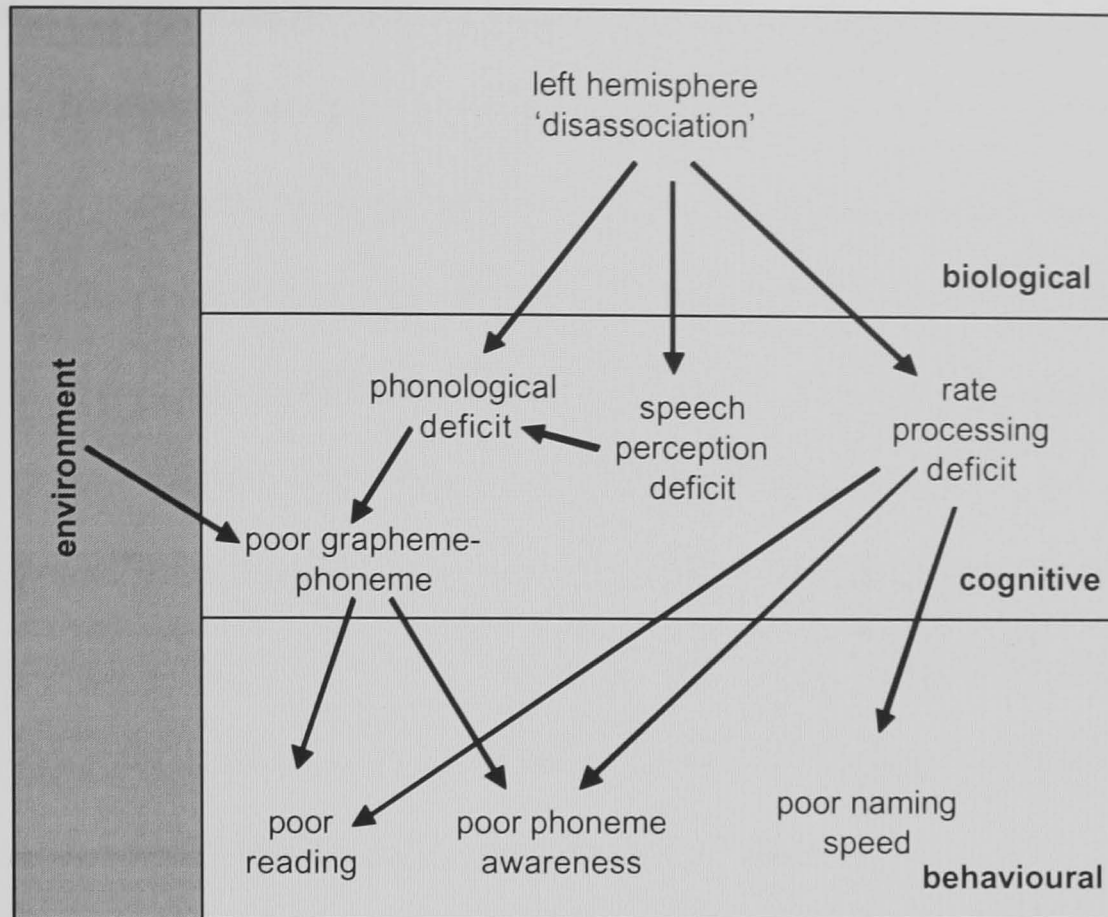


Figure 8.2 Modified version of the model suggested by Frith (1999) to account for the phonological deficit in dyslexia. Frith's original diagram had poor naming speed subsumed under "phonological deficit". In view of the introduction chapter, which reviewed studies such as Wolf and Bowers (1999), a separate cognitive deficit has been included, termed "rate processing deficit" and "poor naming speed" is now shown as being caused by this. "Left hemisphere 'disassociation'" broadly relates to studies such as Georgiewa et al. (2002) who found differences in left hemisphere brain activation for children with dyslexia compared to typically developing children.

As discussed in Chapter One there are few studies of the underlying cognitive causes of DCD. One of the reasons for recruiting a DCD group was to investigate this poorly understood area of developmental difficulty. Research into DCD has primarily looked at visual processing and temporal processing. Studies such as Wilson and McKenzie (1998) argued in support of a visual processing deficit in DCD, whereas studies such as Williams et al. (1992) and Lundy-Ekman et al. (1991), and Piek and Skinner (1999), have proposed that DCD may also be related to a temporal processing deficit.

