Processing speed in children and adolescents

Submitted by Lee Gamman, to the University of Exeter

as a thesis for the degree of Doctor of Clinical Psychology, 2nd May 2019

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: …………………………………………………………..

Acknowledgements

I would like to acknowledge and thank the children and families that took part in the empirical study for their time, commitment and enthusiasm in taking part in this research. I would also like to thank the clinicians, charity and the research group who supported the recruitment for the empirical study.

I would like to thank and share my appreciation to my supervisors, Dr Jennifer Limond and Dr Alicia Smith, for their support, guidance and expertise throughout this process.

Finally, I would like to share my gratitude to my family, in particular my partner, who have been so patient and have always shown unwavering faith in me over the past three years.

Table of Contents

List of Tables

Literature Review

Empirical Paper

List of Figures

Literature Review

Empirical Paper

SCHOOL OF PSYCHOLOGY

DOCTORATE IN CLINICAL PSYCHOLOGY

LITERATURE REVIEW

Processing speed and academic achievement in typically developing children and adolescents

Trainee Name:	**Lee Gamman**
Primary Research Supervisor:	**Dr Jennifer Limond**
	Consultant Clinical Neuropsychologist, and Senior Lecturer, University of Exeter
Secondary Research Supervisor:	**Dr Alicia Smith**
	Research Tutor, University of Exeter

Target Journal:	Journal of Child Psychology and Psychiatry
Word Count:	5597 words (excluding abstract, tables, figures, references, appendices)

Submitted in partial fulfilment of requirements for the Doctorate Degree in Clinical Psychology, University of Exeter

Abstract

Background: Mathematical and reading abilities are predictive of academic achievement. To date, limited research has examined the relationship between processing speed and academic achievement in typically developing children. Greater insight into this relationship could help to identify the impact that reduced processing speed may have on long-term academic achievement. This review aimed to explore the relationship between these variables in typically developing children.

Method: Studies conducted in the past twenty years measuring mathematics and/or reading abilities and processing speed in typically developing children using a standardised assessment measure were included in the review. In total 1278 studies were screened, which led to the identification of eight eligible studies that were included in the review.

Results: No relationship was found between processing speed and reading ability. The findings on mathematics abilities were conflicting, with some studies identifying a relationship and other finding no significant association between these variables. Age appeared to be a moderating factor in studies that reported a significant relationship between mathematics and processing speed.

Conclusions: The findings suggest that the relationship between processing speed and academic achievement is complex and the following review was unable to ascertain the direct relationship between these variables. It is recommended that future research examines the relationship between age and academic achievement in further detail.

Keywords: processing speed, academic achievement, typically developing children, reading, mathematics.

Introduction

Academic achievement refers to how well a child is able to "assimilate, retain, and communicate their knowledge of what has been learnt from an educational programme" (Joe, Kpolovie, Osoniva, & Iderima, 2014). Research has found that there are numerous factors that can impact upon academic achievement. This can include but is not limited to the home environment and parenting behaviours (Taylor, Clayton, & Rowley, 2004), peer cyber-victimisation (Gardella, Fisher, & Teurbe-Tolon, 2017), socioeconomic status (Sinn, 2005), school and classroom climate (Bertowitz, Moore, Astor, & Benbenishty, 2017), motivation (Fong, Davis, Kim, Kim, Marriott, & Kim, 2017; Sing, Granville, & Dika, 2003), child attitudes (Singh et al., 2002), child self-perception (Fong et al., 2017), and intelligence (Deary et al., 2007; Erath et al., 2015).

It has been suggested that the acquisition of early numeracy and literary skills are important for developing academic achievement, with early mathematical concepts, language and reading skills predicting later learning (Duncan, Magnuson, Huston, & Kiebanov, 2007). There is evidence that the development of mathematical and literacy skills are related, with findings that early mathematical language mediates vocabulary and phonological awareness (Purpura, Logan, Hassinger-Das, & Napoli, 2017). Recent research has examined the links between general cognitive skills and academic skills (Namkung & Fuchs, 2015; Schneider & Niklas, 2017), with findings that processing speed and attention predict calculation competence in children with learning difficulties (Namkung & Fuchs, 2015) and general intelligence and working memory predict academic achievement in children (Schnieder & Niklas, 2017). Working memory capacity has also been found to predict skills in reading, spelling and mathematics (Alloway & Alloway, 2009).

The evidence that a variety of cognitive abilities predict and/or influence academic achievement suggests that there are multiple relationships between concepts such as cognition, intelligence and academic skills. Fry and Hale (1996) posit that children go through a developmental cascade in cognition, in which processing speed becomes faster throughout childhood and has a direct effect on the development of working memory capacity. Working memory ability subsequently impacts on other cognitive abilities such as reasoning, with this cognitive cascade determining individual differences in fluid intelligence. More recent evidence supports this view, with findings that reduced processing speed influenced executive functioning, with executive functioning mediating academic performance in premature children (Rose, Feldman, & Jankowski, 2011). An association between these cognitive abilities has also been found in adults with white matter disorders, with performance on executive functioning tasks being highly dependent on processing speed (Genova, Deluca, Chiaravalloti, & Wylie, 2013). If we were to consider the potential role of the developmental cascade on academic achievement, we might predict that gains in processing speed may lead to improvements in cognitive skills such as working memory, thus influencing intelligence, leading to greater academic achievement. If processing speed gains may have an impact on other cognitive skills and potentially academic achievement it is beneficial to have a greater understanding of this relationship.

Processing speed has been defined as ‘the speed of completion of a task with reasonable accuracy’ (Jacobson et al., 2011) and is thought to reflect the overall efficiency of the brain to register and process information (Deary, 2012).

It is not considered to be specific to a single domain but is instead a fundamental part of our information processing system (Kail, 1991). Processing speed has been regarded as a global mechanism which underlies performance in a number of cognitive domains for some time (Kail, 2000; Kail & Salthouse, 1994).

The global trend hypothesis (Hale, 1990) posits that all components of information processing develop at similar rates and that processing speed changes as a function of age. There is much research supporting the view that processing speed holds a developmental course (see for example Kail, 1991a, 1993, 2000; Kail & Salthouse, 1994; Kail & Ferrier, 2007). Kail (1991a) reported that processing speed initially shows a rapid increase in early and middle childhood, before slowing down and showing more gradual improvements in late childhood to early adolescence. By middle to late adolescence, processing speed is believed to have reached the levels of speed achieved in adulthood (Kail, 2000). It has been suggested this developmental change may be linked to neural development and reflect age-related changes in the rate of neural communication (Myerson, Hale, Wagstaff, Poon, & Smith, 1990).

Kail (2000) proposed that the development of processing speed acts as a basic parameter for cognitive functioning and is a key cognitive resource which underlies an individual's performance in a number of cognitive domains (Kail & Salthouse, 1994). This suggests that it may be fundamental to childhood cognitive development and supports the view that the age-related changes seen in processing speed are thought to be related to other cognitive abilities such as working memory and reasoning which also improve with age (Kail, 2000).

A study conducted by Rose et al. (2011) supports the view of a global mechanism and a developmental cascade. They explored the roles of processing speed and working memory on academic achievement in children that were born prematurely. The study provided support for a developmental cascade for academic achievement similar to that of intelligence. Their study found an association between prematurity and slower processing speed and concluded that slow processing speed subsequently leads to poorer working memory, thus leading to lower achievement in mathematics and reading. This finding would suggest that processing speed may have a relationship with academic achievement through its influence on working memory. The notion of a developmental cascade is further supported by a study which found that processing speed influenced academic achievement in school indirectly via reasoning and divergent thinking (Vock, Preckel, & Holling, 2011).

The concept of a developmental cascade is a simplistic model of the relationship between processing speed and cognitive skills required for academic attainment; however this relationship is more complex. Research has produced contrasting findings to this model, demonstrating the relationship between processing speed and school performance is only slightly weaker than the correlation between school performance and intelligence (Dodonova & Dodonov, 2012). This study suggests that processing speed may have a direct relationship with academic achievement outside of the developmental cascade. Unfortunately there is currently a limited evidence base that specifically investigates the relationship between these two variables.

It is pertinent to understand the relationship between these variables as there are a number of children with a range of different disorders that experience processing speed difficulties including children born prematurely (Rose et al., 2011), children who have undergone cranial radiation therapy (Mabbott, Penkman, Witol, Strother, & Bouffet, 2008; Scantlebury et al., 2016), cerebral palsy (Englander et al., 2013), fetal alcohol spectrum disorder (Fryer et al., 2009), acute disseminated encephalomyelitis (Lee, 2011) and dyslexia (Cardillo, Mammarella, Garcia, & Cornoldi, 2017). Developing a clearer understanding of the relationship may help to understand the potential impact that reduced processing speed can have on later academic achievement for children with neurological disorders.

Studies have found that children with mathematical or reading difficulties have reduced processing speed in comparison to their peers (Wang, Georgiou & Tavouktsoglou 2018; Swanson, Howard, & Saez, 2006). Findings suggest that processing speed can predict calculation competence (Namkung & Fuchs, 2015), mathematics (Fuchs, Fuchs, Compton, Powell, Seethaler, & Fletcher et al., 2006) and word reading and comprehension (Christopher, Miyake, Keenan, Pennington, DeFries, Olson et al., 2012; Peterson, Boada, McGrath, Willcutt, Olson, & Peenington, 2017) in children with learning disabilities or difficulties. Whilst these studies provide us with valuable insight into the relationship between these variables, it is also important to develop a clear understanding of their relationship in typically developing children (TDC), with some evidence that processing speed contributes to individual differences in academic achievements (Geary, 2011). This would provide information regarding TDC who do not meet diagnostic criteria for learning difficulties but that process information more slowly than their peers. It would allow exploration of whether there is a relationship on a continuum (i.e. there is variability in TDC's speed). This would provide insight into the impact that reduced processing speed may have on long-term academic achievement in children that do not meet diagnostic criteria.

Therefore, this systematic literature review aims to explore the relationship between processing speed and academic achievement. The research question for this review is: “to what extent does processing speed impact upon academic achievement in typically developing children and adolescents?”

As research has found that mathematics and reading are good indicators of academic success, including later mathematics and reading skills (Duncan et al., 2007), this review will only include studies that examine these abilities.

Method

In order to allow for a standardised non-biased approach to this systematic literature review, both the PRISMA-P reporting protocol (Moher, Shamseer, Clarke, Ghersi, Liberati, Mark, et al., 2015; Shamsear, Moher, Clarke, Ghersi, Liberati, Petticrew et al., 2015. See Appendix A) and the Cochrane Handbook for Systematic Review of Interventions (Higgins & Green, 2011) were used to conduct and structure this review.

Eligibility Criteria

Eligibility criteria for the study were constructed looking at population, exposure, comparator, outcome and study design (PECOS). The full inclusion and exclusion criteria can be found in Table 1.

Table 1. Full inclusion and exclusion criteria for the systematic literature review.

	Inclusion	Exclusion
Population	• Children up to the age of 18 years old • Male or female • TDC • When TDC are used as a comparison group. • Children with identified maths and reading difficulties but no formal diagnosis of a specific learning difficulty or disability.	• Over 18 years old • Young people with neurological impairment, including acquired and traumatic brain injury, preterm, epilepsy etc. • Children with neuro-developmental differences e.g. autism • Children with a diagnosis of specific learning difficulties e.g., dyslexia or dyscalculia. • Children with physical health difficulties • Children with mental health difficulties.
Exposure	• Processing speed will be operationalised as the time it takes to complete a cognitive task. • To include measures of either verbal or psychomotor processing speed, e.g. WISC symbol search and coding.	• Studies that only report on reaction time. • Studies with no inclusion of processing speed measures. • Studies which have a measure of PS within a test of intelligence but do not report specific findings on PS.
Comparison	n/a	n/a
Outcomes	• Studies that specifically examine academic performance • Academic performance may be reported in terms of reading ability, arithmetic ability, and/or academic achievement and attainment • Studies with a clear standardised or validated clinician or	• Studies that only report on intelligence • Studies that only refer to academic achievement with no clear measure of academic performance. • Studies that only report academic grades or teacher reports.

	researcher administered measure of academic achievement e.g. reading measures, arithmetic measures and wide range achievement tests.	
Studies	• Peer review articles • Quantitative studies • Longitudinal studies • Studies written in the past 20 years	• Qualitative studies • Clinical case studies or case series designs • Discussion or opinion papers • Review articles or chapters • Single case-experimental designs • Randomised control trials • Systematic reviews and meta-analyses • Editorials • Papers published in a foreign language where the translation to English is not available • Study proposals • Studies that validate a measure • Studies in which processing speed and academic attainment are studied in isolation from one another (e.g. effect of an intervention on each but not exploring a relationship between the two).

TDC= typically developing children; WISC= Wechsler Intelligence Scale for Children

Population. Participants were typically developing children that were aged up to 18 years old. Studies that considered TDC as a control group where only included if they specifically reported on the control data.

Exposure. Processing speed was operationalised as the time that it takes to complete a cognitive task (Christopher et al., 2012). Studies that included a measure of either verbal, visual or psychomotor processing speed were included in the review; however, studies that purely explored reaction time were excluded. Reaction time can be operationalised as how fast an individual responds to the occurrence of a stimulus (Woods, Wyma, Yund, Herron, &Reed, 2015). No limitations were placed on the type of setting that these measures were completed in, for example, in school settings or through a standardised test sampling.

Comparator. As this review did not look to make comparison between studies involving different groups, no comparator was included in the inclusion criteria.

Outcome. Studies that only reported on school grades or teacher reports were excluded from the review due to the opinion that these measures can be confounded by other characteristics of a child such as effort (Jensen, 1998, cited in Dobonova & Dobonov, 2011, page 163).

Study designs. Only peer reviewed studies that had been completed in the past twenty years (at the time of completing the search) were included. This date limitation was enforced so that the review would capture research conducted after Fry and Hale's (1996) seminal paper which was key in looking at the developmental cascade of processing in children.

Information Sources

In order to identify eligible studies, the following electronic databases were searched: PsycINFO, MEDLINE, EMBASE, CINAHL, and Psychology and Behavioural Science. The reference lists of studies that were included following the full text screening were also scanned for any papers that were not identified in the original search.

Search Strategy

All databases were searched on 5th December 2018. Key search terms were used and can be found in Table 2. Truncation symbols were included to ensure that all words with different endings or spellings were identified in the search.

Table 2. Key Search Terms

	Children Section 1 "OR"	Processing Speed Section 2 "OR"	Academic achievement Section 3 "OR"
Individual Search Terms (In title and abstracts)	child*, adolescent*, teenager, pediatric, paediatric*, "young people", "young person"	"cognitive processing", "processing speed", speed* adj4 "information processing", exp* cognitive processing speed	attainment, achievement, grades, "academic skills", exp* academic achievement
Combined Search (In title and abstracts)	Section 1 "AND" Section 2 "AND" Section 3		

Exp=Terms exploded

Study Records

Data management. All articles identified in the search were exported into Mendeley, a reference management software programme on 5th December 2018.

Selection process. An initial screen by title and abstract was completed against the criteria. The studies identified as appropriate at that this stage were then included in a full text screen to assess the eligibility of the studies against the inclusion and exclusion criteria.

Six studies were randomly selected to be reviewed by a second-rater at the full text screening stage. The second-rater was asked to make an independent yes/no decision regarding whether the studies were appropriate for inclusion based on the PECOS criteria. The second-rate yielded 100% inter-rater reliability.

Data Collection Process

The lead researcher independently extracted all data. A data extraction form was used to monitor eligibility of included studies, record decisions made during the review process and to ensure that appropriate data were extracted from included studies. This is in accordance with guidance from the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Deeks, 2011).

Data Items

Information was extracted from each study based on their study characteristics, including the title and author, the study design, participant characteristics and a description of the primary outcome measures (measures used and if appropriate, the time point collected). Information was also extracted regarding the quality of the studies and the main results.

Quality Appraisal

The Quality Assessment Tool (QAT) for Observational Cohort and Cross-Sectional Studies (National Heart, Lung and Blood Institute, 2017) was used to assess the quality of each study and will be reported in the results section.

Data Synthesis

Due to the diverse nature of the studies included in the review, a systematic narrative synthesis was completed in order to analyse the relationship between processing speed and academic achievement within and between studies, as recommended by guidance from the Centre for Reviews and Dissemination (2009). This allowed for an overall assessment of the evidence. Due to the variety and heterogeneity of the measures and analyses a meta-analysis was not completed.

The narrative synthesis includes descriptions of the study characteristics as well as description of the main findings amongst the studies. Information is summarised in text and through tables.

Results

Search Results

During the initial search, 1277 articles were identified. Following screening of the reference lists of full text papers, 1 additional article was identified for further full screening; however, was not included in the final papers reviewed. This study was missed as “processing speed” was not included in the key terms; however, the remaining key terms did fit the PECOS criteria and therefore search terms were not amended. This brought the total number of articles screened at title to 840 articles. Following screening, a total of 8 studies were included in the review (See Figure 1). A second-rater reviewed three of the studies at random using the QAT and inter-rater reliability was calculated at 99.57%. There was very good agreement between the raters, K= .930, p<.005.

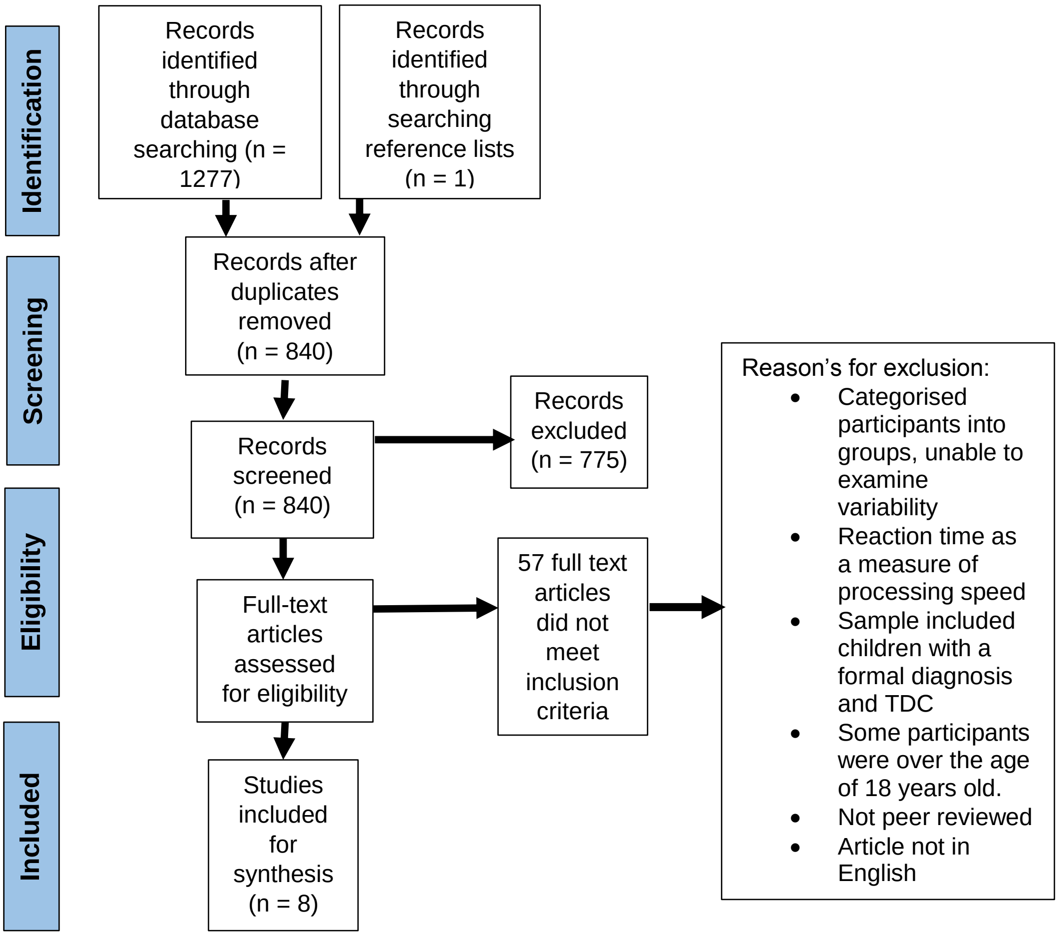


Figure 1. PRISMA-P Flow Diagram.

Excluded Studies

Following the full paper screening, there were four studies that were initially included and were excluded at the data extraction phase as they were unable to address the research question (Andersson, 2010; Floyd, Bergeron, & Alfonso, 2006; Swanson, Howard & Saez, 2006; Wang, Georgiou, Li, & Tavouktsoglou, 2018). These studies examined differences in processing speed and academic achievement between groups and were unable to provide any information regarding the variability on processing speed measures in TDC.

Table 3. A summary of included articles.

Study	Methods/ Participants	Outcome Measures	Results and Conclusions	QAT Rating/ Strengths and Limitations
1. Caemmerer et al., (2018)	**Method:** Cross-sectional **Participants:** N=181 Setting: WISC-V and WIAT-III co-norming sample Population: Typically developing children Age: M=11.82; SD=3.07 Sex: 55% male and 45% female Country: America	**Measures of processing speed**: Coding, Symbol Search and Cancellation Subtests from the WISC-V. **Reading and mathematics abilities**: WIAT-III subtests Mathematics: Math problem solving, math fluency and numerical operations. Reading: oral reading fluency, word reading, pseudoword decoding and reading comprehension.	**Key Findings:** Processing speed influenced oral reading fluency (β= .26. SE=.08, P<.01) with a moderate effect size but no statistically significant effect on basic reading and reading comprehension. Processing speed influenced both numerical operations (β=.21, SE=.09, p<.05) and math fluency (β=.36, SE=.08, p<.001) with large effect sizes. Age moderated the effect of processing speed on math problem solving (b=-.196, SE= .093, p<0.05). **Conclusions:** Processing speed exerts consistently strong effects on reading fluency across all ages but there were no significant effects on basic reading skills or reading comprehension. Processing speed influences all three maths skills however the effects of processing speed on math problem solving were moderated by age and were relatively stronger for younger students.	**QAT:** Poor **Strengths:** Standardised assessments used for exposure and outcome variables which have been found to be reliable and valid. Breaks down reading and math ability into separate skills; allows for the closer examination of relationship with cognitive variables. Sample likely to be representative of the general population. **Weaknesses:** Exposure and outcome variables measured several days apart; possible maturation effects (e.g. tiredness, motivation) that could act as confounders and impact on performance. May not be able to identify weaker interaction effects as a result of low power.

				Oral verbal fluency has a timed element which may influence relationship with processing speed.
2. Peng et al., (2018)	**Method:** Cohort design **Design:** N= 185 Setting: School Population: Children classed as "At risk" readers Age: At beginning of study M=6.46; SD=0.40 Sex: 100 male and 85 female Country: United States	**Measures of processing speed:** the Cross Out subtest from the WJ-III. *Time point*: Time point 0 (fall of first grade) and Time point 1 (spring of first grade). **Reading ability**: Sight-word reading was explored with the TOWRE-Sight Word Efficiency (Torgesen et al., 1999). Reading comprehension was assessed using The Reading Comprehension subtest of the Iowa Test of Basic Skills (ITBS; Hoover, Dunbar, & Frisbie, 2001). *Time points*: Time point 0 (fall of first grade), Time point 1 (spring of first grade), Time point 2 (spring of second grade),	**Key Findings:** Processing speed did not uniquely contribute to growth in reading comprehension (β=.38, p=.15) or word reading (β=.41, p=.03). P value corrected (.05/2=0/25) to reduce possible Type 1 errors. **Conclusions:** Letter knowledge was the sole predictor of growth in word reading, whereas vocabulary and nonverbal reasoning were predictors of reading comprehension development.	**QAT:** Good **Strengths:** Reading difficulties were screened by a standardised assessment. Study examines growth in reading abilities. Inter-rater agreement on scoring of measurements was 90% or better. **Limitations:** Only a single measure of processing speed. Processing speed only measured at first two time points and not across whole study. Study was implemented over 3 successive years and sample represents three cohorts. Study does not consider possible history effects (e.g. change in curriculum, change in teachers) which could

		Time point 3 (spring of third grade), and Time point 4 (spring of fourth grade).		impact on variance.
3. Peng et al (2016)	**Method:** Cohort design **Participants:** N= 176 Setting: Schools Population: Children with mathematics and reading difficulties Age: At beginning of study M= 6.64 years; SD=0.42 Sex: 79 male and 97 female Country: United States	**Measures of processing speed**: Cross Out subtest from the WJ-III *Time point:* Time 1 only (beginning of first grade) **Mathematics ability**: Incoming calculation assessed by the Addition and Subtraction Fact Fluency Test Battery (Fuchs, Hamlett, & Powell, 2003), and numerical competence assessed by the numerical competence subtest from KeyMath 3 (Connolly, 2007). *Time point:* Time 1 only. Calculation was assessed by arithmetic subtests	**Key Findings:** Children with faster processing speed tend to show stronger performance on calculations at the beginning of first grade (standardised coefficient= .23, p=.002). Children with faster processing speed tend to show stronger performance on calculations at the end of the third grade (standardised coefficient= .42, p<.001. Processing speed predicted calculation development on a marginally significant level (standardised coefficient= .26, p=.06); however, marginal significance gone after model ran with bootstrapping (bootstrapping 95% confidence interval (CI) of unstandardized coefficient= -0.001, p=.15). **Conclusions:** Processing speed predicts calculation performance at the beginning of first grade and the end of third grade; however, did not find that processing speed significantly predicted calculation development from the beginning of first grade to the end of third grade.	**QAT:** Fair **Strengths:** Presence of maths and reading difficulties were screened on standardised measures with inclusion and exclusion criteria. All but one measures (numerical competence) has acceptable reliability in current sample. 20% of tapes of testing sessions with research assistants randomly selected and stratified and underwent accuracy checks by an independent scorer- agreement on administration and scoring exceeded 90%. Calculation development findings did not survive bootstrapping **Limitations:** Only examines mathematical calculations

		from the WRAT 4 (Wilkinson & Robertson, 2006). *Time point*: Time 1 (beginning of first grade), Time 2 (end of first grade), Time 3 (end of second grade), and Time 4 (end of third grade).		as outcome; no other mathematical abilities assessed. Processing speed only measured at first two time points and not across whole study.
4. Parkin & Beaujean (2012)	**Method:** Cross-sectional Study **Participants:** N= 550 Setting: The standardised linking sample of the WISC-IV and WIAT-II Population: Typically developing children Age: Ranged from 6 years to 16years (M=11.58, SD=3.22). Sex: Male (N=282); Female (N=268). Country: America	**Measure of processing speed**: Symbol search, Coding and Cancellation subtests from the WISC-IV **Mathematics ability**: Numerical operations and Math reasoning subtests from the WIAT-II.	**Key Findings:** Significant correlations between processing speed and math reasoning (r=.41, p=.05), as well individual subtests of processing speed; symbol search (r=.48, p=.05), coding (r=.34, p=.05) and cancellation (r=.09, p=.05). When just stratum II factors are used as predictors, the magnitudes of their standard errors for the path coefficients are relatively low (<.30). None of the stratum II factors (including processing speed) are very strong predictors of quantitative knowledge (numerical operations and maths reasoning). **Conclusions:** The results indicated that no stratum II factors (processing speed, fluid reasoning, comprehension-knowledge, short-term memory) were significant predictors of mathematics. When general intelligence was a predictor	**QAT:** Poor **Strengths:** Large sample size. A relatively good representative sample of the population. Standardised assessments of both processing speed and academic achievement used. **Weaknesses:** There is a very weak correlation between the cancellation subtest and math reasoning in comparison to other processing speed subtests. Study fails to examine the effect of age as a variable.

			of mathematics, it had a strong, direct effect, suggesting it at least within the context of the WISC-IV assessment, general intelligence represents the strongest predictor of quantitative knowledge.	
5. Passolunghi & Lanfranchi (2012)	**Design:** Cohort design **Participants:** N= 70 Setting: Kindergarten Population: Typically developing children Age: Time 1 (M=5 years 2 month; SD= 4 months. Time 2 (M= 5 years 8 months; SD= 4 months). Time 3 (M= 6 years 6 months; SD= 4 months). Sex:38 females and 32 males Country: Italy	**Measures of processing speed**: WJ III visual matching task and the speed pattern comparison task (Salthouse, 1993, modified). **Mathematics ability**: *Time 1*: Assessed verbal counting using The verbal counting task (Hitch & McAuley, 1991; Passolunghi *et al.*, 2007; 2008) and The counting speed task based on 'Counting Spots Task' (Hitch and McAuley, 1991). *Time 2*: Assessed Numerical competence using the early numeracy test for toddlers (Van Luit *et al.*, 1994).	**Key Findings:** Processing Speed was significantly and positively related to numerical competence; visual matching (r=.37, p<.01), and speed pattern comparison (r=.39, 0<.05). There is a direct relationship between processing speed and numerical competence at time 2 (r=.45, p<.01) and math achievement at time 3 (r=.34, p<.01). Processing speed showed a significant relationship with maths achievement at time 3, after adjusting for numerical competence (R^2 = .23, p=.05). **Conclusion:** Processing speed has a significant relationship with number competence at the end of kindergarten and also has a relationship with mathematical achievement at the end of the first grade.	**QAT:** Fair **Strengths:** Took into account numerical competency as well as mathematical achievement and made adjustments in the analysis. **Weaknesses:** Counting spots task appears to have a processing speed element to the task, may impact upon findings. Questionable internal consistency for the processing speed composite (Cronbach α=.60).

