Out of the lab and into the world of games: Portable dorsal stream tasks with game-like features can predict reading ability

Kayla Marie Tulloch
March 2015

A thesis submitted for the degree of Doctor of Philosophy (Clinical Psychology) of the Australian National University
Declaration

This thesis contains original research undertaken at the Research School of Psychology, Australian National University. The ideas, research and writing contained in these chapters and manuscripts are, to the best of my knowledge, entirely my own, except in instances where I have acknowledged the original source accordingly, and as below (page iv). I hereby declare that I have not submitted this material, either in full or in part for another degree at this or any other institution. This thesis contains two papers that are currently under review (see below). The ideas, development and writing of these papers and the thesis were the principal responsibility of myself, the candidate. The inclusion of a co-author reflects the input of my supervisor, Dr Kristen Pammer, who provided advice on the design, statistical analyses and assisted with proof reading. In the case of publishable papers, my contribution involved the following:

<table>
<thead>
<tr>
<th>Thesis Chapter</th>
<th>Publication Title</th>
<th>Publication Status</th>
<th>Nature and extent of the candidate’s contribution.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Tablet computer games to measure dorsal stream performance in good and poor readers</td>
<td>Under review with <em>Behavior Research Methods</em></td>
<td>Conceptual development, design, participant recruitment, administration, data analysis and principal author.</td>
</tr>
<tr>
<td>5</td>
<td>Spot the difference: Tablet game performance can predict single word reading ability</td>
<td>Under review with <em>PLOS ONE</em></td>
<td>Conceptual development, design, participant recruitment, administration, data analysis and principal author.</td>
</tr>
</tbody>
</table>
Mr Adam Ball and Mr Tony Oakden, of The Academy of Interactive Entertainment (AIE) Canberra, assisted in programming the games which were developed to test the functioning of the dorsal stream.

Ms Chia Pei Shi, Australian National University Psychology Honours Student, assisted in supervising students during game play, for the training component of experiment 4 (Chapter 6).

Ms Kayla Tulloch  
13 March 2015
Acknowledgements

This completed thesis would not have been possible without the guidance and support of my primary supervisor, Associate Professor Kristen Pammer. Whilst there were times that I doubted my own abilities, Kristen believed in me and provided encouragement every step of the way. She generously provided comments on my chapters, often out of hours when needed, and always made time for our discussions. Kristen challenged and inspired me to be the best I could be, and I feel privileged and grateful to have worked under the guidance of such an exceptional supervisor.

A huge thank you to Mrs Iris Carter, a true friend who was always there with words of wisdom and support. From 3am honours statistics, to long talks over coffee that saved my sanity in the final weeks of PhD write up, I will always count Iris as one of my dearest friends.

To Mr Adam Ball and Mr Tony Oakden of the Academy of Interactive Entertainment, I give my deepest gratitude, for seeing my vision and helping with the computer programming needed to see these studies realised.

Thank you to the students who participated in these experiments, their parents who provided permission, and to the teachers for their support. For your time, enthusiasm and willingness to contribute I am deeply grateful.

Thank you to Dr Matthew Knowles, for all the small acts of kindness that made my life easier, and for referring me to ‘Smith and Jones’, which always made me smile.

I would also like to thank Mr Terry Brady for providing feedback on Chapters 1 & 2, and to Mrs Jo Lane for her comments on Chapter 8.

Last but not least, I would like to thank all my wonderful friends, family, and my karate dojo for their understanding, encouragement and support throughout the years as I completed this research.
Abstract

There is now a substantial body of evidence to suggest that visuo–spatial attention, mediated by the dorsal stream, is implicated in reading performance. A deficit in the dorsal stream has been linked with difficulty in reading accuracy, fluency or both types of reading skill. However, research in this area has thus far been undertaken in traditional, tightly controlled lab based settings. The aim of the studies in this thesis was to take the next step, and ascertain whether visual testing can occur in practical school based settings, using portable gamified tasks, and still differentiate between good and poor readers. Specially designed visual search, change detection and tracking games were developed to test unselected samples of primary school children. Children were administered a series of reading and intelligence measures, and provided with the tablet games, with game accuracy and speed performance recorded. As expected, IQ was a strong predictor of reading performance. However, performance on the visual search and change detection games explained additional unique variance in reading rate and single word reading abilities of the students tested. Poor readers were slower in their visual search speed and change detection accuracy compared to good readers. Performance on the tracking program, a new concept to the reading research field, was not correlated with reading ability. Finally, a clinical aim of this experiment was to pilot a visual training program using portable, visual search and change detection games, to determine if training could improve the performance of poor readers who demonstrated these identified visual search and change detection deficits. Utilising participants from the first round of studies, the training group was administered commercially available visual search and change detection games, and the control group played a series of puzzle type games thought to rely less on the visuo–attentional system. Both groups played these games for at least five hours over seven weeks, in blocks of 10-70 minute intervals, within the school setting, using portable computer tablets. Results revealed that the experimental group did not benefit from improved reading accuracy or rate as a result of the training provided. It is suggested that whilst visual search and change detection games can detect visuo–attentional differences, the games administered to the students (and amount of game play) did not provide the necessary challenge to the dorsal stream to elicit significant changes in reading ability. Given that portable, game-like tasks can differentiate good and poor readers in school based settings, it would be worthwhile to determine the potential to utilise these games as part of a
comprehensive reading assessment. This type of non-word testing would be particularly valuable in early intervention, for its potential to identify poor readers before they learn to read. Future directions should also explore the type of games which are best suited to challenging and strengthening the visuo-attentional system, and the frequency and intensity required to encourage stable long lasting changes in reading ability.
# Table of Contents

## Chapter 1

A Clinical Examination of Developmental Dyslexia

- 1.1. The standard reading process .......................................................... 1
- 1.2. A clinical approach to defining dyslexia ........................................... 2
- 1.3. Prevalence ......................................................................................... 3
- 1.5. Comorbidity ...................................................................................... 5
- 1.6. Psychosocial and academic impacts and outcomes .......................... 5
  - 1.6.1. Psychological impacts ............................................................... 6
  - 1.6.2. Social impacts .......................................................................... 7
  - 1.6.3. Educational challenges ............................................................ 8
  - 1.6.4. Occupational impacts ............................................................... 9
- 1.7. Personal strengths ............................................................................ 11
- 1.8. Etiology .......................................................................................... 12
- 1.9 Conclusion ......................................................................................... 12
- 1.10. References .................................................................................... 14

## Chapter 2

The Science of Dyslexia

- 2.1. A scientific approach to defining dyslexia ....................................... 22
- 2.2. Theoretical conceptualizations of dyslexia ....................................... 23
  - 2.2.1. Phonological Theory ................................................................. 24
  - 2.2.2 Auditory Deficit Theory ............................................................ 25
  - 2.2.3. Cerebellar Theory .................................................................... 26
- 2.3. The Magnocellular Theory ............................................................... 27
  - 2.3.1. The neurobiology of the dorsal and ventral stream ................. 27
- 2.4. Biological evidence for a magnocellular/ dorsal stream deficit ........ 29
- 2.5. Behavioural evidence for a magnocellular/dorsal stream deficit ....... 30
  - 2.5.1. Visual search ........................................................................... 31
  - 2.5.2. Coherent motion detection ....................................................... 32
  - 2.5.3. Frequency doubling ................................................................. 33
  - 2.5.4. Spatial cueing ......................................................................... 34
  - 2.5.5. Change detection ..................................................................... 35
- 2.6. How the magnocellular/dorsal stream is implicated in reading ability 36
- 2.7. The Visuo – Spatial Attention Deficit Theory .................................. 37
6.3.1. NARA accuracy and rate results .......................................................... 128
6.3.2. Single word reading results ............................................................... 132
6.4. Discussion .............................................................................................. 134
6.5. References .............................................................................................. 140

Chapter 7 ........................................................................................................ 146
Game Based Training to Improve Visual Attention and Reading: A Clinical Pilot Study .......................................................... 146

7.1. Introduction .............................................................................................. 146
7.2 Method ...................................................................................................... 153
  7.2.1. Participants ....................................................................................... 153
  7.2.2. Stimuli .............................................................................................. 154
  7.2.3. Procedure ......................................................................................... 155
7.3. Results .................................................................................................... 157
  7.3.1 NARA scores .................................................................................... 158
  7.3.2. Single word scores .......................................................................... 160
  7.3.3. Initial reading level and subsequent improvement ......................... 161
  7.3.4. Impact of age on level of reading improvement ............................. 162
7.4. Discussion ............................................................................................... 164
7.5. References .............................................................................................. 171

Chapter 8 ........................................................................................................ 178
Discussion and Conclusions ......................................................................... 178

  8.1. Clinical implications for the future assessment of dyslexia................. 178
  8.2. Clinical implications for future dyslexia intervention programs .......... 180
  8.3. Theoretical implications of the present studies .................................. 183
  8.4. Conclusion ........................................................................................... 185
  8.5. References ........................................................................................... 186

Appendix 1. Consent form for assessment study ...................................... 191
Appendix 2. Consent form for training study ............................................. 193
Appendix 3. Visual Search Computer Programming and Design .............. 195
Appendix 4. Change Detection Computer Programming and Design ...... 196
Appendix 5. Visual Tracking Computer Programming and Design ........... 197
Programming for the design of ‘Space Jump’ ........................................... 197
Table of Figures

Figure 1.2. Diagram of the Dorsal and Ventral Stream ........................................28

Figure 2.2. Spotlight of Attention..........................................................................38

Figure 3.4. An example of Bug City computer program with 12, 24, 36 & 73 items ....................................................................................................................................77

Figure 4.4. An example of Detective Quest easy (top) and hard (bottom) images 79

Figure 5.4. Mean NARA rate discrepancy in months, and visual search speed for the 12 item condition in seconds .........................................................................................................................82

Figure 6.4. Mean NARA discrepancy in months, and change detection speed for the easy item condition .........................................................................................................................85

Figure 7.5. Example of 'easy' image in Detective Quest computer program........105

Figure 8.5. Example of 'hard' image in Detective Quest computer program ......105

Figure 9.5. Regular word z - score discrepancy by number of errors in correctly identifying the difference .........................................................................................................................108

Figure 10.5. Irregular word z - score discrepancy by number of errors in correctly identifying the difference .........................................................................................................................109

Figure 11.5. Non - word z - score discrepancy by number of errors in correctly identifying the difference .........................................................................................................................109

Figure 12.6. An illustration of potential movements of the spotlight of attention for natural scenes (A) and reading (B) ...............................................................................................................121

Figure 13.6. Space Jump game. The spaceman (target) is located on the forth planet of the forth line ..........................................................................................................................127

Figure 14.6. Pearson correlations for tracking accuracy (mean) and NARA rate. 130

Figure 15.6. Pearson correlation for tracking reaction time for the 3 second condition and NARA accuracy. .........................................................................................................................131

Figure 16.6. Tracking accuracy average and irregular word z – scores. ..........133

Figure 17.7. Examples of visual search and change detection games used for the purpose of training ..........................................................................................................................156

Figure 18.7. Example of puzzle games administered to the control group ......157

Figure 19.7. Accuracy discrepancy between time 1 and time 2 by age for participants in the control group ..........................................................................................................................163

Figure 20.7. Rate discrepancy between time 1 and time 2 by age of participants in the control group ..........................................................................................................................164
Table of Tables

Table 1.4. Summary of overall reading performance for visual search ..........81

Table 2.4. Summary of standard multiple regression for variables predicting reading rate in the 12 - item condition .................................................................83

Table 3.4. Summary of standard multiple regression analysis for variables predicting reading rate in the 24 - item condition .....................................................83

Table 4.4. Summary of overall reading performance for change detection participants ..................................................................................................................84

Table 5.4. Summary of standard multiple regression analysis for variables predicting reading rate ..................................................................................................86

Table 6.5. Summary of overall reading performance for change detection participants ................................................................................................................107

Table 7.5. Summary of Pearson Correlation Coefficients between change detection tasks and reading tasks ..............................................................................108

Table 8.5. Summary of standard multiple regression analysis for variables predicting single word reading .................................................................110

Table 9.6. Pearson correlations for NARA results and overall game performance .........................................................................................................................129

Table 10.6. Pearson correlations for different speeds of the target and relationships to NARA discrepancy (n = 68) ........................................................................130

Table 11.6. Summary of standard multiple regression analysis for variables predicting reading accuracy ........................................................................131

Table 12.6. Pearson correlation coefficients for overall tracking accuracy, reaction speed performance and single word reading ability (n = 68) .....................132

Table 13.6. Pearson correlations for different speeds of the target and relationship to single word reading (n = 68) ........................................................................133

Table 14.6. Summary of standard multiple regression analysis for variables predicting irregular word reading ........................................................................134

Table 15.7. Summary of independent samples t - test to measure the effect of training on reading accuracy, comprehension and rate (in months) ...............159

Table 16.7. Summary of independent samples t - tests to measure the effects of training on regular, irregular and non-word reading (z- scores) ..........161
Table 17.7. Correlation analyses between pre-training reading levels and post training discrepancy (in months) ........................................................................................................... 162

Table 18.7. Correlation between age and level of reading discrepancy from time 1 to time 2 ............................................................................................................... 163
Chapter 1.

A Clinical Examination of Developmental Dyslexia

1.1. The standard reading process

"The adult gives no more thought to his reading than he gives to his walking. The process has become automatic; when he sees the printed symbols he reads in spite of himself" (Bowden, 1911, p. 21)

For most individuals, learning to read is a somewhat standard journey, beginning in the early years of life and continuing to be refined into the adult years. Initially, children are exposed to books via stories which are read aloud, followed by learning letters and their sounds, and eventually whole words (Bus, 2001). Models that have attempted to conceptualize reading include the Multiple Levels Model (Shallice, Warrington & McCarthy, 1983) and the Single Route or Parallel Distributed Processing Model (Seidenberg & McClelland, 1989). However, one of the most prominent cognitive theories in reading research is the Dual Route Model of Reading (Coltheart, 1985). According to this model, individuals read out loud by using two separate procedures, the lexical and sublexical procedures. The lexical procedure involves accessing previously learned words from a mental dictionary. This procedure could be used to read words such as yacht, an irregular word. The sublexical procedure is used to ‘sound out’ new words by using grapheme to phoneme conversion rules. This pathway is used to read non-words (such as gop, a non-word that does not have a lexical entry). According to this model, regular words can be read using either route, and can be used as a measure of combined functioning. For skilled reading to occur, children need to learn how to develop skills in both of these pathways (Castles & Coltheart, 1993, Castles, et al., 2009). Since its conception, the Dual Route Model of Reading has continued to gather support via a range of neuroimaging (see Jobard, Crivello & Tzourio - Mazoyer (2003) for a meta-analysis of 35 published neuroimaging studies) and behavioural studies (Coltheart & Leahy, 1996; Coltheart & Rastle, 1994; Paap & Noel, 1991; Rastle & Coltheart, 1998; Rastle & Coltheart, 2000). However, despite the seemingly natural way in which children learn reading skills, not all children become fluent and confident readers. For some, reading is an exhausting and
frustrating process that does not seem to get easier, despite the best efforts of both the student and their school.

1.2. A clinical approach to defining dyslexia

In Australian universities, psychologists in training are introduced to two diagnostic manuals to diagnose psychological disorders; The International Classification of Diseases, 10th Edition (ICD – 10) and the more widely used Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM – 5). The DSM – 5 will be used in the current project.

According to the Diagnostic and Statistical Manual of Mental Disorders 5th Edition (2013) (DSM – 5, American Psychiatric Association) (Pg 66 - 68), Dyslexia falls under the category of ‘Specific Learning Disorder’ with the code 315.00 (F81.0). In the context of dyslexia, the individual exhibits slow and effortful reading which is substantially and quantifiably below what is expected for the child’s chronological age, and causes significant interference in personal, academic and/or occupational domains. This should be ascertained by a comprehensive clinical assessment and standardized measures. For children, this reading difficulty must have persisted for at least six months, and in spite of interventions targeted to address the deficit. For individuals aged 17 years or older, a documented history of learning difficulties may be used in the absence of standardized testing. The learning difficulties may not be fully evident until such time as the demands of reading exceed the individual’s limited capacity (e.g. during timed tests). This diagnosis should not be provided if intellectual disability, visual acuity, neurological disorders, psychosocial adversity, inadequate educational opportunities or other cultural factors can better explain the reading ability presented. If the diagnosis of dyslexia is provided, it is important to also specify type (e.g. reading accuracy, reading fluency, poor spelling) as well as any additional academic difficulties in areas such as reading comprehension or mathematics. Severity of the disorder can also be specified by the level of impairment in functional abilities and the amount of support required (mild, moderate or severe) (American Psychiatric Association (2013).
1.3. Prevalence

According to the DSM – 5, the prevalence of specific learning disorders in school age children across the academic domains of reading, writing and mathematics sits between 5% and 15%. The prevalence within adult populations is largely unknown but is estimated to sit at approximately 4% (DSM – 5, 2013). In Australia, the proportion of children thought to experience a Specific Learning Disorder also varies from 11% (Westwood & Graham, 2000) to over 15% (Prior, Sanson, Smart & Oberklaid, 1995). It is suggested that this high variability may be due to the fact that Australian clinicians have been unable to agree upon a universal definition, and therefore some studies may exclude or include more participants as meeting criteria compared to others (Skues & Cunningham, 2011). One dyslexia specific study took a sample of over 1200 Year 2 Victorian school students and administered a word knowledge test that measured comprehension and decoding skills. From this sample, it was determined that 16% of these students met the criteria for dyslexia, based on scores one or more standard deviations from the Year 2 mean scores (Prior, et al., 1995). According to the DSM – 5 (2013), scores of at least 1.5 standard deviations from the mean are required to provide the greatest diagnostic certainty, however 1 standard deviation below the mean may be used in conjunction with clinical judgment and other supporting tests (American Psychiatric Association, 2013).

1.4. Differential diagnosis

According to the DSM – 5 (2013), there are three types of learning impairments. Impairments in reading (The term Dyslexia can be used in this instance), impairment in written expression, and impairment with mathematics (the term Dyscalculia can be used in this instance). There are also six factors that must be considered when assessing for Specific Learning Disorder (SLD) (with regard to Dyslexia).

**Normal variations in academic attainment:** Dyslexic individuals are distinguishable from their peers because their difficulties in reading persist despite the same opportunities for learning as their peer group, and these difficulties are significant in nature (e.g. 2 years behind their peers in reading skills, as compared to a minor delay of six months).
Intellectual disability (or intellectual developmental disorder): The ‘specific’ in Specific Learning Disorder refers to the concept that there are significant impairments only in reading, and the individual is performing at much higher levels in other academic areas. If a global developmental delay or disability is present, the reading difficulty must be significantly more pronounced than would be expected given the intellectual disability.

Learning difficulties due to neurological or sensory disorders: A diagnosis of dyslexia would not apply if the reading disability is better explained by neurological or sensory disorders such as pediatric stroke, traumatic brain injury, hearing impairment or vision impairment.

Neurocognitive disorders: In order to diagnose Specific Learning Disorder, expression of the disorder must first occur within the early developmental period, whereas neurocognitive disorders can present at any stage and can result in a decline in cognitive performance over time.

Attention – Deficit/Hyperactivity Disorder (ADHD): Dyslexia is different to ADHD whereby the individual may have the capacity to read, or have preexisting skills in reading, but there exists a difficulty in performing these skills. If the individual has the capacity and skills to read successfully, however finds staying on task difficult, ADHD should be queried. However, the co-occurrence of SLD and ADHD is greater than chance levels in the population. That is, an individual with a learning disorder has a greater chance of also experiencing symptoms consistent with ADHD. Therefore, if both criteria are met, both ADHD and SLD (Dyslexia) diagnoses can be given in this instance.

Psychotic disorders: Schizophrenia and psychotic disorders may result in a rapid decline across multiple areas of functioning, whereas SLD, in the case of dyslexia, is specific to the domain of reading.