The findings of the studies in the thesis have implications for previous research. Studies in the past have used test measures similar to the ones used in this thesis. Such as tapping, and perceiving temporal durations and so on. The experimental measures in the thesis were developments of these. However, predicted differences were often not found. Between group comparisons often put the DCD group either in between the children with dyslexia and the typically developing children, or else, in line with the typically developing group. The only time this differed was in measures of reading, spelling, recall of digits backwards, and on one measure of the RAN task. For baselines, the children with DCD were not significantly worse at two measures directly relating to the visual deficit hypothesis: verbal memory, or threading.

Three of the four experimental studies had visual tasks and so some further implications for the proposed visual deficit in DCD can be considered. The studies tapped into various domains of visual processing: visual temporal production (tapping) and perception (temporal generalisation, and temporal order judgement). In each of these, there was no significant difference between the children with DCD and the typically developing children. The findings are, therefore in contrast to a number of other studies that looked at visual processing in DCD. One possibility is that children with DCD do have deficits in visual processing but in different areas of visual processing. Parush et al. (1998) for example, argued that visual-motor integration is a predominant deficit. The experiments also have implications for the temporal processing theory of DCD, whereas no baseline measures directly contribute to temporal processing. The studies that involved tapping, temporal generalisations, and temporal order judgements could be considered to have temporal processing elements. In terms of previous research, Williams et al. (1992) found that children with DCD had less accurate judgements of

acoustically presented temporal information. Piek and Skinner (1999) found that children with DCD had a different pattern of tapping compared with typical children when reproducing a visually presented tap-pattern. And Geuze and Kalverboer (1994) found children with DCD had difficulties in tapping.

It is possible that the nature of the deficit is different in children with DCD. Whereas pure temporal processing deficits might not characterise the disorder, complex coordination might be important. For example, in the tapping study presented in this thesis, there was no significant difference in tapping speed or variability between the children with DCD and the typically developing children. The measure of tapping used throughout all of the tapping study was of unimanual tapping. However, more complex tapping procedures have shown differences in children with DCD, such as tapping patterns (for example, two taps with right hand, one tap with left) used by Geuze and Kalverboer (1994) and where pressure of a tap in a series is also manipulated, for example in Piek and Skinner (1999). It might be that complex procedures are difficult for children with DCD and not temporal processing.

Another possibility is that DCD is a heterogeneous disorder. This was an issue raised in the introduction chapter. And subgroups of DCD might be the reason for the results found here.(see, for example Visser, 2003, and Wann et al., 1998). Schoemaker et al. (2001) found that some children with DCD have widespread deficits in motor coordination but there were children with coordinating difficulties for whom standardised tasks such as threading and moving pegs, or skipping were not a problem. This is certainly echoed in some of the findings from the studies in this thesis, many of the results showed high variability for the children with DCD, for example in the tone accuracy and reaction time for TOJ (Figure 7.2). Therefore, the role of subtypes in the

field of DCD is an issue and is likely to have affected the results found here. In particular, care needs to be taken with respect to both screening potential participants prior to conducting research with them, and considering methods of statistical analysis that will characterise patterns of individual difference with respect to children with DCD.

8.2. Outstanding questions

As discussed above, this thesis has covered a number of areas that had been previously overlooked in research with children with dyslexia and DCD. However, the findings raised a number of questions. The aim of this section is to discuss general issues relating to areas that were not covered in the four main studies of the thesis and also to investigate possible future ways of assessing them.

The first area to focus on is the role of baseline measures in this thesis. Part of the analysis covered in this study used reading and spelling age scores. Singleton and Stuart (2003) notes that reading and spelling age scores are a less accurate measure than actual scores of ability. There is a tendency for reading and spelling ages to group children together who may not actually be reading or spelling at the same level. For example the age equivalent for the WISC III-R (Weschler, 1992) vocabulary test groups raw scores 34 through to 37 as nine years two months, and a raw score of 38 as nine years six months, whilst nine years 10 months comprises raw scores 39 to 41.

In addition, some further baseline assessments would have been helpful for interpretation purposes. For example, more detailed analysis of the coordination difficulties of the groups with DCD would have helped establish the group in the context of other studies and relative to the children with dyslexia and typically

developing group. Also, some measures of phonological awareness would have also proved helpful in attempting to verify the extent to which the difficulties experienced in the auditory conditions of the various tasks were the result of phonological ability.

However, the decision was made early in the design of the research to attempt to keep the test batteries for the children with dyslexia and DCD as small as possible. There was a consideration to limit the disruption to the school and to the children's learning experience. This led to time constraints in the assessments. Within the groups with dyslexia and DCD there may also have been children with attentional difficulties which may have made lengthy test batteries difficult for them. Consequently the study used the reading and spelling tests that the school had recently collected and these were presented as age scores. To ensure comparison was possible the reading and spelling tests for the typically developing children were also converted to reading ages.