		Time 3: Assessed mathematics achievement using a standardised mathematics test for First-year primary school pupils (Amoretti, Bazzini, Pesci, & Reggiani, 1993).		
6. Berg (2008)	**Design:** Cross-Sectional **Participants:** N = Main study (90) Setting: School Population: Typically Developing Children Age: Ranged from 98 to145 months Sex: 46 girls and 44 boys Country: Canada	**Measure of processing speed**: Digit naming and digit articulation **Reading and Mathematics achievement:** Measured by the WRAT3 (subtests not specified)	**Key Findings:** Processing speed was influential in accounting for age-related differences in arithmetic calculation (R^2=.07, p=.002). Processing speed contributed to a small but significant individual variance to arithmetic calculation after accounting for the influence of chronological age (R^2=.05, p=.005), but reading was the strongest contributor to arithmetic calculation, accounting for 15% of the variance (R^2=.15, p<.001). However, processing speed did not significantly contribute to children's arithmetic calculation above the contribution of chronological age and reading (R^2=.01, p=.155). **Conclusions:** Processing speed is a significant contributor of arithmetic calculation only in relation to age-related differences in the general sample. Individual working memory components contributed to unique variance in arithmetic calculation in the general	**QAT:** Poor **Strengths:** Processing speed tests were found to be reliable. Standardised measures of both reading and maths. Took into consideration the role that other academic abilities (e.g. reading) play in arithmetic skills. **Limitations:** Lack of evidence found regarding the validity of the tests used to measure processing speed. Sample not likely to be overly representative of the general population. Socioeconomic status was not assessed but each school was located in a

			sample.	predominantly middle class area.
7. Glutting et al., (2006)	**Design:** Cross-sectional **Participants:** N= 498 Setting: The linking sample of the WISC-IV and WIAT-II Population: Typically developing children Age: Ranged from 6 years to 16years 11 months. Sex: Not reported Country: America	**Measure of processing speed**: Symbol search and Coding Subtests from the WISC-IV **Reading and mathematics ability**: Composite scores for reading (Pseudoword decoding, Word reading and Reading comprehension) and mathematics (Numerical operation and Math reasoning) from the WIAT-II	**Key Findings:** FSIQ by itself explained 60.2% of the variance in the observed reading composite and 59.7% of the variance in the mathematics composite.VC, PR, WM, and PS explained an additional 1.8% of the variance in the reading composite and 0.3% in the mathematics composite; however, none of the specific factors uniquely explained the observed variance in the reading and mathematics composites. Models that attempted to link processing speed to reading failed to demonstrate a statistical fit ($X^2_D(1)=0.0$. $p>.05$). Models that attempted to link processing speed to mathematics failed to demonstrate a statistical fit ($X^2_D(1)= 0.14$, $p>.05$). **Conclusions:** Only general intelligence and verbal comprehension influenced the reading and mathematics achievement constructs.	**QAT:** Poor **Strengths:** Large sample size. A relatively good representative sample of the population. Standardised assessments of both processing speed and academic achievement used. Explores results in relation to an observed and an explanatory relationship between exposure and outcome. **Weaknesses:** Study fails to examine the effect of age as a variable.
8. Bowey et al., (2004)	**Design:** Cross-sectional **Participants:** N = 125 Setting: School Population: Typically	**Measures of processing speed**: The visual matching and cross out tasks from the Woodcock-Johnson Tests of Cognitive Ability, and The identical	**Key Findings:** Processing speed explained only 5.3% of the variation in word reading, $F(1,123)=6.68$, $p<.01$. However, it was not able to explain individual differences in word reading ability once the effects of age were controlled for.	**QAT:** Poor **Strengths:** Uses at least one standardised measure of processing speed. Uses a standardised

	Developing Children Age: M=9 year 9.71 months; SD= 10.59 months Sex: No details provided. Country: Australia	pictures and Number comparison tests. **Word reading ability**: the Word Identification and the Word Attack subtest from the Revised Woodcock Reading Mastery Tests	**Conclusions:** With age controlled effects, general processing speed did not explain significant additional variation in word reading.	measure of word reading ability. **Weaknesses:** May be an administration bias due to administration of measure based on researcher prejudgements. Sample likely to be unrepresentative of the general population as the participants only recruited from one school in a middle-class population.

M= Mean; FSIQ= Full scale intellectual quotient; PR= Perceptual reasoning; PS= Processing speed; QAT= Quality assessment tool; SD= Standard deviation; TOWRE= ;VC= Verbal comprehension; WIAT-II= Wechsler Individual Achievement Test-Second Edition; WIAT-III= Wechsler Individual Achievement Test- Third Edition; WISC-IV= Wechsler Intelligence Scale for Children-Fourth Edition; WISC-V= Wechsler Intelligence Scale-Fifth Edition; WJ-II= Woodcock Johnston Test of Cognitive Abilities-Second Edition; WJ-III= Woodcock Johnston Test of Cognitive Abilities- Third Edition; WM= Working memory; WRAT-3= Wide Range Achievement Test- Third Edition; WRAT-4= Wide Range Achievement Test- Fourth Edition.

Study Characteristics

Eight studies were included in the review and the study characteristics are found in Table 3. All eight studies reported on the relationship between processing speed and reading and/or mathematics; however, this was not the primary research question for any of the studies included in the review.

Design. Five studies used a cross-sectional design (1, 4, 6, 7, 8) and three studies used a cohort design (2, 3, 5).

Sample size. Most studies ranged from 125-181 participants; however, two studies had fewer than 100 participants (5, 6) with the largest study having a total of 498 participants (7).

Participants. Of the eight studies, six in total included typically developing children (1, 4, 5, 6, 7, 8), one study included children which were identified as “at risk” readers (2), and one study included children who were identified with mathematics and reading difficulties with no formal diagnosis (3). In studies 2 and 3 all children identified with reading or mathematics difficulties or “at risk” readers by their school teacher as well as a battery of reading measures were included, and in study 3 mathematics difficulties were confirmed using the Wide Range Achievement Test 4 (WRAT-4). The majority of studies took place in a school/kindergarten setting (2, 3, 5, 6, 8), although three studies were part of linking samples for Wechsler measures (1, 4, 7). The age of participants across studies ranged from M=5 years 2 months (5) to 16 years 11 months old (4, 7).

Outcomes. Processing speed was the outcome for the exposure variable and a variety of measures were used to assess this. Three studies used processing speed subtests for the WISC-V (1, 4, 7); two of these (1, 4) used all three subtests (Coding, Symbol search and Cancellation), whilst one study only used the Coding and Symbol search subtests (7). Four studies used subtests from the Woodcock Johnson-III (WJ-III; 2, 3, 5, 8); two studies only used the Cross out subtest (2, 3), one study used both the Cross out and the Visual matching subtests (8), with one study using the Visual matching subtest (5). Study 5 also used the Speed pattern comparison task. Finally, digit naming and digit articulation were used in one study (6).

Academic achievement was examined looking at reading and mathematics. Four studies examined mathematics alone (3, 6, 4, 5), two studies examined reading alone (2, 8), with two studies examining both mathematics and reading achievement (1, 7).

A range of subtests were used to measure mathematical skills. These included the Addition and Subtraction Fact Fluency Test Battery (3), the Wide Range Achievement Test 4 (WRAT4; 3, 6), the Wide Range Achievement Test 3 (WRAT3; 6), KeyMath (3), the early numeracy test for toddlers (5), the Wechsler Individual Achievement Test-Second Edition (WAIT-II; 4, 7), Wechsler Individual Achievement Test-Third Edition (WIAT-III; 1), the Verbal Counting task and the Counting Speed tasks (5) and a standardised mathematics test for first-year students (5).

Similar to mathematics, various measures were used to measure reading ability. Measures included the TOWRE-Sight Word Efficiency Test (2), WIAT-II (7, 8), the WIAT-III (1) and the Revised Woodcock Reading Mastery Tests (8).

Quality Appraisal

The results for the quality of the studies are presented in Table 3. Five studies received an overall quality rating of ‘poor’ (1, 4, 6, 7, 8), two received a ‘fair’ rating (3, 5), and one study received a rating of ‘good’ (2).

Synthesis of Results

The results can be found in Table 3 including the main findings and conclusions.

Mathematics achievement. Two studies (1, 5) demonstrated statistically significant relationships between processing speed and mathematical achievement. In particular, processing speed was found to influence numerical operations and mathematics fluency demonstrating a large effect size, with a stronger relationship between processing speed and mathematical problem solving in younger children (1). Similarly, processing speed had a significant relationship with number competence in younger children (end of kindergarten) and with mathematics achievement in older children (end of first grade; 5).

Three studies (3, 4, 6) found variable results. Processing speed was found to influence arithmetic calculation but was not found to be a significant contributor to this mathematic skill once age and reading ability were taken into account (6). Although a significant relationship between processing speed and mathematical reasoning was found, processing speed was not found to be a strong predictor of quantitative knowledge (numerical operations and mathematic reasoning; 4). Whilst children with fast processing speed showed stronger performance in calculations at the end of 1^{st} and 3^{rd} grade, processing speed was not found to be a predictor of the development of calculation skills

(3). One study did not find any significant link between processing speed and mathematical ability (7).

Overall, the majority of mathematical studies were rated as ‘poor’ (1, 4, 6, 7), with the exception of studies 3 and 6 which were found to be of stronger quality (rated as ‘fair’). The validity or reliability of the processing speed measures were considered a limitation in three studies (4, 5, 6), and one study appeared to have an unrepresentative sample (6).

Reading achievement. One study found that processing speed influenced oral reading fluency (1); however, all other results failed to reach statistical significance in the four studies that examined reading abilities (1, 2, 7, 8). Processing speed was not found to be significantly related to word reading or reading comprehension (2, 7), with other cognitive skills having an influence over these skills. For example, vocabulary and non-verbal reasoning were found to contribute to reading comprehension, and letter knowledge was found to contribute to word reading (2). Whilst one study found that processing speed did explain some variance in word reading, this finding was not present once age was accounted for (8). One study failed to find a link between processing speed and reading abilities, suggesting that general intelligence and verbal comprehension were the only factors that influenced reading (7).

Overall findings. In summary, this review did not find a significant relationship between processing speed and reading abilities (2, 7, 8) with the exception of oral reading fluency (1). The findings from studies examining mathematical ability produced some variable and conflicting results. Processing speed was found to be significantly related to mathematical calculations (5) and mathematical problem solving (1) however these were moderated by age.

Whilst a large effect size was seen in the relationship between processing speed and mathematical fluency and numerical operations in one study (1), another found that processing speed was not a significant predictor of numerical operations or mathematics reasoning (4). Processing speed was not found to significantly predict calculation development (3), mathematics achievement (7) and numerical competence once age is accounted for (6).

Discussion

The purpose of this systematic literature review was to explore the relationship between processing speed and academic achievement. Studies that examined mathematical and reading abilities were included in the review as measures of academic achievement. Eight studies in total were included and all studies reported on the relationship between these two variables using either a cohort or a cross-sectional study design.

The studies reviewed produced conflicting findings when examining the relationship between processing speed and mathematical ability. Processing speed does appear to have a relationship with certain mathematical skills which can impact on achievement such as numerical operations and mathematical fluency (1), calculations (3, 6), mathematical reasoning (4), mathematical problem solving (1), number competence and mathematical achievement (5). In contrast to these findings, other studies found no direct relationship between these variables, with findings suggesting that intelligence (4, 7) and working memory (6) were contributors to mathematical ability.

The findings were suggestive that age may be a moderating factor in studies that found a relationship with mathematical skills. Although children with faster processing speed demonstrated stronger performance on calculations, processing speed is not related to the development of this skills once age is controlled for (3), or contribute to this skill once age and reading are controlled for (6). Similarly, the relationship between variables differs according to a child's age, with findings that processing speed is related to number competency in younger children and mathematical achievement in older children.

In relation to reading achievement, the findings suggest that processing speed does not have a significant impact on reading achievement, with the possible exception of oral reading fluency (1). It seems logical that processing speed may have affected performance on the oral reading fluency task as this subtest has a timed element to it and is likely to have been more difficult for children with slower processing speed. All other studies produced non-significant findings, with one study finding no relationship between processing speed and reading skills once the effects of age were controlled for (7). The review suggests that alternative cognitive abilities influence different reading skills required for reading achievement. For example, general intelligence and verbal comprehension influence reading ability (7), letter knowledge was found to be the sole predictor of word reading and vocabulary and non-verbal reasoning predicts reading comprehension (2).

The findings that age may moderate the relationship between processing speed and mathematical abilities may reflect developmental changes in processing speed in line with the global trend hypothesis (Hale, 1990). Kail (2000) suggests that processing speed increases quickly in early to middle childhood. This could explain the stronger relationship found in younger children, as this is a period in which there is a rapid increase in processing speed. It is possible that processing speed may have a stronger relationship with mathematical achievement in early childhood as this is a critical period for processing speed development. This relationship may dissipate as developmental age increases, with processing speed failing to predict the trajectory of academic achievement throughout childhood.

It is interesting to note, that age only appears to be a moderator for mathematics and not reading. Purpura et al. (2012) have suggested that early mathematics acts as a proxy measure for later language, with mathematical language mediating vocabulary and phonological awareness skills that are required for reading. A tentative explanation for the findings of this review may be that processing speed influences early mathematical abilities, which then subsequently moderates certain skills for reading achievement; however, future research would benefit from exploring this further.

Studies which failed to find a significant relationship between processing speed and mathematical and reading achievement have demonstrated that other cognitive processes may influence mathematical and reading abilities. General intelligence, vocabulary, non-verbal reasoning, working memory and verbal comprehension were all identified as contributors to either reading or mathematical ability. These findings are in line with other research (Schneider & Niklas, 2017; Alloway & Alloway, 2009) and suggests that processing speed does not impact directly upon certain skills required in academic achievement. Processing speed may have a direct effect on other cognitive abilities that subsequently determine intelligence and impact upon academic achievement as found by Rose et al. (2011) in premature children and may possibly reflect the developmental cascade as outlined by Fry and Hale (1990).

The review identified that a variety of measures were used to measure processing speed. Most studies used a measure of psychomotor processing speed; however, in one study which found no relationship between processing speed and mathematics and reading, the internal consistency of the processing speed measures was questionable (5). Another study found that the cancellation task had a weak correlation with mathematics especially in comparison to other processing speed measures (4); the reasons for this are unclear but it may have important implications for other tests such as the cross-out task, both of which have a visual attention element which could influence performance. One study used a test of verbal processing speed (6). The lack of consistency in the types of measures used (e.g. psychomotor, verbal, visual processing speed) could confound the findings and make it difficult to draw conclusions on the relationship between processing speed and academic achievement. There was also diversity in the mathematical and reading skills examined across the studies, which it made it difficult to draw conclusions on overall ability in these areas. Similarly, studies differed in terms of the representativeness of the sample, with some studies at risk of maturation or history effects, all of which are likely to confound the findings of this review when examining the studies together. These confounders limit the interpretations that can be made from the review as they increase the variance between studies and are likely to introduce bias into the studies reviewed. This may offer an explanation for the variety of findings in the mathematical studies and the lack of significant findings in the reading ability studies.

Finally, it is important to note that five out of the eight studies were rated as ‘poor’ in quality by the QAT. In particular, cross-sectional studies are often found to have a greater risk of internal bias when using this QAT tools due to issues with time frame and delivery of the exposure and outcome variable measures. There is potential that this internal bias could impact on findings; however, often studies within a childhood population employ cross-sectional designs and this is a wider issue that extends beyond this review.

Overall, the findings from this review demonstrate that the relationship between processing speed and academic achievement is complex and it highlights the need for future research to be thoughtful about the methodological designs of studies to adequately investigate this area. The conflicting findings in mathematical abilities in particular make it difficult to ascertain the relationship between processing speed and academic achievement.

Strengths and Limitations

This is the first systematic review to examine the relationship between processing speed and academic achievement in TDC. Several research studies demonstrate that processing speed deficits impact on academic achievement in children with learning disabilities and/or a formal mathematics or reading disability in comparison to TDC (Namkung & Niklas, 2017; Christopher et al., 2016), but there is a limited understanding of this relationship in TDC. Each study included in this review examined this relationship; however, they focused on a range of other cognitive abilities without specifically focusing on processing speed. This review has attempted to explore processing speed in isolation from other cognitive skills to consider the impact on academic achievement.

Despite failing to ascertain a direct relationship between processing speed and academic achievement, a strength of this review is that variables were clearly defined and incorporated standardised measures that have adequate reliability and validity. Geary (2011) reported that processing speed accounts for individual difference in academic achievement but their study measured processing speed through reaction time tasks rather than measures of global processing speed. This brings into question whether the study reliably captured the processing speed construct under examination. In excluding studies that solely examine reaction time and incorporating validated processing speed measures into the inclusion criteria, this review has attempted to include studies examining the same construct although there is still considerable variability in the measures used. The findings of the review are based on the most valid proportion of the literature but there is a broader evidence-base on this topic.

The difficulty drawing conclusions and answering the research question is a limitation of the review. One possible explanation is that academic achievement is such a broad concept. While reading and mathematics tests have been found to be predictors of academic achievement and were therefore used as the outcome measurement, a wide variety of skills come under this umbrella term. At present, there does not appear to be a clear universal definition of academic achievement in research which means that studies examine many facets of this construct. This was evidenced through the wide variety of studies identified in the initial search for this review which included studies such as school grades and teacher ratings under academic achievement. These variables are problematic as they are influenced by external factors such as school and classroom climate (Bertowitz et al., 2017) and motivation (Fong et al., 2017) and may not purely measure academic ability. Including standardised assessments of reading and mathematics resolved the issue of some of these confounding factors but it limited the breadth to which academic achievement could be explored.

Future Research

The studies included in the review have not explicitly examined the relationship between processing speed and academic achievement. Due to conflicting findings examining mathematical skills, further research is needed to consider how processing speed contributes to mathematical abilities, especially as mathematical language abilities are linked to reading (Purpura et al., 2017).

It may be important for future research to examine the association between academic achievement and the different types of processing speed measures. Predominately, research examines processing speed using psychomotor measures; however, it may be that different aspects of processing speed influence different aspects of academic achievement. For example, we could hypothesise that verbal processing may have a greater influence on reading abilities due to the verbal nature of these skills. It is important to have a greater understanding of this relationship as it could have implications for potential recommendations or interventions that are provided in clinical or school settings for children with slower processing speed abilities.

It would also be pertinent for future research to examine the role of age in the relationship between processing speed and academic achievement in more detail, since age has been found to be a moderating factor for mathematical abilities. Clinically this could be advantageous, as it seems likely that this understanding could inform teachers or clinicians of the importance of being aware of developmental issues that could challenge learning and act as a barrier to academic achievement. This could allow for consideration of age appropriate interventions or compensatory strategies to reduce the impact on academic achievement.

Longitudinal studies may be of benefit in examining these issues, as they have the advantage of being able to explore processing speed and achievement at a specific time as a function of age. They also allow for further exploration of the trajectory of these skills during a child's developmental growth. Further clarity around this would beneficial. If future research were to find that there is no direct relationship between processing speed and the trajectory of academic achievement, this could have some important clinical implications. For example, it could be made clear to schools and families that slow processing speed should not affect a child's academic achievement and that the child just may benefit from extra time to respond or participate in school.

Conclusion

In conclusion, this systematic literature review aimed to explore the direct relationship between processing speed and academic achievement in TDC, with a specific focus on mathematics and reading abilities. The findings from this review suggest that processing does not impact on reading abilities; however, there were conflicting findings related to mathematical achievement. Processing speed may have a relationship with certain mathematical skills with age acting as a potential moderating factor; however this finding was not supported by all studies. The findings from this review highlight that the relationship between processing speed and academic achievement is complex. At present, it is difficult to ascertain the direct relationship between these variables. Further research is required to explore this relationship in greater depth in order to consider the clinical implications that reduced processing speed may or may not have on academic achievement in TDC.

References

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of experimental child psychology*, *106*, 20-29. https://doi.org/10.1016/j.jecp.2009.11.003

Andersson, U. (2010). Skill development in different components of arithmetic and basic cognitive functions: Findings from a 3-year longitudinal study of children with different types of learning difficulties. *Journal of Educational Psychology, 102,* 115-134. https://doi.org/10.1037/a0016838

Berg, D. H. (2008). Working memory and arithmetic calculation in children: The contributory roles of processing speed, short-term memory, and reading. *Journal of experimental child psychology*, *99*, 288-308. https://doi.org/10.1016/j.jecp.2007.12.002

Berkowitz, R., Moore, H., Astor, R. A., & Benbenishty, R. (2017). A research synthesis of the associations between socioeconomic background, inequality, school climate, and academic achievement. *Review of Educational Research*, *87*, 425-469. https://doi.org/10.3102/0034654316669821

Bowey, J. A., Storey, T., & Ferguson, A. N. (2004). The association between continuous naming speed and word reading skill in fourth-to sixth-grade children. *Australian Journal of Psychology*, *56*, 155-163. https://doi.org/10.1080/00049530412331283345

Caemmerer, J. M., Maddocks, D. L., Keith, T. Z., & Reynolds, M. R. (2018). Effects of cognitive abilities on child and youth academic achievement: Evidence from the WISC-V and WIAT-III. *Intelligence*, *68*, 6-20. https://doi.org/10.1016/j.intell.2018.02.005

Cardillo, R., Mammarella, I. C., Garcia, R. B., & Cornoldi, C. (2017). Local and global processing in block design tasks in children with dyslexia or nonverbal learning disability. *Research in developmental disabilities*, *64*, 96-107. http://dx.doi.org/10.1016/j.ridd.2017.03.011

Centre for Reviews and Dissemination. (2009). Systematic Reviews: CRD's guidance for undertaking reviews in health care. York: University of York. Retrieved from: https://www.york.ac.uk/crd/guidance/

Christopher, M. E., Miyake, A., Keenan, J. M., Pennington, B., DeFries, J. C., Wadsworth, S. J., ..., Olson, R. K. (2012). Predicting word reading and comprehension with executive function and speed measures across development: a latent variable analysis. *Journal of Experimental Psychology: General*, *141*, 470-488. https://doi.org/10.1037/a0027375

Deary, I. J., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence*, *35*, 13-21. https://doi.org/10.1016/j.intell.2006.02.001

Dodonova, Y. A., & Dodonov, Y. S. (2012). Processing speed and intelligence as predictors of school achievement: Mediation or unique contribution? *Intelligence*, *40*, 163-171. https://doi.org/10.1016/j.intell.2012.01.003

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., ... Sexton, H. (2007). School readiness and later achievement. *Developmental psychology*, *43*, 1428. https://doi.org/10.1037/0012-1649.43.6.1428

Englander, Z. A., Pizoli, C. E., Batrachenko, A., Sun, J., Worley, G., Mikati, M. A., … Song, A. W. (2013). Diffuse reduction of white matter connectivity in cerebral palsy with specific vulnerability of long range fiber tracts. *NeuroImage: Clinical*, *2*, 440–447. https://doi.org/10.1016/j.nicl.2013.03.006

Erath, S. A., Tu, K. M., Buckhalt, J. A., & El-Sheikh, M. (2015). Associations between children's intelligence and academic achievement: the role of sleep. *Journal of sleep research*, *24*, 510-513. https://doi.org/10.1111/jsr.12281

Floyd, R.G., Bergeron, R., & Alfonso, V.C. (2006). Cattell-Horn-Carrol cognitive ability profiles of poor comprehenders. *Reading and Writing, 19,* 427-456. https://doi.org/10.1007/s11145-006-9002-5

Fong, C. J., Davis, C. W., Kim, Y., Kim, Y. W., Marriott, L., & Kim, S. (2017). Psychosocial factors and community college student success: A meta-analytic investigation. *Review of Educational Research*, *87*, 388-424. https://doi.org/10.3102/0034654316653479

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science*, *7*, 237–241. https://doi.org/10.1111/j.1467-9280.1996.tb00366.