Thus, when investigating a diagnosis of dyslexia, it is imperative to differentiate between a slight delay, intellectual disability, medical influences, neurocognitive disorders, ADHD and psychotic disorders to ensure the correct diagnosis is provided (DSM - 5, 2013).
1.5. Comorbidity

Dyslexia can co-occur with a range of mental and neurodevelopmental disorders such as ADHD (Eden & Vaidya, 2008), Autism Spectrum Disorder (Hofvander, et al., 2009), Developmental Coordination Disorder (Visser, 2003), depressive and anxiety disorders (Boetsch, Green & Pennington, 1996). Differentiating between disorders when there are multiple symptoms can be complex, thus a comprehensive assessment is always advised, with additional use of psychometric tests where indicated (DSM – 5, 2013). For example, one of the most common comorbidities occurs with ADHD, where there appears to be a bidirectional relationship (Germano, Gagliano & Curatolo, 2010) whereby children with dyslexia are more likely to meet criteria for ADHD (Willcutt & Pennington, 2000), and children with ADHD are more likely to also meet criteria for dyslexia (Sanson, Prior & Smart, 1996). Additionally, children with dyslexia are more likely to present with the ADHD inattentive type, rather than the hyperactive and impulsivity type. Interestingly, it has been found that weaknesses in pre reading skills were significantly associated with inattention, but not hyperactivity and impulsivity, when a group of 809 twin pairs of preschoolers were tested (Willcutt, et al., 2007). Whilst it is estimated that between 18 – 40 % of children with dyslexia will also meet criteria for ADHD (Willcutt & Pennington, 2000), it remains unclear why such a high level of comorbidity exists. It has been suggested that like dyslexia, ADHD is also highly heritable, and genes associated with dyslexia also share overlap with genes suspected to be involved in ADHD (Gayan, et al., 2005), although research in this area is still in its beginning stages.

1.6. Psychosocial and academic impacts and outcomes

Dyslexia, whilst primarily impacting reading ability, is a disorder which can also have significant secondary impacts on an individual across multiple areas. Thus clinical research into its causes and effective treatment is vital. Areas in which dyslexic individuals are impacted include their overall wellbeing, educational achievement, peer relations, self-esteem and beliefs about the future (Boetsch, Green & Pennington, 1996; Ingeeson, 2007; Mugnaini, Lassi, La Malfa & Albertini, 2009; Terras, Thompson & Minnis, 2009).
1.6.1. Psychological impacts

Huntington and Bender (1993) conducted a review of the literature on learning disabilities and psychological wellbeing, examining research from the past 10 years. They found that dyslexic individuals generally have a less positive academic self-concept (Chapman, Tunmer & Prochnow, 2000; Cooley & Ayres, 1988; Gans, Kenny & Ghany, 2003), are more likely to attribute academic failures to internal factors such as lack of ability (Rogers & Saklofske, 1985), experience more anxiety (Bryan, Sonnefeld & Grabowski, 1983; Hoy, et al, 1997; Jordan, McGladdery & Dyer, 2014; Nelson, 2011) and depression symptoms (Duane, 1991; Weinberg et al., 1989) compared to their normally reading peers. In some cases, dyslexic children also view themselves as being less intelligent in comparison to their peers (Humphrey & Mullins, 2002). For example, in one study 41 learning impaired students (aged 14-20) completed a range of tests to measure their psychological wellbeing and adjustment. Parents also completed questionnaires to compare these self-report measures (Dollinger, Horn & Boarini, 1988). The researchers found that learning disorders were positively correlated with significant sleep disturbance. Students appeared particularly worried about their performance in public, as well as making mistakes and being teased by their peers. In a meta-analysis of 31 studies which examined the relationship between learning disabilities and depressive symptoms, there was a significant relationship of a medium magnitude ($d = 0.75$) between learning difficulties and depressive symptoms such as sadness, low self-esteem and feelings of worthlessness. In considering the results, the researchers cautioned that there was a discrepancy between parent/teacher report, and the student’s self-report, with self-report of depressive symptoms lower than teacher and parent report. The authors suggested that there are two primary possibilities for this result. Firstly, as the depressive symptoms are mostly internal, it may be difficult for parents and teachers to accurately judge levels of emotional wellbeing for the individual. In contrast, it may be the case that students are minimizing or denying unwanted feelings, or may have less insight into their emotions and the subsequent impacts on their wellbeing. Given that parent and teacher reports were fairly consistent, the authors point to the latter as a more reflective explanation, and highlight that further research is needed (Nelson & Harwood, 2011).
1.6.2. Social impacts

Whilst some evidence suggests that children with dyslexia are successful in social pursuits such as finding friends (95%) and getting along with others (93%) (Nugent, 2008), the majority of current evidence suggests that children with learning disabilities such as dyslexia can also experience higher incidences of neglect and isolation (Glazzard, 2010; Margalit & Levin – Alyagon, 1994; Pavri & Luftig, 2001; Valas, 1999), rejection (Kuhne & Weiner, 2000; Tur-Kaspa, Margalit & Most, 1999) and peer related bullying (Hellendoorn & Ruijssenaars, 2000; Luciano & Savage, 2007; Norwich & Kelly, 2004; Singer, 2005) in the school setting compared to their normally reading peers. In some cases, dyslexic students also report more negative experiences with teachers who do not appear to understand dyslexia (Gibson & Kendall, 2010; Stampoltzis & Polychronopoulou, 2009). In one study, over 500 students in upper primary school were examined using a play rating scale (how much peers liked to play with their classmates) and peer nomination measure ("circle the names of the three classmates you like the most"). It was found that learning disabled students received lower play ratings, and significantly lower liking scores compared to their normally reading peers (Stone & Greca, 1990). Sadly, these lower social status scores can persist over time, as much as three years later in one longitudinal study (Estell, et al., 2008). In another study, grade 5 students with a learning disability (and age matched peers) were interviewed to measure their locus of control, self-concept, and experiences with bullying, as well as tests of verbal and reading ability. The researchers found that children with learning disabilities experienced significantly more incidences of bullying compared to their peers. This was especially the case when learning disabled students experienced an external locus of control (felt less control over their environment), and if their verbal abilities were also impaired (Luciano & Savage, 2007). In a recent study, most children with dyslexia (83%) had reported some form of bullying, with 25% being bullied on a weekly basis (Singer, 2005). Additionally, it has been suggested that peer victimization is more likely if the learning disabled student experiences comorbid disorders or symptoms, such as withdrawal, depression, anxiety, social deficits, thought and attention difficulties and disruptive behaviours (Baumeister, Storch & Geffken, 2008). Families of children with learning disabilities also experience more stress compared to families with normally reading children. Parents reported investing higher levels of time and energy into the Specific Learning Disorder, lower expectations regarding future outcomes, having to manage minor behaviour problems such as disruptive
behaviours around meal times, and personal distress regarding the diagnosis and how to best help their child. In contrast, sibling relationships were described as positive, and families are similar to those with normally reading children in terms of positive family cohesiveness and structured family routine (Dyson, 1996; Rimkute, et al., 2014).

1.6.3. Educational challenges

By its very definition, children with dyslexia will experience academic difficulties that impair their ability to function within the school setting. They experience difficulty with reading, writing and spelling (DSM – 5, 2013), but this disorder can also impact other areas. For example, dyslexic children may have difficulty with subjects that include a reading component such as learning a foreign language (Crombie, 1997; Hughes & Smith, 1990), mathematics, science and humanities subjects. If the student is required to read a paragraph and extract the information required for the calculation or question, this could be more difficult for students with dyslexia (Crombie, 1997). Often, if reading deficits are identified early, teachers attempt to spend extra time with students or place them in reading groups to improve their literacy. Small intensive group programs and one – on - one instruction with specialized teachers can benefit children with learning disabilities, but for general reading improvement the effect size was considered small (see Swanson & Hoskyn, 1998 for a meta-analysis). In terms of training specifics, instruction in phonological awareness and letter – sound training appears to be the best treatment currently available (Alexander & Slinger-Constant, 2004; Defior & Tudela, 1994; Schneider, Roth & Ennemoser, 2000). Whilst phonological training is part of the puzzle, and can result in a medium level of improvement (for a meta-analysis see Bus and colleagues, 1999), there is still much work to be done, as there are great levels of variability, and some children still fail to read at expected levels following this intervention (Elbro & Peterson, 2004). For example, an analysis of 23 reading intervention studies found that between 8 – 80% of participants made little or no improvement at all from phonological training (Al Otaiba & Fuchs, 2002). In one study, sixty children (aged 8-10) with severe reading difficulties were provided with 67.5 hours of individual reading tuition in phonemic awareness and decoding over 8 weeks. Although reading accuracy and comprehension improved greatly for most children, reading rate continued to be severely impaired at the end of the training for almost all children. The researchers
explained that this discrepancy may be due to the increasing difficulty of the passages resulting in greater demands in phonological processing, paired with limited orthographic skills and experience (Torgesen, et al., 2001). Whilst dyslexia cannot be completely resolved within the educational setting, some strategies may be useful to increase engagement in the curriculum and the opportunities for the student to learn (Kirby, Silvestri, Allingham, Parrila & La Fave, 2008). For example, students with dyslexia may need to be accommodated with more time in written and reading tasks to be able to process each word, and apply a higher level of cognitive processing to gather the surrounding context (a process that would usually occur rapidly and somewhat automatically)(Shaywitz, 1998). The use of non-written means such as voice recorders and audio books can also be useful in assisting to learn academic concepts, as can laptop computers to assist with spelling (spell checker) and text to speech conversion (Goldfus & Gotesman, 2010). When asked of their own emotional coping strategies, children with dyslexia reported that they; tried to act as if the test/assignment was not that important (when they received a low grade) (59%), tried to hide their feelings from their peers so that they would not appear sad or stupid (59%), and reported seeking the help from their parents (64%) or teachers (32%) (Singer, 2008).

1.6.4. Occupational impacts

As learning disorders are primarily neurological in origin (DSM – 5, 2013), the symptoms associated with the disorder can not only impact academic performance, but also continue to impact the individual well into adulthood (Adelman & Vogel, 1993). In a large scale study by the US Department of Education, data from over 1,000 public and private high schools was collated. In one element of the research, students were asked to predict the job they were likely to secure at 30 years of age. For analysis, types of jobs were collapsed into three categories, requiring high, medium or low levels of education and prestige. Results from the learning disabled groups showed that males were much more likely to envision themselves in occupations of moderate prestige (such as sales representative, office worker, farmer), and females were least likely to see themselves in roles of moderate prestige (and more towards low levels of prestige), compared to their normally reading peers. The researcher suggested that learning disabled adolescents are at greater risk of being indecisive and limiting their occupational aspirations early in life. Although conversely, learning disabled
students are more likely to raise their expectations regarding employment prestige from Grade 8 to Grade 10 (Rojewski, 1996). In a post school study of outcomes, 49 adults with diagnosed learning disorders (average age of 26 years) were interviewed to explore their occupational experiences and outcomes post-secondary school. Of these 35/49 were employed and a further seven were engaged in full time study. The occupations of the participants were quite varied, from bar tender, to social worker, to camp director and office manager. Interestingly, 94% were satisfied with their employment, but over 50% were also actively looking for different employment. Only 20% of the individuals surveyed disclosed their learning disability to their employer at the interview, with the primary reason being fear of discrimination. Following successful application, 57% of participants still refused to reveal their disability, mostly due to discrimination or concerns that fellow staff members will treat them differently (Greenbaum, Graham & Scales, 1996). In terms of salary, lower wages were also reported by dyslexic participants (compared to colleagues with comparable roles), although this finding was somewhat inconsistent with a recent review (33% of cases) (de Beer, Engels, Heerkens & van der Klink, 2014). Dickinson and Verbeek (2002) suggest that whilst a wage gap certainly exists, the discrepancy was primarily due to productivity characteristics. A small amount of wage gap was unexplained, and the authors suggested this could be related to discrimination, but further investigations with a larger sample are needed. The authors noted that in their subsample of employers who were aware of their employees’ learning disability, they did not pay significantly less in salary to these employees. In a very recent meta-analysis (a total of 33 studies), deBeer and colleagues (2014) explored the factors that influenced workplace participation of dyslexic adults. They concluded that dyslexia impacts nearly all areas of functioning, in mostly negative ways. For example, negative feelings of frustration, stress, high anxiety and confusion/anger were common themes in the studies, as were negative self-perceptions. It was found that dyslexic employees gain the greatest sense of satisfaction if they are able to regulate and control their work tasks (such as prioritizing and taking work home if needed). Popular coping strategies included note taking, using specialized computer programs, seeking help from colleagues and working longer hours to complete tasks.
1.7. Personal strengths

Whilst there are a range of challenges and negative experiences reported by dyslexic readers (Ingesson, 2007), there is also a consistent body of evidence that describes personal strengths, such as creativity (Everatt, Steffert & Smythe, 1999; Griffiths, 2012; Wolff & Lundberg, 2002), superior performance in analytic spatial tests (Duranovic, Dedeic & Gavric, 2014), strong work ethic (Hellendoorn & Ruijssenaars, 2000) and empathy (Glazzard & Dale, 2013) in this population of individuals. These strengths are highlighted in a study by Riddick (2003), where dyslexic teachers were interviewed regarding their own school experiences, their experience as a teacher with dyslexia and the challenges of teaching literacy skills. Many teachers reported that they felt being dyslexic gave them an insight and advantage in using alternative teaching strategies, and strong empathy and motivation to help struggling students. One dyslexic teacher explained the dyslexia experience as

"A huge advantage... I think I'm a very much more enthusiastic and sparky teacher than what I would have been if I wasn't dyslexic" (Riddick, 2003, p395).

Another area of strength identified in dyslexic individuals is in the area of performance IQ. Performance IQ is measured using subtests such as block design, picture completion and digit symbol coding. In a study by Ingesson (2006) dyslexic individuals were administered a full scale IQ test at the age of 12, and then again at 16 years of age. It was found that whilst there was a significant decrease in verbal IQ (7.4 IQ points lower), there was a significant increase in performance IQ (10.8 IQ points) at time 2 (no significant change in FSIQ; 98.8 at time 1 and 99.3 at time 2). It was suggested that this increase in performance IQ could represent a type of compensatory process, whereby dyslexic children develop more visual, intuitive and creative ways to solve problems and process information. It may be that these individuals use a wider variety of means to acquire knowledge and to understand information as compared to relying on the process of reading alone, which could be an advantage in many areas, including creative occupations such as architecture and engineering (Ingesson, 2006).
1.8. Etiology

It is widely accepted that dyslexia is a neurodevelopmental disorder with a biological origin that results in cognitive abnormalities that present at the behavioural level (DSM – 5, 2013). There is strong evidence for a genetic component to this disorder, whereby an individual’s risk of dyslexia diagnosis is 4-8 times higher when first degree relatives also experience literacy problems (De Fries, Fulker & LaBuda, 1987; Finucci, Guthrie, Childs, Abbey & Childs, 1976; Raskind, Hsu, Berninger, Thompson & Wijsman, 2000; Williams & O’Donovan, 2006). In the case of monozygotic (identical) twins, the chance of both siblings being diagnosed with dyslexia (in this particular case, spelling deficits) is as high as 73% (when IQ is controlled) (Stevenson, Graham, Fredman & McLoughli, 1987). Whilst an underlying biological cause is widely agreed upon, there exists a highly controversial debate regarding exactly where and how this abnormality occurs in the brain, and how symptoms subsequently present (Symthe, 2011). Some researchers believe that the impairment occurs at the auditory cortex level (Tallal, 1980), and others suggest during phonological processing (Shaywitz, 1998). Some believe the deficit may exist with the cerebellum (Nicolson & Fawcett, 1999), whilst others suggest the problem occurs at the visual (Stein & Walsh, 1997) or visual attentional level (Vidyasagar & Pammer, 2010). It has also been suggested that no single line of evidence best explains dyslexia, but rather deficits across multiple areas (auditory, cerebellar, phonological and visual) are likely to contribute to this complex reading disorder, whereby a slight initial impairment in one modality could cascade in impairments across other modalities critical to the reading process (Pammer & Vidyasagar, 2005). The current project will focus on the visual – spatial attention contributions to reading ability, and how performance in focussing visual attention correlates with components of reading skill.

1.9 Conclusion

Dyslexia is categorized as a Specific Learning Disorder, and is characterized by slow and effortful reading, which is substantially below the performance expected for the individuals' chronological age (DSM – 5, 2013). Whilst dyslexic individuals possess a range of strengths (Everatt, Steffert & Smythe, 1999; Hellendoorn & Ruijssenaars, 2000; Riddick, 2003), their learning disability often results in significant impairments in multiple domains, such as
psychological wellbeing (Nelson & Harwood, 2011), educational (Crombie, 1997) and occupational (deBeer, et al., 2014) performance, and social experience (Glazzard, 2010). Prevalence of dyslexia ranges between 5 and 15% in child populations, and for adult populations the prevalence is largely unknown, but is estimated to be around 4% (DSM – 5, 2013). Although dyslexia is widely accepted as a neurodevelopmental disorder with a largely biological basis (DSM – 5, 2013), the exact cause remains controversial. A variety of theories offer potential explanations, and much needed spirited debate continues regarding the causes of reading disability in the reading research field.


Chapter 2.

The Science of Dyslexia

“... To completely analyse what we do when we read would almost be the acme of a psychologist’s achievements, for it would be to know very many of the most intricate workings of the human mind, as well as to unravel the tangled story of the most remarkable specific performance that civilization has learned in all its history” (Huey, 1908, p. 6).

2.1. A scientific approach to defining dyslexia

For many decades, there has been an ongoing international debate regarding the definition and cause of developmental dyslexia (hereafter dyslexia; and separate to acquired dyslexia, which can occur following a brain trauma (Hinton & Shallice, 1991)). The definitions proposed have reflected the contrasting theoretical perspectives regarding its origin, and the use of exclusionary rather than inclusive criteria. Australia is yet to adopt its own national definition (Skues & Cunningham, 2011). In 2009, an Australian working party was formed and devised a working definition of dyslexia in their report: ‘Helping People with Dyslexia: A National Agenda’. The group proposed this definition of dyslexia as follows –

“Dyslexia is a language - based learning disability of neurological origin. It primarily affects the skills involved in accurate and fluent word reading and spelling. It is frequently associated with difficulties in phonological processing. It occurs across the range of intellectual abilities with no distinct cut - off points. It is viewed as a lifelong disability that often does not respond as expected to best - practice evidence – based classroom methods for teaching reading” (Bond, et al., 2009, p10).

Coltheart and Jackson (1998) argue that dyslexia should not be defined by either a phonological deficit or by exclusion criteria. Instead, they explain that reading disability should be identified by evaluating the child’s set of reading skills against age related norms for these sub-skills. Subsequently, they explain that
intervention should be tailored to the type of sub-skill deficit, whether phonological or surface reading difficulties (or both).

Additionally, according to Castles and Coltheart (1993), dyslexia is not a single disorder, but rather reflects at least two distinct types of reading difficulties. The first is characterized by orthographic difficulties using the lexical procedure, or the mental dictionary, to access irregular or previously learned words (for example, reading the word ‘yacht’). This has also been described as *surface dyslexia*. The second is characterized by phonological difficulties in using the sublexical procedure, responsible for sounding out new or non−words (for example, reading the word ‘gop’). This is also known as *phonological dyslexia*. The Dual Route Model of Reading suggests that the process of reading can be described using these two distinct pathways. When there is a deficit in one (or both) of these pathways, reading difficulties can occur (Castles & Coltheart, 1993). It is important to ascertain which type of words are most problematic for poor readers, to best tailor an appropriate intervention (Castles, et al, 2009). The Castles and Colheart test (1993 & 2009) is a commonly used test in psychology research, to distinguish between phonological and orthographic deficits in reading ability (Adlard & Hazan, 1998; Byrne, Fielding-Barnsley & Ashley, 2000; Kohnen, Nickels, Castles, Friedmann & McArthur, 2012; Newbury, et al., 2011; Talcott, et al., 2000).

2.2. Theoretical conceptualizations of dyslexia

Whilst we have made significant advances in understanding the neurophysiology and cognitive models of the normal reading process and impaired reading, there is still much to learn and many questions left unanswered. There are a number of theories that attempt to explain the underlying causes of developmental dyslexia, which are hotly debated. Ultimately, one theory could fully explain the cause of dyslexia, or – more likely - these theories could in fact be complimentary, contributing different parts to the reading puzzle. An overview of the predominant theories in reading research will be provided, followed by a closer examination of the visual – spatial attention deficit theory, the theory upon which this series of studies will be based.
The phonological theory of dyslexia contends that dyslexia is directly caused by a cognitive deficit in the area of the brain responsible for the representation and processing of speech sounds. Over the past two decades it has been one of the most prominent theories in dyslexia research (Ramus, 2003).