Secondly, there was a difference between the types of reading tests used by the school with the children who had dyslexia and the children with DCD. They used Schonell and Schonell (1970) for reading and Vernon for the spelling tests, whilst the reading and spelling tests for the typically developing children were carried out using the BAS II (Elliot et al., 1996). However, it should be remembered that in the studies, the primary analysis was to determine profiles of skill on the temporal processing tasks; the reading and spelling scores were used to establish group profiles and were primarily there for descriptive purposes. Measures of reading and spelling were used, however, in the correlation analysis of the temporal generalisation study, and the TOJ study, this may have some implications for the interpretability of the findings of these two studies. Notwithstanding the issues of comparability between the tests, the children with

dyslexia and DCD were substantially behind their chronological ages with respect to their reading and spelling.

However, the lack of a comprehensive baseline measures package also raises another issue related to assessment. Although the children were 'statemented' as having special needs, it is possible that they may have had other special needs that either did not fall under these diagnosis criteria or had not been assessed, and these hidden difficulties may have confounded the findings from the experimental measures. For example, in all the studies the children with DCD had spelling and reading ages in line with the group with dyslexia. Whereas it is possible that the underlying causes of these reading and spelling impairments may be different, as no assessments were made to establish this, then it raises a question as to the true nature of this group in particular. As discussed earlier the heterogeneity of the groups may have provided the children with strengths and weaknesses in the tasks that were carried out in the studies that may have confounded the results. However to what degree difficulties in spelling and reading might be a consequence of motor difficulties is an area for future research. The results here suggest that, despite having similar levels of reading and spelling as the children with dyslexia, the children with DCD did not complete the experimental tasks in the same way or exhibit the same degrees of difficulty as those experienced by the children with dyslexia.

Finally, as noted in Chapter 2, the group sizes obtained were small and so limit the generalisability of the studies. In Studies One and Two, the groups comprised ten participants each, and in Studies Three and Four, there were 13 children with dyslexia, seven children with DCD, and 15 typically developing children. However, it is not atypical to have such small numbers in studies of this kind. For example, Williams et al.

(1992) had 13 typically developing children, and 12 children with coordination difficulties; Anderson et al. (1984) had six typically developing children and six children with dyslexia; Tallal (1980) had ten typically developing children and ten poor reading children; Nicolson et al. (1995) compared groups with sizes between nine and 12; and Piek and Skinner (1999) had 15 typically developing children, and 15 children with coordination difficulties. With larger groups, more differences between the groups may have become apparent. However, some strong differences were found and it is possible to suggest that, given the range of evidence presented in this thesis, even with larger groups, a common temporal processing deficit would most likely not have been found.

There are several avenues of future research that arise from this set of studies. These will be dealt with in turn.

The temporal generalisation study (Study Three) found that all the children had difficulties with long duration visual temporal generalisation. That is, the children were able to judge correctly whether the flash the lighthouse made was shorter than the standard flash, but they had difficulty judging whether it was longer than the standard, even when the flash was 300 ms longer than the standard. Further research into the nature of this result would be useful in understanding young children's processing of temporally sensitive information and whether this is related to other domains. In relation to SET, it may be that visual stimuli are treated differently by a central timer. However, future research might investigate the quality of this difference. An outstanding question here is why are visual stimuli shorter than the standard processed more accurately than visual stimuli longer than the standard? Further research, possibly comparing this to

other modalities such as proprioception, or using different durations may help answer this.

A second outstanding question related to children in general comes from the finding in Study Four (TOJ study) that relative to the other conditions, all the children had difficulties with the tone condition in the TOJ task. It may be that there are types of tonal stimuli or ISIs which children do not have difficulties with. Manipulations of this experiment may yield further information into why it has been difficult to further relate Tallal (1980) to reading difficulties and development.

In dyslexia, further research is required on the nature of an auditory deficit in dyslexia. It is possible that the deficit has elements of both a phonological deficit and a low level auditory processing deficit. One possibility is to look at the subcomponents that make up phonological information. For example, the importance of rhythm and tone awareness in children with dyslexia and typically developing children.

Study Three suggested that children with DCD may use a more visual strategy when carrying out motor tasks. Although studies have looked at both visual processing, for example Wilson and McKenzie (1998) and Hulme et al. (1982), and controlling the amount of visual processing in children with DCD, there is a possibility of carrying out further research looking at visual strategies children with DCD use to cope with complex coordination tasks, particularly in the field of visual motor integration.