Fryer, S. L., Schweinsburg, B. C., Bjorkquist, O. A., Frank, L. R., Mattson, S. N.,…., Riley, E. P. (2009). Characterization of white matter microstructure in fetal alcohol spectrum disorders. *Alcoholism: Clinical and Experimental Research*, *33*, 514–521. https://doi.org/10.1111/j.1530-0277.2008.00864.x

Fuchs, L. S., Fuchs, D., Compton, D. L., Powell, S. R., Seethaler, P. M., Capizzi, A. M., ... & Fletcher, J. M. (2006). The cognitive correlates of third-grade skill in arithmetic, algorithmic computation, and arithmetic word problems. *Journal of Educational Psychology*, *98*, 29-43. https://doi.org/10.1037/0022-0663.98.1.29

Gardella, J. H., Fisher, B. W., & Teurbe-Tolon, A. R. (2017). A systematic review and meta-analysis of cyber-victimization and educational outcomes for adolescents. *Review of Educational Research*, *87*, 283-308. https://doi.org/10.3102/0034654316689136

Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: a 5-year longitudinal study. *Developmental psychology*, *47*, 1539. https://doi.org/10.1037/a0025510

Genova, H. M., Deluca, J., Chiaravalloti, N., & Wylie, G. (2013). The relationship between executive functioning, processing speed, and white matter integrity in multiple sclerosis. *Journal of Clinical and Experimental Neuropsychology*, *35*, 631–641. https://doi.org/10.1080/13803395.2013.806649

Glutting, J. J., Watkins, M. W., Konold, T. R., & McDermott, P. A. (2006). Distinctions without a difference: The utility of observed versus latent factors from the WISC-IV in estimating reading and math achievement on the WIAT-II. *The Journal of Special Education*, *40*, 103-114. https://journals.sagepub.com/doi/abs/10.1177/00224669060400020101

Hale, S. (1990). A global developmental trend in cognitive exponential speed. *Child Development, 61,* 653-663. Retrieved from: http://www.jstor.org/stable/1130951

Higgins J.P.T., & Deeks J.J (editors). Chapter 7: Selecting studies and collecting data. In: Higgins JPT, Green S (editors), *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0 (updated March

2011). The Cochrane Collaboration, 2011. Available from www.handbook.cochrane.org.

Higgins, J. P. T., & Green, S. (2011). Cochrane Handbook for Systematic Reviews of Interventions Version 5.1. 0 [updated March 2011]. The Cochrane Collaboration, 2011. Available from www.cochrane-handbook.org.

Jacobson, L.A., Ryan, M., Martin, R.B., Ewen, J., Mostofsky, S.H., Denckla, M.B., & Mahone, E.M. (2011). Working memory influences processing speed and reading fluency in ADHD. *Child Neuropsychology, 17,* 209-224. https://doi:10.1080/09297049.2010.532204

Joe, A. I., Kpolovie, P. J., Osonwa, K. E., & Iderima, C. E. (2014). Modes of admission and academic performance in Nigerian Universities. *Merit Research Journal of Education and Review*, *2*, 203-230. Retrieved from https://meritresearchjournals.org/er/content/2014/September/Kpolovie%20et%20al.pdf

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin*, *109*, 490–501. https://doi.org/10.1037/0033-2909.109.3.490

Kail, R. (1993). Processing time decreases globally at an exponential rate during childhood and adolescence. *Journal of Experimental Child*

Psychology, 56, 254-265. https://doi.org/10.1006/jecp.1993.1034

Kail, R. (2000). Speed of information processing: Developmental change and links to intelligence. *Journal of School Psychology*, *38*, 51–61. https://doi.org/10.1016/S0022-4405(99)00036-9

Kail, R. V., & Ferrer, E. (2007). Processing speed in childhood and adolescence: Longitudinal models for examining developmental change. *Child development*, *78*, 1760-1770. https://doi.org/10.1111/j.1467-8624.2007.01088.x

Kail, R., & Salthouse, T. a. (1994). Processing speed as a mental capacity. *Acta Psychologica*, *86*, 199–225. https://doi.org/10.1016/0001-6918(94)90003-5

Lee, Y. J. (2011). Acute disseminated encephalomyelitis in children: differential diagnosis from multiple sclerosis on the basis of clinical course. *Korean Journal of Pediatrics*, *54*, 234–40. https://doi.org/10.3345/kjp.2011.54.6.234

Mabbott, D.J., Penkman, L., Witol, A., Strother, D., & Bouffet, E. (2008). Core neurocognitive functions in children treat for posterior fossa tumors/ *Neuropsychology, 22,* 159-168. https://doi.org/10.1037/0894-4105.22.2.159

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Systematic reviews and meta-analyses: The PRISMA statement. *Annulas of Internal Medicine*, *151*, 264–269. https://doi.org/10.1371/journal.pmed1000097

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M.,Shekelle, P., & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, *4*, 1. https://doi.org/10.1186/2046-4053-4-1

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G. a. (1990). The information-loss model: a mathematical theory of age-related cognitive slowing. *Psychological Review*, *97*, 475–487. https://doi.org/10.1037/0033-295X.97.4.475

Namkung, J.M., & Fuchs, L.S. (2016). Cognitive predictors of calculations and number line estimation with whole numbers and fractions among at-risk students. *Journal of educational psychology*, *108*, 214-228. https://doi.org/10.1037/edu0000055

National Heart, Lung and Blood Institute. (2017). Quality assessment tool for observation and cross-sectional studies (HTML file). Retrieved from https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools

Parkin, J. R., & Beaujean, A. A. (2012). The effects of Wechsler Intelligence Scale for Children—Fourth Edition cognitive abilities on math achievement. *Journal of School Psychology*, *50*, 113-128.

https://doi.org/10.1016/j.jsp.2011.08.003

Passolunghi, M. C., & Lanfranchi, S. (2012). Domain-specific and domain-general precursors of mathematical achievement: A longitudinal study from kindergarten to first grade. *British Journal of Educational Psychology*, *82*, 42-63. https://doi.org/10.1111/j.2044-8279.2011.02039.x

Peng, P., Fuchs, D., Fuchs, L.S., Elleman, A.M., Kearns, D.M., Gilbert, J.K., Compton, D.L., Cho, E., & Patton, S. (2018). A longitudinal analysis of the trajectories and predictors of word reading and reading comprehension development among at-risk readers. *Journal of Learning Disabilities, 52(3),* 1-14. https://doi.org/10.1177%2F0022219418809080

Peng, P., Namkung, J.M., Fuchs, D., Fuchs, L.S., Patton. S., Yen, L.,………, Hamlett, C. (2016). A longitudinal study of predictors of early calculation development among young children at risk of learning disabilities. *Journal of Experimental Child Psychology, 152,* 221-241. http://dx.doi.org/10.1016/j.jecp.2016.07.017

Peterson, R. L., Boada, R., McGrath, L. M., Willcutt, E. G., Olson, R. K., & Pennington, B. F. (2017). Cognitive prediction of reading, math, and attention: Shared and unique influences. *Journal of Learning Disabilities*, *50*, 408-421. https://doi.org/10.1177/0022219415618500

Purpura, D. J., Logan, J. A., Hassinger-Das, B., & Napoli, A. R. (2017). Why do early mathematics skills predict later reading? The role of mathematical language. *Developmental Psychology*, *53*, 1633-1642. https://doi.org/10.1037/dev0000375

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2011). Modeling a cascade of effects: The role of speed and executive functioning in preterm/full-term differences in academic achievement. *Developmental Science*, *14*, 1161–1175. https://doi.org/10.1111/j.1467-7687.2011.01068.x

Scantlebury, N., Bouffett, E., Laughlin, S., Strother, D., McConnell, D., Hukin, J.,…...Mabbot, D.J. (2016). White matter and information processing speed following treatment with cranial-spinal radiation for pediatric brain tumor. *Neuropsychology, 3,* 425-539. https://dx.doi.rog/10.1037/neu0000258

Schneider, W., & Niklas, F. (2017). Intelligence and verbal short-term memory/working memory: Their interrelationships from childhood to young adulthood and their impact on academic achievement. *Journal of Intelligence*, *5*, 26. https://doi.org/10.3390/jintelligence5020026

Singh, K., Granville, M., & Dika, S. (2002). Mathematics and science achievement: Effects of motivation, interest, and academic engagement. *The Journal of Educational Research*, *95*, 323-332. https://doi.org/10.1080/00220670209596607

Sirin, S. R. (2005). Socioeconomic status and academic achievement: A meta-analytic review of research. *Review of educational research*, *75*(3), 417-453. https://doi.org/10.3102/00346543075003417

Swanson, L. H., Howard, C. B., & Saez, L. (2006). Do different components of working memory underlie different subgroups of reading disabilities? *Journal of Learning Disabilities*, *39*, 252-269. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1021.6409&rep=rep1&type=pdf

Taylor, L. C., Clayton, J. D., & Rowley, S. J. (2004). Academic socialization: Understanding parental influences on children's school-related development in the early years. *Review of General Psychology*, *8*, 163-178. https://doi.org/10.1037/1089-2680.8.3.163

Vock, M., Preckel, F., & Holling, H. (2011). Mental abilities and school achievement: A test of a mediation hypothesis. *Intelligence*, *39*, 357-369. https://doi.org/10.1016/j.intell.2011.06.006

Wang, X., Georgiou, G.K., Li, Q., & Tavouktsoglou, A. (2018). Do Chinese children with math difficulties have a deficit in executive functioning? *Frontiers in Psychology, 9:* 906. https://doi.org/10.3389/fpsyg.2018.00906

Woods, D. L., Wyma, J. M., Yund, E. W., Herron, T. J., & Reed, B. (2015).

Factors influencing the latency of simple reaction time. *Frontiers in human neuroscience*, *9*, 131. http://doi.org/10.3389/fnhum.2015.00131

Appendices

Appendix A: PRISMA-P Reporting Protocol

PRISMA-P (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols) 2015 checklist: recommended items to address in a systematic review protocol*

Section and topic	Item No	Checklist item	(Page No.#)
ADMINISTRATIVE INFORMATION			
Title:			
Identification	1a	Identify the report as a protocol of a systematic review	1
Update	1b	If the protocol is for an update of a previous systematic review, identify as such	1
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number	1
Authors:			
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author	1
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review	10
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments	1
Support:			
Sources	5a	Indicate sources of financial or other support for the review	1
Sponsor	5b	Provide name for the review funder and/or sponsor	
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol	
INTRODUCTION			
Rationale	6	Describe the rationale for the review in the context of what is already known	3
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators,	4

		and outcomes (PICO)	
METHODS			
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review	4-5
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage	6
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated	6 and Appendix-A
Study records:			
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review	7
Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)	7
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators	7
Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications	7
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale	8
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis	8
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesised	9
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2, Kendall's τ)	
	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression)	
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned	
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)	10
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)	10

From: Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart L, PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ. 2015 Jan 2;349(jan02 1):g7647.

Appendix B: Journal of Child Psychology and Psychiatry- Dissemination of Finding and Instructions for Authors

The aim is for this systematic literature review to be disseminated via publication in the Journal of Child Psychology and Psychiatry.

Instructions for Authors

Manuscript preparation and submission
Papers should be submitted online. For detailed instructions please go to: http://mc.manuscriptcentral.com/jcpp_journal. Previous users can check for an existing account. New users should create a new account. Help with submitting online can be obtained from the Editorial Office at publications@acamh.org

1. The manuscript should be double spaced throughout, including references and tables. Pages should be numbered consecutively. The preferred file formats are MS Word or WordPerfect, and should be PC compatible. If using other packages the file should be saved as Rich Text Format or Text only.

2. Papers should be concise and written in English in a readily understandable style. Care should be taken to avoid racist or sexist language, and statistical presentation should be clear and unambiguous. The Journal follows the style recommendations given in the *Publication manual of the American Psychological Association* (5th edn., 2001).

3. The Journal is not able to offer a translation service, but, authors for whom English is a second language may choose to have their manuscript professionally edited before submission to improve the English. A list of independent suppliers of editing services can be found here. All services are paid for and arranged by the author, and use of one of these services does not guarantee acceptance or preference for publication.

Layout
Title: The first page of the manuscript should give the title, name(s) and short address(es) of author(s), and an abbreviated title (for use as a running head) of up to 60 characters.

Abstract
The abstract should not exceed 300 words and should be structured in the following way with bold marked headings: Background; Methods; Results; Conclusions; Keywords; Abbreviations. The abbreviations will apply where authors are using acronyms for tests or abbreviations not in common usage.

Key points and relevance
All papers should include a text box at the end of the manuscript outlining the four or five key (bullet) points of the paper. These should briefly (80-120 words)

outline what's known, what's new, and what's relevant.

Under the 'what's relevant' section we ask authors to describe the relevance of thier work in one or more of the following domains - policy, clinical practice, educational practice, service development/delivery or recommendations for further science.

Headings
Articles and research reports should be set out in the conventional format: Methods, Results, Discussion and Conclusion. Descriptions of techniques and methods should only be given in detail when they are unfamiliar. There should be no more than three (clearly marked) levels of subheadings used in the text.

Acknowledgements
These should appear at the end of the main text, before the References.

Correspondence to
Full name, address, phone, fax and email details of the corresponding author should appear at the end of the main text, before the References.

References
The *JCPP* follows the text referencing style and reference list style detailed in the *Publication manual of the American Psychological Association* (5th edn.)i.

References in text
References in running text should be quoted as follows:
Smith and Brown (1990), or (Smith, 1990), or (Smith, 1980, 1981a, b), or (Smith & Brown, 1982), or (Brown & Green, 1983; Smith, 1982).

For up to five authors, all surnames should be cited in the first instance, with subsequent occurrences cited as et al., e.g. Smith et al. (1981) or (Smith et al., 1981). For six or more authors, cite only the surname of the first author followed by et al. However, all authors should be listed in the Reference List. Join the names in a multiple author citation in running text by the word ‘and’. In parenthetical material, in tables, and in the References List, join the names by an ampersand (&). References to unpublished material should be avoided.

Reference list
Full references should be given at the end of the article in alphabetical order, and not in footnotes. Double spacing must be used.

References to journals should include the authors’ surnames and initials, the year of publication, the full title of the paper, the full name of the journal, the volume number, and inclusive page numbers. Titles of journals must not be abbreviated and should be italicised.

References to books should include the authors’ surnames and initials, the year of publication, the full title of the book, the place of publication, and the publisher's name.

References to articles, chapters and symposia contributions should be cited as per the examples below:

Kiernan, C. (1981). Sign language in autistic children. *Journal of Child Psychology and Psychiatry*, *22*, 215-220.

Thompson, A. (1981). *Early experience: The new evidence*. Oxford: Pergamon Press.

Jones, C.C., & Brown, A. (1981). Disorders of perception. In K. Thompson (Ed.), *Problems in early childhood* (pp. 23-84). Oxford: Pergamon Press.

Use Ed.(s) for Editor(s); edn. for edition; p.(pp.) for page(s); Vol. 2 for Volume 2.

Tables and Figures

All Tables and Figures should appear at the end of main text and references, but have their intended position clearly indicated in the manuscript. They should be constructed so as to be intelligible without reference to the text. Any lettering or line work should be able to sustain reduction to the final size of reproduction. Tints and complex shading should be avoided and colour should not be used unless essential. Authors are encouraged to use patterns as opposed to tints in graphs. In case of essential colour figures, authors are reminded that there is a small printing charge. Authors will be contacted during the proofing stage of thier accepted paper. Figures should be originated in a drawing package and saved as TIFF, EPS, or PDF files. Further information about supplying electronic artwork can be found in the Wiley electronic artwork guidelines here.

Nomenclature and symbols

Each paper should be consistent within itself as to nomenclature, symbols and units. When referring to drugs, give generic names, not trade names. Greek characters should be clearly indicated.

Supporting Information

Examples of possible supporting material include intervention manuals, statistical analysis syntax, and experimental materials and qualitative transcripts.

1. If uploading with your manuscript please call the file 'supporting information' and reference it in the manuscript.
2. Include only those items - figures, images, tables etc that are relevant and referenced

SCHOOL OF PSYCHOLOGY

DOCTORATE IN CLINICAL PSYCHOLOGY

EMPIRICAL PAPER

The effectiveness of a processing speed training intervention in children with suspected white-matter damage.

Trainee Name:	**Lee Gamman**
Primary Research Supervisor:	**Dr Jennifer Limond**
	Consultant Clinical Neuropsychologist, and Senior Lecturer, University of Exeter
Secondary Research Supervisor:	**Dr Alicia Smith**
	Research Tutor, University of Exeter

Target Journal:	Brain Injury
Word Count:	8366 words (excluding abstract, references, appendices)

Submitted in partial fulfilment of requirements for the Doctorate Degree in Clinical Psychology, University of Exeter

Abstract

Processing speed interventions have been found to be acceptable in children; however, there is limited evidence that they are effective in this population. This study investigated whether a processing speed intervention was effective in improving processing speed (PS) in children with suspected white matter disorders. The study hypothesised that children would demonstrate improvement on a daily outcome measure and between pre-baseline and post-intervention measures of PS. A single case experimental design utilising a multiple baseline approach was used to observe the effect of the intervention within and across participants. Three participants were recruited, each completing a choice reaction time (CRT) task three times a week that acted as the outcome measure. The processing speed intervention involved playing single player, multiplayer and iPad/android games. Overall there was no significant change in CRT between phases; however two participants demonstrated a medium effect size. There was no significant change in pre- or post-PS measures but there was evidence of reliable change in overall and cognitive fatigue. These findings suggest that the processing speed intervention was not effective in improving PS abilities. This paper highlights a number of challenges in implementing a processing speed intervention and explores the clinical implications of these findings.

Keywords: processing speed, white-matter damage, intervention, children, adolescents

Introduction

Processing speed (PS) is regarded an essential global mechanism that may be associated with performance in various cognitive domains (Fry & Hale, 1996; Kail, 2000; Kail & Salthouse, 1994; Rose et al, 2011). Numerous studies lend support to this view, with findings that PS correlates with cognitive performance (DeLuca & Kalmar, 2013; Salthouse, 2005; Turken, Whitefield-Gabrieli, Bammer, Baldo, Dronkers, & Gabrieli, 2008). From this research, it could be predicted that reduced PS could have detrimental effects on cognitive ability.

Studies have reported an association between PS and white matter volume (Borghesani et al., 2013; Jacobs et al., 2013; Posthuma et al., 2003). Individual differences in cognitive PS are likely to depend upon structural variations and interactions of white matter fibre systems, which constrain and facilitate communication amongst cortical nodes of brain-wide networks (Turken et al., 2008). The speed at which neural signals are conducted is related to the thickness and degree of myelination along the axons (Tuch et al., 2005; Turken et al., 2008), and it has been suggested that white matter is important for the development of PS because it manages the speed of neural transmission (Koster, 2014). This premise is supported by research demonstrating a general slowing of cognitive processes over the progression of white matter disease with increased demyelination and damage across fibre systems (Turken et al., 2008).

Processing speed interventions have been found to increase functional activity, inducing plasticity of functions and structures of the brain associated with speeded cognitive processing in adults (Takeuchi et al., 2011). Lövdén, Bäckman, Lindenberger, Schaefer, and Schmiedek (2010) proposed a theoretical framework that suggests the brain has the capacity to manage changing demands by altering its structure, thus demonstrating a large degree of plasticity. Their framework suggests that environmental experience, such as repetitive practising of cognitive tasks, can result in plastic alterations of the brain as demonstrated by improved performance and structural brain alterations. They posit that in order for a plasticity reaction an individual needs to experience increased environmental demands. For example, tasks that challenge the individual functional capacity of the brain system but are not too taxing. This theoretically implies that processing speed interventions that are challenging and repetitive could induce neuroplasticity processes, which is further supported by extensive evidence of neuroplasticity in the developing brain (Johnston, 2004; Mundkur, 2005; Stiles, 2000).

There is growing evidence that processing speed interventions could have positive effects on improving PS abilities. In older adults, PS training has been found to increase PS and impact on everyday functions (Edwards, Wadley, Vance, Wood, Roenker, & Ball, 2005). Similarly, it has been found that video gaming can lead to PS improvements in a number of perceptual and attentional tasks (Dye, Green, & Bavelier, 2009), with faster speed in visual processing abilities found in video game players compared to non-video game players (Castel, Pratt, & Drummond, 2005).

Although there is limited understanding of the factors that underpin the PS improvements seen in video-gaming interventions, research has looked at how computerised training and games can improve working memory and executive functioning difficulties in children (Holmes, Gathercole & Dunning, 2009; Holmes, Gathercole, Place, Dunning, Hilton & Elliot, 2009; Klingberg et al., 2005; Thorell, Lindqvist, Bergman, Bohlin & Klingberg, 2009). Diamond (2013) posits that there are number of essential principles that underlie executive functioning interventions, regardless of the type of intervention delivered (i.e. computerised training, games, and martial arts). Firstly, children that are behind in executive functioning benefit the most from intervention. Secondly, executive demands need to be continually increased for improvements to be seen. Improvement stops when an individual is not attempting to do better and preventing the activity from becoming boring can maintain motivation and interest. Finally, executive gains rely on the amount of time spent on the intervention and repeated practice. We can assume that these principles are also likely to apply to interventions aimed at increasing PS.

Mackey, Hill, Stone, and Bunge (2011) explored whether two training programs (reasoning training or speed training) improved cognitive skills in economically disadvantaged children using commercial and non-commercial games that were entertaining and similar in nature. PS games were selected if they involved rapid visual and motor processing to complete simple task rules. Children in the PS training group showed improvement in PS abilities with little improvement in reasoning, whilst children in the reasoning training group showed the reverse. This suggests that processing speed interventions can be effective and that effects were not merely a result of generic game training but can be attributed to the specific nature of the games practiced.

As processing speed interventions have been found to be effective in children from deprived environmental backgrounds, this raises the question of whether interventions can improve PS abilities in children with white matter damage. Children with white matter damage demonstrate a number of cognitive difficulties including reduced PS. Disorders associated with white matter damage and PS difficulties include children born prematurely (Rose et al, 2011), children who have undergone cranial radiation therapy for a brain tumour (Mabbott, Penkman, Witol, Strother & Bouffet, 2008; Scantlebury et al., 2016), fetal alcohol spectrum disorder (Fryer et al., 2009), and acute disseminated encephalomyelitis (Lee, 2011). To date, there has been only one unpublished study that has explored cognitive speed training in neurologically impaired children (Oatman-Stanford, 2013). Oatman-Stanford (2013) explored whether speeded training could be feasible or acceptable for children with acquired brain injury and examined any changes on PS measures pre- and post- intervention. The speeded training intervention in this study was based on Mackey et al's. (2011) study with some adaptation to the games provided. Children were asked to complete one hour of training twice a week, for a total of eight weeks. Oatman-Stanford found the speeded intervention was highly acceptable and feasible to this clinical population and participants demonstrated some gains in PS; however, these positive gains failed to reach statistical significance. The study provided preliminary evidence that cognitive speed training can positively influence PS ability.

As research is beginning to explore the benefits of processing speed interventions, it is also helpful to consider the construct which is under investigation. PS has been a construct that has received much attention over the years; however, theoretical perspectives and measurement of this construct have often come from different schools of thought. For example, the terms 'processing speed' and 'speed of information processing' are used interchangeably but they can refer to slightly different constructs (Silva, 2009). 'Processing speed' is referred to as "the time an individual completes a sequence of processing in a cognitive task" (Stenberg, 1969, cited in Silva, 2009, pg1) in psychometric literature, whilst 'speed of information processing' is considered the "time required for stimuli to be perceived, understood and acted upon" (page 1, Silva, 2009) in information processing models.

Due to different theoretical perspectives there is variance in the measures that are used in research. Reaction time tasks are used to measure the speed to complete a mental operation (Neubauer, Riemann, Mayer & Angleitner, 1997), with evidence that choice reaction time (CRT) is an important component for measuring information processing speed (Hamilton & Launay, 1976, cited in Silva, 2009). Alternatively, there are psychometric paper and pencil measures such as the coding and symbol search subtests of the Wechsler Intelligence Scale for Children-Fifth Edition (WISC-V, Wechsler, 2016), that assess non-verbal psychomotor PS, and measures of verbal PS found in tests such as the Speed and capacity of language processing test (SCOLP, Baddeley, Emslie, & Nimmo-Smith, 1992). There is concern that measures involve varying degrees of executive control (Cepeda, Blackwell & Munakata, 2013), with deficits in slowed speech or movement impacting upon performance (Gehrke, 2011). Due to the variety of measures available, it is difficult to ascertain the best method of measurement of PS. Despite these theoretical and measurement issues, it has been reported that regardless of the type of PS task, that PS is associated with globally distributed white matter structures (Magistro, 2015), therefore, the current study will incorporate several different PS measures.

Current Study

Due to promising evidence that speed training may improve PS, this empirical study aims to explore whether a speed training intervention helps to improve global processing speed in children with suspected white-matter damage. The processing speed intervention is based on Oatman-Stanford's (2013) feasibility study, with increased frequency and acceptability of the training intervention, as recommended.