According to Shaywitz (1998), a deficit in phonological processing impairs the reader’s ability to break words down into their individual speech sounds. Consequently, the reader experiences difficulty not only sounding out word and language components but also in identifying them. The deficit is domain specific whereby it does not impact the higher levels of cognition required for comprehension such as vocabulary, syntax and reasoning. Evidence for the phonological deficit theory is provided through a range of studies which examine phonological performance in poor readers including phoneme perception (Hazan, 1998; Masterton, Hazan & Wijayatilake, 1995; Mody, Studdert-Kennedy & Brady, 1997; although also see Brandt & Rosen, 1980), phoneme awareness (Bruck & Trieman, 1990; Elbro & Jensen, 2005; Hulme, et al., 2002; Pennington, Orden, Smith, Green & Haith, 1990; although see Castles & Coltheart, 2004 and Wimmer, Landerl, Linortner & Hummer, 1991), lexical retrieval (Katz, 1986; Swan & Goswami, 1997; Wolf & Goodglass, 1986), phonetic coding in verbal short term memory (Macaruso, Locke, Smith & Powers, 1996; Siegel & Linder, 1984) and articulation speed (Johnston & Anderson, 1998; McDougall, Hulme, Ellis & Monk, 1994; although see Di Filippo and colleagues, 2005 for an alternative view). In a typical example, Bruck (1992) tested phonological awareness using three separate tests. For syllable counting, participants were presented with five blocks on the table. They were given a non-word and were asked to use the blocks as counters to tell the researcher how many syllables were in the presented word. For phoneme counting the procedure was similar, whereby participants were asked to indicate with blocks how many phonemes were in the non-word (for example ‘tisk’ has four phonemes whereas ‘leem’ has three). For the deletion task participants were asked to delete the first or last sound in a word. To make this easier, the researcher pointed to ‘first’ or ‘last’ on a strip of paper that was placed in front of the participant (for example, for ‘snup’ becomes ‘nup’ when the first phoneme is deleted). Bruck (1992) found that children with dyslexia make significantly more errors on these tasks, compared to normally reading participants in the control group. Early phonological awareness performance can also predict subsequent reading ability (Badian, 1995; Muter, Hulme & Snowling, 1998;
Hulme, et al., 2002; Nation & Hulme, 1997). Interventions that include phonological training components have resulted in marked reading improvements for most children (Defior & Tudela, 1994; Poskiparta, Niemi & Vauras, 1999), although some children fail to demonstrate post training benefits (Torgeson, Morgan & Davis, 1992).

2.2.2 Auditory Deficit Theory

Related to the Phonological Theory, the Auditory Deficit Theory suggests that reading difficulties in some individuals may be related to a low level auditory perceptual dysfunction that impairs the ability to learn phonic skills successfully (Tallal, 1980). Specifically, it is believed that reading impaired individuals have difficulty processing rapid auditory stimuli when compared to normally reading controls (Tallal & Gaab, 2006). Numerous studies have found that dyslexic readers have reduced sensitivity (higher thresholds) on tasks of differentiation between tones (Talcott, et al., 2002; Witton, et al., 1998), change within a single tone (McAnally & Stein, 1996), and determining the order of tones (Nagarajan, et al., 1999). For example, in a study of 135 primary school children, each child was instructed to indicate if they had heard one or two tones over the space of 270 trials. The time between each tone varied by 0 – 40 milliseconds. The researchers found that reading impaired students were less efficient in determining if there was a gap between tones as the time between the tones decreased (McCronskey and Kidder, 1980). In 1995 a review was conducted by Farmer and Klein to examine the evidence for a temporal processing deficit in dyslexic readers stemming from a general processing difficulty. In their review they reject the notion that auditory deficits could be attributed to a general attention disorder. Rather, they suggest that there is considerable evidence related to performance on tasks of gap detection (stimulus individulisation) and temporal order judgments, and that a causal link between these auditory deficits and reading disability is quite plausible. More recently, a systematic review of electroencephalographic and magnetoencephalographic studies pertaining to auditory processing deficits also found that dyslexic individuals were more likely to present with deficits in the areas of frequency, rise time, duration discrimination, amplitude modulation and frequency modulation (Hamalainen, Salminen & Leppanen, 2013). Studies which have combined rapid auditory and visual processing tasks have discovered that individuals with dyslexia can be impaired across both these domains (Lallier, et al., 2010). For example, dyslexic readers can demonstrate deficits in both auditory...
discrimination between rapidly presented tones, and in visually discriminating the
direction of moving dots in a random dot kinematogram (RDK) when compared to
their normally reading peers (Witton, et al., 1998).

2.2.3. Cerebellar Theory

The Cerebellar or Dyslexic Automatization Deficit Theory contends that
dyslexia is caused by an abnormality in the functioning of the cerebellum
(Nicolson & Fawcett, 2006). The cerebellum is considered critical to the act of skill
automatisation. Impairments are suggested to impact reading ability in areas such
as phonemic awareness and speech production, procedural learning (and blending
of two skills) and hand writing skills (Nicolson, Fawcett & Dean, 2001). Evidence
for a cerebellum impairment includes reduced brain activation in the areas of the
right cerebellar cortex and left cingulate gyrus during task performance (Nicolson,
et al., 1999), as well as differences in performance on tasks thought to rely on the
cerebellum such as toe tapping (Fawcett & Nicolson, 1999), hypotonia (reduced
muscle tone)(Fawcett, Nicolson & Dean, 1996), bead threading (Fawcett, Nicolson
& Maclagan, 2001), time estimation (Nicolson, Fawcett & Dean, 1995), and
balance (Needle, Fawcett & Nicolson, 2006). For example, 11 year old and 15 year
old groups of dyslexic readers and controls were matched for age and IQ, and were
asked to complete a series of single and dual tasks under observation. The
researchers found that that there was no between - group differences for single task
performance such as standing on a beam with one foot in front of the other or on
standing on one foot only. However, when participants were asked to balance on
the beam and count backwards in groups of two, the dyslexic participants were
significantly less stable and made more counting errors compared to normal
readers (Fawcett & Nicolson, 1992). Researchers contend that this hypothesis is
not in opposition to the phonological theory of dyslexia, but rather suggest that
phonological impairments arise due to difficulties with impaired articulatory
control, which is also indicative of a cerebellar impairment (Fawcett, Nicolson &
Dean, 1996).

Considering the range of evidence that supports the phonological, auditory
and cerebellar deficit theories of reading disability, it is reasonable to suggest that
dyslexia is a complex disorder, with a range of deficits and symptom variability
between each individual. Rather than these theories existing in opposition to each
other, it is likely that they complement each other and may (in combination) lead to
a greater understanding of reading disability. The magnocellular theory is one such theory that attempts to account for the variability demonstrated by dyslexic readers across a variety of domains.

2.3. The Magnocellular Theory

The magnocellular theory of dyslexia suggests that many of the symptoms of dyslexia can be explained by an overarching deficit within the magnocellular pathway/dorsal visual stream. That is, the deficits dyslexic readers demonstrate in phonological, motor and visual domains may be related to the inability to successfully process fast sensory information, which is controlled by the magnocellular stream (Stein & Walsh, 1997, Stein, 2001). More specifically, in the visual domain, it has been suggested that the visual pathway is vitally important in the accurate visual coding of letters and words, as well as navigation across the text that is required for successful reading (Vidyasagar, 2004).

2.3.1. The neurobiology of the dorsal and ventral stream

Within the visual system it has been suggested that there exists two distinct pathways responsible for different elements of visual performance (there is also a third, known as the koniocellular pathway (Hendry & Reid, 2000), but this pathway will not be discussed here). Known as the dorsal and ventral stream, the dorsal stream is thought to be responsible for ‘where’ the viewer attends, and the ventral stream responsible for the ‘what’ the viewer can see (Goodale & Milner, 1992). The ventral stream, which contains parvocells, is suggested to be the slower of the two pathways, and is responsible for processing fine details and colour. It consists of a multisynaptic occipitotemporal pathway with limbic structures located within the temporal lobe and with ventral sections of the frontal lobe (Goodale & Milner, 1992). In contrast, the dorsal stream is faster, and contains magnocells, thought to be important in the ability to analyse movement and the positioning of objects in space. It consists of a multisynaptic occipitoparietal projection system that moves along the superior longitudinal fasciculus. This pathway interconnects with the striate, prestriate, and inferior parietal areas (Mishkin, Ungerleider & Macko, 1983) (see Figure 1.2).
Figure 1.2. Diagram of the Dorsal and Ventral Stream. A very basic illustration of the neural circuitry utilized during the reading process. Starting with the lateral geniculate nucleus (LGN), then the visual cortex (V1), followed by the middle temporal area (MT) and the posterior parietal cortex (PPC). Information is used by the frontal parietal network (FPN) to select the object location to be analysed further, this signal loops back through the PPC, through to V1, where by the slower parvocellular channel processes object information in greater detail through the ventral stream (Vidyasagar & Pammer, 2010).

The argument for separate but interacting dorsal and ventral pathways is supported by a range of evidence including findings from animal experimentation (Ungerleider, Desimone, Galkin & Mishkin, 1984; Young, 1992), observations following brain trauma (Binkofski, et al., 1998; Goodale, et al., 1994; Jacobson, Archibald, Carey & Goodale, 1991), fMRI (Culham, et al., 2003; Grill – Spector, Kourtzi & Kanwisher, 2001; Malach, et al., 1995) and behavioural studies (Goodale & Westwood, 2004; Steeves, et al., 2004). For example, individuals with brain damage to the occipitotemporal region are often unable to describe or recognize once familiar faces or objects, but can continue to navigate effectively through their everyday environment (Farrah, 2004). Conversely, individuals with brain damage to the posterior parietal region have demonstrated difficulties in reaching for objects that they can readily recognize (Perenin & Vighetto, 1988). Whilst there may be some cross talk between pathways, evidence suggests specific roles in visual processing for each of these pathways (Merigan & Maunsell, 1993; Tanné-Gariépy, Rouiller, & Boussaoud, 2002).
Visual processing begins by the signals proceeding from the eyes to the lateral geniculate nucleus (LGN), then onto the primary visual cortex (V1), with the fast signals from the magnocellular channel arriving at the dorsal stream areas. Following this, information is processed through the middle temporal area (MT) and the posterior parietal cortex (PPC) (Goodale & Milner, 1992). This occurs very quickly, as fast as 40 milliseconds for these steps (Bisley, Krishna & Goldberg, 2004). From this point, the location and general pattern information is used by the frontal parietal network (top down process) to select the object location to be analysed further, this signal loops back through the PPC, through to V1, where the slower parvocellular channel processes object information in much more detail through the ventral stream. Once the object is recognized, such as when searching for an object in a cluttered scene, or during reading, then this process would start again (Vidyasagar & Pammer, 2010). Therefore, in the context of reading, it may be counter intuitive to suggest that a deficit in the dorsal stream could result in reading difficulties, as it is the ventral stream that is considered responsible for the intricate processing of fine details such as letters associated with reading. However, whilst it is important to correctly identify letters and words, the visual system is also required to utilise the dorsal stream to visually guide attention in an accurate sweeping motion for reading to occur, as well as provide a spatial mapping of letters within words and words within text (Vidyasagar, 1999).

2.4. Biological evidence for a magnocellular/ dorsal stream deficit

Whilst debate is ongoing (Amitay, Ben-Yehudah, Banai & Ahissar, 2002; Skottun, 2000), evidence continues to build in this field, with a range of anatomical, imaging and behavioural studies that support a magnocellular/dorsal stream deficit in poor readers (Stein & Walsh, 1997), and more specifically, a deficit in visuo – spatial attention (Vidyasagar & Pammer, 2010).

2.4.1. Anatomical studies

Interested in previous behavioural studies which had demonstrated a relationship between magnocellular functioning and reading ability, Livingstone and colleagues (1991) compared anatomical differences between five dyslexic brains and five control brains post mortem. They examined the lateral geniculate nucleus (LGN) of one female and four male dyslexic readers, with a mean age of 34 years. The control subjects were all male with an average age of 40 years. Upon examination, it appeared that whilst the parvocellular layers were similar between the two groups, the magnocellular layers were more disorganised with smaller cells
in the dyslexic readers brains compared to the controls. When cell area was measured the dyslexic readers’ magnocells were significantly smaller - on average 27% smaller - than control brains. There were no differences in cell size between groups for parvocells. Decreased size and thinner axons of the magnocellular geniculate neurons was suggested to result in slower conduction velocity. Impairment in the magnocellular system could thus have significant impacts upon the ability to rapidly guide visual attention, which is critical to the successful action of reading. Additional investigations by Galaburda and Livingstone (1993) did not reveal any differences between groups in the V1 area of the visual system.

2.4.2. Imaging studies

Imaging studies have also found a relationship between brain activation in the area of the magnocellular pathway and reading disability. Demb, Boynton and Heeger (1998) used functional magnetic resonance imaging (fMRI) to measure activity during conditions designed to specifically stimulate the magnocellular pathway. Five dyslexic (2 female) and five control subjects (2 female) completed a battery of reading tests to confirm their reading abilities. They also completed a series of speed discrimination tests (which box of dots is moving faster), whilst their brain activity was concurrently measured using fMRI. They found that the dyslexic participants performed significantly worse in these tasks compared to controls (struggled as level of difference between two speeds decreased), and their brain activity was significantly reduced compared to controls, in both the primary visual cortex (V1) and in other extrastriate areas including areas Mt and MT+, which are areas thought to receive primarily magnocellular input. Likewise, other fMRI studies have also provided evidence of a magnocellular deficit in poor readers, by way of reduced activation along the magnocellular pathway (Eden, et al., 1996; Yamamoto, et al., 2013).

2.5. Behavioural evidence for a magnocellular/dorsal stream deficit

The magnocellular/dorsal stream deficit theory is controversial in the reading research field, partly due to the mixed findings related to behavioral studies examining this theory. For example, Illes, Walsh and Richardson (2000) tested two groups of dyslexic adults on a coherent motion task prior to providing a series of visual search tasks. They found that only the group with higher coherent motion detection sensitivity demonstrated significant visual search impairments. The dyslexic readers with normal coherent motion detection thresholds (compared to
controls) only showed deficits on one of eight tasks. This suggests that only a proportion of dyslexics will demonstrate magnocellular/dorsal stream deficits. However those who do are also more likely to present with concurrent visual – spatial attention deficits (Illes, Walsh & Richardson, 2000).

In a study by McLean and colleagues (2011), the strength of the association between magnocellular temporal thresholds and reading ability was classified as weak. Whilst the associations between reading ability and performance in the unselected sample were statistically significant, they accounted for no more than 9% of the variance in reading ability. In contrast, phonological and rapid naming tasks explained 35% and 29% of the variance in reading ability, respectively. Correlations between magnocellular performance and certain types of reading ability were also quite low, with no significant correlations between magnocellular temporal thresholds and non-words, and a very modest correlation between magnocellular temporal thresholds and irregular word reading (r(80) = .22, p < .05).

Despite mixed and contradictory findings related to this theory (e.g. Kronbichler, Hutzler & Wimmer, 2002; Ramus, 2003; Sperling, et al., 2005), evidence continues to mount which suggests that magnocellular/dorsal stream performance can significantly differentiate the performance of good and poor readers. These behavioural tests thought to rely on the dorsal stream include visual search (e.g. Casco and Prunetti, 1996), coherent motion detection (e.g. Cornelissen, et al., 1998), frequency doubling sensitivity (e.g. Kevan & Pammer, 2008), cueing sensitivity (e.g. Hari & Renvall, 2001) and change detection ability (Rutkowski, Crewther & Crewther, 2003).

2.5.1. Visual search

Visual Search tasks typically involve extracting a target amongst a range of distractors (clutter). Simple features can be detected in parallel (e.g. a green circle amongst red circles) and are not thought to be affected by number of distractors. On the other hand, a target defined by a series of conjunctions (e.g. searching for a red triangle in a series of red circles and green triangles) requires serial search involving focused visual attention, with search time decreasing as the number of distractors increases (Treisman & Gelade, 1980). Efficient use of the spotlight of attention, mediated by the dorsal stream, is critically vital for this search function. If this function is impaired, visual search for a conjunction of features such as colour and form, will show impairment as the amount of distractor items in the
display is increased (Vidyasagar & Pammer, 1999). Sireteanu and colleagues (2008) used a visual search task to measure visual selective attention in children and adolescents, and then compared their visual search performance to their reading ability. The letter-like (conjunction) search stimuli consisted of one target item amongst a group of 8, 16 or 24 distractor items, and participants were asked to press a key on a keyboard to indicate the presence or absence of the target. They found that dyslexic readers made significantly more errors on this task (were less accurate) compared to their normally reading peers. The authors suggested that children with developmental dyslexia possess deficits in complex visual search; indicative of an impairment in goal directed sustained visual – spatial attention. Other studies have also found that poor readers are equivalent on tasks of parallel search (Illes, Walsh & Richardson, 2000), but are less accurate (Moores, Cassim & Talcott, 2011; Casco, Tressoldi & Dellantonio, 1998; Liu, Chen & Chung, 2015) and require more processing time in conjunction searches (Buchholz & McKone, 2004; Casco & Prunetti, 1996), especially when the set size is increased (de Boer-Schellekens & Vroomen, 2012; Jones, Branigan & Kelly, 2008; Vidyasagar & Pammer, 1999). When set size is increased, this has been described as a ‘crowding’ of the visual field. A study which explored these effects found if crowding was decreased, by increasing spacing between letters in words, this improved the ability of dyslexic participants to read more accurately and fluently, compared to dyslexic readers who were given words with regular spacing. The authors agreed that the effect of extra-large letter spacing may have helped to reduce the impact of a sluggish visual attention system, which would struggle to accurately identify a target in increased clutter (Zorzi, et al., 2012).

2.5.2. Coherent motion detection

Coherent motion detection tasks require the participant to view a computer monitor which contains a random dot kinematogram (RDK). The participants’ coherence threshold is determined by a few different methods. One is to present two boxes and ask the participant which box contains the dots that are moving in the same direction (as compared to the other box where the dots are moving randomly)(Cornelissen, et al., 1998). Another method is to ask the participant the direction of the movement in a single display (Talcott, et al., 2000). Usually this is a forced choice procedure. The percentage of dots moving in the same direction is adjusted, until the participant can no longer detect the direction reliably (and this percentage is recorded as their individual threshold). Evidence suggests that
functioning in the magnocellular/dorsal pathway is correlated with successfully detecting motion in RDK's (Cornelissen, Richardson, Mason, Fowler & Stein, 1995). For example, responses of cortical neurons were recorded whilst blocking responses in the magnocellular or parvocellular layers of the LGN. It was found that the motion sensitivity of MT was reduced when magnocellular, but not parvocellular suppression was conducted (Maunsell, Nealy & DePriest, 1990). To explore the suggestion that poor readers possess magnocellular/dorsal stream deficits, various studies have shown that poor readers have difficulty at differentiating direction of movement (are less sensitive to motion) when compared to their normally reading peers (Conlon, Sanders & Zapart, 2004; Conlon, Lilleskaret, Wright, & Stuksrud, 2013; Cicchini, et al., 2015; Kassaliete, et al., 2015; Qian & Bi, 2014; Witton, et al., 1998). When signal dots are a lower contrast compared to the noise dots, this appears to further detriment some poor readers in their ability to detect motion direction compared to normal readers (Conlon, Lilleskaret, Wright & Power, 2012). For example, Cornelissen and colleagues (1995) found that when controlling for gender, IQ and age, dyslexic readers were worse at detecting coherent motion compared to their normally reading peers. Other studies have also demonstrated a relationship between coherent motion detection and reading performance. For example, a meta-analysis of 35 studies found a moderate effect size overall ($d = 0.675$, 2334 subjects), and a large effect size ($d = 0.747$) between groups of good and poor readers and their coherent motion performance (Benassi, Simonelli, Giovagnoli & Bolzani, 2010). Interestingly, evidence also suggests that coherent motion detection performance can predict orthographic (Boets, Wouters, Van Wieringen & Ghesquiere, 2006) and phonological performance (Kevan & Pammer, 2008) before children learn to read.

2.5.3. Frequency doubling

The frequency doubling illusion was first described by Kelly in 1966, and refers to a visual phenomenon whereby if a 0.1-4 c/degree grating is flickered at a speed greater than 15Hz, the viewer perceives a still grating at double the actual spatial frequency. It is suggested that tests based on the frequency doubling illusion can ascertain functioning of the magnocellular/dorsal pathway at the retinal level (Maddess, et al., 1999). The original idea for the use of FD tests in glaucoma studies comes from the idea that the FD illusion might be produced by the y – like retinal ganglion cells of the magnocellular pathway (My – cells). Specifically, the
illusion is thought to be produced by rectification, like that found in Y – cells, and
correlation studies based PERG and psychophysical studies support a Y – cell
origin for FD. Also, the process that produces the FD illusion appears to have the
same retinal density as My –cells (Maddess, et al., 1999). When FD phenomenon
was tested with dyslexic participants, many seemed less sensitive to this illusion
(Kevan & Pammer, 2008). For example, in a study by Pammer and Wheatley
(2001), it was revealed that dyslexic children were less sensitive to the frequency
doubling illusion, for both right and left eyes, when compared both to their
normally reading peers and to a standardized age cohort. Similar studies have also
revealed FD sensitivity differences between reading groups (Gori, Cecchini,
Bigoni, Molteni & Facoetti, 2014; Pammer, Lavis & Cornelissen, 2004; Pammer &
Kevan, 2007; Buchholz & McKone, 2004), providing further evidence for a
relationship between magnocellular/dorsal functioning and reading ability.