Study One (RAN) was the first to investigate the ability of children with DCD to carry out RAN type tasks, the evidence here was that the children had difficulties with articulation during a short form RAN task. Future research investigating RAN and DCD might help to develop research into the underlying causes of DCD. In addition, contrasting a clearly verbal process such as RAN with a non verbal version of RAN,

possibly involving matching pictorial icons may provide a more refined assessment of the deficits in RAN in children with DCD.

In concluding this section, although there are lessons to be learnt to apply to future research, the findings from this set of studies are likely to lead to new insights into the nature of difficulties of children with dyslexia and DCD, and to the role of temporal processing in children's cognition.

8.3. Technical innovation and achievement

The thesis provided an opportunity to develop several areas of technical innovation with respect to conducting research into aspect of temporal processing ability. These will be discussed below. All four of the experimental studies have implications for new and established assessment methods. They will be discussed in the order that they were presented in the thesis.

RAN has already been included in a number of assessment batteries, for example, the Phonological Assessment Battery (Frederickson et al., 1997) and the Comprehensive Test of Phonological Processing (Wagner, Torgensen, and Rahtote, 1999). In these two assessment batteries, a 50 item RAN task is used. The outcome measure is the time taken to name all stimuli. The research for this study would suggest that the modifications suggested by Compton et al. (2002), to count the number of stimuli named in 15 seconds, could be incorporated into future assessments. Furthermore, careful analysis of the articulation and non-articulation durations indicated differences between the children with dyslexia and the children with DCD that would not have been found had a more global measure, such as the total number of stimuli named in 15 seconds, been used. The findings would suggest that development of this type of

analysis could provide a more detailed study of RAN ability in children with special needs.

Unlike RAN, it is not clear if temporal production has been used as a formal method of assessing children with dyslexia or children with DCD. To take dyslexia as an example, in comparison to other methods of assessment such as measures of phonological awareness, there have been very few studies of temporal production. Nevertheless, the evidence from this study would suggest that there is a specific pattern in auditory temporal production responses that differentiates children with dyslexia from typically developing children. Furthermore, studies involving reading aged matched groups (see Bradley and Bryant, 1978) might help develop this area further. Further research might also establish this as a consistent deficit, but the technical difficulties of administering and scoring the test would still need to be resolved. For example, each participant yielded 1,920 data points (40 button press and 40 button releases for 48 trials). Piek and Skinner (1999) is one of the few studies to systematically examine on-contact and off-contact duration for tapping in a special needs population prior to this study. In each trial, they had five button presses and five button releases, a total of 15 trials per participant and consequently, 150 data points in total.

The temporal generalisation task did not clearly differentiate the three groups, but it is possible that a subgroup of children does have a temporal generalisation deficit. Some children across all three groups did poorly at both the visual and auditory tasks and this may be related to as yet undiscovered deficits which may impact on their school and home life and such a deficit may still subtly affect skills such as reading and complex movement. As studies involving measures of temporal generalisation are only beginning to be systematically studied in children, there is still a need to conduct research into how

temporal generalisation and, more generally, temporal processing are related to other cognitive processes. This may then lead to the development of these tests as assessments.

TOJ had mixed results for each group. If assessments were to be designed using this type of measure, a further development of the consonant-vowel task would be important for dyslexia. For DCD, the shapes condition might be useful within conditions, children with DCD showed problems with this task. The reaction time data provided a useful second dependent variable in the TOJ task as the TOJ accuracies were often near ceiling. Further development of this may also be useful to the TOJ research field as a whole.

Another aspect of the collection of studies is the technical accomplishments of the study. Whilst the baseline measures were primarily carried out using pen and paper, the experimental measures were exclusively computer based. The thesis demonstrated that a multimedia laptop can now carry out much of what, only a few years ago, required laboratory based assessment. Computerised assessments have become more prevalent as a method of gaining a profile of abilities and difficulties of children with special needs, such as those developed by Singleton, Thomas, and Horne (2000). In addition, in interventions, computer based training programmes are beginning to support children with special needs (for example, Singleton and Simmons, 2001). This is particularly the case for learning difficulties such as dyslexia. Software can be used to either control the presentation of text (or allow the user to do so) or provide means of displaying information in a non-textual way. However it has been more difficult to develop computer based assessments for disorders such as DCD primarily as one of the main design considerations may not be with the nature of the software but human-computer

interaction especially with respect to input devices, such as rollerballs, mice, or keyboards. However new technologies may help change this. Tasks where users can interact with a computer using hand gestures recorded by webcams, may be useful in the future.