Research question. Does a brief intervention increase the speed of information processing in children who have conditions associated with reduced white matter integrity?

Hypotheses.

1. Participants will demonstrate an improvement in performance on the daily outcome measure during the intervention phase seen through a reduction in CRT
2. There will be a significant improvement in performance on pre-baseline and post-intervention measures following the intervention seen by improved standard scores on PS tests and improved scores on quality of life measures.

Method

Design

An experimental multiple-baseline single case experimental design (SCED) was used to determine whether there is causal relationship between the processing speed intervention (independent variable) and a meaningful change in the target behaviour, speed of processing (dependent variable).

PS ability was measured within each participant across baseline (Phase A) and intervention (Phase B) conditions, with each participant acting as their own control. In order to enhance external validity, the multiple baseline design (MBD) uses between participant replication across multiple participants (Onghena & Edgington, 2005). The baseline phase had a non-concurrent start across participants; however, the final participant started the baseline phase within the same time testing period as the first participant to permit simultaneous analysis.

Introduction of the intervention was randomly staggered across participants in order to enhance internal validity (Onghena & Edington,2005). The study required participants to complete an outcome measure (online) 3 days a week, over a 10 week period. Each participant was required to complete 30 measurements (baseline= 15 days +/-9 days & intervention= 15 days +/-9 days). A minimum of 6 measurements were required for both Phase A and B, meaning that 18 days were available for the staggered phase change over the 10 week period, leaving a total of 19 possible phase changes for participants (See Appendix A for potential phase changes). Each participant was randomly assigned to one of the possible 19 moments of phase change.

Sample

Recruitment. The study aimed to recruit 10-12 children aged between 6-16 years, who have conditions associated with white matter damage and presented with a reduced PS. Suspected white matter disorders were defined as disorders in which previous research has demonstrated damage to the white matter via imaging, including disorders such as fetal alcohol spectrum disorder (FASD), brain tumours, premature babies, acute disseminated encephalomyelitis (ADEM) and periventricular leukomalacia (PVL). Purposive sampling was used and participants were recruited via a number of different methods:

1. Paediatricians working within a local NHS hospital working with children with FASD and brain tumours
2. A national charity for children with acquired brain injury
3. A local research group for children with disability

Paediatricians identified children that they felt met criteria for the study when they attended a clinic. They provided the parents with a study information sheet (See Appendix B), which asked parents to contact the researcher if they were interested in the study. An advertisement for the study (See Appendix C) was posted on the charity's national and regional Facebook pages and circulated through the research groups email database to families who expressed interest in completing research. The advertisement provided a link that directed parents to the Centre for Neuropsychology Research webpage at the University of Exeter. In order to increase recruitment, these recruitment methods were regularly followed-up by the researcher.

Inclusion and exclusion criteria. Participants were eligible for an initial assessment if they were aged between 6-15 years 11 months old with a neurological disorder that increased the risk of white matter damage with a suspected reduced PS. At assessment, eligibility was reached if participants scored a scale score (SS) of 6 or below (i.e. <10th percentile) on the Wechsler Intelligence Scale for Children- Fourth Edition (WISC-IV; Wechsler, 2003) coding and symbol search subtests. If there was a discrepancy between subtests an average score of the two subtests was used. Participants were excluded from the study if they were actively undergoing treatment for a brain tumour, had significant motor difficulties or if they were taking part in an alternative study that may impact upon their cognition.

Participants. Thirteen parents contacted the researcher for their child to participate in the study. Two parents decided not to go ahead with the initial appointment. One family were deemed geographically too far to participate. Two children were excluded during the initial contact, one child being under the age limit and one with significant motor difficulties.

Of the remaining families, eight potential participants completed a brief cognitive assessment to assess eligibility for the study. Of these, four children were excluded as they did not meet criteria on the WISC-IV subtests. Five children were assessed as eligible to participate in the study; one of these withdrew from the study during Phase A. One further participant was initially identified as eligible and was included in the study; however, when completing post-intervention measures it was apparent that an error had been made in the scoring of the pre-study measures. This meant that the child would not have been eligible for the study and as a result this participant's data had to be excluded from the analysis. This left three remaining participants.

Individual characteristics of the three participants included in the study can be found in table 1. One participant was male and two were female. Participant ages ranged from 8 years 7 months to 12 years 5 months (M= 10.83; SD= 1.58) at the time that they were recruited for the study.

Table 1. Characteristics of participants

Participant Number	Gender	Age	Diagnosis	WASI-II FSIQ	SS on the WISC-IV Subtests	
1	Female	12 years 5 months	Arteriovenous Malformation and left parietal intra haemorrhage	89	Coding	8
					Symbol Search	4
					Average	6
2	Female	8 years 7 months	Pilocytic astrocytoma	81	Coding	6
					Symbol Search	6
					Average	6
3	Male	11 years 3 months	Traumatic birth with suspected hypoxic-ischaemic injury. Autism.	106	Coding	3
					Symbol Search	7
					Average	5

WASI-II: Wechsler Abbreviated Scale of Intelligence-Second Edition; FSIQ: Full scale intellectual quotient

Measures and materials

Characterisation data.

Wechsler Abbreviated Scale of Intelligence- Second Edition (WASI-II). The WASI-II (Wechsler, 2011) provides a brief measure of intellectual functioning. It is designed to be used with individuals between 6 years- 90 years 11months old. It consists of four subtests; vocabulary, similarities, block design and matrix reasoning and provides an estimate of full scale intellectual quotient (FSIQ). The WASI-II was used to obtain the overall level of intellectual functioning of each participant. The FSIQ has a mean of 100 and a standard deviation of 15.

Pre- and post-intervention measures.

Measures of PS. PS measures were collected prior to baseline and after the intervention in order to identify any reliable and measureable change in PS.

Non-verbal PS was measured using subtests from the WISC-IV. In the coding subtest, either shapes (6-7 year olds) or numbers (8+ years old) are paired with symbols and participants are required to correctly match pairs by completing as many items on a grid as possible within two minutes. In the symbol search subtest, participants have to work through rows of symbols as quickly as possible trying to identify if symbols in the right column appear amongst symbols in the left column. Raw scores are then converted to scaled scores. The average mean score is 10 with a standard deviation of 3.

The silly sentences test was used as a measure of verbal PS. This measure is based on the Speed of Comprehension test, which is taken from SCOLP (Baddeley, Emslie, & Nimmo-Smith, 1992). Silly sentences is a research measure that has been adapted from the adult test and has normative data for use in children (Emslie, personal communication). Participants are provided with different sentences and within two minutes have to identify if the sentence is true or false.

PedsQL. The PedsQL (Varni, 1998) is a measure of health-related quality of life in healthy children and children with acute or chronic health conditions aged 2-18 years old (see appendix D). The PedsQL generic core scale has 23 items that measure four multidimensional scales; physical functioning, emotional functioning, social functioning, and school functioning. The PedsQL multidimensional fatigue scale has 18 items that measure general fatigue, sleep/rest fatigue and cognitive fatigue, with a specific item under cognitive fatigue that looks at processing speed. On both the generic core and the multidimensional fatigue scales parents are asked to rate whether each item has been a problem for their child over the past month as ‘never’, ‘almost never', 'sometimes', 'often' and 'almost always'. For the purpose of this research parents were asked to complete the measure before baseline and after intervention to allow for the exploration of any measureable change in health-related quality of life following intervention.

Outcome measurement. The outcome measure used to study the target behaviour, PS, was constructed for the purpose of this study using a computer programming system called OpenSesame. CRT was selected as the most appropriate measure that could be repeated without the likelihood of practice effects. While the 'cognitive' load of the task is minimal, it still requires a level of information processing (Hamilton & Launay, 1976, cited in Silva, 2009). Participants were presented with a shape on the screen and were instructed to press the 'z' key if they saw a red shape and the 'm' key if they saw a black shape. Participants were asked to complete this measure three times a week for the duration of the study. This specific measure was produced solely for the purpose of this study and therefore there is no data available regarding the reliability and validity of this particular version of the measure. Versions of the CRT task are well established and widely used measures with good reliability (Deary, Liewald & Nissan, 2011) and validity (Maruff et al., 2009).

In order to ensure that the outcome measure was acceptable for use with children, the measure was taken for user consultation. The researcher attended a paediatric clinic through the NHS trust supporting the recruitment and asked children to trial the measure and provide feedback. Initially the measure was developed to last for several minutes but after receiving feedback from the clinic, it was felt that the CRT measure could be shortened and would still provide accurate reaction time data. The measure consisted of 24 trials and lasted approximately sixty seconds.

Intervention

The intervention was based on that used in Oatman-Stanford's (2013) study, in which a number of computerised and non-computerised games were played which involved individual, multi-player and iPad/android games (See Appendix E). As recommended by Oatman-Stanford, the current study adapted this intervention to include parallel and updated versions of the games, using smartphones and tablet devices that children had access to at home. All games were provided to the participants so that they could be conducted in their own home. Participants were asked to play at least thirty minutes of games a day over at least four days a week. They were provided with a processing speed intervention manual (Appendix F) to provide an explanation of the games as well as a games checklist (Appendix G) to monitor the games played.

Procedure

Pilot of intervention. A brief pilot study was carried out with three children from two different families, aged 7, 8 and 10 years old. Families were provided with games, the intervention manual and the games checklist and were asked to trial the intervention for one week. Amendments were made to the intervention based on the feedback received (e.g. a greater variety of card games and iPad/Android games were added).

Procedure. Participants were screened via a telephone call between a parent and the researcher. An initial meeting with the families then took place in which consent (Appendix H) and assent (Append I) were obtained. An initial assessment was completed which involved the WASI-II, the PS measures and the PedsQL Core and Fatigue scales. Participants were included or excluded from the study dependent on if they met eligibility criteria. If any child was noted to have cognitive difficulties, a report was sent to the participant's general practitioner (See Appendix K).

If participants met the eligibility criteria, a further meeting was arranged to provide them with the CRT outcome measure to begin completing. The researcher then met with the participant's parents at the point of their staggered phase change to provide the processing speed intervention. Participants were then required to complete the intervention at home.

Weekly contact was made via telephone to check-in with families and/or provide any advice or assistance as needed. On completion of the intervention a follow-up visit was arranged to re-administer the PS measures and the PedsQL Core and Fatigue scales.

Ethics. NHS ethical approval was obtained prior to ethical approval being obtained through the University of Exeter research and ethics committee (Appendix O).

Data Analysis Plan

Hypothesis One. Visual analyses (VA) of graphical data obtained from the CRT outcome measure were completed. This is considered the most longstanding and popular technique for exploring SCED data (Bulté & Onghena, 2009). It allows researchers to inspect graphical data and make a judgement about the reliability and consistency of the data (Bulté & Onghena, 2009; Kazdin, 1982) by examining the central location, trend, variability of data within phases and overlap in data between phases (Morley, 2018). Microsoft Excel was used to complete the VA. There are limitations to VA, with reported low average inter-rater agreement and inflated type 1 error rates; therefore, randomisation tests were used alongside VA in order to account for this (Heyvaert & Onghena, 2014).

Randomisation tests (RT) are not based on the assumptions of homogeneity of variance or distributional assumptions, and are free from assumptions of random sampling (Bulté & Onghena, 2009). They require that some aspect of the experimental design is randomised and is based on the randomisation of phase change *a priori* (Onghena & Edgington, 2005; Morley, 2018). RT ask the probability of the particular set of observations occurring, given all the potential ways in which the data can be arranged, i.e. possible randomisations (Morley, 2018). The test statistic is calculated for each possible randomisation and looked at where the observed test statistic falls within the distribution of all possible test statistics (Hayvaert, Moeyaert, Verkempynck, Van der Noortgate, Vervloet, Onghena et al., 2017). The RT were carried out using the R package.

For this study there were 41,154 potential randomisations. A Monte Carlo method of the RT was therefore used as recommended by Morley (2018) where there are a sufficiently large number of test statistics to compute. The smallest obtainable probability (p) for this study, is the inverse of the randomised phase change which is 1/19. This sets the smallest possible p value at 0.052, which is slightly higher than the conventional $p<0.05$.

Effect size was measured using the Non-overlap of All Pairs (NAP; Parker & Vannest, 2009). NAP compares every data point in the baseline phase against every data point in the intervention phase (Morley, 2018). In order to compute the NAP, a NAP calculator was used at https://web.archive.org/web/20180404183208/http://www.singlecaseresearch.org/calculators/nap.

Hypothesis Two. The reliable change index (RCI) was computed on the WISC-IV subtests and the PedQL Core and Fatigue measures to assess for any change over the course of the study. The RCI is considered a sophisticated way of measuring change, which controls for the test's reliability and provides a precise estimate of change (Duff, 2012). The RCI was computed using a calculator at https://www.psyctc.org/stats/rcsc.htm. Unfortunately, data are not available regarding standard deviations and reliability of the Silly Sentences Test so the RCI could not be completed on this measure; therefore, the standard scores were reported on. There was also specific interest in the PS question under cognitive fatigue on the PedsQL Fatigue questionnaire. A z-score cannot be computed for this data so the categorical data will be presented.

Adherence to intervention and informal feedback. Information on adherence to the intervention was collected through the games checklist and informal feedback was collected from participants at the end of treatment. This information was examined in a narrative synthesis.

Power

Mackey et al (2011) detected a large effect size (d = 1.15) when comparing their similar processing speed intervention with a reasoning intervention. However, smaller effect sizes are predicted in the current study due to the population having greater neurological impairment.

Ferron and Sentovich (2002, Heyvaert & Onghena, 2014) recommend that MBD's with four participants and a total of twenty data points produces adequate power (>.80) to detect treatment effects in SCED research ($d \geq 1.5$) for the RT. Despite this, it has been suggested that the minimum number of participants for a MBD approach is three (Kratochwill, Hitchcock, Horner, Levin, Odom, Shadish et al., 2010).

Results

Three participants completed the ten week data collection period (including baseline and intervention phases). Prior to running analyses, the CRT data were cleaned for outliers. Responses within 5 milliseconds (ms) of the stimulus onset are considered physically impossibly short reaction times (Baayen & Milin, 2010), whereas long outliers hide in the tail of the distribution (Ratcliff, 1993). Ratcliff (1993) recommends that outlier reaction times are eliminated using some number of standard deviation (SD) above the mean which is appropriate for the distribution shape of the data. For distributions with a thick right tail, it is recommended that no more than 5% of the data should be excluded (Baayen & Milin, 2010).

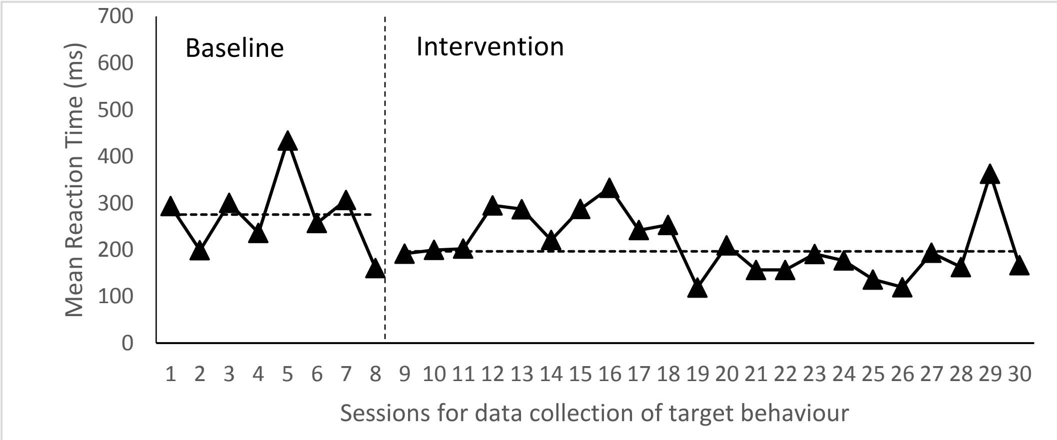
In this data set, the three participants CRT data showed a negative skew with a thick right tail, therefore no more than 5% of the data were excluded. For participants 1 and 2 the required exclusion of outliers was 3 SD's from the mean; however, participant 3 had less than 5% excluded at 2 SD's from the mean CRT. Any reaction time below 5 ms was considered a short response. Every CRT response for each participant was examined and any outliers were removed before a mean CRT was computed for each individual data point.

Two participants had missing data points. Participant 2 had four data points missing from the intervention phase. Participant 3 had three data points missing in total, two points from the baseline phase and one from the intervention phase. The reasons provided regarding missing data were families forgetting to complete the outcome measure or families were on holiday and had no access to the outcome measure.

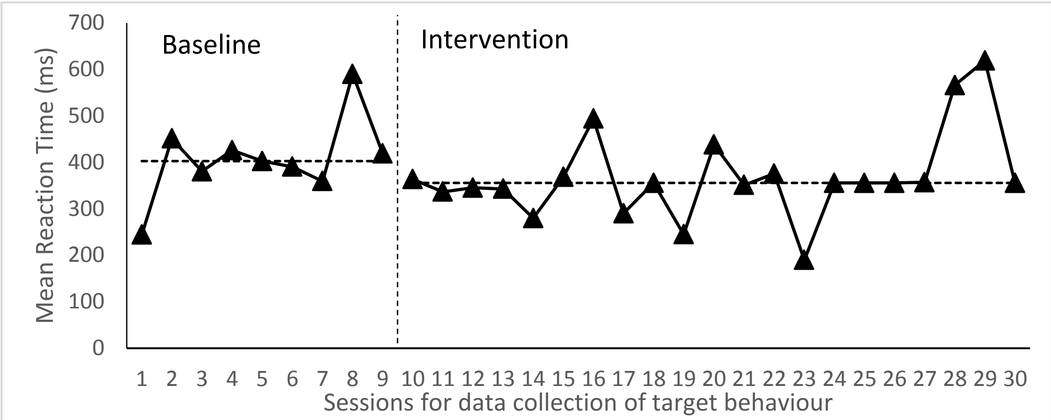
In order to deal with the missing data points during the visual analysis and effect size calculations, median substitution was used. The median for each phase was computed and each missing data point was replaced with the phase median.

Hypothesis 1

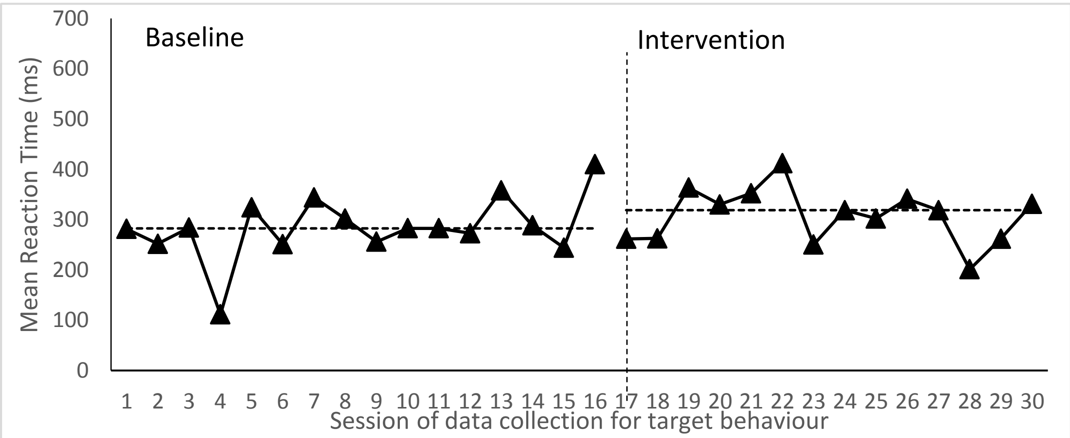
The measure of central tendency (median) per participant on the CRT outcome measure can be found in Figure 1 and the trend data can be found in Figure 2. Trend was assessed using the split-middle method and variability was assessed using the trimmed trended range (Morley, 2018). The remaining graphs from the VA can be found in Appendix L. Graphs outlining the number of errors that participants made whilst completing the outcome measure can also be found in Appendix L. For participant 1 only raw data on the number of errors made was presented as these are likely to represent a lapse in concentration or an interruption; however, for participants 2 and 3 a measure of central tendency was completed on their data as several errors were made across baseline and intervention (Appendix L). Table 2 provides information on the length of the baseline and interventions phase, the descriptive statistics per phase, the statistical p value of the RT alongside the effect size calculation.



Participant 1: Median



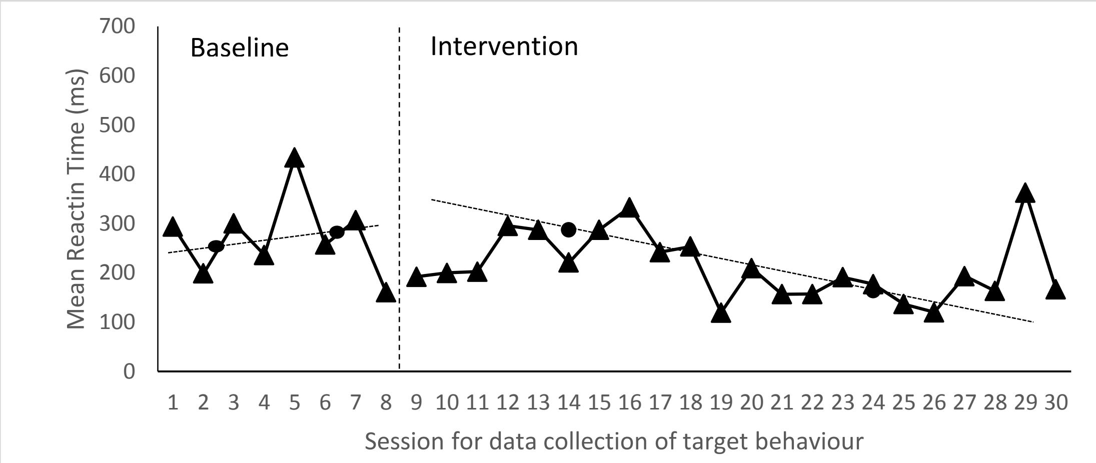
Participant 2: Median



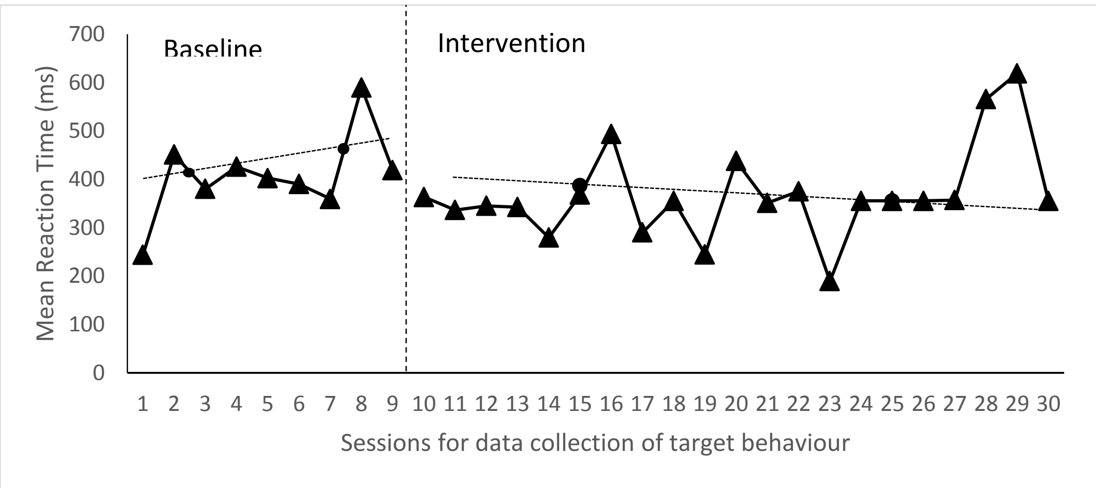
Participant 3: Median

Figure 1. The measure of central tendency for each participant.

Participant 1: Trend



Participant 2: Trend



Participants 3: Trend

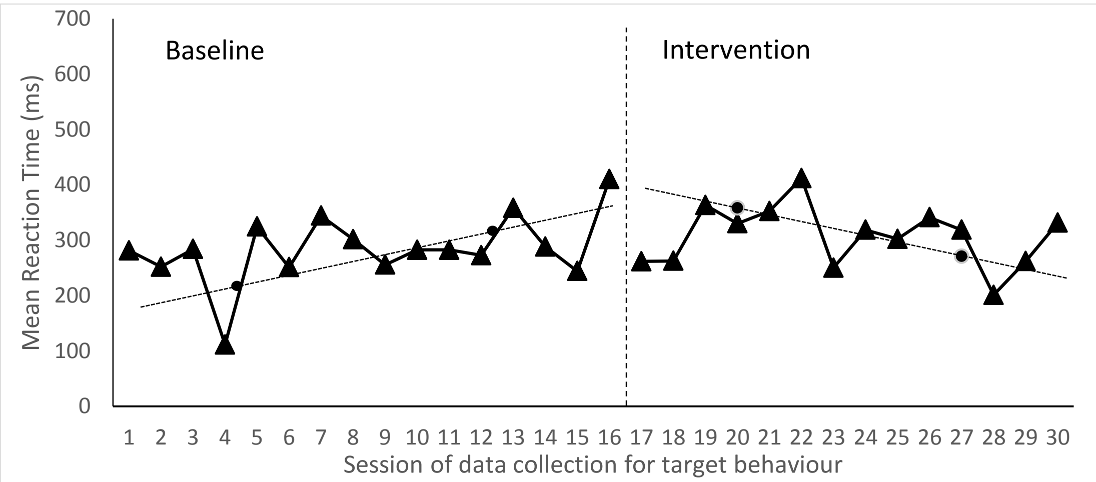


Figure 2. The trend data for each participant.