2.5.4. Spatial cueing

Spatial cueing refers to presenting a peripheral cue in visual space which
results in an orienting of attention, that aids in detection of targets in the cued area
(Posner & Cohen, 1984). Experiments which explore spatial cueing and shifting of
attention typically involve measuring reaction speed in the context of a cue or no
cue (as well as catch trials where the participant is not required to respond). Of
these cues, they can be either valid (the clue is correct) or invalid (the clue is
incorrect), and it is believed that invalid cues result in longer response times
compared to valid cues. This applies to both overt shifts of attention - where the
eyes are allowed to move freely-, and covert shifts of attention, where the
participant is asked to fixate on a point, such as a fixation cross, and not move their
eyes during the task (Posner, 1980). In spatial cueing experiments, shifts of
attention from one area in space to another are generally very rapid (from 50 – 100
milliseconds for exogenous cues) (Roach & Hogben, 2008). Spatial cueing is
believed to be a measure of magnocellular/dorsal stream processing because the
dorsal stream is responsible for executing fast attentional shifting and allocation of
attention (Kinsey, Rose, Hansen, Richardson & Stein, 2004). Increasing evidence
suggests that children with dyslexia may possess ‘sluggish attentional shifting’, or
difficulty executing and shifting attention quickly (Facoetti, et al., 2003; Hari &
Renvall, 2001; Lallier, et al., 2010). This could subsequently impair their ability to
rapidly shift visual attention - which (in the case of reading) - may impact their
efficiency to successfully process letter strings (Facoetti, et. al., 2010). Ongoing
testing in this area has revealed dyslexic children appear to have greater difficulty quickly orienting, engaging and disengaging attention (Faccoetti, et al., 2000, 2001, 2003, 2005; Ruffino, et al., 2014), tend to dwell on stimuli more than normal readers (Hari, Valta & Uutela, 1999), and do not benefit from spatial cues to the same extent as normal readers (Roach & Hogben, 2004). To test attentional shifting and cueing, Faccoetti and colleagues (2006) studied focused visual spatial attention in 20 dyslexic and 12 control children. Participants were asked to focus on a fixation cross, and when they detected a target dot (in one of the two circles presented), they were required to press the space bar as quickly as possible. Prior to this target, there was a cross, presented in the middle, or the right or left visual field. The arrow was valid 80% of the time, and invalid 20% of the time. On the valid trials, the arrow was pointing in the same direction as the subsequent target, on the invalid trials it was presented in the opposite visual field. As expected, overall reaction times were faster in valid as compared to invalid conditions. However, children who experienced difficulty in non-word reading demonstrated a different reaction time pattern. In the left visual field, the cue effect was present (slower on invalid trials), whereas in the right visual field, no cue effect existed. That is, dyslexic readers were not slower in responding to the invalid trials. This suggested that dyslexic readers with non-word reading difficulties also experience a lack of attentional inhibition in the right visual field, when attention is covertly focused to the left visual field (Faccoetti, et al., 2006). Overall, this pattern of evidence suggests that dyslexic readers may have dorsal stream deficits that impact their ability to rapidly orient and shift visual spatial attention, whilst suppressing distracting information (e.g. correctly identifying a target word in a collection of words (clutter)), which is critical for successful reading to occur (Faccoetti, et. al., 2010).

2.5.5. Change detection

Change detection is the noticing of changes in the world in which we live. It involves not only the noticing of the change, but also the ability to report what and where the change is (Rensink, 2002, p. 246). According to Rutkowski and colleagues (2003), reading engages spatio–temporal processing, by the process of systematically decoding spatially arranged visual symbols. Given the links between reading ability and magnocellular/dorsal stream attentional performance, the researchers decided that change detection tasks, which also engage spatio–temporal processing, would be another effective means by which to measure dorsal
stream performance. If magnocellular/dorsal stream attentional deficits were associated with dyslexia, then dyslexic readers would demonstrate impaired performance compared to average readers on change detection tasks. Three groups of participants (86 children in total) were tested; developmental dyslexics, learning disabled participants and normal readers, to measure their performance on general change detection performance and performance with the addition of visual cues. Participants were asked to view a computer screen with four circles and a fixation cross. In experiment one the cue was not present. Participants were asked to remember the letter presented in each of the four circles. The stimulus was replaced with a fixation cross, then the second image was displayed. The participants were required to indicate if there was change in the image (i.e. different letter in one of the four circles) or no change. If they selected change, they were subsequently asked to indicate which letter had changed. In the second experiment, a small line was presented in one of the four quadrants with the fixation cross, which indicated where the change would appear. If there was no change in letters, the position of the cue was random. Results revealed that dyslexic readers required significantly longer exposure to the initial stimulus to correctly identify the change, compared to normal readers. Consistent with spatial cueing findings (Faccoetti, Lorusso, Paganoni, Cattaneo, Galli & Molteni, 2005; Roach & Hogben, 2004), dyslexic readers also did not receive the same benefit from the presentation of a cue, as compared to learning disabled and normal readers who were faster when presented with cues regarding target location. The authors noted that this deficit in rapidly processing visual information could be explained by an overarching magnocellular/parietal dysfunction. As the magnocellular input via the dorsal pathway is a major source of information provided to the posterior parietal cortex (PPC), a fault along this pathway could impair the ability of the PPC to alert visual attention, which is needed prior to conscious perception of the change in the image (Rutkowski, Crewther & Crewther, 2003).

2.6. How the magnocellular/dorsal stream is implicated in reading ability

An ongoing research question remains as to if the fault is with the magnocells (Galaburda & Livingstone, 1993), or if deficits along specific components of the visual dorsal stream (impacting different types of reading skills – such as speed, phonological and orthographic processing) are responsible for the visual performance differences identified in poor readers (Kevan & Pammer,
2008). According to Vidyasagar & Pammer (2010), the ability to read successfully could be affected by a deficit at any stage along the neural pathway such as (1) Impoverished sampling density of the magnocellular system of the retina, (2) A specific deficit along any section of the visual pathway to the dorsal stream, (3) Damage in other parallel pathways (e.g. koniocellular) that could otherwise compensate for any magnocellular damage, (4) Impairment in feedback pathways from the dorsal stream areas to visual area V1 or the ventral stream, (5) Impairment in the dorsal cortical stream, to area V5/MT or the PPC, or (6) Lesion at the area where attention modulation occurs (Vidyasagar & Pammer, 2010). Therefore, in recognition of this ongoing research question, the following chapters will use the term magnocellular/dorsal stream as a broad term when referencing visual system deficits. The Visual - Spatial Attention Deficit Theory, the focus of the present research, conceptualises how a magnocellular/dorsal stream deficit could be detrimental to the process of successful reading (Vidyasagar & Pammer, 2010).

2.7. The Visuo - Spatial Attention Deficit Theory

The act of reading is not considered a natural process, or a requirement of our evolution. It is a trained visual/language skill, usually taught at an early age, with improvements in this skill usually expected over time. In our everyday environments, our eyes do not move in set order, or in the sequential pattern required for skilled reading. Rather, our eyes dart around a scene, from one object to the next, with the visual system not keeping track of where it has been (Horowitz and Wolfe, 1998). In contrast, reading involves the meticulous process of sequentially guiding a spotlight of attention across the letters of a word, then on to the next part of the text (Vidyasagar, 1999) (see Figure 2.2). The spotlight of attention, mediated by the dorsal stream, is a mechanism through which attention can be concentrated to locate complex target information. Similar to the ‘zoom lens’ of a camera, the spotlight can adjust its range of focus, but at a cost. As the size of the attentional field is increased, the number of processing resources decreases (Eriksen & St James, 1986). The integrity of the dorsal stream is critical to the spotlight of attention and reading, as it is believed that whilst the ventral stream can identify individual letters, it needs the spotlighting assistance of the dorsal stream to order the letters of a word and words in a sentence for further (ventral stream) analysis (Vidyasagar, 2004, 2005). It is suggested that it is no coincidence that the average adult is able to read approximately 3000 English characters in a minute (taking 20 milliseconds per character), and the speed of the
spotlight of attention is said to be 20-30 milliseconds per item. The speed at which reading can occur is limited by the capacity of the spotlight of attention (Vidyasagar, 1999). Following the proposition that the spotlight of attention is critical to the reading process, the visuo- spatial attention deficit theory suggests that a deficit in the dorsal pathway could impair the ability to rapidly focus visuo – spatial attention, which is required for successful reading to occur (Vidyasagar & Pammer, 2010).

**Figure 2.2.** Spotlight of Attention. When we read, we guide our spotlight of attention from one word to the next. This is not a smooth process, but rather involves a series of saccades, fixations and regression (Vidyasagar, 2005).

2.7. Conclusion

Whilst the phonological theory of reading disability is the most thoroughly researched and popular theory in the reading research field (Ramus, 2003), growing evidence suggests that the visuo – spatial attention deficit theory may offer new insights into why significant reading disability occurs (Vidyasagar & Pammer, 2010). Specifically, it is argued that the prominent theories on reading disability are not necessarily in opposition, but rather form different parts of the reading performance puzzle. As reading demands the efficient functioning of a number of modalities within the neural network, a deficit in one modality could result in impairments in another or multiple modalities (Pammer & Vidyasagar, 2005). The magnocellular/dorsal stream is critically responsible for the deployment.
of fast and accurate visuo-spatial attention (Goodale & Milner, 1992). The visuo-spatial attention deficit theory fits at the earliest stage of the reading puzzle, in suggesting deficits in the ability to rapidly focus attention may subsequently impair the ability to read accurately and fluently (Facoetti, et al., 2010; Vidyasagar & Pammer, 2010). This has been evidenced by anatomical (Livingstone, et al., 1991), imaging (Eden, et al., 1996) and behavioural studies (Facoetti, et al., 2006) which have identified deficits in the dorsal stream performance of poor readers.

Given that dorsal stream deficits have been repeatedly detected using basic computerized tests in controlled laboratory settings, a new question emerges. Can these deficits be detected using more novel programs, capable of engaging the participant, within more flexible and familiar settings? Traditional testing could be considered repetitive and tedious to the child participant (and indeed adults), which is challenging for the experimenter who aims to successfully ascertain a true measure of visual functioning. If testing could be successfully evolved towards a more practical and engaging administration, this would have important implications not only for the ability to test the dorsal stream performance of children (and adults), but also have ramifications for designing interventions to target these dorsal stream deficits.
2.8. References


luminance levels in dyslexics and controls. *Vision Research, 35*(10), 1483-1494.


48


Chapter 3.

Serious Games for Reading Remediation

“Although video game playing may seem to be rather mindless, it is capable of radically altering visual attentional processing” – Green & Bavelier (2003)

3.1. The rise of video games and gamification

Video games exist within mobile technologies, education, museums, family interactions and workplaces. They are played by gamers of all ages, genders, races, religions, sexualities and nationalities (Shaw, 2010). Since the creation of the first video game in 1958 (by Willy Higinbotham), and the introduction of the Magnavox Odyssey video games console in 1972 (Guttenbrunner, Becker & Rauber, 2010), video and computer games continue to increase in popularity both in Australia (Sweetser, Johnson, Ozdowska & Wyeth, 2012) and internationally (Przybylski, Rigby & Ryan, 2010). As technology has advanced, the accessibility of games has increased, from the classic console and arcade mode, to present day games which are readily available on portable tablet computers and smart phones. Australian gamers play on average for one hour per day, with play most common during evenings, weekends and holidays (Brand, Lorentz & Matthew, 2014). With participation in games becoming an exceedingly popular leisure activity in modern society, researchers have begun to explore the use of computer game frameworks within classic psychological experiments, to improve engagement and motivation (Berger, Jones, Rothbart & Posner, 2000), with encouraging results (Boets, Wouters, Van Wieringen & Ghesquiere, 2006).

Traditional psychological experiments, especially in the field of vision research, could be considered by children to be tedious, due to their carefully controlled environments and often large numbers of repetitive trials. It is imperative to note that in many cases, it is critical to conduct experiments in this way, to ensure that the data is not manipulated by unintended factors. For example, to determine the relationship between age and selective attention, children (and adults) were presented with 160 trials over 2 (20 minute) sessions. During this time, children sat 75 centimetres from the screen with their index finger resting on the response buttons, and attended to a fixation point. They were directed to indicate with the left or right button as quickly as possible as to the direction of the
arrow presented on screen. The stimuli were presented on a high contrast green and white video monitor. During some of these trials a distractor arrow was present, and in other trials the arrow was located in an unexpected location. From the results the researchers confirmed that visual search, filtering and priming all improve significantly from four years of age to seven years of age, with a more modest improvement from 7 – 24 years of age (Enns & Cameron, 1987). This process could potentially be viewed as tedious by the young participant, due to the level of repetition and the basic nature of the stimuli. However, this finding was unlikely to be the result of chance, unintended stimuli, or attending in a visually inconsistent manner (e.g. looking around the room). Clean, controlled vision experiments like the study by Enns and Cameron (1987) will always have an important place within the field of psychology research. However, where it is desired and practical, measuring visual performance with games could offer the participant the chance to be challenged, entertained and engaged. This process of changing the properties of traditional scientific experiments to be more game-like falls within an emerging field known as “Gamification”.

According to Huotari and Hamari (2012), gamification is defined as ‘enhancing a service with (motivational) affordances for game-like experiences in order to support the users overall value creation’ (p19). They assert that in order for gamification to be successful, the program must elicit the same psychological experiences that games can create. Gamification as a field has been studied most extensively in the educational domain, with researchers discovering positive effects including higher student motivation to learn class material and lower fail rates (Charles, Charles, McNeill, Bustard & Black, 2011), higher levels of engagement and interest (Bellotti, et al., 2013), and general user enjoyment of a gamified system (Dominguez, et al., 2013) (although also see Hanus & Fox (2015) for an alternative view). In other domains such as business (Dale, 2014) and health (Miller, Cafazzo & Seto, 2014), gamification has also been utilised to explore new ways of presenting standard concepts, with promising results. For example, a ‘Fit Game’ was developed in schools for students where incentives were provided for eating of fruit and vegetables, which included the use of heroes and villains in an engaging storyline. On intervention days consumption of fruit increased by 39% and intake of vegetables increased by 33%. Students reported that they enjoyed playing the game, and grade 1-3 teachers subsequently recommended that it continue to be used in their schools (Jones, Madden & Wengreen, 2014a; see also Jones, Madden & Wengreen, 2014b). However, perceived usefulness, playfulness and enjoyment have been shown to decrease over time, hypothesized to be due to
the novelty wearing off as the user becomes more familiar with the game during play (Koivisto & Hamari, 2014).

In a review of empirical studies on gamification, Hamari and colleagues (2014) concluded that gamification can have positive effects, but this is dependent upon the way in which the game is constructed (context), as well as the qualities of the users that are engaging in the program. It is suggested that gamification has three main parts; the motivational affordances, the psychological impacts, and the behavioural outcomes. Motivational affordances or strategies can include; points, leaderboards, badges, levels, storylines, feedback, rewards and challenges. The resulting psychological experiences may include increased motivation, positive attitude and higher levels of enjoyment. Behavioural outcomes may include measures such as level of engagement (or time invested) in the task. At present, it appears that overall the highest incidences of gamification is occurring in the education sector, and whilst more research is needed (as it appears mostly qualitative), the effects of gamifying academic learning has been mostly positive (Hamari, Koivisto & Sarsa, 2014).

3.2. The benefits of gamification in psychology research

Use of ‘cover stories’ are common when testing participants in a traditional lab based setting, especially child participants. The stimuli are basic and repetitive, but a story is provided as to the ‘aim of the game’ with a view to keeping the child engaged in the task provided. For example, Kevan and Pammer (2008) used a cover story in presenting a standard visual frequency doubling task to primary school aged participants. The stimuli consisted of low spatial frequency sinewave gratings displayed within a square aperture on a grey background. Children were told that a zebra (the spatial frequency grating) was hiding to the left or right of the screen, and children could ‘catch’ the zebra by pointing to the left or right of the screen or responding verbally. This was a simple story which was designed to make the game more appealing for the five year old participants.

Gamification in psychology research takes this cover story concept one step further, because it significantly changes the way in which the stimuli are presented to the participant, in an attempt to make the experiment more engaging and entertaining. For example, the experiment may be more colourful and animated, with illustrations relevant to the aim of the game that makes the program more visually appealing. In most cases there is very little control over the visual parameters of the task. Whilst it is assumed that gamifying results in a more
pleasant experience and can produce reliable findings, this had not been explicitly tested. To address this concern, Hawkins and colleagues (2013) examined the use of game like - concepts in psychology research, and the potential impacts of these games on performance and data collection. Two hundred undergraduate psychology students were randomly allocated to a gamified or standard versions of change detection and choice tasks. For the change detection task participants were presented with a series of boxes containing dots, with one box (the target) collecting dots faster than the remaining squares. The task was to select this target form the range of distractor boxes. To gamify this task, the stimuli remained the same (the stimuli on the screen was the same colour, shape and size as the standard version), however the background appearance changed, and participants were given a detailed back story, animations, a points based scoring system and audio feedback. The researchers demonstrated that whilst one version of the task had been gamified, there was no significant difference in visual performance between the two tasks. Additionally, when a second experiment was conducted with a different task, this finding was replicated. However, with the addition of a questionnaire in the second study, it was confirmed that those who were administered the gamified version of the task experienced significantly greater enjoyment of the task compared to the standard test group. They also rated the task as more interesting as compared to the standard test group (Hawkins, et al., 2013). These motivational factors are likely to be important considerations when working with young children. If children find a task boring, they are much less likely to persevere with lengthy and repetitive trials, and this may have a significant impact on the quality of the data collected. Thus, ensuring attention is maintained in child populations is a critical issue, and gamifying experimental programs could be an effective means to ensure continued interest in the tasks presented.

In psychology research, game like tasks have been used in a variety of psychological studies with adults and children, to gather targeted information whilst enhancing the user enjoyment of the experiment conducted. For adults, one of the longest running games developed for psychological testing is “Space Fortress” (Mane & Donchin, 1989). This game was designed to test complex skill and its acquisition. The object of the game is to shoot missiles to attack a space fortress. Whilst attacking, the participant must also protect their own ship from damage. Game - like qualities include points for successfully hitting the target, a limited number of missiles (challenge), bonus rewards and sound effects. The game is suggested to be able to record performance in perceptual, cognitive and motor domains. As the popularity of game play has increased, the gamification concept
has been used in the study of visual attention (Arthur, Day, Bennett, McNelly & Jordan, 1995), training schedules and supervision (Foss, Fabiani, Mane & Donchin, 1989; Mane & Donchin, 1989; Shebilskem, Regian, Arthur & Jordan, 1992), skill acquisition (Arthur, et al., 1997), and impacts of perceived challenge versus threat on complex performance (Gildea, Schneide & Shebilske, 2007). Gamification of child experiments is also common. For example, Boets and colleagues (2006) modified a typical coherent motion detection task to be more game-like and enjoyable for their young participants. Testing a group of five year old pre-school children, he began the experiment with a short animation of little dog and bear getting lost in the snow. The participants were then informed that their task was to tell the researcher which of two patches has ‘the road to get home’. Threshold was determined by selection of the panel of coherent moving dots and a two down, one up, staircase method, starting at 100% coherence. This is just one example of many experiments that have been gamified to test psychological properties within child populations (for more examples see Berger, Jones, Rothbart & Posner, 2000 – “Feed the Fish”; Dunbar, Hill & Lewis, 2001 – “The Frog Game”; Metcalfe, Kornell & Finn, 2009 – “Dragon Master”; Spencer & Hund, 2003 – “Spaceships”), with the list almost certainly to continue to grow.