8.4. General conclusions

Overall, the four studies in this thesis did not provide support for a common temporal generalisation deficit in dyslexia and DCD. The evidence from the studies broadly supported the phonological processing theory in dyslexia. However, the findings from the DCD groups emphasise the heterogeneity of this group, and did not find evidence of a deficit in temporal processing for these children. The research, did, however, indicate new avenues of research of dyslexia, DCD, and typically developing children in both auditory and visual temporal processing.

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Appendix One: Scripts for Experimental Tasks

1 Instruction Script for the Temporal Production Task

1.1 Introduction

Taking part in this task you will be asked to tap to a beep or to a circle that flashes.

If you hear the beep you will have to tap in time with the beep. The beep will then stop, and you need to keep tapping at the same speed until the computer tells you to stop.

If you see a flashing circle you will need to watch the circle carefully and tap in time with the flashing circle. The flashing circle will then stop and you need to keep tapping at the same speed until the computer tells you to stop.

After each go each go, this screen will appear. The more blue that the progress bar shows, the more of the task that has been finished.

The program then proceeds to the practice session.

1.2 Practice

This is the practice session. Remember to tap in time with the beep and when the beep stops keep tapping at the same speed.

Remember to tap in time with the beep and when the beep stops, keep tapping at the

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same speed.

Remember to tap in time with the flashing circle and when the circle stops, keep tapping at the same speed.

2 Instruction Script for Auditory Temporal Generalisation

Included here is the auditory temporal generalisation task. The script for visual temporal generalisation task was similar.

2.1 Introduction

Taking part in this task you'll hear some sounds and have to make some judgements about their length.

The owl always makes a sound of the same length. Listen carefully. *500 ms tone played.*

Here is the sound played again. *500 ms tone played five times.*

You are now going to hear some more sounds and your task is to judge whether the sound are the owl's sound.

This sound is not the owl's sound because it is too long. *750 ms tone played.*

The correct response is to click on the crossed out owl.

This sound is the correct sound. *500 ms tone played.*

The correct response is to click on the owl picture.

This sound is not the owl sound because it is too short. *250 ms tone played.*

The correct response is to click on the crossed out owl.

2.2 Practice

This is the practice trial.

You will hear a number of different sounds and your task is to judge if any of these sounds are the owl's sound.

You will now hear more sounds and you will need to judge again whether they are the owl's sound.

As a reminder, here is the sound of the owl again. *500 ms tone played five times.*

3 Instruction Script for the Temporal Order Judgement Task

3.1 Introduction

The script for the ba da will be presented, however, the scripts for the other three conditions was very similar.

Taking part in this task you will hear two short words.

In this example the short words are ba and da.