Table 2. Choice reaction time: Descriptive statistics, Randomization tests and effect size

Participant	**Phase A length (data points)**	**Phase B length (data points)**	**Phase A Mean (ms) *(Median)* *{SD}***	**Phase B Mean (ms) *(Median)* *{SD}***	**NAP***	***p* value**	**Statistically significant change?**
1	8	22	273.3578 *(275.3261)* *{77.4387}*	211.8637 *(196.3958)* *{65.4649}*	0.733	0.473	No
2	9	21	406.7473 *(402.4167)* *{85.4324}*	368.3383 *(355.4167)* *{94.3955}*	0.704	0.052	Yes
3	16	14	283.9553 *(282.5611)* *{61.9517}*	307.6312 *(318.6087)* *{53.0424}*	0.325	0.315	No
Group	33	57	314.8749 *(293.7391)* *{92.1331}*	293.0341 *(295.1364)* *{101.5505}*	0.588	0.41	No

**NAP = Non-overlap All Pairs effect size measure. Scores range from .50 to 1.00 for non-deteriorating data. Scores < .50 represent an effect in the unwanted direction. Tentative NAP ranges: 0-0.65 for weak effect; 0.66-0.92 for medium effect; 0.93-1.00 for large effect (Parker & Vannest, 2009).*

When examining central tendency (median; Figure 2), Participant 1 demonstrated a visible drop in CRT during the intervention, whilst participant 2 showed a slight reduction; however participant 3 demonstrated an increase in CRT during the intervention phase.

Participant 1 had a noticeable negative trend during intervention indicating a reduction in CRT in the desired direction, with the variability in data appearing to reduce towards of the end of intervention phase. Despite demonstrating a medium effect size (NAP=.733), there was considerable overlap between baseline and intervention, with the data failing to show statistically significant reduction in CRT across phases (p=.473).

Only participant 2 demonstrated a statistically significant change across phases (p=0.052), with a medium effect size (NAP=0.704). Despite this, VA only demonstrated a very slight negative trend in the direction of a reduction in CRT during the intervention, with considerable variability in the data as the intervention progressed and overlap with all but one data point between phases. When examining the number of errors made, participant 2 showed a slight increase in errors made in the intervention phase compared to the baseline phase (See Appendix L).

Participant 3 demonstrated a reduction in trend during the intervention phase, with variability in the data settling in comparison to the baseline; however, there was complete overlap between all data points in the baseline and intervention phases. A statistical significant change in CRT was not found (p=.315), and a weak effect size (NAP= .325) was found indicating a deterioration in performance (e.g. an increase in CRT). When considering the number of errors made by participant 3 during the CRT measures, the errors made were relatively similar across phases (See Appendix L).

Overall, the study failed to demonstrate a statistically significant reduction in CRT (p=.588) at a group level, with a small effect size (NAP=.41).

Hypothesis 2

Table 3. Reliable change of pre- and post- study outcome measures.

Measure	Participant 1					Participant 2					Participant 3				
	Pre-score	Post-score	Difference	RCI	Is there reliable change?	Pre-score	Post-score	Difference	RCI	Is there reliable change?	Pre-score	Post-score	Difference	RCI	Is there reliable change?
WISC-IV-Scaled Score															
Coding	8	9	+1	2.68	No	6	5	-1	2.68	No	3	4	+1	2.68	No
Symbol Search	4	3	-1	3.49	No	6	5	-1	3.49	No	7	9	+2	3.49	No
PedsQL Core-Mean scores															
Total Score	43.47	53.26	+9.79	9.67	Yes	41.40	47.82	+6.42	9.67	No	25	50	+25	9.67	Yes
Physical	28.12	25	-3.12	14.33	No	43.75	53.12	+9.37	14.33	No	28.12	59.37	+31.15	14.33	Yes
Psychosocial	51.66	68.33	+16.67	12.78	Yes	40	45	+5	12.78	No	23.33	45	+21.67	12.78	Yes
PedsQL Fatigue- Mean scores															
Total Score	30.27	38.88	+8.61	8.35	Yes	37.5	51.38	+13.88	8.35	Yes	31.9	70.83	+38.93	8.35	Yes
General Fatigue	16.66	29.16	+12.50	13.32	No	25	50	+25	13.32	Yes	37.5	87.5	+50	13.32	Yes
Sleep/Rest Fatigue	45	33.33	-11.67	15.27	No	66.66	66.66	0	15.27	No	54.16	79.17	+25.01	15.27	Yes
Cognitive Fatigue	29.16	54.16	+25	11.11	Yes	20.83	37.5	+16.67	11.11	Yes	4.16	45.83	+41.67	11.11	Yes

RCI= Reliable change index; WISC-IV= Wechsler Intelligence Scale- Fourth Edition

Table 4. Pre- and post-scores on the Silly Sentences subtest (Scaled score) and the PedsQL Fatigue processing speed question (Categorical data)

Participant	Silly Sentences (Scaled Score)		PedsQL Processing speed question (Categorical data)	
	Pre	Post	Pre	Post
1	4	<1	Often	Sometimes
2	5	7	Often	Sometimes
3	<1	1	Almost always	Sometimes

Table 3 presents reliable change data for the WISC-IV measures and the PedsQL Core and Fatigue. Table 4 details the standardized scores for the Silly Sentences subtest and the ordinal data for the PS question of the PedQL Fatigue.

When examining the RCI, no reliable change was found for all three participants between pre- and post-scores on the coding and symbol search subtests of the WISC-IV. There was variance found across participants in the RCI for pre- and post-scores of the PedQL Core, with participant 1 demonstrating improvement in psychosocial and overall quality of life, participant 2 demonstrating no improvement across all subscales and participant 3 demonstrating an improvement on all subscales. There was also a reported reliable change in pre- and post-scores on the PedsQL Fatigue for all three participants in overall and cognitive fatigue.

There appears to be some variability in the pre- and post-scores on the Silly Sentences subtest, with participants 2 and 3 demonstrating an improvement in scaled score and participant 1 demonstrating a decline in score on this measure.

Adherence to Intervention and Informal Feedback

Adherence to the intervention differed across participants. It was requested that all participants play the games for 30 minutes a day over 4 days, equating to 120 minutes a week. All participants consistently played 120 minutes or more of games a week, with the exception of participant 2 who played just under the requested time for one week (110 minutes). Participant 1 and 2 played games between 4 and 6 days, with the exception of one week when participant 1 only played games over 3 days due to illness. The number of days that games were played by participant 3 varied; games were played 4 days over two of the weeks, 3 days over two of the weeks and for one week games were only played over 2 days.

The variety of games differed across participants. Table 5 provides details regarding the approximate amount of time that each participant spent playing the different games across the intervention phase.

Table 5. Approximate time playing games per participant.

	Participant 1 Time playing games (min*)	Participant 2 Time playing games (min)	Participant 3 Time playing games (min)
Individual games	205	85	200
Multi-player games	540	340	115
iPad/tablet games	80	560	360
Total	825	995	675

**minutes*

Participant 1 predominately spent more time playing the group games and there were two weeks in which no iPad/tablet games were played. When iPad/tablet games were played, only one particular game was played throughout the whole intervention. Participant 2 spent more time playing iPad/tablet games, with two weeks in which no individual games were played. Timeshock (individual game) was not played during the intervention. Participant 3 predominately played more iPad/tablet games with only one week when they did not play any multi-player games. Whilst both participants 2 and 3 predominately played iPad/tablet games, participant 2 only played two games and participant 3 only played five games from a choice of eighteen games.

Informal feedback received from participants and parents was that overall participants had enjoyed the intervention. Feedback from two participants (1 and 2) was that participants had played some of the games on the iPad/tablet previously and therefore had found these less interesting. It was also highlighted that games such as Timeshock (Participant 1) and Pass the bomb (Participant 2) were not enjoyed as they were too noisy for the participants, as they provide an auditory time pressure by ticking more rapidly when time is running out. Two parents (1 and 3) reported that the school had noted an improvement in participants' performance. Participant 3 was reported to be more focused in lessons and more willing to persevere with lesson tasks when they would previously have given up, whilst it was reported that participant 1 was concentrating better and appeared to pick things up quicker in lessons.

Discussion

The purpose of this study was to examine the effectiveness of a processing speed intervention in children with suspected white matter damage. The first hypothesis that performance on the CRT outcome measure will improve as a result of intervention was not supported, with findings comparing phase A and B at a group level failing to reach statistical significance. The second hypothesis was partially supported with findings demonstrating a reliable improvement in overall fatigue and cognitive fatigue for all participants (PedsQL Fatigue), but failing to find reliable change between pre- and post- PS measures (WISC-IV).

In relation to hypothesis one, although findings did not reach significance across participants, it was of interest that the difference between phase A and B reached statistical significance for participant 2. This finding was not replicated by participants 1 and 3 whose data did not demonstrate a statistically significant change across phases. These overall findings are suggestive that the processing speed intervention was not effective at increasing PS, unlike the findings of Mackay et al (2011). It is possible that the positive results in that study were due to environmental enrichment rather than neurological change. This may explain why the intervention was not effective at increasing PS in a population with neurological impairment.

Despite this finding there were some interesting results when looking at individual performance across phases for all participants. Whilst participant 2 demonstrates a significant change in CRT this change is difficult to identify through VA. Only a slight negative trend and reduction in central tendency is evident indicating a reduction in CRT. This participant had missing data points at the end of the intervention (data points 24-26); whilst median replacement was utilised it is possible that these scores inflated the CRT data, leading to a smaller identifiable trend. If data collection had stopped at point 24, then a greater trend in the intervention phase in the desired direction may have been found. It is also important to note that this participant demonstrated a mild increase in errors during the intervention phase. Whilst these could represent a speed accuracy trade off, the sporadic nature of these errors are likely to be representative of potential environmental or cognitive confounders (e.g. distraction, fatigue) that impacted upon the participant's attention. This could also reflect the findings for participant 3 who similarly made several errors; despite an increase in median CRT during the intervention, this participant showed a trend in the right direction during the intervention phase. These confounders may have impacted upon the speeded response of participants 2 and 3 and prevented any further improvements in processing speed being evidenced.

Participant 1 did not evidence a significant change between phases; however, the data were encouraging. They demonstrated the greatest trend in the direction of faster CRT during intervention and a reduction in the level of variability between data points across the intervention phase. The greater variability in data at the start of the intervention phase for this participant may have inflated the overall CRT scores for this phase. Whilst there was no statistically significant reduction in CRT, the medium effect suggests that this reduction may not be inconsequential.

In relation to the second hypothesis, the RCI on the PS measures supports the finding that the processing speed intervention was not effective at improving PS ability. Whilst participant 3 demonstrated an improvement on measures, participants 1 and 2 exhibited a decline in at least one PS measure. There was no obvious reason for this decline and it is possible that other behavioural (e.g. motivation) or environmental factors (e.g. the sibling of participant 2 kept entering the room during testing) may have impacted upon performance at the time of testing. Despite this, it is positive that all participants demonstrated reliable change on overall fatigue and cognitive fatigue on quality of life measures, with participants 1 and 3 also showing improvement on their overall scores on the PedsQL Core questionnaires. It could be argued that this may be due to a placebo effect with parents being vigilant to their child’s cognitive PS; however, this finding is supported by school reports in two of the participants. This suggests that there may be some cognitive improvement in PS that is not captured by the PS measures. It may also be suggestive that the intervention may have other benefits for this client group such as improvement in motivation or attention.

Overall, there was not sufficient evidence that this processing speed intervention improved PS. Although evidence in adults demonstrates improvements in PS as a result of intervention (Castel et al., 2005; Edwards et al., 2005; Takeuch et al., 2011), this current study fails to support these findings in a child population. A potential explanation for the study failing to provide support to the hypotheses may be that the length of intervention for participants was not adequate. In both the Oatman-Stanford (2013) and Mackey et al (2011) studies, participants were provided the intervention for eight weeks. The nature of this study’s design with a randomised phase change, meant that all three participants received the intervention for less than eight weeks. Lovden et al (2010) highlighted the importance of a mismatch between the supply of the functional capacity of brain systems which may be affected by a brain injury, and placing environmental demands such as cognitive practice on the systems that operate the functional capacity through experience. They suggest that it is this mismatch that induces plastic alterations in the brain and demonstrates improved performance. This is reinforced by the effectiveness of working memory interventions (Holmes et al., 2009; Holmes et al., 2009; Klingberg et al., 2005; Thorell et al., 2009) that directly practice the skill, with improvements relying on the amount of time children have to practice the intervention (Diamond, 2013). If we apply these principles to this processing speed intervention, it is likely that the limited length of time that participants received the intervention may have prevented the level of cognitive practice required for this mismatch to take place and for structural brain alterations to occur. This is likely to have been a limitation of the study which may have prevented improvements in processing speed abilities occurring.

It is interesting to note that each participant had a different preference for games (single player, multiplayer and iPad/android), with all three playing a limited selection of games under each category. Edwards et al. (2005) found improvements in PS if tasks gradually increased in complexity once mastery was achieved. It is possible that participants in this study had too much choice and therefore only played games that they enjoyed. This led to good acceptability of the processing speed intervention but may not have challenged them sufficiently to make PS gains. As with executive functioning interventions in children (Diamond, 2013), if the demand on PS were not increased, the likelihood of this ability improving is limited. Adult studies have also used videogames or computerised tasks in their interventions (Castel et al., 2005;

Edwards et al., 2005; Takeuchi et al., 2011), this may be suggestive that more computerised based interventions are more effective at improving PS abilities.

Whilst the study's findings did not demonstrate improvements in PS abilities, processing speed intervention studies in children are a relatively novel area of research with few studies exploring this area in child populations. A strength of this study is that it examines an intervention in a client group that can have significant impairment in PS. The results suggest that there are some considerations for clinicians employing PS interventions in practice. The processing speed intervention involved minimal support from a researcher/clinician but regular contact may be important to ensure adherence to intervention. Despite weekly contact, this was not sufficient to ensure that the wide selection of games were played. In clinical settings, clinicians have limited time to follow-up and ensure intervention compliance over extended periods of time, and future research could explore the feasibility of processing speed interventions in paediatric services. Equally, there was a large expectation and burden placed on parents to ensure that the intervention was followed correctly and consistently, and this study highlights that this was difficult over a prolonged period of time. For interventions to work in clinical settings, this expectation and burden often falls to parents which is difficult to sustain, and difficulties in upholding the repetitive and challenging nature of intervention are likely to impact on effectiveness.

A further strength of the study was that the design allowed for various measures of PS abilities, including pre- and post-measures, a continual measure of CRT and parental report. Examining pre- and post-measures alone would have provided limited information about the intervention. The use of a

CRT measure allowed for a live measure throughout the duration of the study. Whilst the data were non-significant, the medium effect size in two participants suggests that these participants made some potential gains in PS and with further adaptation (e.g. longer length, more challenging games) the intervention could hold some benefits.

There were however several limitations to the study. Firstly, the use of a CRT measure may not have been a wholly appropriate measure as it has a limited cognitive load and may not capture global PS (Kail, 2000). Unfortunately, there are limited measures of PS that can be used repeatedly due to the influence of practice effects which provides a challenge to research. Secondly, whilst the study has the minimum number of participants and enough data points for power, the limited number of participants is likely to have prevented replication of the findings for participant 2 and exploration of alternative characteristics that may impact upon the intervention. For example, it is interesting to note that both female participants demonstrated an effect size, whilst a male participant did not. Finally, Mackey et al's (2011) study examined children from low socioeconomic status (SES) backgrounds, and a limitation of this study was that due to recruitment restrictions all participants came for a higher SES background. It is possible that SES could have an influence on the impact of PS interventions due to environmental enrichment which would not have been captured in this study.

Clinical Implications

Clinically, the findings are suggestive that this intervention aimed at increasing PS could be promising in treating children with reduced PS in clinical settings; however, further research and evaluation is required.

Assessment implications. It is interesting that only participant 2 demonstrated a significant change in CRT; this participant was younger and had treatment for a brain tumor. This may be suggestive that the intervention could be effective for clients with certain white-matter illnesses or injuries, or is influenced by certain characteristics such as age, motivation, or types of games that children chose to play. Clinically, services could encourage children to participate in this home-based intervention but would ideally assess which children receive benefits from the intervention and examine the characteristics of these children. Clinicians would need to ensure that they assess PS abilities in children attending clinic in order to identify who may benefit from this intervention. In addition, it would be beneficial to assess a broad range of cognitive abilities and motivational factors in order to establish their potential impact on the outcomes observed.

Treatment implications. The variance in games played, days playing games and time playing games, suggests that services would also benefit from considering family factors that may influence a child’s suitability for the intervention during assessment. The family’s capacity to facilitate and adhere to the intervention may contribute to the effectiveness of the intervention, and services would need to be mindful that clients in families with limited capacity to support this may not benefit from the intervention or may need further support. For clients who experience cognitive difficulties (e.g. poorer attention) or have limited motivation, services may need to consider whether support around these issues can be provided to support the clients ability to engage in the intervention or consider adaptations that may suit specific clients’ cognitive needs.

Service implications. It would be important for services to evaluate the use of this intervention and add to the evidence base in order to a gain a better understanding of the factors that influence effectiveness. In order to do this, services may need to consider providing clinicians with time to facilitate this home-based intervention in order to allow for its evaluation. Whilst services often have limited time available to support home-based interventions, once clients are enrolled in the intervention, this intervention requires relatively limited involvement from clinicians. As PS has a significant impact on daily functioning, providing clients with an intervention which could have positive benefits on PS could have the potential to reduce the burden placed on services, which in the long-term could reduce the overall costs for services.

Future Research

Future research into this area would benefit from ensuring that PS interventions are delivered for an extended period of time. Studies with children to date have examined interventions delivered over eight weeks or less; however, some adult studies have been delivered over significantly longer periods of time. Increasing the length of intervention may be of benefit in increasing plasticity. It may also be interesting to consider the impact of SES on processing speed interventions in this population to consider if this plays a role in the intervention’s effectiveness. Due to the limited clinical resources available, it is important that research continues to develop effective processing speed interventions which can be utilised by parents and clinicians in this client group.

Conclusion

The current study aimed to examine whether a processing speed intervention was effective at improving PS abilities in children with suspected white matter damage. Participants were required to play a number of computerised and non-computerised games for up to two hours a week over several days. The findings from this study suggest that the PS intervention was not effective at improving PS; however, there is evidence that it may have benefits on overall and cognitive fatigue on quality of life measures. There are a number of potential explanations for the lack of significant findings on PS including the length of intervention, lack of repetition in games and a limited variety of games that prevents the increasing level of challenge needed for interventions to be effective. Future research would benefit in continuing to develop PS intervention in this population and considering extending the length of the intervention provided.

References

Baayen, R. H., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research*, *3*, 12-28.

Baddeley, A., Emslie, H., Nimmo-Smith. (1992). *Speed and capacity of language processing test (SCOLP).* UK: Psychologial Corporation

Borghesani, P. R., Madhyastha, T. M., Aylward, E. H., Reiter, M. A., Swarny, B. R.,…., & Willis, S. L. (2013). The association between higher order abilities, processing speed, and age are variably mediated by white matter integrity during typical aging. *Neuropsychologia*, *51*, 1435–1444. https://doi.org/10.1016/j.neuropsychologia.2013.03.005

Bulté, I., & Onghena, P. (2009). Randomization tests for multiple-baseline designs: An extension of the SCRT-R package. *Behavior Research Methods*, *41*, 477–485. https://doi.org/10.3758/BRM.41.2.477

Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta Psychologica*, *119*, 217–230. https://doi.org/10.1016/j.actpsy.2005.02.004

Cepeda, N.J., Blackwell, K.A., & Munakata, Y. (2013). Speed isn't everything: Complex processing speed measures mask individual differences and developmental changes in executive control. *Developmental Science, 16,* 269-286. https://doi:10.1111/desc.12024

Deary, I. J., Liewald, D., & Nissan, J. (2011). A free, easy-to-use, computer-based simple and four-choice reaction time programme: the Deary-Liewald reaction time task. *Behavior research methods*, *43*, 258-268. https://doi.org/10.3758/s13428-010-0024-1

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Duff, K. (2012). Evidence-based indicators of neuropsychological change in the individual patient: relevant concepts and methods. *Archives of Clinical Neuropsychology*, *27*, 248-261. https://doi.org/10.1093/arclin/acr120

Dye, M. W. G., Green, C. S., & Bavelier, D. (2009). Increasing speed of processing with action video games. *Current Direction in Psychological Science*, *18*, 321–326. https://doi.org/10.1111/j.1467-8721.2009.01660.x.Increasing

Edwards, J.D., Wadley, V.G., Vance, D.E., Wood, K.., Roenker, D.L., & Ball, K.K. (2005). The impact of speed of processing training on cognitive and everyday performance. *Aging and Mental Health, 9,* 262-271. http://dx.doi.org/10.1080/13607860412331336788

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science*, *7*, 237–241. https://doi.org/10.1111/j.1467-9280.1996.tb00366.

Fryer, S. L., Schweinsburg, B. C., Bjorkquist, O. A., Frank, L. R., Mattson, S. N.,…., Riley, E. P. (2009). Characterization of white matter microstructure in fetal alcohol spectrum disorders. *Alcoholism: Clinical and Experimental Research*, *33*, 514–521. https://doi.org/10.1111/j.1530-0277.2008.00864.x

Gehrke, A. K. (2011). *Differential performance of children with and without cerebral palsy on graphomotor cognitive processing speed measures.* (Unpublished BsC Thesis). University of Michigan.

Heyvaert, M., & Onghena, P. (2014). Analysis of single-case data: Randomisation tests for measures of effect size. *Neuropsychological Rehabilitation*, *24*, 507–527. https://doi.org/10.1080/09602011.2013.818564

Heyvaert, M., Moeyaert, M., Verkempynck, P., Van den Noortgate, W., Vervloet, M., Ugille, M., & Onghena, P. (2017). Testing the intervention effect in single-case experiments: A Monte Carlo simulation study. *The Journal of Experimental Education*, *85*, 175-196. http://dx.doi.org/10.1080/00220973.2015.1123667

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental science*, *12*, F9-F15. https://doi.org/10.1111/j.1467-7687.2009.00848.x

Holmes, J., Gathercole, S. E., Place, M., Dunning, D. L., Hilton, K. A., & Elliott, J. G. (2010). Working memory deficits can be overcome: Impacts of training and medication on working memory in children with ADHD. *Applied Cognitive Psychology*, *24*, 827-836. https://doi.org/10.1002/acp.1589

Jacobs, H. I. L., Leritz, E. C., Williams, V. J., Van Boxtel, M. P. J., Elst, W. Van Der, Jolles, J., Salat, D. H. (2013). Association between white matter microstructure, executive functions, and processing speed in older adults: The impact of vascular health. *Human Brain Mapping*, *34*, 77–95. https://doi.org/10.1002/hbm.21412

Johnston, M. V. (2004). Clinical disorders of brain plasticity. *Brain and Development*, *26*, 73–80. https://doi.org/10.1016/S0387-7604(03)00102-5

Kail, R. (2000). Speed of information processing: Developmental change and links to intelligence. *Journal of School Psychology*, *38*, 51–61. https://doi.org/10.1016/S0022-4405(99)00036-9

Kail, R., & Salthouse, T. A. (1994). Processing speed as a mental capacity.

Acta Psychologica, *86*, 199–225. https://doi.org/10.1016/0001-6918(94)90003-5

Kazdin, A.E. (1982). *Single-case research designs: Methods for clinical and applied settings.* New York: Oxford University Press

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., ... & Westerberg, H. (2005). Computerized training of working memory in children with ADHD-a randomized, controlled trial. *Journal of the American Academy of Child & Adolescent Psychiatry*, *44*, 177-186. https://doi.org/10.1097/00004583-200502000-00010

Koster, E. (2014). *The relationship between information processing speed, reaction time & cognitive functioning in patients with gliomas (Bachelor Thesis).* Tilburg University.

Kratochwill, T. R., Hitchcock, J., Horner, R. H., Levin, J. R., Odom, S. L., Rindskopf, D. M., & Shadish, W. R. (2010). Single-case designs technical documentation. *What works clearinghouse*. Retrieved from: https://files.eric.ed.gov/fulltext/ED510743.pdf

Lee, Y. J. (2011). Acute disseminated encephalomyelitis in children: differential diagnosis from multiple sclerosis on the basis of clinical course. *Korean Journal of Pediatrics*, *54*, 234–40. https://doi.org/10.3345/kjp.2011.54.6.234

Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin*, *136*, 659–676. https://doi.org/10.1037/a0020080

Mabbott, D.J., Penkman, L., Witol, A., Strother, D., & Bouffet, E. (2008). Core neurocognitive functions in children treat for posterior fossa tumors/ *Neuropsychology, 22,* 159-168. https://doi.org/10.1037/0894-4105.22.2.159

Mackey, A. P., Hill, S. S., Stone, S. I., & Bunge, S. A. (2011). Differential effects of reasoning and speed training in children. *Developmental Science*, *14*, 582–590. https://doi.org/10.1111/j.1467-7687.2010.01005.x

Magistro, D., Takeuchi, H., Nejad, K. K., Taki, Y., Sekiguchi, A., Nouchi, R., ..., Yokoyama, R. (2015). The relationship between processing speed and regional white matter volume in healthy young people. *PloS one*, *10*, e0136386. https://doi.org/10.1371/journal.pone.0136386

Maruff, P., Thomas, E., Cysique, L., Brew, B., Collie, A., Snyder, P., & Pietrzak, R. H. (2009). Validity of the CogState brief battery: Relationship to standardized tests and sensitivity to cognitive impairment in mild traumatic brain injury, schizophrenia, and AIDS dementia complex. *Archives of Clinical Neuropsychology*, *24*, 165–178. https://doi.org/10.1093/arclin/acp010

Morley, S. (2018). *Single-case methods in clinical psychology. A practical guide.* Abington, Oxon: Rougtledge.

Mundkur, N. (2005). Neuroplasticity in children. *Indian Journal of Pediatrics*, *72*, 855–857. https://doi.org/10.1007/BF02731115

Nettelbeck, T., & Burns, N. R. (2010). Processing speed, working memory and reasoning ability from childhood to old age. *Personality and Individual Differences*, *48*, 379-384. https://doi.org/10.1016/j.paid.2009.10.032

Neubauer, A. C., Riemann, R., Mayer, R., & Angleitner, A. (1997). Intelligence and reaction times in the Hick, Sternberg and Posner paradigms. *Personality and Individual Differences*, *22*, 885-894. https://doi.org/10.1016/S1091-8869(97)00003-2

Oatman-Stanford, D. (2013). *Cognitive speed training for children who have survived an acquired brain injury: A feasibility and acceptibility study* (Unpublished MSc Dissertation). The University of Edinburgh, Scotland.