3.3. The potential for games in visual attention assessment and intervention

Traditionally, in the area of reading disability research, dorsal stream testing has comprised of very tightly-controlled stimuli, as is required to understand performance without the influence of unintended factors. Such stimuli include black dots on a white background to measure coherent motion perception (Cornelissen, Hansen, Hutton, Evangelinou & Stein, 1998); carefully selected shapes with single colours to measure visual search performance (Vidyasagar & Pammer, 1999); and a central fixation cross with peripheral circles containing letters (black stimuli on white background) to measure change detection (Rutkowski, Crewther & Crewther, 2003). Taking a different direction, Van den Audenaeren and colleagues (2013) have designed a tablet computer game using more dynamic visual stimuli. Titled ‘Diesel – X’, it is a computer game designed to improve early detection of dorsal stream deficits in poor readers. This is a specially designed game, taking game elements that are highly engaging to preschool children, however it is yet to be tested with dyslexic and normal readers. The authors explained that it can be difficult to maintain the attention of young children during traditional types of testing. By using an interface that is gamified, this may
result in higher levels of motivation, and higher accuracy in gauging the true visual abilities of each participant and subsequently detecting visual and auditory deficits in poor readers.

With increasing evidence to suggest a deficit in the magnocellular/dorsal pathway of poor readers (e.g. Buchholz & McKone, 2004; Casco, Tressoldi & Dellantonio, 1998; Illes, Walsh & Richardson, 2000, Kevan & Pammer, 2008) attention has also turned towards interventions that could potentially remediate these attentional deficits and improve reading ability (Franceschini, et al., 2013). Previous research has suggested that both visual (Blacker, Curby, Klobusicky & Chein, 2014; Castel, Pratt & Drummond, 2005; Dobrowolski, et al., 2015; Green & Bavelier, 2006a, 2006b; Gopher, Well & Bareket, 1994; Greenfield, DeWinstanley, Kilpatrick & Kaye, 1994; Okagaki & Frensch, 1994; Quaiser – Pohl, Geiser & Lehmann, 2006; Terlecki & Newcomb, 2005; Trick, Jaspers – Fayer & Sethi, 2005) (although see Murphy & Spencer (2009) for alternative findings) and auditory (Green, Pouget & Bavelier, 2010) attention abilities can be enhanced with video/computer games exposure and training (also see Green & Bavelier (2012) for informative methodological considerations for video game training studies). For example, Green and Bavelier (2003) investigated the visual performance of 18 – 23 year old video game players (VGP) and non-video game players (NVGP). VGP’s played action video games at least four days per week, for at least one hour per day, for at least the past six months. NVGP’s reported little or no game experience in the past six months. Analyses of the data revealed that VGP’s had enhanced attentional capacity (more resources to allocate to distractors during complex visual tasks), an increased ability to process a greater number of visual items, enhanced allocation of visual – spatial attention across a display, and the ability to rapidly process information faster (and more accurately). In a follow up study, the authors were interested in whether video games training could improve non – gamers attentional abilities. A group of non - gamers were asked to play ‘Medal of Honor’, an action video game, for one hour per day over ten days. A non-gamer control group was trained using a game called ‘Tetris’. Both groups improved in their abilities to play their respective games, as measured by pre and post testing, indicating sufficient engagement in the task. Following action video game training, non-gamers significantly improved their Useful Field of View and demonstrated faster recovery from attentional blink tasks. The action video game play resulted in much greater improvements, as compared to the non-action ‘Tetris’ video game. The authors concluded that 10 days of training in action video games is sufficient to detect significant improvements in visual attention functioning, and that whilst it
seems leisurely, action video game play is capable of significantly improving visual attention functioning (Green & Bavelier, 2003, p. 536). Playing video games has also been associated with better performance on change detection tasks, which is thought to occur through broader scanning of the scene when searching for change, compared to non-video game players (Clark, Fleck & Mitroff, 2011). Bavelier and colleagues (2012) explain that action video games alter the visual system in such a way that it is more efficient in detecting task relevant information and also suppressing potentially distracting and irrelevant sources of information. Excitingly, specific games’ training has also been directly correlated with improvements in reading ability (Franceschini, et al., 2013).

Specific to visual spatial attention, action video games have been shown to improve visual attention, and also reading abilities in dyslexic participants. Franceschini and his colleagues (2013) took measures of spatial attention, as well as decoding of non-words and word text reading skills, before and after training in video games. Ten dyslexic children were allocated to a game which was action based (Nintendo Wii *Rayman Raving Rabbids*), and ten were allocated to a game which did not have action components (mini games that were assessed as being less reliant on the dorsal stream). The authors defined action video games as meeting four requirements; 1) extraordinary speed for both transient events and the speed of moving objects, 2) a high level of cognitive, perceptual and motor load to execute the motor plan, 3) temporal and spatial unpredictability and 4) the need for peripheral processing. Each child played this game individually for a total of 12 hours (9 sessions, 80 minutes each), and did not receive additional phonological or orthographic training. Spatial attention was measured by a cueing tasks. In the focused spatial attention task, participants were asked to focus on a fixation point, and following a red dot (cue), a string of six symbols appeared, from which the participant had to identify the target. In the distributed spatial attention task, the red dot appeared after the symbols disappeared. In the cross modal attention task, two circles were displayed on the left and right side of the fixation point. An auditory cue was presented on the left, right or to both ears prior to the presentation of the target (stylized dog). In this task both reaction times and accuracy were recorded. When measuring reading performance from time 1 to time 2, it was discovered that reading performance improved for the action video game players, but not for the non-action video game players. Both non-word reading and word text reading were significantly improved for this action video games group. The authors suggested that the improvements made for this group were equivalent to 12 months of
spontaneous improvement of reading ability, and were also highly correlated with improvements in spatial and temporal attention (from time 1 to time 2). They suggested that action video game training may be a better type of training to improve reading due to the demands placed on the magnocellular / dorsal pathway. Specifically, these type of games are fast, utilise peripheral information and require the spotlight of attention to be engaged under high load, all of which could be useful in ‘working out’ or strengthening the visuo – spatial attentional system (Franceschini, et al., 2013).

Given the benefits of gamifying basic psychophysics tasks (Hawkins, et al., 2013), and the documented visual training (e.g. Green & Bavelier, 2006a, 2006b; Terlecki & Newcomb, 2005; Trick, Jaspers – Fayer & Sethi, 2005) and subsequent reading outcomes (Franceschini, et al., 2013), it is important to understand how the dorsal pathway might respond to less controlled psychophysical tasks, and whether such tasks can be used in the context of dyslexia research. If children could be successfully tested and trained using portable gamified versions of classic visual attention tasks in environmentally variable settings, this would have significant implications for both increasing the understanding of dorsal stream functioning (in the context of reading ability), and the administration of early intervention training programs within practical settings such as the home or school.

3.4 Conclusion

Gamification refers to changing the properties of a task so that it encourages motivation and simulates a game-like experience for the user (Huotari & Hamari, 2012). The gamification of psychology experiments to measure visual performance has increased steadily over the past few decades (e.g. Arthur, et al., 1995; Mane & Donchin, 1989), and more recently, video games have also been investigated for their potential to improve a wide variety of cognitive functions such as spatial abilities (Okagaki & Frensch, 1994; Quaiser – Pohl, Geiser & Lehmann, 2006; Terlecki & Newcomb, 2005), visual response times to target stimuli (Castel, Pratt & Drummond, 2005; Dye, Green & Bavelier, 2009; Green & Bavelier, 2003) and tracking multiple objects (Green & Bavelier, 2006b; Trick, Jaspers – Fayer & Sethi, 2005). In the area of reading research, gamified visual experiments have been used to identify dorsal stream deficits in poor readers (e.g. Kevan & Pammer, 2009), and recently, to determine if visual attention can be trained with action video games to improve reading ability (Franceschini, et al., 2013). With these
recent discoveries, a question emerges as to whether a portable series of gamified
tasks (thought to rely on dorsal stream functioning) could be used to both assess
and remediate poor readers within less controlled environments, where reading is
most likely to occur. If this were possible, it would have exciting implications for
comprehensive assessment and early intervention for children with reading
disorders.

3.5 General Conclusion and project aims

The effective assessment and intervention for dyslexia is clearly a
significant issue, especially given the secondary psychological (Gans, Kenny &
Ghany, 2003), social (Glazzard, 2010) and occupational (Greenbaum, Graham &
Scales, 1996) impacts that affect individuals with this disorder. There are a number
of reading remediation programs (that include phonological awareness) currently
available (Elbaum, et al., 2000; Iversen & Tunmer, 1993), and should continue to
be offered to all students as needed. However, phonological functioning does not
appear to be the complete picture in the dyslexia puzzle. Many readers with severe
reading delays who undertake phonological awareness interventions will only
receive some benefit (Al Otaiba & Fuchs, 2002), with phonological awareness
thought to explain approximately 12% of the variance in word identification skills
(for a meta – analysis see Bus & Ijzendoorn, 1999). Given that phonological
awareness does not fully explain the deficits experienced by poor readers, attention
has turned to other theories which may help to understand why this disorder occurs.
The visual – spatial attention deficit theory contends that an impairment in the
dorsal stream in the visual system may impact the ability to read at the very earliest
levels, due to a difficulty in rapidly focusing the spotlight of attention sequentially,
an action critical to the process of successful reading (Vidyasagar & Pammer,
2009). Evidence from anatomical (Galaburda & Livingstone, 1993), imaging
(Demb, Boynton and Heeger, 1998) and behavioural (Faccoetti, et al., 2000) studies
provide support for this theory, and early studies examining attentional training
have resulted in promising outcomes for poor readers (Franceschini, et al., 2013).

As early research has demonstrated that specific visual attention training
can improve reading ability (Franceschini, et al., 2013), the next logical step is to
determine if assessment and intervention can occur outside controlled laboratory
based settings. From a clinically practical perspective, it is not always viable for
participants to attend a lab or clinic, or for the clinician to carry cumbersome
equipment to schools or home settings. Moreover, traditional psychology vision
experiments could be considered tedious and repetitive to the younger participant. The aim of the following studies was to determine if assessment and intervention can be successfully undertaken in the setting where reading most frequently occurs, the child’s school. The primary phase of testing was to determine if dorsal stream deficits are still able to be detected in reading disabled children in settings that are less controlled, using gamified traditional dorsal stream tests, presented in a portable format. These specially designed games were intended to be child friendly and purposely constructed without sound effects. Previous research suggested that the addition of sound can improve visual performance in dyslexic readers (de Boer – Schellekens & Vroomen, 2012; Hairston, et al., 2005), and the current studies aimed to focus exclusively on the relationship between visual performance and reading ability. The second phase of testing was to select commercial games similar to those (custom made games) which were successfully correlated with reading performance, to determine if visual spatial attention training could improve reading fluency and accuracy. It was hypothesized that portable gamified dorsal stream tasks, administered in school settings, would be able to differentiate good and poor readers in terms of their game performance. It was also anticipated that reading abilities could be improved using games that target the visual – spatial attention deficits that were identified in poor readers during the first phase of testing.
3.6. References


Elbaum, B., Vaughn, S., Tejero Hughes, M., & Watson Moody, S. (2000). How effective are one-to-one tutoring programs in reading for elementary


Evidence suggests a link between deficits in visuo spatial attention, and subsequent reading ability. However, all the research in the area thus far has been conducted using traditional, lab-based psychophysics, with very tightly controlled visual parameters. In order to take this research further, such as using visuo-spatial tasks to train the visual system and reading skills, it must first be established that such tasks can be taken out of the laboratory, ‘gamified’, and still predict reading ability. This study aimed to determine if subtle visual deficits in poor readers could be detected outside a traditional laboratory, in relatively uncontrolled settings using portable game-like technology. Classic visual search and change detection programs, thought to rely on the visual dorsal stream, were modified to a game-like format. They were administered on a portable computer tablet within the participants’ school setting. Whilst IQ was a strong predictor of reading rate, visuo-spatial tasks such as visual search speed, and change detection, each accounted for unique variance in reading rate over and above IQ, age and phonological ability. These results are consistent with the visuo – spatial attention deficit hypothesis, and provide support for the development of portable computerised games which may assess and potentially target this deficit in poor readers.
4.1. Introduction

Reading is a complex skill that is usually acquired during childhood, and continues to be developed into adulthood. One way to view reading skill is across a continuum, with very good readers at one end of the spectrum, average readers in the middle and poor readers at the opposite end (Bell & Perfetti, 1994). Beginning in the 1980’s, there has been increasing evidence to suggest that impairment in visual coding within the reading network may uniquely influence the development of good reading skills. Growing evidence suggests that a deficit in the dorsal stream, specifically the visual pathway responsible for visuo-spatial attention, may be one of the areas most closely linked with reading development and reading delay (e.g., Facoetti, Paganoni, Turatto, Marzola & Mascetti, 2000; Facoetti, Turatto, Lorusso & Mascetti, 2001; Vidyasagar & Pammer, 2010). The proposition that a dorsal/magnocellular deficit may be associated with reading difficulties, is supported by a large amount of converging behavioural and neuroimaging evidence (e.g., Boets, Wouters, Van Wieringen & Ghesquiere, 2006; Casco & Prunetti, 1996; Cornelissen, Hansen, Hutton, Evangelinou & Stein, 1998; Demb, Boynton & Heeger, 1998; Eden, et al., 1996; Facoetti, et al., 2010; Gori, et al., 2014; Kevan & Pammer, 2008; Livingstone, Rosen, Drislane & Galaburda, 1991; Lovegrove, Bowling, Badcock & Blackwood, 1980; Talcott, Hansen, Assoku & Stein, 2000; Yamamoto, et al., 2013) (although refer to Ramus, 2001 & Skottun, 2000; 2005 for counter arguments). During reading, the visual system makes a series of saccades, fixations and sometimes regressions whilst reading words and sentences (McConkie & Rayner, 1975). In terms of visuo-spatial coding, the visual system is required to track words along a line of text, isolate and identify individual words within text, different letters within words, and different features within words. This all happens extremely quickly, within the space of a fixation, which can be as fast as a few hundred milliseconds (Rayner, 1998). Emulating these fast visual signals, it has been demonstrated that reading skills are associated with many other, well-controlled visual task such as coherent motion (for a meta-analysis see Benassi, Simonelli, Giovagnoli & Bolzani, 2010), visual frequency doubling (Buchholz & McKone, 2004; Kevan & Pammer, 2008; Pammer & Wheatley, 2001), visual search (Casco & Prunetti, 1996; Casco, Tressoldi & Dellantonio, 1998; Iles, Walsh & Richardson, 2000; Sireteanu, et al., 2008; Vidyasagar & Pammer, 1999), temporal order judgement (for review, see Farmer & Klein (1995)), and change detection (Rutkowski, Crewther & Crewther, 2003).
Historically, the behavioural experiments investigating dorsal stream performance have generally occurred within a laboratory setting, in which the visuo-spatial factors are as tightly controlled as possible. For example, in a typical vision experiment, the participant is placed in a room that is relatively quiet and free from distraction. The lighting is most likely controlled, with some experiments also providing time for dark adaptation. Usually seating position and viewing distance from the screen are controlled (including visual angle), and sometimes with the addition of a chin rest, or fixation cross. The screen itself will be meticulously measured for luminance, and this will be maintained for consistency between participants unless an element is purposely modified as required by the experimental design. This type of testing occurred because the dorsal and ventral visual pathways are highly sensitive to very specific types if visual information, such as motion and spatial coding (Merigan & Maunsell, 1993). Thus in order to be certain that a study was in fact isolating the dorsal/magnocellular pathway, it was important to control the visual factors that would illustrate this. However, over three decades later, and with significant advances in technology, a more practical question emerges. Can tablet computer systems using custom made game-like programs, predict reading ability? And can this technology be successfully implemented in school based settings where reading is most likely to occur? This is important for the development of this research, because gamifying these tasks this would obviate the need for tightly constrained visual parameters and settings, and open up the possibility of in-class, in-house games that can be carefully designed to achieve the same objectives as the original psychophysical research but with far more attention, and engagement from the child.

During the reading process the visual system is required to identify and extract a target – in this case a word – within a cluttered array. This is analogous to a visual search task, in which a target must be found within a cluttered scene. The difference between natural search, and reading, is that in reading, the search mechanism is a trained movement, such that the search mechanism must work in a sequential and linear way across the page (see Rayner, 1998 for a review). This differs from natural search, which typically occurs by scanning the environment in a non-fixed fashion until we locate a specific target amongst a range of distracters (Horowitz & Wolfe, 1998). Thus effective reading requires training the visual system to search in a specific way, and such training probably occurs as part of the development of the reading process itself (Vidyasagar, 1999). However there is also some very recent evidence to suggest that such training can be separate to the
reading process, and facilitate reading acquisition. Franceschini and colleagues (2012) conducted a three year longitudinal study that demonstrated that pre-reading attentional orienting (as assessed by visual search) predicted future reading skills in grades 1 and 2. Thus, a visual search task administered prior to the onset of learning to read can be useful in detecting visual attention deficits during early development.

There are two types of visual search (Treisman & Gelade, 1980); a feature search is described as a parallel process whereby the target and distracters are differentiated by a single element (such as colour) which automatically ‘pop out’, and are quickly identified in the scene, such as finding a red circle within an array of blue triangles (or in ‘real-world’ terms, finding an orange in a fruit bowl of apples). Speed of search within this domain is not thought to be impacted by number of distracters (Treisman, 1982). This is contrasted with a conjunction search, where the target shares more than one element (colour, shape, orientation, size) with the distracters and thus takes longer to find due to the decreased discriminability between items. An example of this might be finding a ‘red circle’ target within an array of red triangles and blue circles (or finding a green apple amongst red apples and green limes). It is also influenced by the number of distracters in the scene. Feature searches are thought to occur automatically, whereas conjunction searches place higher demands on the visual system due to serial scanning and thus requires focussed attention (Treisman & Sato, 1990).

When engaging in search, the visual system utilises a ‘spotlight of attention’. This is similar to shining a torch in a dark room, or hitting the zoom function on a camera. Objects that fall within the spotlight of attention can be detected or identified more quickly than objects outside of this spotlight, and area of the spotlight can increase, but at a cost to reaction time. This spotlight of attention can be guided through a cluttered array to detect a sought after target (Eriksen & James, 1986). Each time the spotlight of attention is moved, it determines the next most likely position of the target based on pre-attentive information (Wolfe, Cave & Franzel, 1989). In the case of reading, it is thought that the attentional spotlight is used as a way to selectively attend to the letters and words on a page. That is, the visuo-attentional system scans, using a spotlight of attention in a sequential order along the letters of a word during fixation, and also provides a spatial navigation mechanism for reading to occur. Without a trained spotlight of attention moving skilfully from left to right across the page, fluent reading would be unlikely to occur (Vidyasagar, 1999).
A second visuo–spatial search task is change detection. Change detection refers to the ability to notice change between two images, or in a single image which slowly changes over time. When two complex images are presented one after the other, the viewer can sometimes fail to recognise the change. This can occur even though the viewer is specifically looking for a change, is provided with a long preview (8 seconds) of the image before detecting change, the change is repeatedly shown, and the viewer would normally recognise the change if the flicker between images was not present (Rensink, Regan & Clark, 2000). Change detection ability is incredibly important because it helps us to notice differences in the world around us (Rensink, 2002), and is considered to be analogous to visual search in the real world because of the requirement to search two items or scenes for similarities and differences (Hyun, Woodman, Vogel, Hollingworth & Luck, 2009). Given the requirement to visually focus attention on a scene to detect a target or change (Rensink, 2002), change detection is also suggested to draw upon the dorsal spotlight of attention to successfully detect a target. Consistent with visual search, change detection has been used as an index of dorsal processing to discriminate between dyslexic and non-dyslexic readers, resulting in success within child populations. For example, a change detection task was utilised with a group of dyslexic children to determine if, like visual search, change detection is also impaired in poor readers. Children were asked to view a set of four letters, followed by a fixation cross, then another set of four letters. They were then required to indicate if the scene was the same or different, and if so, which letter was different. The authors found that children with developmental dyslexia were equally as accurate in detecting change, however took significantly longer to detect this change, when compared to their normally reading, age matched peers. Given the similarities between visual search tasks, and reading skill, the range of studies linking visual search performance and reading ability (Moores, Cassim & Talcott, 2011; Casco, Tressoldi & Dellantonio, 1998; Sireteanu, et al., 2008), and the relative simplicity of the tasks (finding a target or a change in a cluttered scene), visual search tasks are likely to be sufficiently robust to make the transition out of the laboratory and into the classroom, and still be able to predict reading ability over good and poor readers.