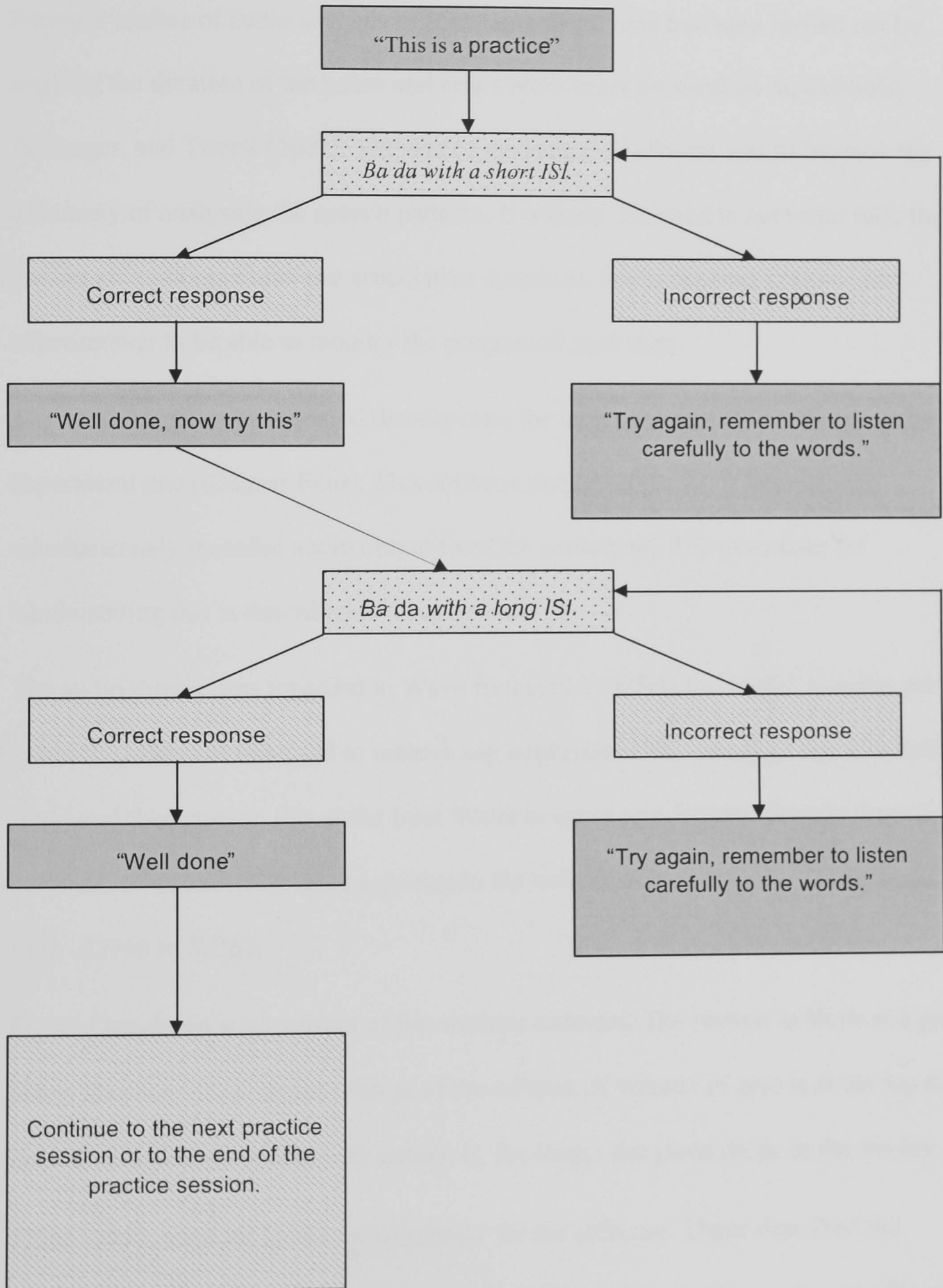
You will need to click on the button that stands for this word and then on the button that stands for this word.

3.2 Practice

The practice session software's reactions to the participant's responses are presented in diagrammatical format below (See Figure 3.2). The practice stimuli for the other three trials were:

- “p” and “d”, long ISI and “d” and “p”, long ISI.
- “hi” and “low”, long ISI and “low” and “low”, short ISI.
- Octagon and circle, long ISI and circle and octagon, long ISI.

Figure 3.2. Diagram depicting the script for the temporal order judgement practice task.



Appendix Two: A Description of the Rapid Automated Naming Analysis Software

Previous studies of audio analysis of RAN speech patterns had been carried out by marking the duration of the pause and articulation times by hand, as in, Cobbold, Passenger, and Terrell (2003). The aim of devising the software was to improve the efficiency of analysing the speech patterns. It was not designed to automate fully the process of marking pause and articulation durations. It was devised to allow the experimenter to be able to monitor the program at each step.

The audio sample was recorded directly onto the laptop using software designed for experiment one (Chapter Four). This software displayed the RAN stimuli and simultaneously recorded audio output from the participant. The procedure for administering this is described in Chapter Four.

The audio sample was recorded in Wave format at 11025Hz (or 11,025 samples per second). Goldwave was used to remove any background noise (using a noise reduction filter) and then convert this audio from Wave to into a text format. The text format consisted of a numerical value referring to the volume of each sample. These ranged from -32768 to 32767.

Figure One shows a screenshot of the analysis software. The section in black and green below shows a visual representation of the volume. A volume of zero is at the top and the higher in volume the speech sample is, the longer the green drops in the display.

Three values were set by the experimenter for the software. These described the following: (a) the threshold above which it would consider a value on the text file as articulation (b) the threshold below which it would consider a value as a pause and (c)

the amount of samples it would use to establish whether a value was an articulation or pause. (a) and (b) could be checked to make sure that the threshold above and below captured only articulation and pause durations. To do this the experimenter chose the “overlay speech” and “overlay silence” buttons (see Figure One). This would draw a line across the graphical display for the thresholds for the sample and the thresholds could be amended if needed. (c) could be checked once the software had been run. Once the software had been run, the visual display marked the beginning of articulation and the beginning of pause durations with coloured bars, yellow for articulation and blue for pause. Should these not match the green spikes of the volume then the analysis could be re-run with amended values for (a), (b), or (c).