Onghena, P., & Edgington, E.S. (2005). Customization of pain treatments: single-case design and analysis. *The Clinical Journal of Pain, 21,* 56-68. https://doi.10.1097/00002508-200501000-00007

Parker, R. I., & Vannest, K. (2009). An improved effect size for single-case research: Nonoverlap of all pairs. *Behavior Therapy*, *40*, 357-367. https://doi.org/10.1016/j.beth.2008.10.006

Posthuma, D., Baaré, W. F. C., Hulshoff Pol, H. E., Kahn, R. S., Boomsma, D. I., & De Geus, E. J. C. (2003). Genetic correlations between brain volumes and the WAIS-III dimensions of verbal comprehension, working memory, perceptual organization, and processing speed. *Twin Research*, *6*, 131–139. https://doi.org/10.1375/twin.6.2.131

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological bulletin*, *114*(3), 510. https://doi.org/10.1037/0033-2909.114.3.510

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2011). Modeling a cascade of effects: The role of speed and executive functioning in preterm/full-term differences in academic achievement. *Developmental Science*, *14*, 1161–1175. https://doi.org/10.1111/j.1467-7687.2011.01068.x

Silva, L. (2009). The construct of cognitive processing and speed: test performance and information processing approaches. *Electronic Theses and Dissertations.* https://digitalrespository.umn.edu/psy_etds/128

Scantlebury, N., Bouffett, E., Laughlin, S., Strother, D., McConnell, D., Hukin, J.,…...Mabbot, D.J. (2016). White matter and information processing speed following treatment with cranial-spinal radiation for pediatric brain tumor. *Neuropsychology, 3,* 425-539. https://dx.doi.rog/10.1037/neu0000258

Stiles, J. (2000). Drawing abilities in williams syndrome: A case study. *Developmental Neuropsychology*, *18*, 237–272. https://doi.org/10.1207/S15326942DN1802_5

Takeuchi, H., Taki, Y., Hashizume, H., Sassa, Y., Nagase, T., Nouchi, R., & Kawashima, R. (2011). Effects of training of processing speed on neural systems. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *31*, 12139–48. https://doi.org/10.1523/JNEUROSCI.2948-11.2011

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental science*, *12*, 106-113. https://doi.org/10.1111/j.1469-7687.2008.00745.x

Tuch, D. S., Salat, D. H., Wisco, J. J., Zaleta, A. K., Hevelone, N. D., & Rosas, H. D. (2005). Choice reaction time performance correlates with diffusion anisotropy in white matter pathways supporting visuospatial attention. *Proceedings of the National Academy of Sciences of the United States of America*, *102*, 12212–7. https://doi.org/10.1073/pnas.0407259102

Turken, A. U., Whitfield-Gabrieli, S., Bammer, R., Baldo, J. V., Dronkers, N. F., & Gabrieli, J. D. E. (2008). Cognitive processing speed and the structure of white matter pathways: Convergent evidence from normal variation and lesion studies. *NeuroImage*, *42*, 1032–1044. https://doi.org/10.1016/j.neuroimage.2008.03.057

Varni, J.W. (1998). *Pediatric quality of life inventory (UK).* France: Mapi Research Trust.

Wechsler, D. (2003). *Wescheler intelligence scale for children- Fourth edition.* UK: Psychological Corporation.

Wechsler, D. (2011). *Wechsler abbreviated scale of intelligence- Second edition.* UK: Psychological Corporation

Wechsler, D. (2016). *Wechsler intelligence scale for children- Fifth edition.* UK: Psychological Corporation

Appendices

Appendix A: Potential Phase Change

AAAAAABBBBBBBBBBBBBBBBBBBBBBBB

AAAAAAABBBBBBBBBBBBBBBBBBBBBBB

AAAAAAAABBBBBBBBBBBBBBBBBBBBBB

AAAAAAAAABBBBBBBBBBBBBBBBBBBBB

AAAAAAAAAABBBBBBBBBBBBBBBBBBBB

AAAAAAAAAAABBBBBBBBBBBBBBBBBBB

AAAAAAAAAAAABBBBBBBBBBBBBBBBBB

AAAAAAAAAAAAABBBBBBBBBBBBBBBBB

AAAAAAAAAAAAAABBBBBBBBBBBBBBBB

AAAAAAAAAAAAAAABBBBBBBBBBBBBBB

AAAAAAAAAAAAAAAABBBBBBBBBBBBBB

AAAAAAAAAAAAAAAAABBBBBBBBBBBBB

AAAAAAAAAAAAAAAAAABBBBBBBBBBBB

AAAAAAAAAAAAAAAAAAABBBBBBBBBBB

AAAAAAAAAAAAAAAAAAAABBBBBBBBBB

AAAAAAAAAAAAAAAAAAAAABBBBBBBBB

AAAAAAAAAAAAAAAAAAAAAABBBBBBBB

AAAAAAAAAAAAAAAAAAAAAAABBBBBBB

AAAAAAAAAAAAAAAAAAAAAAAABBBBBB

Appendix B: Parent/Carer Information Sheet

UNIVERSITY OF EXETER

Information sheet
(Parent/Carer)

Study title: Processing speed training in children and adolescents

Name of researcher: Lee Gamman Name of supervisor: Dr Jennifer Limond

We would like to invite you and your child to take part in a research study. Before, you decide if you would agree to your child or adolescent taking part, it is important that you understand why the study is being done and what it will involve for your child or adolescent's participation. Please take time to read the information provided.

If you have any questions about the study or if you would like your child or adolescent to take part in the study, please get in contact. Contact details are at the bottom of this sheet.

Thank you for reading this information sheet.

Who is organising the research?
This study is being conducted by Lee Gamman as part of a Doctorate in Clinical Psychology at the University of Exeter and is being supervised by Dr Jennifer Limond, Consultant Clinical Neuropsychologist.

What is the study about?
This study is about how quickly our brains help us to process and use information. This is known as processing speed.

Processing speed is linked to our thinking abilities (such as problem solving and memory), and how well we do at school. Some children may have slower processing speed, which makes it harder for them to follow conversations, television programmes and complete home/school tasks.

Studies have shown that processing speed can be improved in some children by playing certain games such as card games, computer games and board games. We would like to know if playing these games can help children with a medical condition associated with the brain (white matter integrity) improve their processing speed.

Why has my child/adolescent been invited to take part?
We are hoping to recruit children between 6 and up to 16 years, who may have difficulties with processing speed.

We would like to invite your child/adolescent to take part because they are in the age range that the study is researching and because your child/adolescent has a medical condition associated with the brain and may have possible processing speed difficulties.

Does my child/adolescent have to take part?
No. The decision on whether or not you child/adolescents wishes to take part in this study is entirely up to you and your child/adolescent. If you decide you would prefer that your child/adolescent does not take part, it will not affect your child's access to healthcare or any legal rights that you or child/adolescent has.

If you and your child/adolescent do wish to take part, you can contact the researcher, Lee Gamman (details below), who will arrange an appointment to come and meet with you. You can change your mind and withdraw from the study at any time without needing to provide a reason. Your decision will not affect the standard of care your child/adolescent receives either now or in the future.

What will happen in the study?
If you agree that your child/adolescent would like to take part in the study and if they too agree to take part, then a time will be arranged to meet with you and your child at home to talk through the study. The study will last up to 14 weeks. You will be asked to sign a consent form which says that you are happy for you child/adolescent to take part in the study and they too will be asked to sign an Assent Form if they agree to take part. The details of the different stages of the study are outlined clearly in the flow chart on page 3 of this information sheet.

Flow chart for ***Processing speed training in children and adolescents***

Meet with the researcher to discuss the study and complete the consent form (up to 15 minutes)

Decide to take part

Step 1 Assessment

If you give consent, your child will be asked to complete a short assessment of processing speed and other thinking abilities (up to 45 minutes). This assessment will involve some paper and pencil tasks.

You will be asked to complete a brief questionnaire.

If the assessment shows that your child has some difficulty with processing speed, you and your child will be invited to take part in the processing speed training.

Decide not to take part

If you and your child decide you do not wish to take part, you will be thanked for your time and no further involvement will be required.

If the assessment shows that you child does not have any difficulties with processing speed, you will be thanked for your time and no further involvement will be required.

Step 2 Computer Task

Before the training starts, your child will be asked to complete a short task (approximately 3 minutes) on the computer that measures processing speed. You will be asked to do this 3 times a week for approximately 2 weeks.

Step 3 Training sessions

After these 2 weeks, your child will start the processing speed training. The training involves playing a number of games (computer games, board games and card games). The games will need to be played at 2 hours a week over at least 4 different days. The training will last for approximately 8 weeks.

Step 4 Repeat Assessment

At the end of training, your child will be asked to repeat the short assessment of processing speed and other thinking abilities (up to 45 minutes).

You will also be asked to repeat the brief questionnaire.

The study involves:

1. Completing pencil and paper assessment
2. Completing a short computer task, 3 times a week for 10 weeks
3. Completing the training sessions by computer or iPad, card and board games, 2 hours a week over at least 4 days.

The whole study will last for up to 14 weeks. The amount of time spent each week on the training programme will be 2 hours. Although this seems like a lot of work, the game are all commercially available and are meant to be enjoyable for you and your child.

Lee will need to visit your house four times during the study:
1. To collect consent and complete the first assessment
2. To provide you with the short computer task to measure processing speed
3. To provide you with the games and instructions for the intervention
4. To collect the games and repeat the assessment.

What equipment will I need?
To take part in the study, your child/adolescent will need access to either a computer, an iPad, or an android tablet or phone.

Lee will provide you with the games that your child/adolescent will need for the intervention.

Are there any risks to my child?
The study will be completed with minimal risk of distress to your child/adolescent.

During the assessment, your child/adolescent will be told how to complete all tasks, and will be told that "nobody gets all of the questions right". Your child/adolescent may become tired during the assessment so regular breaks will be taken to reduce this risk.

If the assessment shows that your child/adolescent has some difficulties with their thinking abilities, we would tell you. We would also ask for your permission to inform your child's paediatrician and/or GP so that they can consider a referral for a full assessment.

In the event that your child/adolescent becomes distressed, the assessment will be stopped and your child/adolescent will be given the opportunity to talk about their distress if they want too, and reminded that they can withdraw from the study if they want to.

What are the potential benefits?
By taking part in this study, you and your child/adolescent will be helping us to find out if these games help improve processing speed.

What will happen to my child's information?
Information collected from you and your child/adolescent will be kept anonymous and safe. This means that your child's name will not be written on any questionnaires or any assessment measures. Instead your child/adolescent will be given a participant ID number that will be used throughout the study to keep your child's details anonymous.

Information will be kept in a locked filing cabinet and on a password protected and encrypted computer. When the study is finished, information from questionnaire and assessment measures will be kept in a locked filing cabinet and stored for a minimum of 5 years and a maximum of 10 years.

Your child's information will not be shared with anyone outside the research team. The only time that information would be shared, would be if you or child/adolescent gave us information that suggested that your child/adolescent is at risk. In this instance, we would contact the necessary agencies as appropriate in the interest of the safety of your child/adolescent. If this were to happen, we would try to discuss this with you beforehand if it was appropriate to do so.

As stated above, if the assessment shows that your child/adolescent has some difficulties with their thinking abilities, we would tell you and with you permission write to your child's paediatrician and/or GP so that a referral can be made for a full assessment.

What will happen to the results of the study?
The results of this study will be written up into a journal paper and will be submitted as part of the assessment criteria for the Doctorate in Clinical Psychology at the University of Exeter.

The written journal paper may also be submitted to academic journals to inform future research in this area. In both instances, you child's personal details will not be identifiable and will remain anonymous.

What should I do if I and my child/adolescent wish to take part in the study?
If you or your child/adolescent have any questions about the study, or if you wish to take part, please send an email with your contact details to Lee Gamman at lg439@exeter.ac.uk. You will then be contacted to arrange a time to meet.

Who can I contact if I want further information about the study?
If you have any questions about the study, please contact
Lee Gamman (lg439@exeter.ac.uk)

OR

If you have any complaints about any aspect of the study, please contact Dr Jenny Limond (j.limond@exeter.ac.uk).

Dr Jennifer Limond
Sir Henry Welcome Building for Mood Disorders
University of Exeter
Perry Road
Exeter
Devon
EX4 4QG
01392 724657

Thank you for reading this information sheet.

Appendix C: Children/adolescents Information Sheet

Information Sheet
(Children and Adolescents)

Study title: Processing speed training in children and adolescents

Name of researcher: Lee Gamman Name of supervisor: Dr Jennifer Limond

We would like you to take part in a research study?

This sheet tells you what the study is about.

If you have any questions, you can ask your mum, dad or your carer and they can contact me.

What is the study about?
Our brain takes in lots of information.

How fast our brains can take in this information is called processing speed.

Some children's brains take information in a little bit slower. This can make it hard to watch TV and do homework.

We would like to know if playing games can make our brains work faster.

Why have I been asked?
Because of how old you are – between 6 and 16 years.

Because your doctor thinks that your brain might take information in a little bit slower.

Do I have to be in the study?
No. It is okay if you do not want to be in the study.

If you DO want to be in the study, your mum, dad or carer can contact me.

Even if you have already started the study, you can stop if you don't want to carry on.

You can say no to the study at any time and you will not be in trouble.

What will I be asked to do?
You will be asked to do some tasks to look at how you think.

Then you will be asked to do a task on the computer three times a week for at least two weeks

Then you will be asked to play some games. There will be board games, card games and games on your computer, tablet or iPad for 2 hours a week over at least four days.

This will take up to fourteen weeks.

Will it hurt me?
No. The paper tasks might make you tired but we can take some breaks.

If you do get upset, we can stop at any time.

Who will know that I am in the study?
Only you, your parents, the doctor who told you about the study and the researcher, Lee will know you are in the study.

Your information will be kept safe. You will be given a number so that no one except Lee will know which paper and computer tasks are yours.

If the tasks that look at how you think find that some tasks are difficult for you, Lee will tell your GP so that they can look at ways to get you some help for this. She will speak to you about this before she tells your GP.

If you tell Lee something that makes her think that you are not safe, she will have to tell someone. She will speak to you first.

What is the study for?

The study is part of Lee’s work at university, it will help us to understand if young people’s brains can be trained to process information more quickly.

She may write it up for a journal but your name and information will not be used.

What should I do if I want to be in the study?
Tell your mum, dad or carer and they can get in contact with Lee.

She will ask them to read some more information and sign a consent form to agree you can take part

Thank you for reading this.

Appendix D: Advertisement for Study

UNIVERSITY OF EXETER

Can you help with a research project at the University of Exeter that involves children with an acquired brain injury or illness?

This study is about how quickly our brains help us to process and use information. This is known as processing speed.

The title of the study is: **Processing speed training in children and adolescents**

The researcher, Lee Gamman, from the University of Exeter is undertaking a study as part of a Doctorate in Clinical Psychology. The study will be recruiting children aged between 6 years and up to 16 years old that have an acquired brain injury or illness and who may have difficulties with processing speed. We will ask parents/carers to provide consent for their children to take part.

The study is looking to see if a speed training intervention that involves playing computerised and non-computerised games, can help to improve processing speed abilities. If you are interested in the study your child's participation will last for up to 14 weeks and involves:

1. Completing a pencil and paper assessment
2. Completing a short computer task, 3 times a week for 10 weeks. This measure will see how quickly your child can spot something on the screen and will only takes a few minutes.
3. Completing the training sessions by computer or iPad, both single-player and multi- player card and board games, for 2 hours a week over at least 4 days.

Involvement in the study will be kept strictly confidential at all times.

If you and your child are interested in taking part in the study, please follow this link:
http://psychology.exeter.ac.uk/research/centres/ccnr/getinvolved/clinical/speedtraining/

Appendix E: PedsQL and PedsQL Fatigue

PedsQL™ Pediatric Quality of Life Inventory (UK)

Version 4.0

PARENT REPORT for **CHILDREN**
(ages **8-12**)

DIRECTIONS

On the following page is a list of things that might be a problem for **your child**. Please tell us **how much of a problem** each one has been for **your child** during the **past ONE month** by circling:

0 if it is **never** a problem
1 if it is **almost never** a problem
2 if it is **sometimes** a problem
3 if it is **often** a problem
4 if it is **almost always** a problem

*In the past **ONE month,** how much of a **problem** has your child had with …*

PHYSICAL FUNCTIONING *(problems with…)*	**Neve r**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. Walking down the road a little bit	0	1	2	3	4
2. Running	0	1	2	3	4
3. Participating in sports or running games	0	1	2	3	4
4. Lifting heavy things	0	1	2	3	4
5. Having a bath or shower by him or herself	0	1	2	3	4
6. Tidying up around the house	0	1	2	3	4
7. Having hurts or aches	0	1	2	3	4
8. Feeling very tired	0	1	2	3	4

EMOTIONAL FUNCTIONING *(problems with…)*	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. Feeling afraid or scared	0	1	2	3	4
2. Feeling sad or unhappy	0	1	2	3	4
3. Feeling angry or cross	0	1	2	3	4
4. Trouble sleeping at night	0	1	2	3	4
5. Worrying about what will happen to him or her	0	1	2	3	4

SOCIAL FUNCTIONING *(problems with…)*	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. Getting on with other children	0	1	2	3	4
2. Other kids not wanting to be his or her friend	0	1	2	3	4
3. Getting bullied by other children	0	1	2	3	4
4. Not able to do things that other children his or her age can do	0	1	2	3	4
5. Keeping up when playing with other children	0	1	2	3	4

SCHOOL FUNCTIONING *(problems with…)*	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. Paying attention in class	0	1	2	3	4
2. Forgetting things	0	1	2	3	4
3. Keeping up with schoolwork	0	1	2	3	4
4. Having days off school because of not feeling well	0	1	2	3	4
5. Having days off school to go to the doctor or hospital	0	1	2	3	4

PedsQL ™

Multidimensional Fatigue Scale

Standard Version

PARENT REPORT for **YOUNG CHILDREN** (ages **5-7**)

DIRECTIONS

On the following page is a list of things that might be a problem for **your child**. Please tell us **how much of a problem** each one has been for **your child** during the **past ONE month** by circling:

0 if it is **never** a problem
1 if it is **almost never** a problem
2 if it is **sometimes** a problem
3 if it is **often** a problem
4 if it is **almost always** a problem

There are no right or wrong answers.
If you do not understand a question, please ask for help.

In the past ***ONE month,*** *how much of a* ***problem*** *has this been for your child …*

General Fatigue ***(PROBLEMS WITH…)***	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. Feeling tired	0	1	2	3	4
2. Feeling physically weak (not strong)	0	1	2	3	4
3. Feeling too tired to do things that he/she likes to	0	1	2	3	4
4. Feeling too tired to spend time with his/her	0	1	2	3	4
5. Trouble finishing things	0	1	2	3	4
6. Trouble starting things	0	1	2	3	4

Sleep/Rest Fatigue ***(PROBLEMS WITH…)***	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. Sleeping a lot	0	1	2	3	4
2. Difficulty sleeping through the night	0	1	2	3	4
3. Feeling tired when he/she wakes up in the	0	1	2	3	4
4. Resting a lot	0	1	2	3	4
5. Taking a lot of naps	0	1	2	3	4
6. Spending a lot of time in bed	0	1	2	3	4

Cognitive Fatigue ***(PROBLEMS WITH…)***	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. Difficulty keeping his/her attention on things	0	1	2	3	4
2. Difficulty remembering what people tell him/her	0	1	2	3	4
3. Difficulty remembering what he/she just heard	0	1	2	3	4
4. Difficulty thinking quickly	0	1	2	3	4
5. Trouble remembering what he/she was just	0	1	2	3	4
6. Trouble remembering more than one thing at a	0	1	2	3	4

Appendix F: Processing Speed Intervention Manual

Processing speed training in children and adolescents

Processing speed training instructions

Chief Investigator: Lee Gamman

lg439@exeter.ac.uk

Supervisor: Dr Jenny Limond

j.limond@exeter.ac.uk

Contents Page

Instructions for the games

Thank you for agreeing for you child/adolescents to take part in this study. Enclosed are the instructions on how often to play the games and how to play each game.

Intervention

There are three different types of games:

1) Single player games
2) Multiple player games
3) PC, iPad or tablet games

There are a selection of games that your child/adolescent can chose to play.

We would like your child/adolescent to play the games for 2 hours a week over at least 4 different days.

Please try to rotate what types of games your child/adolescent plays on each day. Please also rotate between the PC, iPad or tablet games, e.g. some days do subway surfer and some days do fruit ninja. An example of this would be:

- Day 1- single player games and multiple player games
- Day 2- PC, iPad or tablet games and single player games
- Day 3- play multiple player games and PC, iPad or tablet games
- Day 4- play single player and PC, iPad or tablet games

You will be given a games sheet to help you to monitor what games are being played and how often. Please complete this each week.

If you find that your child/adolescent is having any difficulties playing a certain game and you would like some advice on if the game can be adapted in any way, please email Lee on lg439@exeter.ac.uk and she will get in contact with you.

Single player games

Time shock

1. Make sure the Start/Stop button is pushed to the stop position
2. Press down and turn the timer knob to 50 seconds
3. Slide the Start/Stop button to the start position
4. Try to put all of the pieces in the correct position before the time runs out

Bop it

To turn the game on pull the blue lever. Continue to pull the blue lever until it says solo. Press the bop it button in the middle to start the game

Bop it will yell out commands for your child to complete on the device.

- Pull it: when it says “pull it”, pull the blue lever as fast as you can
- Twist it: when it says “twist it”, twist the yellow lever as quickly as you can
- Bop it: when it say “bop it”, push the bop it button as fast as you can
- Shout it: when it says “shout it”, shout any loud sound into the green microphone

Multiple player games

Card games

Spoons

To play this game you will need the pack of playing cards and a spoon for every player except one. For example, if you have 4 players, you only need 3 spoons.

Deal 4 cards to each player and keep the rest of the pack next to the dealer. Everyone takes one of their cards and places it face down to the person to their left, who will then pick it up. The dealer will then discard one of their cards into a discard pile.

The dealer then picks up another card and then repeat the process of passing to the left.

When a player gets 4 of a kind (e.g. aces, 4's, kings etc) they should pick up a spoon from the middle. All the other players then need to pick up a spoon as quickly as they can. The player without a spoon is out.

A spoon then needs to be removed before the game continues.

The player that wins the game is the player to pick up the final spoon.

Snap

Separate the cards out equally between all players. Each player takes a turn to turn a card over and place it face up on a pile in the centre of the table. If two cards match (e.g. 2 kings, or 2 6's) the fastest player to say snap and put their hand on top of the pile wins that pack.

The winner is the person who wins all the cards (or has the most cards at the end of an agreed time for playing the game).

Racing demons

Each player should start with a pack of cards. Each player should have a different design on their pack.

Players should be facing each other.

Each player should deal out 13 cards face down except for the top card which is face up (this is called the croupette).

Deal four more card in a line face up, next to the croupette (this is called the line-up).

Keep the rest of the cards in your hand.

When everyone has set up their cards, someone shout GO.

If a player has an ace in their line-up they move it into the middle. They then replace that card with the card on top of the croupette, and turn the next card on the croupette over. Each player should always have 5 cards face up.

Each player turns over the cards in their hand as quickly as they can. If they have an ace it goes in the middle.

There is no turn taking. Each player turns over their cards as quickly as they can. They can build up the suits in the middle with either the cards in their hand or the cards from their line-up.

Cards from the line-up are always replaced with the top card of the croupette, and the next card in the croupette is turned up. The player who puts the final King onto a suit in the middle takes that pile and puts it to one side.

The winner is the first player to get rid of all their CROUPETTE - not including the line-up: when they play their final card, putting it onto one of the suits in the middle, they shout OUT and play stops IMMEDIATELY.

The games is then scored:

- 10 points to the winner
- 2 points to any player who finished a suit
- Each player collects their cards from the middle, and counts how many cards they have
- Each player then subtracts the number of cards they have in the croupette from the number of cards in the middle to get their final score.

Speed

This is a 2 player game. Players should sit across from each other.

The aim of the game is to be the first player to play all of the cards in their deck and say “Speed!”

Deal 20 cards face down to each player.

Deal the remaining cards face down in 4 piles between the players. There should be 2 outside piles with 5 cards and 2 inside piles with only 1 card.

Pick up 5 cards in your deck and arrange them in your hand.

Simultaneously turn over the 2 single card in the centre of players.

Begin playing your cards in your hand by placing them onto of the face-up card. You can place cards on the face-up pile in number order (you can go both up and down). Either a King or a 2 can be played on an Ace.

As you go, pick up cards from your deck, keeping 5 cards in your hand at all times.

When neither player has a card that they can play on the centre piles, flip over a card from the outer face-down pile. If this pile runs out of cards, turn the face-up pile over and start using the top card.

Once you've used all 20 cards in your hand and deck, shout "speed" and you have won.

Crazy Eights

The aim of the game is to be the first player to get rid of all the cards in their hand.

Deal 5 cards to each player face down.

The remaining cards should be placed face down in the centre of the table and is called the stock. The dealer turns over the top card and places it in a separate pile; this card is called the "starter". If an eight is turned over, it should be put back into the middle of the pack and the next card should be turned over.

Players should pick up their cards and then taking it in turns to place a card on the starter pile. Each card placed on the starter pile must match the starter pile in either suit or number.

If a player is unable to play a card, cards can be drawn from the top of the stock until it is possible to play or until the stock has run out of cards. If the player is unable to play and the stock has run out of cards, the player must pass.

All 8's are wild! An 8 can be played at any time. The player that uses an 8 must say what suit they want to change the start pile too. The next player must then play a card of that suit or another 8.

The player who is the first to have no cards left wins the game. The winning player can then collect points from the other player based on the cards that they have left in their hand.