Researchers have begun to explore the computerised gamification of traditional psychology experiments within a controlled setting. For example, Berger and colleagues (2000) designed a series of game-like computer tasks to measure attention properties such as executive control, alertness and orienting, for use with child populations. In the game which measures alertness, children were
asked to “help the farmer to catch the animals that want to run away” (Berger, et al., 2000, p. 298), by tapping on animals which appear on the screen as fast as possible. At the conclusion of the task, children were shown an image of all the animals they had successfully ‘caught’. A warning tone was provided at various times before stimulus onset, with the influence of tone versus no tone assessed to determine its influence on reaction speed (Berger, et al., 2000) (see also Dunbar, Hill & Lewis, 2001 – “The Frog Game” to measure switching attention abilities; Metcalfe, Kornell & Finn, 2009 – “Dragon Master” to provide motivation for correct responses; for more examples of standard psychological experiments modified into game like formats). This modification to classic psychology experiments can be considered a type of ‘gamification’. According to Huotari and Hamari (2012), “gamification” is defined as “enhancing a service with (motivational) affordances for game - like experiences in order to support the users overall value creation” (p19). They assert that in order for gamification to be successful, the program must invoke the same psychological experiences that games can create. At present, it appears that overall the highest incidences of gamification are occurring in the education sector, and whilst more research is needed, the effects of gamifying academic learning have been mostly positive (Hamari, Koivisto & Sarsa, 2014). In relation to reading research, exploration of gamification of visuo – spatial tasks has commenced, most notably by Gaggi and colleagues (2012), who have proposed a series of games based on dorsal stream tasks. For example, their ‘paths’ game involves engaging visual search skills to define a path through crowded open C shapes to reach an identified target. They propose that providing these game – like visual tasks to pre readers may assist in identifying poor readers, as well as provide training opportunities for early intervention.

In agreement for the need to explore the value of game - like dorsal stream tests, the aim of the present experiment was to create portable and ‘gamified’ visual search and change detection tasks to determine if dorsal stream deficits are still indicative of reading ability, even when the environment is more ‘messy’, and representative of school and home settings. Of the known tasks that are thought to access the dorsal stream, it was hypothesised that ‘spot the difference’ (change detection) and ‘find the object’ (visual search) type activities may be more appealing to the demographic being tested for the present study based on their game - like qualities. Administering the testing using a game like format may influence motivation and subsequently performance, as participants may be more willing to attend as compared to classic visual search tasks. However, this type of
testing may have enormous variability in terms of contrast, colour and viewing angle, which has been previously tightly controlled. Whilst the testing environment may be relatively uncontrolled, if the dorsal/magnocellular pathway is robust to variants in visual presentation, then like in the laboratory, dorsal/magno paths should predict reading ability. If this is the case, then this would have enormous implications for developing magnocellular-driven computer games to engage children for subsequent research or even training purposes.

4.2. Method

Participants
Eighty three children, (49 males), participated in the experiment. Children were aged between six and 12 years, with an average age of nine years, and were tested within the school setting. Data collected from two children was excluded due to difficulty following instructions, and data from two were excluded due to low IQ (below 70). Data from two were excluded as there minimum reading rate was below the cut off (6 years, 0 months), and unable to be reliably assessed and six outliers were removed as they were more than two standard deviations below the mean for their search speed ability in the visual search task or change detection task, resulting in a speed accuracy trade off. Two excluded participants demonstrated reading speeds more than 2SD’s above the mean (32 and 43 months above their expected reading speed), indicating a tendency to rush through the tasks provided. Children participated in both search and change detection tasks, with the exception of five children who participated in the change detection task only. All parents provided informed consent, and children also provided consent prior to testing. Information regarding previous diagnoses was not collected as the aim was to explore the relationship between dorsal stream functioning and reading across the continuum (from very poor to very good readers), as compared to an exclusively diagnostic perspective. Children wore corrective glasses during the experiment where this was required. All our methods conformed to the Declaration of Helsinki and had Department of Education and university ethics approval.

Portable tablet
Visual search ability was measured using a Samsung Galaxy Tab 10.1 touch screen tablet computer. Display size 10.1 inch widescreen, 1280x800 WXGATFT LCD, 149 pixels per inch (ppi). Processor was a 1GHz dual core NVIDIA Tegra 2 processor, with 1GB (RAM), 16GB (ROM). Video consisted of full HD video
playback (1080p) @ 30 fps. The tablet utilised an android operating system
(Honeycomb), Android Version 3.1, Kernel Version 2.6.36.3, root@DELLl37#1.
Model number GT-P7510. The stimuli were designed using a computer games
engine called ‘Unity’, version 4.0 released in November 2012 by Unity
Technologies. Unity is a cross platform game engine and Integrated Development
Environment (IDE), and was selected for its ability to make the visual stimuli game
like and enjoyable for the participant.

Visual Search Game

A classic visual search format was modified to create a game-like experience for
the participant, and we named this game “Bug City”. Children were asked to tap on
the correct stimuli (or bug) from an array of other ‘bug’ distracters. Each bug was
approximately 2 cm by 2 cm on the computer screen, and the target bug was
located at least once in each of the 73 areas on screen during the game. The target
bug was in the bottom right corner through each trial, the target was always
present, and the target bug changed from trial to trial. It was designed this way so
as to maintain the child’s interest, but reduce the memory component required to
remember the target bug. This is very different from other visual search tasks in
this field, which have typically presented the target as separate to the array of
distractors. For example, in a study by Casco and Prunetti (1996) participants were
shown a white sheet with the target and were asked to fixate on this target for a few
seconds, and were then asked to find the target in a varying number of distractors.
This instruction requires the participant to engage short term memory which could
entail a type of memory strategy that includes the phonological loop to remember
the target. The game used in the current experiment was purposely designed with
the target on screen to reduce the memory component associated with previous
visual search tasks. Whilst recent dyslexia evidence exists for serial order deficits
in short term memory rather than deficits in memory for single items (Hachmann,
et al., 2014), it was nevertheless considered advantageous to remove this potential
factor from the present study. It is difficult to determine the visual angle as one of
the core aims of the experiment is that children could use and position the tablet in
any way that they felt comfortable. Each bug appeared once in each display array,
so that the display was made up of an array of different bugs of varying size, colour
and shape, refer to Figure 3.4. Consistent with the aims of the study, colour, shape,
complexity or contrast was not controlled over stimuli. Some stimuli were similar
(for example butterflies) and varied in terms of pattern and colour, to provide a
challenge to the participant. The display remained on the screen until the child responded. Speed was calculated from the time the trial was presented until the child tapped the screen. Incorrect responses were not included in calculations of speed performance. The next trial started automatically following their response. This format is also more consistent with off-the-shelf ‘hidden object’ computer games that the children are likely to be familiar with, thus increasing the game-like quality of the task. There were four conditions, with 12, 24, 36 or 73 items (bugs) on screen. There were 25 trials for each of the four randomly presented conditions, resulting in a total of experimental 100 trials. There were also 2 trials at the beginning of the experiment that were not included in the analysis, as these were classified as practice trials to familiarise the child with the experiment. Searching requires the ability to visually guide attention through a cluttered array, which is thought to be controlled through the dorsal stream (Ungerleider & Haxby, 1994). It is suggested that this program may reflect the functioning of the dorsal stream by collecting the information regarding the individual speed and accuracy performance during the search task.
Figure 3.4. An example of Bug City computer program with 12, 24, 36 & 73 items
Change Detection Game

Change detection ability was assessed using the same computer tablet as described above. The stimuli consisted of a game called ‘Detective Quest’, whereby children are asked to spot the difference between two images presented side by side. In change detection studies, it is common for images to be presented one after the other, with a disruption in between, such as a mask or blank screen (Simons, Franconeri & Reimer, 2000). In the present experiment, images were presented on the same screen. Children were directed to tap exactly where the difference appeared in the right box, outlined in red, as fast as possible. This method was selected for two reasons. Firstly, it is suggested that by having a ‘spot the difference’ type format; the task may be more child friendly and game-like for the participant. Secondly, it was thought that this method may more closely match reading, whereby children naturally moved their eyes back and forth across a single image. For example, in a study by Shore and Klein (2000), participants completed a change blindness task with two different photographs presented on one laminated card. They explained that they chose this method over the flicker paradigm because they wished to make the task as natural as possible to regular viewing by allowing the participant complete control over the timing and scanning demands associated with detecting the difference. For the present task, children were allowed a maximum of 30 seconds to identify the difference before being asked to move on. Speed was calculated from the time the trial was presented until the child tapped the screen. Incorrect responses were not included in calculations of speed performance. The next trial started following a ‘ready screen’ that the participant tapped. There were 40 images in total, consisting of both line drawn and photographic images (see Figure 4.4). There were also 2 trials at the beginning of the experiment that were not included in the analysis, as these were classified as practice trials. Like visual search, this change detection task is also considered a behavioural measure of dorsal stream functioning due to the need to visually focus attention to detect a target or change. Visual search and change detection are suggested to rely on very similar neurocognitive mechanisms. For example, it is easier to find a target that is present than one that is absent, in a similar way that it is easier to search for the presence of a change compared to the absence of a change. The presence of a change in a change detection task can also be detected in an unlimited – capacity parallel process if the change is distinctive, just like the
presence of, say for example, a red square in an array of green squares during visual search (Hyun, et al., 2009).

Figure 4.4. An example of Detective Quest easy (top) and hard (bottom) images

Instructions

Children were introduced to the study and asked if they would like to participate prior to commencement. Upon obtaining verbal consent, participants were then given instructions to play the programs or 'games' provided. They were advised to rest their hands below the screen on the table between trials to minimise differences due to motor strategies. Children were also administered a series of
standardised tests, under standardised (minimised distraction) conditions. The Woodcock – Johnson III Brief (BIA) was administered to obtain a brief measure of intellectual ability. The Castles and Coltheart II (CC2)(2009) was used to obtain a measure of phonological ability using the non-word component, as it has been suggested that early phonological performance is a strong predictor of later reading ability (Torgesen, Wagner, Rashotte, Burgess & Hecht, 1997) – (see Witton and colleagues (1998) who have also used the CC2 non-word component as a measure of phonological decoding). The Neale Analysis of Reading Ability (NARA)(3rd ed.) was used to obtain baseline data on reading ability. The NARA is an Australian standardised reading test that measures reading accuracy, comprehension and rate. Comprehension was not analysed as part of this study as the researchers were specifically interested in accuracy and rate. Accuracy was measured by number of single word errors during reading of the passage. Rate was measured by stopwatch, and refers to the speed or fluency of the passage read. In this test, children are timed whilst reading stories which increase in difficulty, and are asked a series of questions following each story. Children received a certificate or small reward (eraser or pencil) for their participation in the study. The children participated in a variety of settings, such as other classrooms or reading rooms, often with other children. Again, consistent with the experiment's aims, the environment, lighting, and noise levels were not controlled.

4.3. Results

Visual Search
Results from the study were first analysed to ensure the visual search task represented a true conjunction search, which would reflect performance of the dorsal visual pathway (Vidyasagar & Pammer, 1999). An increase in reaction speed was evident as the number of distracters increased. For the 12 item condition \( (M = 2.935s, SD = .607) \), participants were the fastest, followed by the 24 condition \( (M = 3.528s, SD = .700) \), 36 condition \( (M = 4.509s, SD = .986) \), with the 73 condition \( (M = 8.206s, SD = 2.63) \) being the slowest. Also, over the 100 trials accuracy was high with a low number of incorrect responses \( (M = 4.43, SD = 3.31) \), suggesting participants were working hard to find the target in each trial. A summary of overall reading performance is provided in Table 1.4.
Table 1.4.

*Summary of overall reading performance for visual search participants*

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>NARA Accuracy</td>
<td>-6.3</td>
<td>23.3</td>
<td>-43.0</td>
<td>55.0</td>
</tr>
<tr>
<td>NARA Rate</td>
<td>4.9</td>
<td>20.2</td>
<td>-39.0</td>
<td>43.0</td>
</tr>
</tbody>
</table>

M = Average discrepancy from the child’s expected reading score, in months. SD = Standard Deviation, Min= Minimum score obtained in months, Max= Maximum score obtained in months.

The relationship between NARA reading rate and accuracy, and visual search speed was investigated using the Pearson product – moment correlation coefficient. Reading rate and accuracy was determined by calculating the discrepancy between the child’s chronological age their expected reading age for accuracy and rate. The overall relationship between reading accuracy and visual search speed was not significant ($r = -0.021$, $n = 67$, $p = .868$). However, the correlation between visual search speed and reading rate at the 12 ($r = -0.361$, $n = 67$, $p = .003$, $B = -.011$)(Figure 5.4), and 24 – item conditions ($r = -0.311$, $n = 67$, $p = .010$, $B = -.011$) was significant, suggesting a medium, negative correlation between reading rate and visual search speed when fewer distractors are present. Collapsing over all four item distractor conditions, there was a significant medium correlation between visual search speed and reading rate abilities ($r = -0.317$, $n = 67$, $p = .009$, $B = -.016$).
Figure 5.4. Mean NARA rate discrepancy in months, and visual search speed for the 12 item condition in seconds

Because of the wide age range, we investigated the relationship between age and search; There was no significant correlation between age and visual search speed ($r = -0.160, n = 67, p = 0.195$) across all participants. This was unusual, as it was expected that visual search speed would improve with age. A further investigation examining scatterplots suggested an interesting interaction; when the data was grouped by good readers (no reading rate delay), poor readers (a reading rate delay of 1 month to 23 months) and dyslexic readers (2 or more years reading rate delay), an interesting finding emerged. The ‘good reader’ group were significantly faster in their visual search speed as they aged ($r = -0.396, n = 35$), however the poor readers ($r = -0.227, n = 26$) and dyslexic readers ($r = -0.180, n = 6$) did not demonstrate significant improvements in search speed.

Standard multiple regression analysis was used to determine whether visual search speed performance could predict reading rate ability over and above IQ, age and phonological ability. Preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity. Visual search speed for the 12 item condition revealed that although IQ was the best predictor of reading rate, explaining 14% of the variance, visual search speed also explained an additional 7% of the total variance in reading rate (see Table 2.4). Adding age and phonological ability variables did not appear to significantly impact the ability to predict reading rate.
Standard multiple regression analysis was also used to determine whether visual search speed performance for the 24 item condition could predict reading rate ability over and above IQ, age and phonological ability – as measured by non-word reading. Results were similar whereby IQ was the best predictor of general reading ability, explaining 11% of the variance, and visual search speed explained an additional 4% of the total variance in reading rate (see Table 3.4). Adding age (rate is standardised with age using the NARA) and phonological ability variables did not appear to significantly impact the ability to predict reading rate.

Table 2.4.

**Summary of standard multiple regression for variables predicting reading rate in the 12 - item condition**

<table>
<thead>
<tr>
<th></th>
<th>β</th>
<th>p</th>
<th>sr²</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ</td>
<td>.538</td>
<td>.000</td>
<td>.379</td>
</tr>
<tr>
<td>Visual Search Speed</td>
<td>-.264</td>
<td>.014</td>
<td>-.256</td>
</tr>
<tr>
<td>Age</td>
<td>.017</td>
<td>.887</td>
<td>.014</td>
</tr>
<tr>
<td>Phonological Ability</td>
<td>-.055</td>
<td>.657</td>
<td>-.045</td>
</tr>
</tbody>
</table>

*Note*: β for standardised coefficient; R²A = .370, p= <.000 ; sr² = semi partial correlation; IQ = Woodcock Johnson III Brief Intellectual Ability score; Visual Search Speed = for 12 item visual search condition.

Table 3.4

**Summary of standard multiple regression analysis for variables predicting reading rate in the 24 - item condition**

<table>
<thead>
<tr>
<th></th>
<th>β</th>
<th>p</th>
<th>sr²</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ</td>
<td>.502</td>
<td>.002</td>
<td>.339</td>
</tr>
<tr>
<td>Visual Search Speed</td>
<td>-.242</td>
<td>.044</td>
<td>-.210</td>
</tr>
<tr>
<td>Age</td>
<td>-.068</td>
<td>.623</td>
<td>.051</td>
</tr>
<tr>
<td>Phonological Ability</td>
<td>-.069</td>
<td>.584</td>
<td>-.056</td>
</tr>
</tbody>
</table>

*Note*: β for standardised coefficient; R²A = .306, p= <.000 ; sr² = semi partial correlation; IQ = Woodcock Johnson III Brief Intellectual Ability score; Visual Search Speed = for 24 item visual search condition.
Data was screened prior to the commencement of analysis to check for outliers and errors in data entry, and three outliers were removed from the analysis. Homogeneity of variance and normality tests were conducted and there were no violations, therefore data analysis proceeded without the need for transformations. A summary of overall reading performance is provided in Table 4.4. Given that significant effects were found at the ‘easier’ 12 and 24 item conditions in visual search, we were prompted to perform a similar ‘easy vs. hard’ analysis with change detection data. For each of the 40 images, a mean speed of response was recorded. Images were classified as being ‘easy’ if the mean speed of response was six seconds or less. Items were classified as being ‘hard’ if the group mean response was over six seconds. This distinction was made on the basis that there appeared to be a trend whereby participants were answering relatively fast (M = 4.01 for under 6s condition) or much slower (M = 13.269 for over 6s condition) and it appeared reasonable to draw the line of difficulty at this point.

Table 4.4.

Summary of overall reading performance for change detection participants

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>NARA Accuracy</td>
<td>-3.1</td>
<td>22.9</td>
<td>-43.0</td>
<td>55.0</td>
</tr>
<tr>
<td>NARA Rate</td>
<td>7.7</td>
<td>18.8</td>
<td>-18.0</td>
<td>53.0</td>
</tr>
</tbody>
</table>

M = Average discrepancy from the child’s expected reading score, in months. SD = Standard Deviation, Min= Minimum score obtained in months, Max= Maximum score obtained in months.

For NARA reading accuracy, there was no significant relationship with speed of detection for easy images (r = .077, n = 65, p = .543) or hard images (r = .042, n = 65, p = .742). However, for NARA reading rate, there was a significant negative correlation between reading rate and ‘easy’ images (r = -.334, n = 65, p = .007, B = -.021) (Figure 6.4), but not ‘hard’ images (r = -.201, n = 65, p = .108, B = -.025). This suggests that slower readers are also slower at detecting the change in the easy images, when compared to average and above average readers. There was also a significant correlation between speed of response and age, with younger participants taking longer to identify the change when compared to older participants (r = -.452, n= 65). Similar to visual search, the groups were split to
explore if both good and poor readers were faster in their search ability as they aged. When participants were divided between good and poor reading groups, the good readers (no reading rate delay) improved over time \((r = -0.372, n = 35)\), as did the poor readers (reading rate delay of up to 2 years)\((r = -0.506, n = 30)\).

\[\text{Figure 6.4. Mean NARA Rate discrepancy in months, and change detection speed for the easy item condition}\]

Standard multiple regression analysis was used to determine whether change detection speed for easy images could predict reading over and above IQ, age and phonological ability. Preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity. Results indicate that change detection speed was the best predictor, explaining 9% of the variability in reading rate performance, followed by IQ which explained 7% of the variability in reading rate. Age (as rate is standardised with age) and phonological ability did not appear to significantly predict reading rate in this model (see Table 5.4).
Table 5.4.

Summary of standard multiple regression analysis for variables predicting reading rate

<table>
<thead>
<tr>
<th></th>
<th>$\beta$</th>
<th>$p$</th>
<th>$sr^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ</td>
<td>.321</td>
<td>.013</td>
<td>.260</td>
</tr>
<tr>
<td>Change Detection</td>
<td>-.374</td>
<td>.004</td>
<td>-.299</td>
</tr>
<tr>
<td>Speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-.120</td>
<td>.361</td>
<td>-.094</td>
</tr>
<tr>
<td>Phonological Ability</td>
<td>.186</td>
<td>.129</td>
<td>.157</td>
</tr>
</tbody>
</table>

Note: $\beta$ for standardised coefficient; $R^2A = .275, p = <.000$; $sr^2$ = semi partial correlation; IQ = Woodcock Johnson III Brief Intellectual Ability score; Change detection speed = for easy items.

4.4. Discussion

In this study, a portable computer tablet was utilised to administer specially designed visual dorsal stream games to children who as a group, presented with a range of reading abilities. The testing environment contained all the sensory complexity of normal, everyday school settings. These environments were varied, and not controlled in terms of noise, light and viewing distance, in order to test the hypothesis that dorsal stream deficits predict reading ability in everyday settings. The results indicate that portable technology using specifically targeted games can differentiate good and poor readers. However, the findings of the study were mixed, whereby visual search and change detection speed of response predicted reading rate, but not accuracy in the easier versions of both tasks.