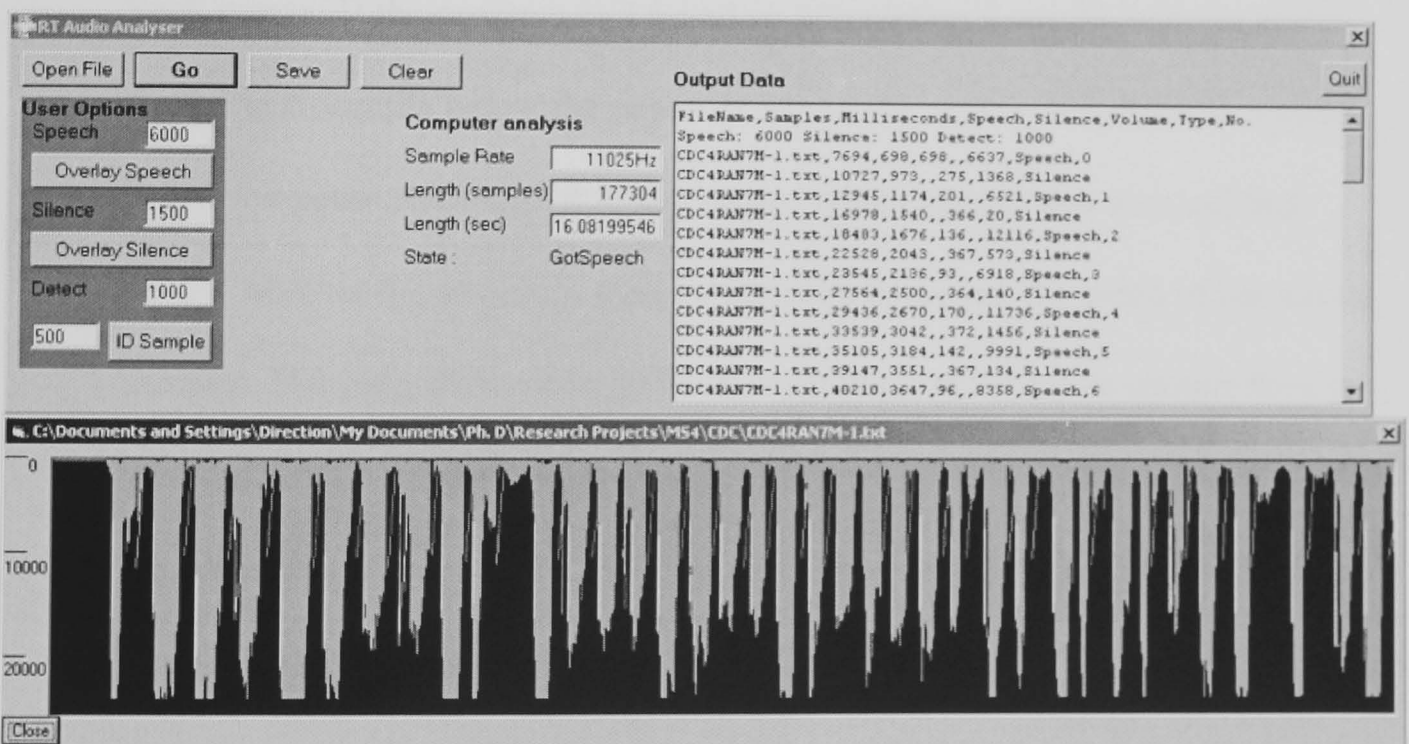


Figure 1. A screenshot of the RAN analysis software

In order to determine the placement of the yellow and blue markers for the beginning and end of the articulation and pause durations, the computer had two “behaviours”: seek articulation and seek pause.