The scoring is as follows:

- Each 8 = 50 points
- Each K, Q, J or 10= 10 points
- Each ace= 1 point

Board games

Dobble

Every dobble card has 8 symbols on the card. Draw two cards from the pack at random and place them face up on the table so that all players can see.

Look for the matching symbol between the two cards. The first player to name the matching symbol wins those cards.

There are different mini games that can be played and the instructions for these can be found in the dobble game instruction manual.

Pass the bomb

The pack of cards is laid face down on the table. The first player presses the red button on the bottom of the bomb and turns over a card.

Each card shows a familiar scene, for example the beach. The player that has turned over the card must say a word which would fit with the scene. For example ‘spade’ would fit in with a scene of the beach.

If the player gets the answer right, they pass the bomb to the player on their left who then tries to think of another word that fits in that scene.

The player who is holding the bomb when it explodes picks up the card in the middle and the game starts again with a new card.

The player with the least number of cards at the end of the game wins.

There are additional instructions in with the game if you wish to make the game harder.

PC, iPad or Android Tablet games

It is recommended that for the first week, you child only picks four of the PC, iPad or Android tablet games below to play. Each week, you can introduce at least one new game for your child to play. This will help to keep your child more motivated and prevent them from getting bored with the games.

Subway surfer and Talking Tom gold run are very similar games, and your child can chose which of these two games they would prefer to play.

Piano Tiles 2

It is best to play this game with the sound on. Press start.

The aim of the game is to only touch the black tiles on the screen to make the sound of the tune.

The tiles will move quicker as the game goes on.

If you click on a blue tile, the game will be over.

Subway surfer

In this game, the runner is trying to get away from the subway policeman. If you bump into anything the policeman will catch you.

1. To jump, swipe up
2. To roll, swipe down
3. To change lanes, wipe left or right
4. Double tap to use a hover board.

Try to collect as many coins as possible. Jump over or roll under any obstacles.

Move left or right to avoid bumping into the trains. Some trains are standing still whilst others are moving.

Collect glowing power-ups by running into them:

1. Jetpack: This helps you to fly above the trains
2. Super sneakers: Helps you to jump higher
3. Coin Magnet: Helps you to attract coins close by
4. 2x multiplier: Doubles your score

Try to beat your own score each time.

Talking Tom Gold Run

In this game, the Tom is trying to get catch the robber. If you bump into anything, Tom gets dizzy and you have to start again.

1. To jump, swipe up
2. To roll, swipe down
3. To change lanes, wipe left or right

Try to collect as many gold bars as you can. Jump over or roll under any obstacles.

Move left or right to avoid bumping into the cars and buses. Some buses are standing still whilst others are moving.

Fruit Ninja

Choose a mode to play in (Classic, Arcade, or Zen) by swiping across the name with your finger. You can play in any mode you like, the rules are the same.

Swipe ‘play game’.

The aim is to try to swipe as many fruits as you can. If you hit more than one fruit with a swipe, you get extra points.

Try not to swipe the bombs, as these take points away from you or it ends the game.

If you can, try to beat your score.

Feeding Frenzy- Eat Fish

Move your fish around the screen with your finger. Try to eat as many smaller fish as you can. You can do this by swimming into them. The more fish you eat the bigger you get and the higher your score.

As you start to get bigger, you can eat any fish that is smaller than you.

Try to avoid swimming into the bigger fish or the jelly fish or you will lose a life.

Rush

Press the play button.

Put your finger on the ball. Move you finger left to move the ball to the left, and move your finger right to move the ball to the right.

Move the ball from left to right to avoid the numbered triangles. If you hit a numbered triangle you have to start the game again.

Try to collect the gems if you can.

MouseBot

Press play and click on level one. As you go on through the game you will go up levels.

Click on the right and left arrows on the screen to move the mousebot.

If you want to jump over an object, press the up arrow.

Try to collect as much cheese as you can. Different levels will ask for a different number of cheeses.

Try to avoid the mouse traps and the roller grater or you will have to start again.

Jungle Monkey Run 1

Press play.

Run to collect as many bananas as you can. Coloured bananas give you extra protection.

To jump, swipe up. To jump higher, double tap the screen.

Try not to run into any obstacles as the game will end. Sometimes you need to jump across to a bridge.

Try to beat you score each time you play.

Snake vs Block

Tap the screen to start.

Swipe your finger across the screen to move the snake.

Move your snake into as many yellow circles as you can to collect them. This will make your snake bigger.

Each yellow circle has a number. The higher the number the bigger the snake gets. For example, if you collect a circle with the number 4, you snake gets 4 extra yellow circles to make it bigger.

The will be a number at the top of your snake. This tells you how many yellow circles make up your snake.

As your snake moves up the screen, you will see coloured blocks with numbers on them. When you go through a block, your snake will lose yellow circles.

The number on the block tells you how many circles your snake will lose. For example, if the block says 2, your snake will lose 2 circles.

Try to go through the block with the smallest number. If your snake is not big enough (does not have enough yellow circles) to go through a block with a big number, the game will be over.

NinJump Rooftops

Press Play then press Go.

Your ninja will run along the rooftops. The aim is to collect as many coins as you can and to avoid the other animals.

Tap the screen once to jump across the rooftops.

Double tap the screen if you want you ninja to jump higher.

Stack Jump

Press the start button.

Every time a block comes in from the side, tap the screen to jump on top of the block.

The block will start to move quicker. If you tap too slowly, you will be knocked of the stack of blocks and will start the game again.

Cooking Fever

Before you start each level you will be told how much money you need to earn.

You are working in a burger restaurant and need to give each customer their order.

Tap on the bun that you need. Then tap on either the burger or sausage that you need to cook.

To put your burger or hot dog together, slide the burger over to the bun using your finger. To give the customer their order, slide the order over to customer. The customer will then leave you money; you have to tap on the money to collect it.

You must make your order as quickly as you can before your time runs out.

You can buy upgrades for your restaurant with the money that you make. This will make it easier as your restaurant gets busier.

Restaurant Dash: Gordon Ramsay

Tap on the level and tap on play.

A customer will appear with an order. You must make the order. Before you start each level you will be told how much money you need to make.

There is a timer on each level, you need to make the money before the timer runs out.

To make the food, tap on the food item that you need. The waitress will collect the food. To cook the food, tap on the stove. Once the food is cooked, tap on the burger to pick it up and the tap on the next food item that you need (e.g. burger bun).

Tap on the customer’s order and the waitress will serve the food. Once they have eaten, the customer will leave their money. To collect the money, tap on the money.

Burger

Press the play button.

You can play in either career or time attack mode.

Click on the burger to start the game. An order will show up on the right hand side of the page. You must make the food in the order that is shown.

Tap on the ingredients that you need to make the order. Make sure that you put the ingredients together in the right order.

Try to make as many order as you can in the time shown.

Temple Run

Press start to play,

You need to run away from the monsters. If you are too slow, the monsters will catch up with you.

To jump, swipe up. To run around corners, swipe to the right or the left. To slide under objects, swipe down.

Try to collect as much gold as you can.

Color Road

Tap to start.

You will have either a red, yellow or green ball. Your ball will roll down the track. Try to run into the balls that are the same colour as your ball. If you hit a different colour ball, you will need to start again.

You will go over coloured fences. Each time you go over a fence, the colour of your ball will change to the colour of the fence. You will then need to run into balls that are the same colour as your new ball.

Move your finger from left to right to change the direction of your ball.

Banana Kong

Tap start.

The aim of the game it to collect as many banana's as you can whilst you are running.

Tap the screen to jump. If you need to glide in the air, double tap the screen. This will give you a leaf that will help you to glide.

Jump over any obstacles and collect as many banana's as you can.

Minion Rush

You need to collect as much fruit as you can. You will be told the total amount of fruit that you need to collect at the start of the level.

To move your minion, swipe to the left or the right. You will need to avoid the missiles.

To jump, swipe up with your finger. To slide under an object, swipe down with your finger.

Appendix G: Games Checklist

Games Checklist

Study title: Processing speed training in children and adolescents

Researcher: Lee Gamman

Participant Study ID: Date:

We would like to monitor how often your child plays each game. Please complete this form on the days that your child plays the computerised or non-computerised games. Please write down roughly how long your child played each game.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Time Shock							
Bop it							
Spoons							
Snap							
Racing Demons							
Speed							
Crazy Eights							
Dobble							
Pass the bomb							
Snake vs block							
Stack Jump							

Piano tiles 2							
Cooking Fever							
Feeding frenzy							
Restaurant Dash							
Jungle run							
Burger							
Temple Run							
Color Road							
Banana Kong							
Fruit Ninja							
Minion Rush							
Subway surf							
Talking Tom Gold Rush							
Rush							
MouseBot							
NinJump Rooftops							

Appendix H: Consent Form

Consent Form
Parent/Carer

Study title: Processing speed training in children and adolescents

Researcher: Lee Gamman

Participant ID number:

Please **initial** each box:

1. I confirm that I have read the information sheet dated 16 April 2018 (version 1.0) for the above study and
   I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my child's participation is voluntary and that I am free to withdraw at any time without giving any reason, without any medical care or legal rights being affected. ☐

3. I understand that data collected during the study, may be looked at by individuals from the University of Exeter, from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my data. ☐

4. I understand that all information provided by me or my child will remain confidential, unless significant or urgent risk issues are identified, then I understand that the research team will contact the necessary agencies as appropriate. ☐

5. If the assessment shows that my child has some difficulties with their thinking abilities, I give permission
   to the research team to send a letter to my child's paediatrician and/or GP ☐

6. I am fully aware that the data collected about my child will be stored securely, safely and will not be ☐

recognised in any publications.

7. I agree to complete the questionnaires for the above study ☐

8. I agree for my child to take part in the above study. ☐

Name of parent: Signature:

Researcher: Signature:

Date:

One copy for the participant and one for the researcher

Appendix I: Assent Forms

UNIVERSITY OF EXETER

Assent Form
(Children under 10 years old)

***Study title:* Processing speed training in children and adolescents**

Researcher: Lee Gamman

Participant ID number:

1. I have been told what the study is about and I have asked any questions and had them answered. ☐
2. I can say no if I don't want to do it ☐
3. I know my answers will be kept safe ☐
4. I know that Lee might have to tell someone if I tell her something that is worrying me. ☐
5. I know that Lee will tell my GP if I find the tasks hard to do. ☐
6. I would like to do the study ☐

Name: Date:

Name of parent/carer: Signature:
Date:

Name of researcher: Signature:

Date:

When completed: One copy for the participant and one for the researcher

Assent Form

(Children 10+ years old and adolescents)

Study title: Processing speed training in children and adolescents

Researcher: Lee Gamman

Participant ID number:

1. I understand what the study is about and I have been able to ask any questions and have had them answered. ☐
2. I understand that I can take part in the study if I want to, and that I can stop taking part at any time without giving a reason ☐
3. I understand that only the research team will know the answers I give in the study. ☐
4. I understand that Lee will tell my GP if I have some difficulties on the tasks that look at how I think. If this happens, Lee will talk to me about it first. ☐
5. I understand that Lee might have to tell someone if I tell her something that is worrying me. This is to keep me safe. If this happens, then the research team will try to talk to me about it first. ☐
6. I understand that the research team will keep my information safe and that I will not be able to be identified in any of the reports or papers. ☐
7. I would like to take part in this study. ☐

Name of participant: Signature:

Date:

Name of parent/carer: Signature:

Date:

Name of researcher: Signature
Date:
When completed: One copy for the participant and one for the researcher

Appendix J: GP Letter

RESEARCH REPORT

<Date>

Dear <*NHS Clinician and/or GP*>,

Re. <insert child's name and address>

We are writing to inform you that <insert child's name> has agreed to take part in our research study: ***Processing speed training in children and adolescents.*** We are writing to summarise the results of the assessment completed by <child's name> and <parents name>, with Lee Gamman (Trainee Clinical Psychologist) on <date>, at the University of Exeter.

The enclosed report details assessments which were conducted for research purposes. The report does not provide a full clinical interpretation of the results of these assessments. The report describes <child's name>'s behaviour during the assessments, a brief history, the results of the assessments and an interpretation of the results.

<The results of the study suggest that it may helpful for <child's name> have further clinical assessment>.

Yours sincerely,

Lee Gamman
Principal Investigator
Trainee Clinical Psychologist

Dr Jenny Limond
Research supervisor
Consultant Clinical
Neuropsychologist

Dr Jenny Limond is a Senior Lecturer at the University of Exeter, and a Consultant Clinical Neuropsychologist registered with the Health and Care Professionals Council (PYL23823)

Lee Gamman is a Trainee Clinical Psychologist at the University of Exeter. This research is being undertaken as part of a doctorate in Clinical Psychology.

Cc <child's parents>

Processing speed training in children and adolescents: RESEARCH REPORT

<child's name> <child's surname> <age>

Date of Assessment: xxx

Date of Report: xxx

Purpose of the report

This report has been prepared and written by Lee Gamman, Trainee Clinical Psychologist, and Dr Jenny Limond, Research Supervisor, for the purpose of the research study: Is speed training an effective way to improve brain processing speed in children and adolescents? (<AND ETHICS DETAILS>). Dr Jenny Limond is a Senior Lecturer at the University of Exeter and a Consultant Clinical Neuropsychologist registered with the Health and Care Professions Council. The assessments summarised in this report were conducted for research purposes and, therefore, a full clinical interpretation is beyond the remit of this report. Any concerns about <child's name>'s performance on the measures should be discussed with his GP, school, and/or other health professionals working with <child's name>.

Behaviour during the assessments

<child's name> <engaged well/struggled to engage> with the assessments and <gave his best effort throughout/found it difficult to concentrate>. It is likely that <child's name>'s performance on these measures is an accurate reflection of his ability when tasks are completed in a calm, quiet, one-to-one setting.

Brief history

<child's name> was born at <x> weeks gestation. He weighed <x>. He has been diagnosed with….<has hearing aids/glasses> (<state any other difficulties that may have impacted on the assessment>.

Results

<child's name> was <age> at the time of the assessment. The Tables below summarise <child's name>'s performance on the measures administered as part of the research assessment. A brief description of the measures can be found in the Appendix. The Tables include: T Scores (mean of 50, standard deviation of 10), standard scores (mean of 100, standard deviation of 15), percentiles (indicating the percentage of children in a typically developing population, of the same age, who perform at or below that score), and age equivalents (indicating the age at which children in a typically developing population achieve the same score). When raw scores are presented, these are interpreted in the text.

Table 1: Results for Standardised Measures

	T score	Standard Score	%ile
Wechsler Abbreviated Scale of Intelligence Second Edition (WASI-II)			
Block Design			
Vocabulary			
Matrix Reasoning			
Similarities			
Estimated Full-Scale IQ			
Wechsler Intelligence Scale for Children- Fifth Edition (WISC-IV)			
Coding subtest			
Symbol Search Subtest			

Table 2: Results for Questionnaires

	Raw Scores	Descriptor
The PedsQL		
Generic Scale		
Physical Health		
Psychosocial Health		
Total Score		
Multidimensional Fatigue Scale		
General Fatigue		
Sleep/Rest Fatigue		
Cognitive Fatigue		

Interpretation of the results

On a measure which estimates intellectual ability (WASI-II, Table 1), <child’s name> performed in the <x range>. Based on these scores, in a typically developing population, approximately <x%> of children would perform the same or below <child’s name> on this measure.

Two subtests of the WISC-IV, Coding and Symbol Search, were administered to assess <child’s name>’s non-verbal processing speed performance. His performance on these tasks indicated that <child’s name>’s non-verbal processing speed ability falls in the <x range>.

In addition to the standardised assessments, the PedsQL was completed (Table 2). <child’s name>’s mother, Mrs <surname>, completed the PedsQL which measures <child’s name>’s health-related quality of life. Mrs <surname> reported that <child’s name> has no difficulties with <state domains>. Mrs <surname>’ ratings were high for difficulties with <state domains>.

Summary and recommendations

The measures reported here were conducted as part of a research assessment, and therefore, a full clinical interpretation is beyond the remit of this report. Any recommendations presented here are made in the context of the available research assessment information and are not intended to replace clinical or educational recommendations resulting from a full clinical assessment.

Overall, <child's name> performed in the <x ranges> in <state domains> with <x domains> being in the . <Summary of child's strengths and weaknesses>

It should be noted that this assessment took place in a quiet, structured setting. In situations where there is more noise and distractions <child's name> may find it difficult to perform at the levels demonstrated in this assessment.

APPENDIX: DESCRIPTION OF MEASURES

Standardised measures

Wechsler Abbreviated Intelligence Scale Second Edition (WASI-II)

The WASI-II is a test of intelligence with four subtests: Vocabulary, Block Design, Matrix Reasoning and Similarities. The Vocabulary subtest measures a person's ability to express themselves using words and their ability to reason verbally in order to solve problems. The Block Design and Matrix Reasoning subtests measure a person's ability to reason non-verbally in order to solve problems. The Similarities subtest measures a person's ability to reason verbal information. Combining the scores from these four subtests provides a measure of general IQ.

Wechsler Intelligence Scale for Children Fifth Edition (WISC-IV)

The WISC-IV is a test of intelligence using a series of subtests. Two subtests were used: the coding test and the symbol search test. These subtests assess children's ability to focus attention and quickly scan, discriminate between and order information in a sequence. These subtests produce a processing speed index and have been used for this study as measure of non-verbal processing speed.

Parent rated questionnaires

The PedsQL

The PedsQL is a short screening questionnaire for children that gives reliable information of health-related quality of life. The generic form provides information on psychosocial health, including emotional, social and school functioning, and physical health functioning. The multidimensional fatigue scale provides information on general fatigue, sleep/rest fatigue and cognitive fatigue.

Appendix K: Ethical Approval

UNIVERSITY OF EXETER

CLES – Psychology

Psychology

College of Life and Environmental Sciences University of Exeter

Washington Singer Building Perry Road

Exeter EX4 4QG

Web: www.exeter.ac.uk

CLES – Psychology Ethics Committee

Dear

Ethics application - eCLESPsy000102

A brief intervention aimed at improving processing speed abilities in children and adolescents who have conditions associated with white matter. Your project has been reviewed by the CLES – Psychology Ethics Committee and has received a Favourable opinion.

The Committee has made the following comments about your application:

- Please view your application at https://eethics.exeter.ac.uk/CLESPsy/ to see comments in full.

If you have received a Favourable with conditions, Provisional or unfavourable outcome you are required to re-submit for full review and/or confirm that committee comments have been addressed before you begin your research.

If you have any further queries please contact your Ethics Officer.

Yours sincerely

Date: 18/09/2018

CLES – Psychology Ethics Committee

Washington Singer Building
University of Exeter
Perry Road
Exeter
Devon
EX4 4QG

26 June 2018

Dear

HRA and Health and Care Research Wales (HCRW) Approval Letter

Study title:	**A brief intervention aimed at improving processing speed abilities in children and adolescents who have conditions associated with white matter integrity.**
IRAS project ID:	**240283**
Protocol number:	**1718/21**
REC reference:	**18/LO/1045**
Sponsor	**University of Exeter**

I am pleased to confirm that HRA and Health and Care Research Wales (HCRW) Approval has been given for the above referenced study, on the basis described in the application form, protocol, supporting documentation and any clarifications received. You should not expect to receive anything further relating to this application.

How should I continue to work with participating NHS organisations in England and Wales? You should now provide a copy of this letter to all participating NHS organisations in England and Wales, as well as any documentation that has been updated as a result of the assessment.

Participating NHS organisations in England and Wales **will not** be required to formally confirm capacity and capability before you may commence research activity at site. As such, you may commence the research at each organisation 35 days following sponsor provision to the site of the local information pack, so long as:

- You have contacted participating NHS organisations (see below for details)
- The NHS organisation has not provided a reason as to why they cannot participate

- The NHS organisation has not requested additional time to confirm.

You may start the research prior to the above deadline if the site positively confirms that the research may proceed.If not already done so, you should now provide the local information pack for your study to your participating NHS organisations. A current list of R&D contacts is accessible at the NHS RD Forum website and these contacts MUST be used for this purpose. After entering your IRAS ID you will be able to access a password protected document (password: **Whale33**). The password is updated on a monthly basis so please obtain the relevant contact information as soon as possible; please do not hesitate to contact me should you encounter any issues.

Commencing research activities at any NHS organisation before providing them with the full local information pack and allowing them the agreed duration to opt-out, or to request additional time (unless you have received from their R&D department notification that you may commence), is a breach of the terms of HRA and HCRW Approval. Further information is provided in the "*summary of assessment*" section towards the end of this document.

It is important that you involve both the research management function (e.g. R&D office) supporting each organisation and the local research team (where there is one) in setting up your study. Contact details of the research management function for each organisation can be accessed here.

How should I work with participating NHS/HSC organisations in Northern Ireland and Scotland?

HRA and HCRW Approval does not apply to NHS/HSC organisations within the devolved administrations of Northern Ireland and Scotland.

If you indicated in your IRAS form that you do have participating organisations in either of these devolved administrations, the final document set and the study wide governance report (including this letter) has been sent to the coordinating centre of each participating nation. You should work with the relevant national coordinating functions to ensure any nation specific checks are complete, and with each site so that they are able to give management permission for the study to begin.

Please see IRAS Help for information on working with NHS/HSC organisations in Northern Ireland and Scotland.

How should I work with participating non-NHS organisations?

HRA and HCRW Approval does not apply to non-NHS organisations. You should work with your non- NHS organisations to obtain local agreement in accordance with their procedures.

What are my notification responsibilities during the study?

The document "*After Ethical Review – guidance for sponsors and investigators*", issued with your REC favourable opinion, gives detailed guidance on reporting expectations for studies, including:

- Registration of research
- Notifying amendments
- Notifying the end of the study

The HRA website also provides guidance on these topics, and is updated in the light of changes in reporting expectations or procedures.

I am a participating NHS organisation in England or Wales. What should I do once I receive this letter?

You should work with the applicant and sponsor to complete any outstanding arrangements so you are able to confirm capacity and capability in line with the information provided in this letter.

The sponsor contact for this

application is as follows:

Name: Ms Pam Baxter

Email: p.r.baxter2@exeter.ac.uk

Who should I contact for further information?

Please do not hesitate to contact me for assistance with this application. My contact details are below. Your IRAS project ID is **240283**. Please quote this on all correspondence.

Yours sincerely

HRA Assessor

Email: hra.approval@nhs.net

Copy to: *(Sponsor Contact)*
(Lead NHS R&D Contact)