The results from the visual search experiment are consistent with previous findings which suggest that visual search performance can predict reading ability (de Boer – Schellekens & Vroomen, 2012; Vidyasagar & Pammer, 1999), and that visual performance can predict reading over and above intellectual ability and phonological skills (Pammer & Kevan, 2007). Visual search speed did not differentiate good and poor readers in terms of reading accuracy, only reading speed. Unexpectedly, only visual search speeds in the 12 and 24 item conditions were correlated with reading rate, compared to the higher load (36 and 73 item) conditions. Contrary to this finding, previous studies have demonstrated that dyslexic individuals may have more difficulty as scenes became more cluttered or
crowded. For example, Moores, Cassim and Talcott (2011) found that compared to normal readers, dyslexic adults were significantly impacted by closer spacing of visual stimuli and increased numbers of stimuli in visual search tasks. Similarly, Vidyasagar and Pammer (1999) suggested that differences between dyslexic and non-dyslexic readers emerge when the search array becomes more cluttered, and the attentional spotlight becomes stretched to its limits. However, in the current study, a relationship with reading ability occurs in the ‘easier’ tasks, there is no relationship with reading ability when the search array is very cluttered, or it takes a long time to detect the change in the change detection task. A potential explanation is that the 36 and 73 item conditions in the search task were simply too difficult to process quickly for all the participants, resulting in minimal differences between groups. In the study by Moores and colleagues (2011), the stimuli consisted of 1, 8 or 16 items on 22 inch screen. Illes, Walsh and Richardson (2000) used 1,2,4,8 or 16 items in their visual search display (28x20cm screen). Vidyasagar and Pammer (1999) used 10, 24, 36 and 70 distractors, and found performance in the dyslexic group was impaired with the larger set size. However, their distractor items were very basic (e.g. red circles and blue triangles), whereas in the present study each bug was complex with varying combinations of colours and shapes. It is possible that a smaller screen (10.1 inch), with greater complex clutter (36 and 73 items), resulted in an ‘overload’ of the visual system for all participants in our higher load conditions. This is difficult to confirm with the outcome measures; the target was always present, so accuracy simply reflects the participant selecting a different target. There was no indication of decreasing accuracy with increasing array sizes (with an average accuracy rate of 96%), suggesting that children were working to find the correct target and taking longer to do it. Additionally, this was a unique search task compared to previous experiments; the program was designed to game-like, and the target was located on the screen with the distractors, thus minimising memory effects as the child could constantly refer back to the target. Another possibility then, is that memory may have provided a confound in previous search tasks – the larger or more cluttered the array, the longer that a child has to hold the target in working memory. It is well known that there is a strong relationship between short term/working memory and poor reading skills (for a meta-analysis see Swanson, Zheng & Jerman, 2009), thus it is not implausible that removing the memory component in the current task changes the outcome profiles of the search strategies. This relationship between memory and visuo-spatial coding like search, provides a valuable avenue for future research.
The results from the change detection experiment also support previous research which suggests that change detection abilities can predict reading ability in good and poor readers (Rutkowski, Crewther & Crewther, 2003). In the current study, when reading performance was compared with general change detection abilities there were no significant relationships. However, when the task was divided into ‘easy’ (under 6 seconds) and ‘hard’ (over 7 seconds) conditions an interesting finding emerged. Children who were slower at reading were also more likely to be slower at detecting the change in ‘easy’ but not ‘hard’ images. This finding appears consistent with the results of the present visual search experiment. Easy images can differentiate good and poor readers where more complex images which take longer to process cannot. It is suggested that the harder version of both tasks resulted in a type of ‘floor effect’, resulting in difficulty extracting group differences. Consistent with the search task, memory does not play a strong role here because again, both targets are on the screen at the same time. We suggest that the ability to engage and disengage attention between images in the present experiment may involve similar processes to those used during reading. According to Facoetti and colleagues (2000), orienting and focussing of attention is important in the process of reading because these processes may play a critical role in the control of saccades that occurs during reading. In their study, they found that dyslexic children are significantly slower at shifting their visual attention between locations, and maintain attention for shorter periods of time compared to normal readers. A study by Buchholz and Davies (2005) similarly found significant difficulties for dyslexics in shifting attention between objects. In the present study, difficulty shifting attention was also demonstrated, with the ability to detect changes between two images predictive of reading ability.

The finding that performance speed did not improve with age for visual search in the poor and dyslexic reading group is an interesting one. Over the course of normal development, a child’s magnocellular functioning gradually improves, and fully matures by about 11 years of age (Crewther, Crewther, Barnard & Klistorner., 1996). Thus, it makes sense that visuo spatial attention appears to improve and children become faster as they age. It is also plausible that if there is an impairment in the dorsal stream, this may result in failure to improve or inconsistent improvement over time. However, in the change detection task both good and poor older readers tended to perform better than younger readers. It is unclear as to why this difference between tasks has occurred. Perhaps the change detection program was more game - like and motivating for the younger participants or perhaps the timed instructions of the task created a greater sense of
urgency, compared to the visual search task. As change detection and visual search are considered to engage similar visual processes (Hyun, et al., 2009), further research into this question is needed to determine why there appears to be age related differences in performance across only one task.

It was noted during testing that some children explained that they played computer tablets in the home, whilst others only had access at school. Previous familiarity with touch tablet games and hours of game play were not recorded in the current experiment. Therefore some children may have been more familiar with the tablet game concept. It is believed that this would not have a significant impact on the ability to play the games (visual experiments) provided, as all children had practice time pre experiment and the games were considered intuitive and basic by nature (i.e. tap the bug once you find it on the screen). However, emerging evidence suggests that playing action based video games can improve visual attention. In a study by Li and colleagues (2009) non-gamers who played action video games for 50 hours over nine weeks improved their ability to detect contrast, and this improved contrast sensitivity remained five months to two years later. When comparing video game players to non-video game players, they also discovered that in general, that people who played action video games had higher contrast sensitivity compared to non-gamers. They suggested that this change in sensitivity represented a type of cortical plasticity. Therefore, when considering the present experiment, it may be important in the future to document each participant’s familiarity with tablets and average hours of game play each week, and to take this into account when examining the visual performance findings.

A comparison of controlled lab versus flexible school based testing environments would have been valuable in the present experiment, in order to compare the relative contributions of visual factors such as viewing distance, lighting and colour, as well as potential motivation and social factors on visual performance. Unfortunately, due to time constraints we were unable to pursue this comparison, but feel it would be a worthwhile area for future research. It may also be useful to use eye tracking technology to gain a better understanding of eye movements whilst children engage in these games. Research suggests that the reader makes 90% of saccades in a left to right manner across the page (Rayner, 1998). It would be useful to determine if children are darting their eyes randomly around the display to find the target in these games (visual search has no memory, see Horowitz & Wolfe, 1998), or if they are engaging in a systematic left to right serial search to locate the target in the array. This would provide greater insight into if these specially designed games encourage visual strategies similar to
reading, and if good and poor readers differ in visual strategy during these dorsal stream tasks.

As suggested by Castles and Coltheart (2004), it is now time to explore both longitudinal studies to determine deficits that precede and predict reading ability, and training programs that could address these identified deficits. A longitudinal study conducted by Franceschini and colleagues (2012) has demonstrated that serial search and spatial cueing performance in pre readers can predict reading performance in Grades 1 and 2. Similarly, Kevan and Pammer (2009) also confirmed that dorsal stream performance can predict reading ability, with frequency doubling sensitivity in pre readers predicting literacy skills in grade one. There is also some early success in the exploration into remediation programs that target visuo–spatial attention deficits using computer games (Franceschini, et al., 2013). It is suggested that in order to effectively treat the deficit, it is crucial to first identify the visual deficit so that the intervention can appropriately match the visual problem. The primary aim of this experiment was to determine if dorsal stream deficits can be detected outside of the laboratory in clinically relevant settings. This study illustrates that identification of subtle visual deficits can be assessed and successfully detected in everyday environments using practical and portable equipment. However, replication is required, to confirm that portable technology with visual programs can robustly predict reading ability across a variety of settings. If effective, these early steps may provide a platform for exploring the use of carefully constructed, targeted computer games as training devices in the classroom and at home. Remediation programs within a visual attention focus are still in their early days, and further studies are needed to explore the impact of type, frequency and duration of these programs on reading ability and the maintenance of these potential gains for poor readers over the longer term.
4.5. References


Crewther, S. G., Crewther, D. P., Barnard, N., & Klistorner, A. (1996). Electrophysiological and psychophysical evidence for the development of


Gaggi, O., Galiazzo, G., Palazzi, C., Facoetti, A., & Franceschini, S. (2012, July). A serious game for predicting the risk of developmental dyslexia in pre-
readers children. In Computer Communications and Networks (ICCCN), 2012 21st International Conference (pp. 1-5). IEEE.


Chapter 5.

Spot the Difference: Tablet Game Performance Can Predict Single Word Reading Ability

Abstract

The ability to read successfully involves fast processing of visual information, mediated by the dorsal visual pathway. Previous research has demonstrated that poor readers demonstrate difficulties focusing visuospatial attention during tasks which activate the dorsal pathway. Whilst the need for carefully controlled experiments to confirm this deficit was vital, questions arise regarding the robustness of dorsal stream differences between good and poor readers outside of carefully controlled laboratory environments. The present study aimed to create child friendly games which tapped dorsal stream functioning and that could be administered in real world settings using portable technology. A change detection program was developed to test dorsal stream functioning, alongside measures of IQ and single word reading. Results revealed that even when IQ was taken to account, change detection ability – namely the number of detection errors, can uniquely predict both phonological and orthographic single word performance. Children who were better at reading single words made less visual detection errors compared to their poorer reading peers. Future directions for these findings are discussed in the context of portable visual assessment and intervention.

This manuscript is under review with PLOS ONE
5.1. Introduction

It is estimated that at least 5% of the population may have difficulty reading, with the severity of this impairment ranging along a continuum [1]. Most commonly known as developmental dyslexia (hereafter dyslexia), it is characterised by difficulty with inaccurate and slow word reading that is well below the individual’s chronological age, and significantly interferes with academic or occupational performance [2,3,4]. It occurs despite sufficient educational opportunity and without history of intellectual or related medical disability. Individuals with dyslexia can have difficulty with reading accuracy, fluency or both [5]. The phonological theory, a significant theory in reading research, contends that dyslexia is caused by a deficit in the ability to represent and process speech sounds in the reading process [6]. Whilst there is a large body of evidence suggesting a causal link between phonological awareness and dyslexia [7, 8, 9, 10, 11, 12, 13] evidence has also emerged which suggests that some people with reading difficulties demonstrate specific deficits in the dorsal/magnocellular stream area of the visual system.

In the 1980s, the first studies emerged exploring possible links between visual performance utilising the dorsal stream, and reading ability (see [14]). Since this time, a range of visual tests have been used to explore visual performance and reading ability. For example, when a 0.1-4 c/degree grating is flickered at a speed greater than 15Hz, a participant perceives a still grating at double the actual spatial frequency – referred to as the frequency doubling illusion [15] it is believed to be mediated by magnocellular cells in the dorsal visual pathway [16]. Dyslexic readers are less sensitive to this illusion [17,18], pre-readers at risk of dyslexia are less sensitive to the illusion than their pre-reading peers [19], and it predicts subsequent reading ability [20]. Dyslexic participants are also less sensitive at detecting coherent motion, which is also believed to be mediated by the magnocellular/dorsal pathway [21, 22, 23]. That is, they require more dots to be moving in the same direction to be able to detect the direction of motion, compared to normal readers (for a meta – analysis see [24]). In visual search, they also experience slower reaction speeds when detecting a target in a range of distractors, especially as the number of distractors increase, compared to regular readers [25, 26, 27, 28, 29]. A change detection task is one in which participants have to report the difference between two visual objects or scenes. Focussed attention is required to successfully recognise the change between two images [30]. Various methods
have been used to study change detection. The ‘flicker paradigm’ involves switching between two slightly different images until the observer notices the change. Using this method, participants rarely notice the change in the first cycle of the alternation. This is contrasted with the ‘forced choice detection paradigm’, whereby participants are required to respond after only one viewing of each image [31]. In the first study to explore change detection and reading ability, poor readers took longer to notice which letters in a display had changed, when compared to normal readers [32]. With evidence suggesting that there is a deficit in visuo-spatial coding for poor readers, subsequent questions emerge regarding exactly how a visual deficit might impact the ability to fluently read.

Reading is a complex skill which requires the coordination of a range of visual actions including visual saccades, fixations and regressions. When we engage in the skill of reading, we constantly make a series of saccades, or small jumps from one part of the text to the next. During the fixation that precedes a saccade, a complex array of visuo-spatial processing is required, such as extracting relevant visual information, binding relevant visual features to form letters and words, and placing the letters in the correct spatial sequence. An attentional mechanism is then required to guide the eye to the next relevant location in the line of text. Thus, the act of reading is not a natural process, but rather requires skilled and focussed attention [33]. The dorsal stream receives input from the fast magnocellular pathway, which controls visually guided actions, depth, movement and spatial localisation [34]. It has been suggested that the attentional mechanisms controlled by the dorsal stream may be impaired in poor readers, resulting in a difficulty in focussing visuo-spatial attention during the process of reading [35]. During reading, an attentional spotlight is focussed on one to two letters at a time, to be processed by the ventral stream. After the fixation, a saccade occurs which sweeps past 6 or 7 characters, which brings attention to the next set of letters. This is a trained movement, specific to reading, as our attentional spotlight usually darts around a scene in a fairly random fashion. It is suggested that poor readers may experience difficulty in executing this highly complex attentional skill [36].

Poor readers have consistently demonstrated a difficulty in the automatic orienting of attention [37, 38, 39] and shifting attention between stimuli [40]. In a study by Facoetti and colleagues [41], children were compared on measures of non-word reading and reaction times for a basic cueing task. The researchers found that children who were impaired in non-word reading did not show a cueing effect (faster response when correctly cued) when the cue was presented in the right
visual field. Facoetti and colleagues [42] have also demonstrated that visual spatial attention is also impaired for pre-reading children at risk for developmental dyslexia. In a study of pre-schoolers at familial risk for reading disability, the researchers used a cueing task whereby the child was asked to watch the screen carefully for a target, and to then pick this target from four items on screen. Prior to the target, there was either a valid (cued in the same location as the target) or invalid cue (in a different location to the target) presented on the left or right of the screen. Children at risk for dyslexia did not display a faster response time when presented with a valid cue, suggesting an inefficient orienting of visual attention. In order to gain a better understanding of the complex act of reading, various models have been proposed, including the Multiple Levels Model [43] and the Parallel Distributed Processing Model [44]. The theory of reading utilised in the present paper is the Dual Route Model of Reading [45].

According to the Dual Route Model of Reading [46], a well-researched theory of the reading process (see [47] for a meta-analysis of neuroimaging studies), there are two distinct pathways to reading. One involves the lexical route, whereby a reader can recognise words from sight alone, and these words are stored in a type of mental dictionary for later retrieval (also known as orthographic processing). The other route, called the non-lexical route (or sub-lexical), is where a reader sounds out unfamiliar words using letter–sound rules (also known as phonological processing). It is suggested that the lexical route, which stores irregular words, uses less attentional resources. It is also thought to be the faster of the two pathways, with readers identifying irregular words faster than regular words, especially when the participant is placed under a high cognitive load [48]. To test the robustness of the dual route model, and to provide an assessment tool of the functioning of lexical and sublexical reading procedures, The Castles and Coltheart test was developed. The Castles and Coltheart II (CC2) [49] is a test that can be used to assess the ability to read regular, irregular and non-words and is normed for children aged 6 – 12 years. It is a revision of the original Castles and Coltheart [50], with the CC2 adding additional words for a total of 40 per category, including more words at the difficult end of the scale to reduce ceiling effects. A stopping rule was also added, with the ability to cease testing of one type of word (e.g. irregular words) after five consecutive errors. New normative data was also collected from 1000 children between the ages of 6 and 12 in Australian schools [51]. It is a test that can be administered relatively quickly (less than 15 minutes),
and has been utilised in studies which have examined visual sensitivity and the efficiency of the two routes of reading.

There is some evidence to suggest that visual sensitivity might underlie the efficacy of processing in the two pathways. However this evidence is mixed; for example, visual performance has been specifically linked with the phonological pathway [23], orthographic pathway [52, 53] or both pathways [54]. Talcott and his colleagues [55] tested single non-word reading in relation to visual motion and flicker sensitivity, and found that visual performance on both these measures correlated strongly with non-word reading ability. Random dot kinematograms (RDK’s) and critical flicker fusion tests were used for their rapidly changing stimuli, which were believed to rely heavily upon the magnocellular system. Both the Snowling non-words and Castles and Coltheart non-word measures were used to measure phonological performance. Dyslexics with poor non-word reading skills demonstrated significantly lower flicker fusion frequencies compared to controls, and needed approximately 8% greater motion coherence to detect the direction of the motion. When Talcott and colleagues [52] used the Castles and Coltheart (1993) test to assess both phonological (non-words) and orthographic (irregular words) single word performance, it was discovered that phonological performance was predicted by auditory processing of frequency modulation (FM), and orthographic performance was predicted by coherent motion processing. This finding was partially replicated two years later, however the proportion of single word reading variance explained by visual and auditory performance was lower [53]. However, in contrast to these findings, Kinsey and colleagues [54] found visual performance correlated most highly with non-word reading as compared to irregular word reading. Using a cueing task which utilised RDK’s, participants were provided with a valid or invalid spatial cue followed by a set of four RDK patches. The participant was advised to indicate which of the four patches contained the coherent motion. In two thirds of the trials, a visual cue was given that correctly identified the position in which the coherent motion would be found. The results demonstrated that a significant amount of reading variance in both irregular and non-word reading was explained by performance in the valid trials condition. Additionally, non-word performance was associated with visual performance in both the valid and invalid condition. That is, participants with poorer non-word reading skills were worse in their attention shifting and ability to detect coherent motion, compared to those with higher non-word scores.
Thus the aetiology of dyslexia remains controversial and these opposing views have required carefully controlled experiments in order to disentangle the competing roles of visuo-spatial coding in different reading processes. Indeed, previous experiments conducted in the area of visual performance and reading have traditionally occurred in laboratories, where the visual stimuli were tightly controlled for variables such as ambient light, colour, luminance, contrast, size, motion and viewing distance. Indeed, this was imperative to ensure that the visual system could be accurately tested, extracting the relevant contributions of the different visual pathways. However, a more practical question has emerged. Children generally undertake the majority of their reading tasks within the school setting, yet testing has traditionally occurred in laboratory settings. The present experiment aimed to determine if visuo-spatial attentional deficits were so robust that they could be detected in a variable school setting where reading most frequently occurs and determine if tests of visuo-spatial attention, mediated by the dorsal stream, can differentiate good and poor readers in terms of phonological and orthographic performance, within a naturalistic setting. Additionally, given current explorations into visual performance and reading performance with respect to the Dual Route Model of Reading, it would be useful to obtain visual performance measures with respect to orthographic and phonological performance, to ascertain any individual contributions of visual performance to specific pathways in the Dual Route Model of Reading. In addressing the practical elements of testing, a second aim was to determine if this visual testing could be administered using portable technology and child friendly game-like software, to attempt to make the test engaging for this particular demographic. Previous researchers have successfully cosmetically modified classic experiments into games (for examples see [56, 57, 58]). Also known as ‘gamification’, it refers to attempts to create a game-like experience though motivational elements, and more complex, colourful stimuli [59]. Furthermore it is suggested that making psychophysical tasks game-like does not change the cognition that is measured (e.g. does not result in faster reaction times), and can indeed result in a more pleasant experience for the participant [60]. With this in mind, change detection tasks were selected for the experiment, due to the ability to make these task engaging and game-like for young participants (i.e. Can you spot the difference? Where is the bug hiding? – this is suggested to present a challenge for the participant). A tablet computer was selected to present the stimuli due to its potential ease of use by researchers and clinicians in the field, specifically for its small size (10.1 inches), light weight (560g) and minimal cables, thus maximising
portability and game-like presentation of the tasks. We predict that despite significant changes in the presentation and administration of this change detection task, game performance will differentiate good and poor readers in both their orthographic and phonological single word reading ability.

5.2. Method

Participants

Seventy seven children (43 males), participated in the experiment. Children were aged between six and 12 years, with an average age of nine years, and were tested within the school setting. Data collected from two children was excluded due to difficulty following instructions, and data from three were excluded due to low IQ (below 70). There is a wide age range here, however this allows us to also look at reading across primary school ages and the reading test we used is standardised for age. One outlier was removed from the analysis due to being more than two standard deviations above the mean in terms of accuracy errors (27/40 errors). Six participants were removed from the data set due to reading difficulties in rate only, and the present study is interested in reading accuracy. Children wore corrective glasses during the experiment where this was required. The experiment was undertaken with the understanding and written informed consent of the parents and guardians of the children who participated, the verbal consent of child participants before testing commenced, and with the approval of the appropriate local ethics committee [Australian National University Human Research Ethics Committee protocol 2011/628], The ACT Catholic Education Office and in compliance with national legislation and the Code of Ethical Principles for Medical Research Involving Human Subjects of the World Medical Association (Declaration of Helsinki), and Australian Psychological Society (APS) ethical standards.