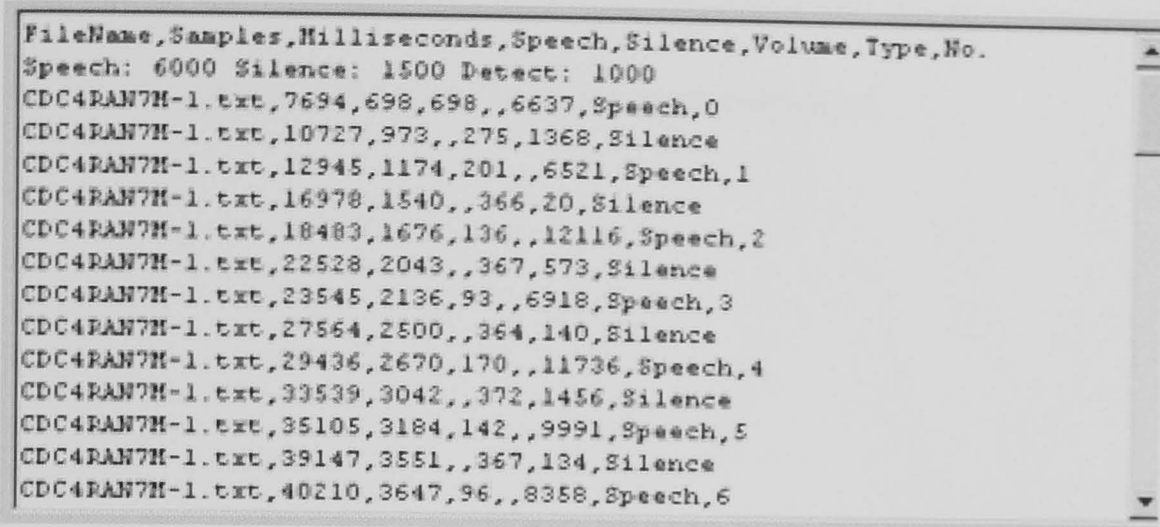
Seek articulation: This was the first behaviour the software would use. In this, it would search for the first sample with a value higher than the articulation threshold (a). It would record which sample this was (*sample zero*) and then take the mean of the next n samples. n is the value of (c), the number of samples required to establish an articulation or pause. Should the mean of n samples also be higher than the articulation threshold then the software judged it had found an articulation and it would record *sample zero* as the starting point for this articulation. If the mean of n samples was below the articulation threshold, it would discard *sample zero* and begin searching for the next sample above the articulation threshold.

Seek pause: If the program had found an articulation it would begin to search for the next sample below the pause threshold (b). Again, if it found a sample below the pause threshold, it would record which sample this was and then decide whether the sample is a pause duration by taking the mean of the next n samples. If it judged the value to be the beginning of the pause sample then it would record this sample as the beginning of the pause duration and then seek the beginning of the next articulation duration, if not then it would discard the sample and start searching for the pause duration again.

As noted above, the values ranged between -32768 to 32767. The numerical values for each sample were made absolute in order to calculate the mean of a set of samples for the software.

Output data and verification

The computer then recorded the output in the Output Data text box (Figure 2) and this output could be saved in comma separated value format for later analysis in excel.



FileName	Samples	Milliseconds	Speech	Silence	Volume	Type	No.
Speech: 6000 Silence: 1500 Detect: 1000							
CDC4PAN7M-1.txt	7694	698,698	,,6637	Speech			0
CDC4PAN7M-1.txt	10727	973,,275	1368	Silence			
CDC4PAN7M-1.txt	12945	1174,201,,6521	Speech				1
CDC4PAN7M-1.txt	16978	1540,,366	20	Silence			
CDC4PAN7M-1.txt	18483	1676,136,,12116	Speech				2
CDC4PAN7M-1.txt	22528	2043,,367	573	Silence			
CDC4PAN7M-1.txt	23545	2136,93,,6918	Speech				3
CDC4PAN7M-1.txt	27564	2500,,364	140	Silence			
CDC4PAN7M-1.txt	29436	2670,170,,11736	Speech				4
CDC4PAN7M-1.txt	33539	3042,,372	1456	Silence			
CDC4PAN7M-1.txt	35105	3184,142,,9991	Speech				5
CDC4PAN7M-1.txt	39147	3551,,367	134	Silence			
CDC4PAN7M-1.txt	40210	3647,96,,8358	Speech				6

Figure 2. Output data text box. The computer recorded the number of samples then converted this into number of milliseconds. Following this, it calculated the duration of each articulation and pause duration.

The visual display meant that the experimenter could see if the software had produced any false positives or negatives (yellow or blue bars which did not match articulation and pause durations). If any were found then the experimenter could re-run the software with different parameters (a, b, or c). Any doubt as to whether the software had recorded the correct samples as the beginning of an articulation or a duration could be resolved in two ways.

Option one. This used the analysis software. The Output Data text box recorded the sample at the beginning of each articulation and pause. The experimenter could enter a sample in the box next to ID Sample button and click on the button. A visual display of which sample this referred to appeared in the visual display.

Option two. This used Goldwave. Comparisons were made between carrying out the analysis using the software and marking the RAN Wave file by hand using Goldwave.

The output text data was then imported into Excel and the mean and standard deviation of the articulation and pause durations were calculated.