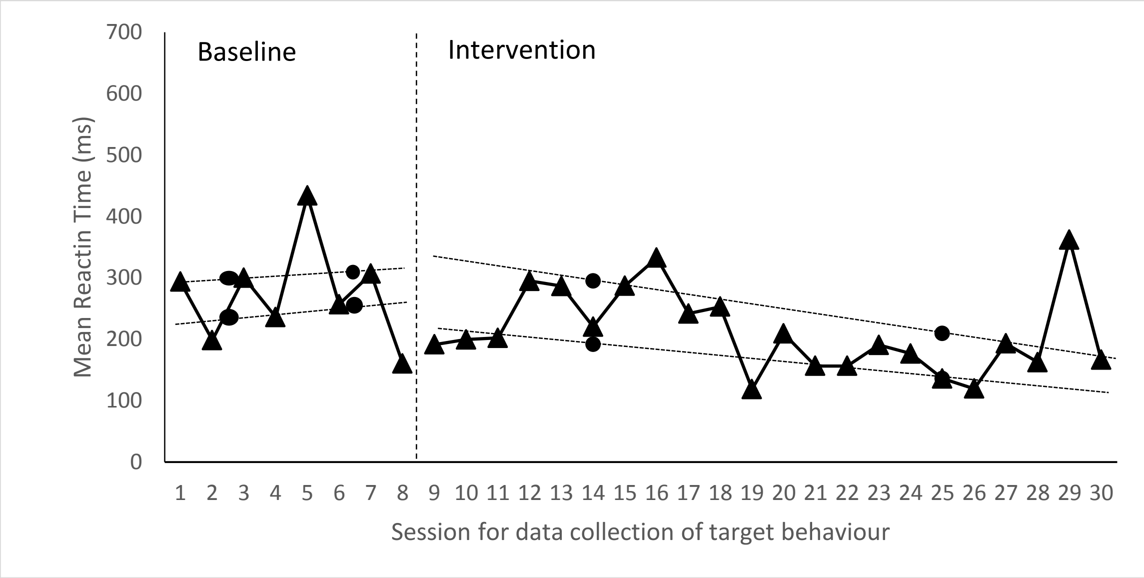
Appendix L: Visual analysis

Participant 1

Raw data- Reaction Time

Raw data- Number of errors on reaction time task

Variability- Trimmed Trended range

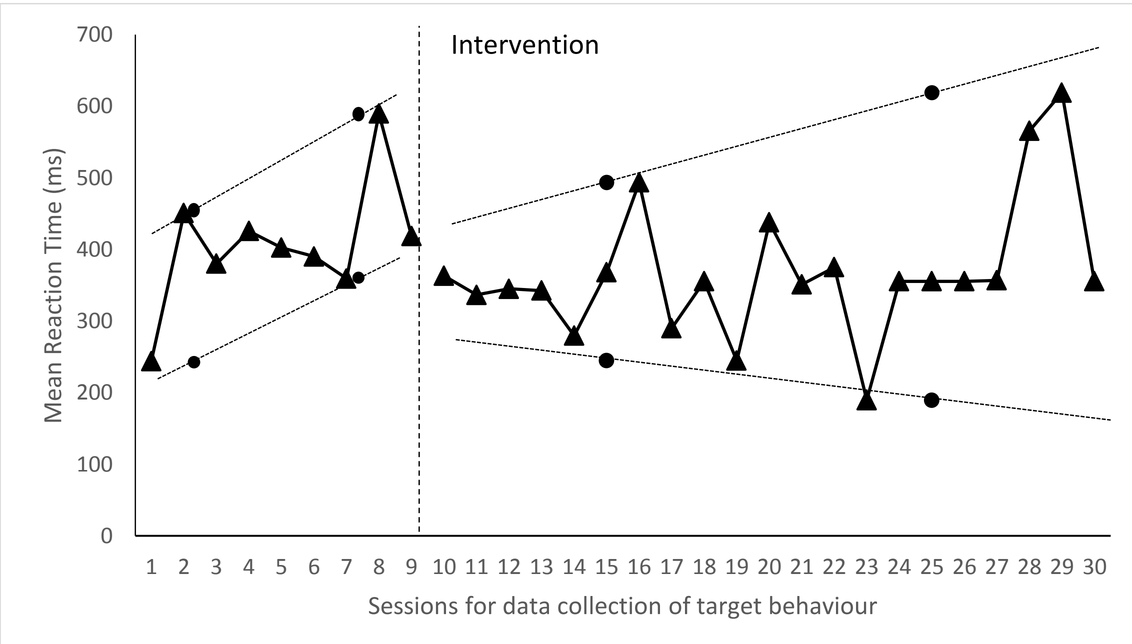


Overlap between phases- Reaction Time

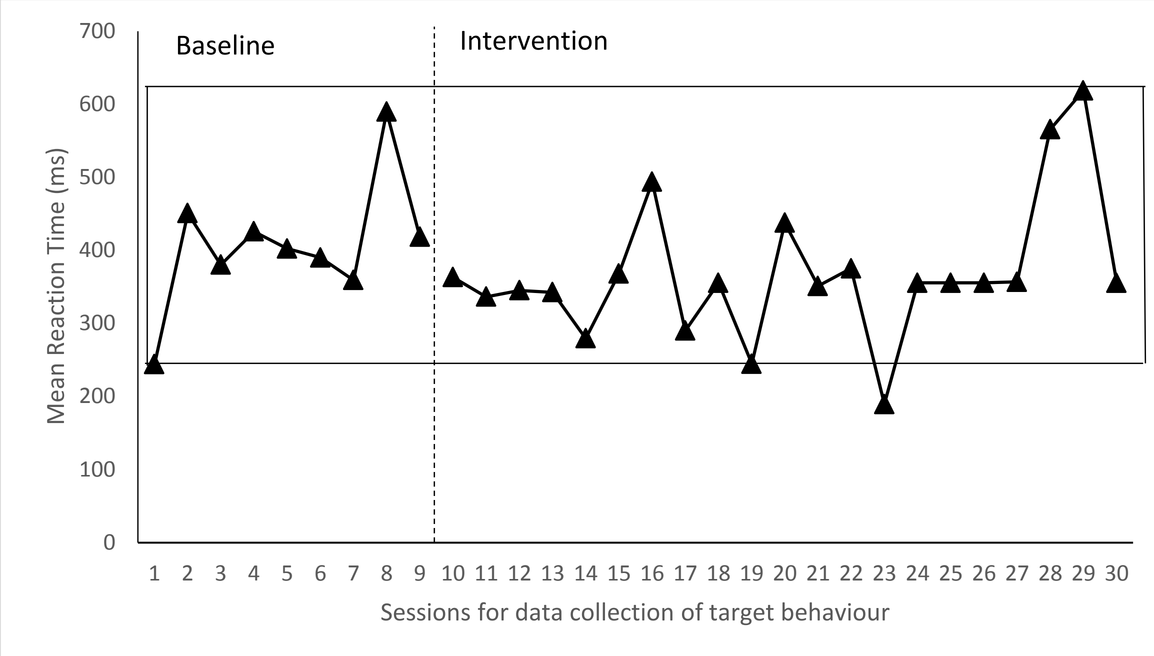
Participant 2

Raw data- Reaction Time

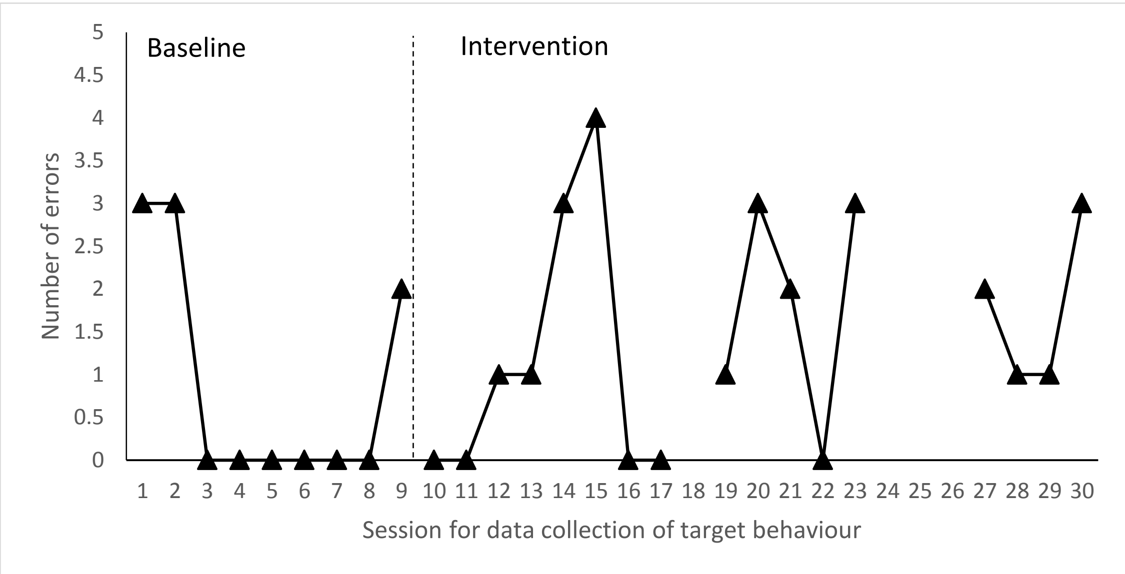
Variability- trimmed trended range: Reaction time



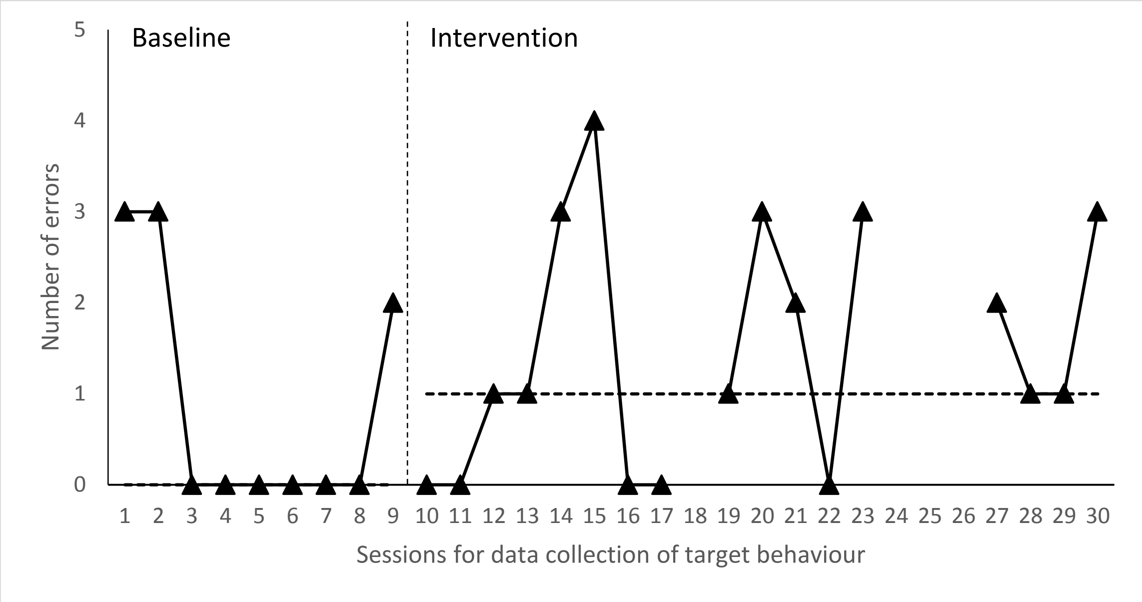
Overlap: Reaction Time



Raw data- number of errors on computer measure

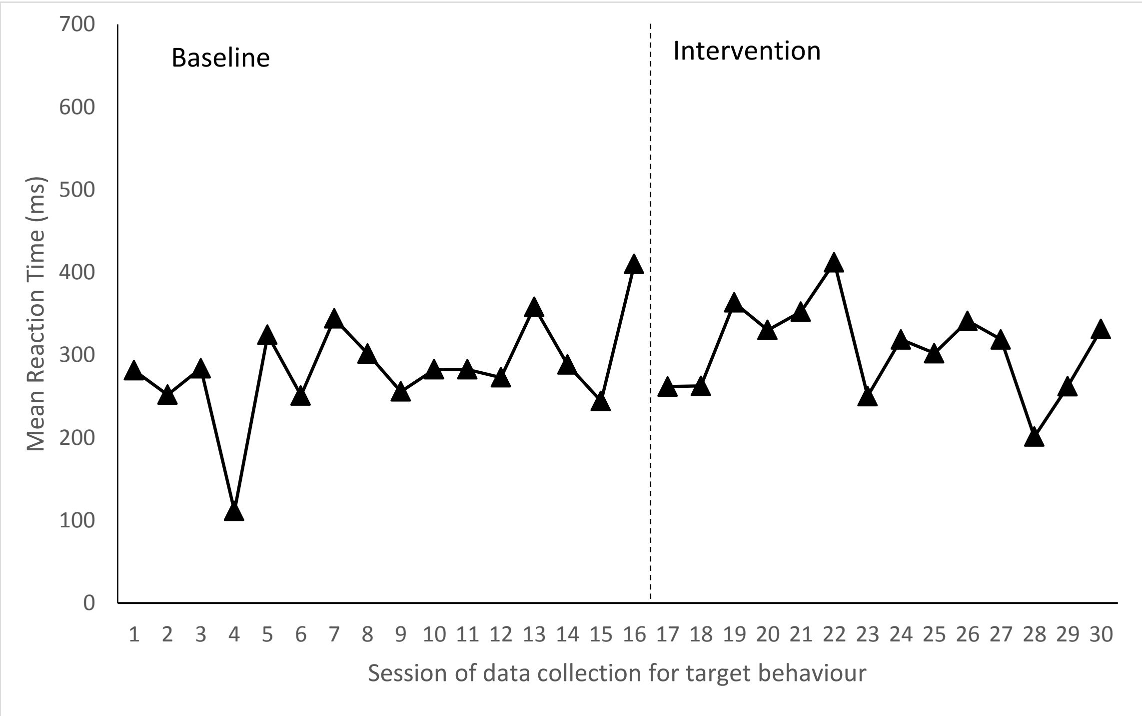


Central Tendency (Median): Number of errors

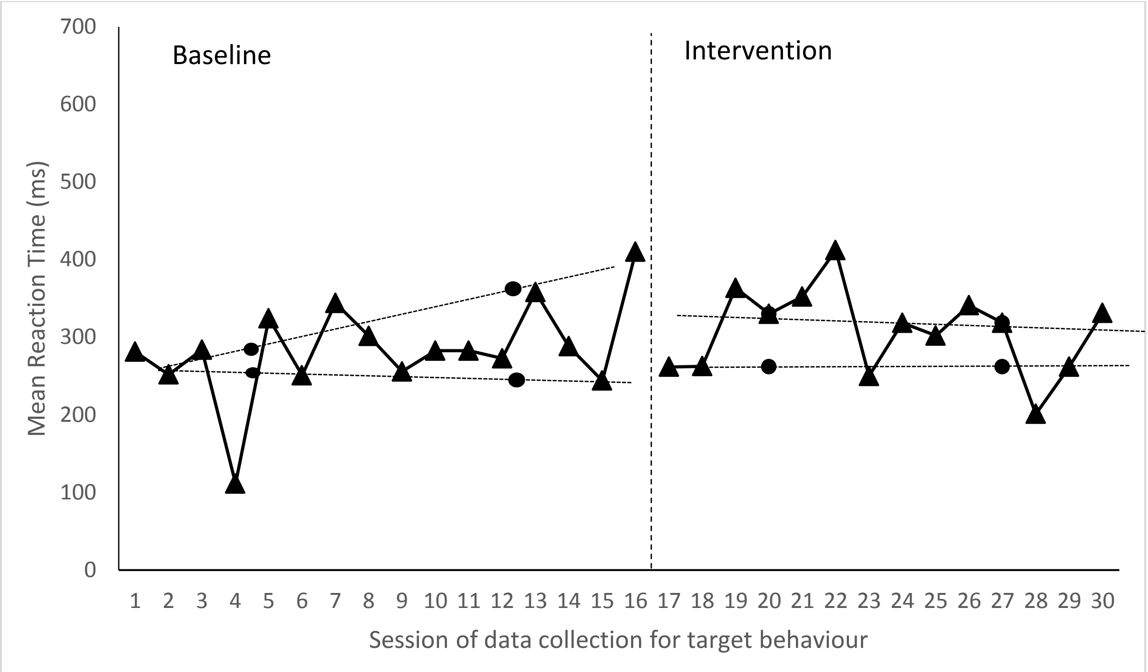


Participant 3

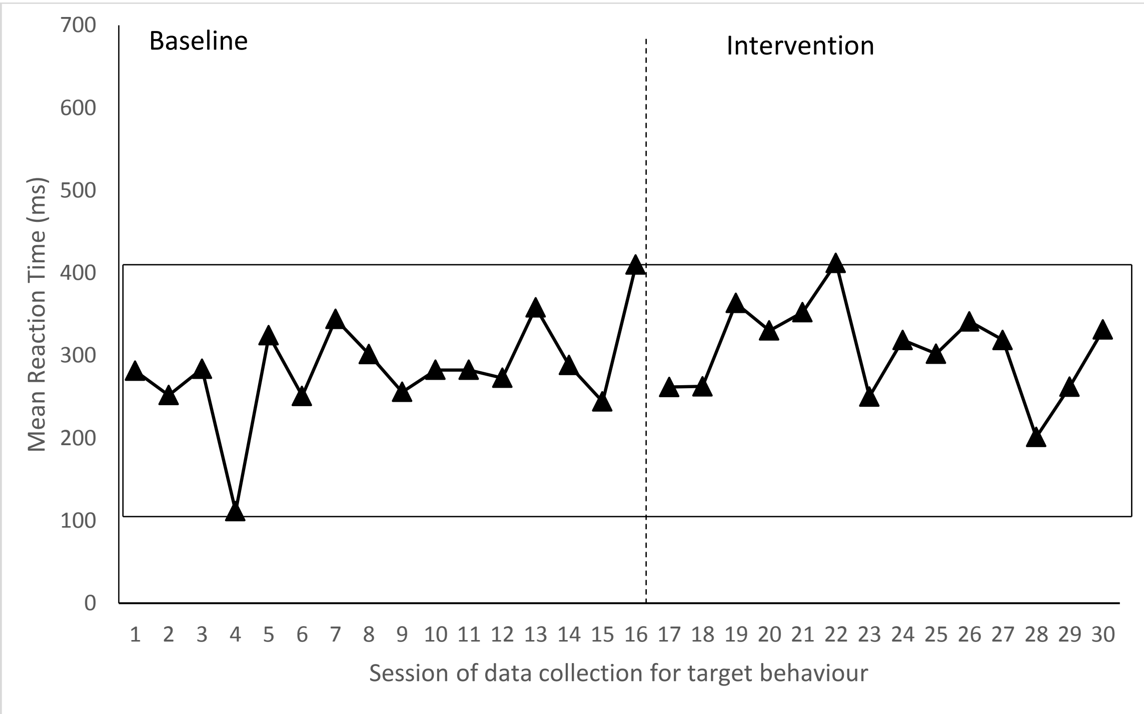
Raw data RT



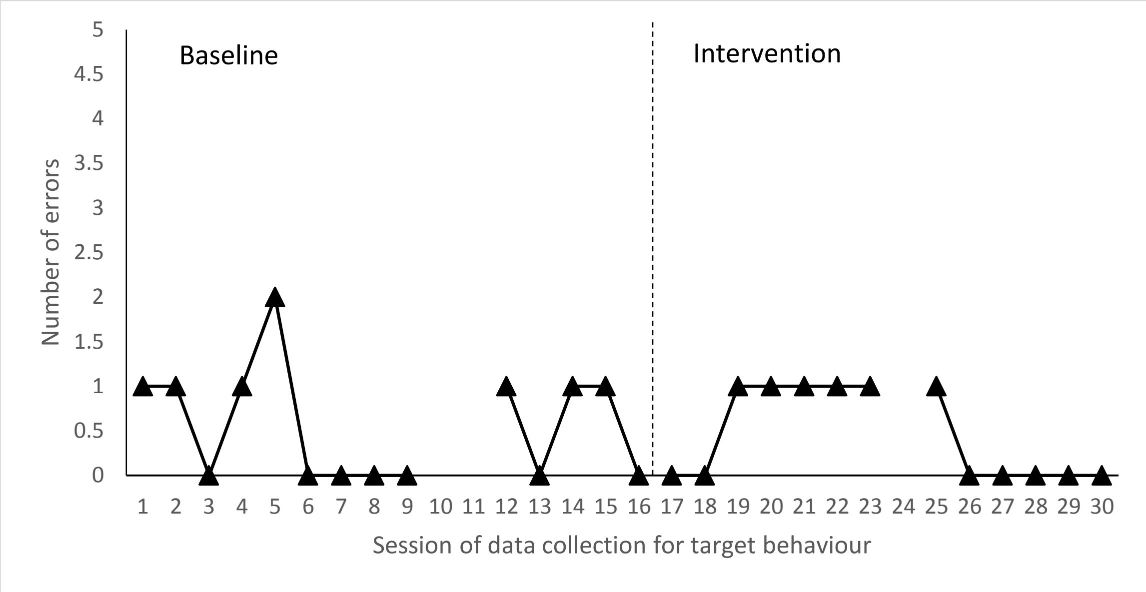
Variability- Trimmed trended range RT



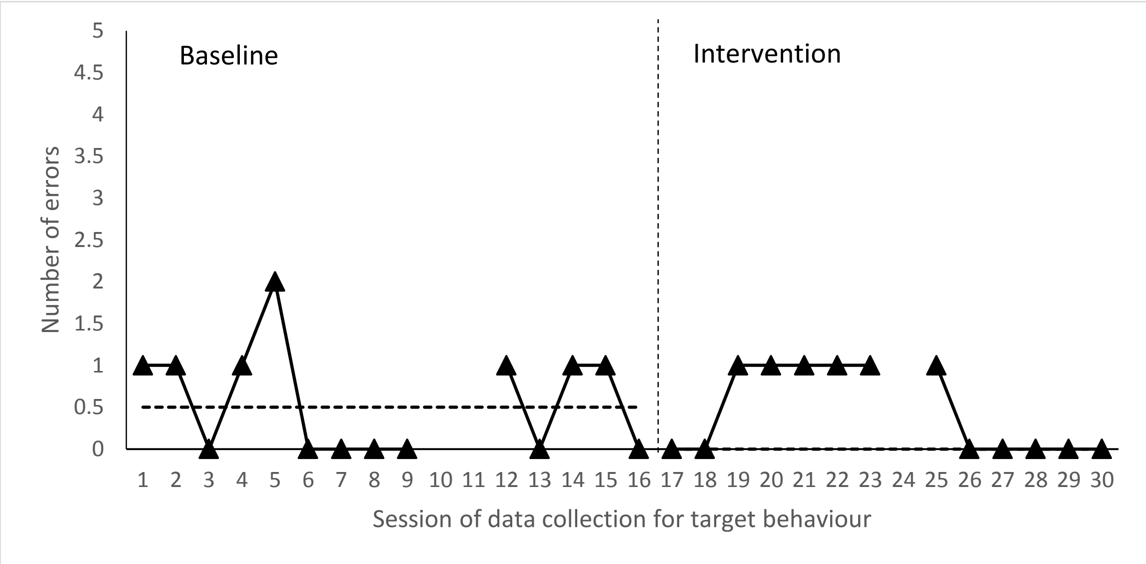
Overlap RT



Raw data- number of errors



Central Tendency (Median): Number of errors



Appendix M: Brain Injury- Statement of Dissemination and Instructions for Author

State of Dissemination

This empirical paper will be disseminated in the Brain Injury journal. Participants will also be offered the change to receive a summary of the results.

Instructions for Authors

Preparing Your Paper

All authors submitting to medicine, biomedicine, health sciences, and allied and public health journals should conform to the Uniform Requirements for Manuscripts Submitted to Biomedical Journals, prepared by the International Committee of Medical Journal Editors (ICMJE).

Structure

Your paper should be compiled in the following order: title page; abstract; keywords; main text introduction, materials and methods, results, discussion; acknowledgments; declaration of interest statement; references; appendices (as appropriate); table(s) with caption(s) (on individual pages); figures; figure captions (as a list).

Word Limits

Please include a word count for your paper.

A typical paper for this journal should be no more than 5000 words.

Style Guidelines

Please refer to these quick style guidelines when preparing your paper, rather than any published articles or a sample copy.

Please use American spelling style consistently throughout your manuscript.

Please use double quotation marks, except where “a quotation is ‘within’ a quotation”. Please note that long quotations should be indented without quotation marks.

Brain Injury accepts the following types of submissions: original research and Letters to the Editor. Letters to the Editor will be considered for publication subject to editor approval and provided that they either relate to content previously published in the Journal or address any item that is felt to be of interest to the readership. Letters relating to articles previously published in the Journal should be received no more than three months after publication of the original work. Pending editor approval, letters may be submitted to the author of the original paper in order that a reply be published simultaneously. Letters to the Editor can be signed by a maximum of three authors, should be between 750 and 1,250 words, may contain one table/figure and may cite a maximum of five references. All Letters should be submitted via ScholarOne Manuscripts and should contain a Declaration of Interest statement. Some journals set a maximum length for submissions. Though Brain Injury does not have a specific limit, we prefer that manuscripts not exceed 5,000 words excluding abstract, references, tables, and figure legends. If articles are greater than 5,000 words, authors may be asked to shorten their manuscript. Your paper should be compiled in the following order: title page; abstract; keywords; main text; acknowledgments; declaration of interest statement; references; appendices (as appropriate); table(s) with caption(s) (on individual pages); figures; figure captions (as a list).

Formatting and Templates

Papers may be submitted in Word or LaTeX formats. Figures should be saved separately from the text. To assist you in preparing your paper, we provide formatting template(s).

Word templates are available for this journal. Please save the template to your hard drive, ready for use.

If you are not able to use the template via the links (or if you have any other template queries) please contact us here.

References

Please use this reference guide when preparing your paper.

Taylor & Francis Editing Services

To help you improve your manuscript and prepare it for submission, Taylor & Francis provides a range of editing services. Choose from options such as English Language Editing, which will ensure that your article is free of spelling and grammar errors, Translation, and Artwork Preparation. For more information, including pricing, visit this website.

Checklist: What to Include

1. **Author details.** Please ensure everyone meeting the International Committee of Medical Journal Editors (ICMJE) requirements for authorship is included as an author of your paper. All authors of a manuscript should include their full name and affiliation on the cover page of the manuscript.

Where available, please also include ORCiDs and social media handles (Facebook, Twitter or LinkedIn). One author will need to be identified as the corresponding author, with their email address normally displayed in the article PDF (depending on the journal) and the online article. Authors' affiliations are the affiliations where the research was conducted. If any of the named co-authors moves affiliation during the peer-review process, the new affiliation can be given as a footnote. Please note that no changes to affiliation can be made after your paper is accepted. Read more on authorship.

2. Should contain a structured abstract of 200 words. For papers reporting original research, state the primary objective and any hypothesis tested; describe the research design and your reasons for adopting that methodology; state the methods and procedures employed, including where appropriate tools, hardware, software, the selection and number of study areas/subjects, and the central experimental interventions; state the main outcomes and results, including relevant data; and state the conclusions that might be drawn from these data and results, including their implications for further research or application/practice. For review essays, state the primary objective of the review; the reasoning behind your literature selection; and the way you critically analyse the literature; state the main outcomes and results of your review; and state the conclusions that might be drawn, including their implications for further research or application/practice.
3. You can opt to include a **video abstract** with your article. Find out how these can help your work reach a wider audience, and what to think about when filming.
4. Between 3 and 5 **keywords**. Read making your article more discoverable, including information on choosing a title and search engine optimization.
5. **Funding details.** Please supply all details required by your funding and grant-awarding bodies as follows:
   For single agency grants
   This work was supported by the [Funding Agency] under Grant [number xxxx].
   For multiple agency grants
   This work was supported by the [Funding Agency #1] under Grant [number xxxx]; [Funding Agency #2] under Grant [number xxxx]; and [Funding Agency #3] under Grant [number xxxx].
6. **Disclosure statement.** This is to acknowledge any financial interest or benefit that has arisen from the direct applications of your research. Further guidance on what is a conflict of interest and how to disclose it.
7. **Biographical note.** Please supply a short biographical note for each author. This could be adapted from your departmental website or academic networking profile and should be relatively brief (e.g., no more than 200 words).
8. **Data availability statement.** If there is a data set associated with the paper, please provide information about where the data supporting the results or analyses presented in the paper can be found. Where applicable, this should include the hyperlink, DOI or other persistent identifier associated with the data set(s). Templates are also available to support authors.
9. **Data deposition.** If you choose to share or make the data underlying the study open, please deposit your data in a recognized data repository prior to or at the time of submission. You will be asked to provide the DOI, pre-reserved DOI, or other persistent identifier for the data set.

10. **Supplemental online material.** Supplemental material can be a video, dataset, fileset, sound file or anything which supports (and is pertinent to) your paper. We publish supplemental material online via Figshare. Find out more about supplemental material and how to submit it with your article.
11. **Figures.** Figures should be high quality (1200 dpi for line art, 600 dpi for grayscale and 300 dpi for color, at the correct size). Figures should be supplied in one of our preferred file formats: EPS, PDF, PS, JPEG, TIFF, or Microsoft Word (DOC or DOCX) files are acceptable for figures that have been drawn in Word. For information relating to other file types, please consult our Submission of electronic artwork document.
12. **Tables.** Tables should present new information rather than duplicating what is in the text. Readers should be able to interpret the table without reference to the text. Please supply editable files.
13. **Equations.** If you are submitting your manuscript as a Word document, please ensure that equations are editable. More information about mathematical symbols and equations.
14. **Units.** Please use SI units (non-italicized).