2.21 – Computer Program

Change detection ability was recorded using a Samsung Galaxy Tab 10.1 touch screen tablet computer. Display size 10.1 inch widescreen, 1280x800 WXGATFT LCD, 149 pixels per inch (ppi). Processor was a 1GHz dual core NVIDIA Tegra 2 processor, with 1GB (RAM), 16GB (ROM). Video consisted of full HD video playback (1080p) @ 30 fps. The tablet utilised an android operating system (Honeycomb), Android Version 3.1, Kernel Version 2.6.36.3, root@DELL137#1.
Model number GT-P7510. The stimuli were designed using a computer games engine called ‘Unity’, version 4.0 released in November 2012 by Unity Technologies. Unity is a cross platform game engine and Integrated Development Environment (IDE), and was selected for its ability to make the visual stimuli game-like and enjoyable for the participant. The stimuli consisted of a game called ‘Detective Quest’, whereby children are asked to spot the difference between two images presented side by side (See Figure 7.5 & 8.5). Children were directed to tap exactly where the difference appeared in the right box, as fast as possible. Children were allowed a maximum of 30 seconds to identify the difference before being asked to move on. There were 40 images in total, consisting of both line drawn and photographic images. For statistical purposes, images were classified by the researchers as being either ‘easy or difficult’ based on the complexity of the image. There were 24 ‘hard’ images and 16 ‘easy’ images in the experiment, and in total the game took about 15 minutes to complete. For each of the 40 images, a mean speed of response was recorded. Images were classified as being ‘easy’ if the mean speed of response was six seconds or less, and ‘hard’ if the group mean response was over six seconds. This distinction was made on the basis that there appeared to be a trend whereby participants were answering relatively fast (M = 4.01 for under 6s condition) or much slower (M = 13.269 for over 6s condition) and it appeared reasonable to draw the line of difficulty at this point.

There were also 2 trials at the beginning of the experiment that were not included in the analysis, as these were classified as practice trials.
Figure 7.5. Example of 'easy' image in Detective Quest computer program

Figure 8.5. Example of 'hard' image in Detective Quest computer program
Participants were introduced to the study and asked if they would like to participate prior to commencement of testing. Upon obtaining consent, participants were then given instructions to play the programs or ‘games’ provided. They were instructed to rest their hands below the screen on the table between trials to minimise differences due to motor strategies. Following a short break, children were then administered the Neale Analysis of Reading Ability (NARA)(3rd Ed), Woodcock – Johnson III Brief (BIA) and the Castles and Coltheart II (CC2)(2009). The Woodcock – Johnson III Brief (BIA) is a short intelligence test that provides a brief intellectual ability score based on verbal comprehension, concept formation and visual matching scores. The CC2 battery was used to gather data regarding specific word performance through presentation of 40 regular (e.g. bed), irregular (e.g. eye) and non-words (e.g. gop) (120 words total). It is an untimed test that includes a discontinuation rule after five consecutive errors in the same word category. Individual black words were presented on a 12cm by 8.5cm white cards, and font was Arial 36 point font as specified by Castles and colleagues (2009). All testing was conducted by a Clinical Psychology Registrar. Children received a small reward for their participation in the study. The children participated in a variety of settings, such as other classrooms, often with other children. Again, consistent with the experiment’s aims, the environment, lighting, and noise levels were not controlled.

5.3. Results

Analyses were conducted to explore the relationship between change detection speed and accuracy and reading ability in terms of regular, irregular and non-word reading scores. Regular, irregular and non-word reading scores were calculated as each child’s z – score for each word category. Raw scores were added (score out of 40), and this was matched to the child’s Australian Norms table, based on age. If the child did not pronounce the word correctly or was unable to provide a response, that word was marked as incorrect. Z – Scores which corresponded to each child’s raw scores for the three types of words were obtained. A z – score of 0 indicates average performance, with -1 to +1 an average range, +2 well above average and -2 well below average (see Table 6.5).
Table 6.5.

Summary of overall reading performance for change detection participants

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Words</td>
<td>-0.293</td>
<td>1.10</td>
<td>-2.07</td>
<td>2.37</td>
</tr>
<tr>
<td>Irregular Words</td>
<td>-0.437</td>
<td>1.03</td>
<td>-2.03</td>
<td>2.44</td>
</tr>
<tr>
<td>Non-Word Words</td>
<td>-0.354</td>
<td>1.22</td>
<td>-3.09</td>
<td>2.29</td>
</tr>
</tbody>
</table>

M = Z-score average, SD = Standard Deviation, Min = Minimum Score, Max = Maximum score

Change detection speed was defined as how fast the participant noticed the change between the two images, as measured from the time the image appears on screen to the time the participant taps the image in response. "Time-Outs" were defined as when the participant reached the 30 second limit for the search, and were asked to end the present search and begin the next image. Change detection accuracy was defined as whether the participant was correct in their selection of the change location on screen. Slight deviations from the true centre of the change of approximately 1 cm by 1 cm were permitted. Incorrect responses were defined as selecting a location where the change did not appear. Pearson's correlation coefficients indicated that for regular, irregular and non-word words there were no relationships between single word reading and change detection speed of response for easy or hard images. Likewise, there were no relationships between any type of single word reading and number of time outs for searching the images. However, there was a significant negative relationship between regular word reading and incorrect responses (see Figure 9.5), irregular word reading and incorrect responses (see Figure 10.5), and non-words and incorrect responses (see Figure 11.5)(see Table 7.5).
Table 7.5.

*Summary of Pearson Correlation Coefficients between change detection tasks and reading tasks*

<table>
<thead>
<tr>
<th></th>
<th>$r$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Irregular Words</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of Response for easy items</td>
<td>-.086</td>
<td>.497</td>
</tr>
<tr>
<td>Speed of Response for hard items</td>
<td>-.072</td>
<td>.568</td>
</tr>
<tr>
<td>Incorrect Response</td>
<td>-.294</td>
<td>.017*</td>
</tr>
<tr>
<td>Time out</td>
<td>.215</td>
<td>.086</td>
</tr>
<tr>
<td><strong>Regular Words</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of Response for easy items</td>
<td>.037</td>
<td>.769</td>
</tr>
<tr>
<td>Speed of Response for hard items</td>
<td>-.050</td>
<td>.695</td>
</tr>
<tr>
<td>Incorrect Response</td>
<td>-.306</td>
<td>.013*</td>
</tr>
<tr>
<td>Time out</td>
<td>.084</td>
<td>.508</td>
</tr>
<tr>
<td><strong>Non-Words</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of Response for easy items</td>
<td>.153</td>
<td>.225</td>
</tr>
<tr>
<td>Speed of Response for hard items</td>
<td>.095</td>
<td>.450</td>
</tr>
<tr>
<td>Incorrect Response</td>
<td>-.274</td>
<td>.027*</td>
</tr>
<tr>
<td>Time out</td>
<td>.154</td>
<td>.220</td>
</tr>
</tbody>
</table>

*Note* *Correlation is significant at the 0.05 level (2-tailed)*

*Figure 9.5. Regular word z-score discrepancy by number of errors in correctly identifying the difference*
Figure 10.5. Irregular word z-score discrepancy by number of errors in correctly identifying the difference

Figure 11.5. Non-word z-score discrepancy by number of errors in correctly identifying the difference
Following these results, a standard multiple regression analysis was conducted to determine how well incorrect responses for change detection can predict single word reading when IQ and age is also taken into account (see Table 8.5), particularly given the wide age range. Change detection errors uniquely predicted 7% of the variance in regular word reading ability even when IQ was taken into account ($F(3,61) = 7.720, p <.001$). Change detection errors also uniquely predicted 5% of the variance in irregular word reading when IQ was also taken into account ($F(3,61) = 5.875, p <.001$). Likewise, change detection errors predicted non-word reading, with change detection errors explaining 6% of the unique variance in non-word reading once IQ is also taken into account ($F(3,61) = 9.802, p <.0001$). Age did not uniquely predict single word reading ability in this model, as standardised scores were used in determining single word reading ability.

Table 8.5.

Summary of standard multiple regression analysis for variables predicting single word reading

<table>
<thead>
<tr>
<th></th>
<th>$\beta$</th>
<th>$p$</th>
<th>$sr^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Irregular Words</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQ</td>
<td>.376</td>
<td>.002</td>
<td>.358</td>
</tr>
<tr>
<td>Age</td>
<td>.210</td>
<td>.084</td>
<td>.198</td>
</tr>
<tr>
<td>Incorrect Response</td>
<td>-.236</td>
<td>.044</td>
<td>-.232</td>
</tr>
<tr>
<td><strong>Regular Words</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQ</td>
<td>.444</td>
<td>.000</td>
<td>.423</td>
</tr>
<tr>
<td>Age</td>
<td>.079</td>
<td>.496</td>
<td>.075</td>
</tr>
<tr>
<td>Incorrect Response</td>
<td>-.266</td>
<td>.020</td>
<td>-.260</td>
</tr>
<tr>
<td><strong>Non-Words</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQ</td>
<td>.493</td>
<td>.000</td>
<td>.470</td>
</tr>
<tr>
<td>Age</td>
<td>-.025</td>
<td>.822</td>
<td>-.024</td>
</tr>
<tr>
<td>Incorrect Response</td>
<td>-.247</td>
<td>.025</td>
<td>-.242</td>
</tr>
</tbody>
</table>

Note: $\beta$ for standardised coefficient; Regular Words - $R^2A = .240, p <.000$; Irregular Words - $R^2A = .186, p <.001$; Non-Words - $R^2A = .292, p <.000$; $sr^2$ = semi partial correlation; IQ = Woodcock Johnson III Brief Intellectual Ability score; Incorrect Response = Number of incorrect taps during change detection game.
5.4. Discussion

In this experiment, a portable change detection game was developed to determine if dorsal stream performance is indicative of reading ability, even when the environment is uncontrolled and the program is game-like in presentation. The results of the present study support the hypothesis that a change detection game that tests dorsal stream functioning can predict single word reading in school settings using portable technology. Specifically, change detection errors can uniquely predict regular, irregular and non-word reading. That is, performance in this task can predict performance in both pathways utilised in the Dual Route Model of Reading. This is possible even when intellectual ability and age are taken into account. Previous research has recognised that the relationship between word reading and IQ is substantial, however a large proportion of variance remains once IQ is controlled. In one such study which explored unexplained variance, researchers found that sensory measures such as coherent motion and frequency modulation detection accounted for less than 1% of the variance in single word reading [66]. Given that intellectual ability is a strong predictor of reading skill in the present study, it is impressive that change detection errors can uniquely predict between 5 and 7 percent of the unique variance in single word reading performance. This is consistent with the findings of Kevan and Pammer [20] who also found visual sensitivity uniquely predicted reading ability over and above IQ, and supports the suggestion that dorsal stream performance (in this case, change detection) plays a unique role in reading abilities.

The results of the present study suggest that accuracy, but not speed of change detection, can be indicative of single word reading abilities. That is, participants were responding at a similar speed to all the visual stimuli presented, however poor readers tended to make more mistakes in identifying the correct change. These results are consistent with previous researchers who have utilised the Castles and Coltheart in exploring dorsal stream performance, and have discovered relationships between dorsal stream functioning and components of the reading test. For example, Witton and colleagues [23] found that non-word reading performance was related to coherent motion visual performance. Kinsey and colleagues [54] found (cued) coherent motion detection predicted both regular and irregular word reading. Additionally, Talcott and colleagues [52] and Boets and colleagues [21](using letter knowledge as a representation of orthographic ability) found visual performance predicted irregular or orthographic decoding. However,
the present finding suggests that change detection can predict all three types of single word reading. One possible explanation for this finding could relate to the type of visual test administered. The present program utilised a relatively new method – change detection – to measure dorsal stream functioning. It is possible that this method is more sensitive in detecting visual deficits, due to the requirement to move attention from right to left (and back again) upon a static image, similar to the process of reading. Similarly, it is possible that constant shifting between images placed a greater load on the visual attentional system, and has thus resulted in a useful measure of the system under strain. These two possibilities suggest that this change detection task may tap into the general characteristics of the reading process at the pre-lexical level, which may explain why there is little distinction in significance between types of word performance. This suggestion highlights the need for future research in this area to examine why some forms of visual testing are more predictive of one element of reading ability (e.g. orthographic processing) and not the other (phonological processing), and in this case, both types of single word reading performance. Ascertaining why this occurs, and which tests are most sensitive, may assist in the development of the most effective assessment and intervention programs tailored to phonological and/or orthographic reading deficits.

Given that dorsal stream performance can predict single word reading using specialised portable games; it is time to pilot potential visual attention interventions in the field. As discussed previously, studies have found that children at risk for dyslexia demonstrate visual attention impairments before they learn to read [61,19] thus development of visual assessment tools could provide a unique opportunity for early intervention in visual spatial attention abilities. However, to be clear, this should be explored alongside continued traditional phonological training, which has demonstrated success both with early intervention (see 62 for a Reading Recovery Meta-Analysis) and with older children [63]. In exploring effective visual attention training, Gaggi and colleagues [64] have developed a range of game-like programs which are designed to train both visual – spatial attention and speech segmentation, and early studies have indicated that visual training can improve reading abilities of dyslexic participants when the games are action based and visually challenging [65]. However there is still much work to do. Investigations should continue into the contributions of visual performance in relation to specific skills, to ascertain which visual tests are most sensitive in detecting orthographic and phonological skills. Experiments with larger
populations of participants, who have a demonstrated visual and reading deficit, are needed. Also, the frequency and duration of training for effective intervention requires further investigation, to determine the time investment required to secure visual attention improvements and lasting improvements in reading ability.

Acknowledgements

The authors would like to thank Mr Adam Ball and Tony Oakden from The Academy of Interactive Entertainment (AIE) Canberra for their assistance in developing the change detection game. The authors would also like to express their appreciation to the students, teachers and schools for their participation in this study.
5.5. References


Chapter 6.

A Gamified Tracking Program to Test the Spatial Navigation Capabilities of Dorsal Stream Functioning in Good and Poor Readers

6.1. Introduction

The visual – spatial attention deficit theory contends that an impairment in the dorsal/magnocellular stream of the visual system may influence the ability to sequentially focus visual attention, in order to read fluently and accurately (Vidyasagar & Pammer, 2010). It is hypothesised that there are two possible ways in which this dorsal stream deficit could influence reading ability (Pammer, 2012). One possibility is that the dorsal/magnocellular stream acts as a preattentive spotlighting and spatial information gathering system, which – in the case of reading – assists the ventral stream in ordering features and letters in the correct locations, or ordering letters within words correctly so that words can be successfully identified (e.g. see Pammer, et al., 2004). Another possibility is that the dorsal/magnocellular stream may assist in spatially guiding attention across the page, providing a spatial navigating system for the fixations, saccades and regressions that are required for fluent reading to occur (Vidyasagar, 1999). If the dorsal stream is impaired, this may subsequently impact this spatial navigation function and subsequent reading ability (for a full review of visual – spatial encoding in word recognition see Pammer (2012)).

In addition to the dorsal stream being involved in the perception of motion direction and speed, depth, and processing the spatial relationships among objects, it is also involved in the visual guidance of movements towards items in space (Ungerleider & Haxby, 1994). In studies by Newsome and colleagues (1985a; 1985b), it was discovered that when small chemical lesions were inflicted upon the medial temporal (MT) region of the dorsal stream, there was observable differences in the abilities of a monkeys to use smooth pursuit and saccadic eye movements to track a moving object. These findings were supported by a further study by Dursteler and colleagues (1987), in which lesions to MT resulted in difficulties in tracking a moving object with a velocity error (MT lesions did not have the same effect when the monkey pursued a target with a constant position error). Damage to
MT can also result in an impaired ability to visually search a space for significant visual stimuli (e.g. locating a 'wax worm' reward in a number of distractor circles) in bush babies and monkeys (Wilson, et al., 1977; 1979). Whilst lesion experiments possess some methodological pitfalls, it is reasonable to suggest that the behaviours demonstrated following damage, support the notion of the importance of the dorsal stream in visual – spatial attention (Maunsell & Newsome, 1987), particularly smooth pursuit and saccadic eye movements. A well-functioning visual – spatial attention system is subsequently able to facilitate the spatial navigation that is required to systematically guide attention across the words in a sentence (Vidyasagar, 2004).

In our everyday environment, when scanning for a target, our eyes usually dart about a scene, in a somewhat random manner, until such time as the target is detected (see Figure 12.6 A). The visual system does not search for a target sequentially, but rather natural search occurs by random scanning, without accumulating information about previously searched locations (Horowitz & Wolfe, 1998). In the case of reading, however, sequential attention is required to read words and sentences successfully (Rayner, 1978) (see Figure 12.6 B).

Figure 12.6. An illustration of potential movements of the spotlight of attention for natural scenes (A) and reading (B)
In order for reading to occur, the spotlight of attention is required to be trained, to rapidly and sequentially direct attention spatially across the page in an ordered manner. This is a direct contradiction to the way that the spotlight of attention functions naturally, and one step in learning to read is learning how to control the movements of the attentional spotlight (Vidyasagar, 2004). It is suggested that a deficit in the dorsal stream could impact this ability to skillfully deploy the preattentive visual guiding of saccades and fixations required to read accurately and fluently (Vidyasagar, 2004, 2005; Vidyasagar & Pammer, 1999).

During reading the eyes move skillfully in a series of saccades, fixations and regressions. Saccades are rapid eye movements, as fast as 500° per second, which move the eyes forward from one part of the text to the next. The time taken by each saccade is influenced by the distance covered, which can be influenced by the complexity of the text (Rayner, 1998). Between these saccades are fixations, where the eyes are relatively still for approximately 200 – 300 milliseconds. Not all words in a sentence are fixated, for example, words of eight letters or more are almost always fixated (and often multiple times), whereas short 2-3 letter words are only fixated on approximately 25% of the time (Rayner & McConkie, 1976). When reading a passage in English, the eyes almost always saccade from left to right, however sometimes the eyes dart backwards. This type of saccade is called a regression. It is usually only a few letters long, and accounts for approximately 15% of all saccades (Frazier & Rayner, 1982). The complex eye movements of saccades, fixations and regressions could potentially be mimicked in a behavioural measure, designed to resemble the process of reading. Designing a new dorsal stream measure that closely imitates the visual actions associated with reading may provide a sensitive measure of dorsal stream functioning in the context of reading. A visual tracking task would be a good candidate for this new program, as both complex eye movements (like those associated with reading) and visual tracking of moving objects are controlled by the dorsal stream of the visual system (Ungerleider & Haxby, 1994).

Visual tracking is an action that has been extensively studied in the field of vision research, across varied domains, and could also have potential in the testing of the dorsal stream in the context of reading. In 1983, Sakata and colleagues used electrophysiological recording to measure brain activation in the posterior parietal association cortex whilst monkeys watched a stationary or moving visual target. They discovered that there are two types of visual tracking (VT) neurons, those that are sensitive to the light and others that are sensitive to the dark. The majority of the neurons (48/70) displayed less discharge in the dark, but a small proportion
showed a higher rate of discharge in the dark (7/70), and only a small amount showed no difference at all (15/70), which lead the researchers to conclude that most VT neurons are influenced by the surrounding environment. They also discovered that VT neurons responded to moving stimuli (34/43), however half of these (17/34) preferred the direction that was opposite to the trajectory of the tracked object, and were classified as “antidirectional VT neurons”. These “antidirectional VT neurons are most likely to be associated with motion perception, whereas VT neurons that favour the same direction as the tracked object are most likely to be implicated in smooth pursuit eye movements (Sakata, Shibutani & Kawano, 1983). Visual tracking performance also appears to be dependent upon the behaviour of the moving object itself. Predictability of the direction of movement is a strong indicator of tracking accuracy, with targets that are more erratic in their movements being much harder to successfully follow (Michael & Jones, 1966). Additionally, tracking ability appears to decline with age, with older seniors (75 years and older) demonstrating lower smooth pursuit gains (especially at higher velocities) and slower saccade velocities compared to young adults (mean age of 25 years). However, there appears to be no difference in saccade accuracy between younger and older adults (Moschner & Baloh, 1994). In the area of child development, the visual tracking of 3-9 month old infants was observed to determine infant responses in a basic accommodation task. The researchers were interested in determining how quickly an infant will go from looking at where an object disappeared, to anticipating trajectory of where an object will reappear. They found that even young infants had the capacity to improve their ability to visually track and anticipate a moving object, and as expected, older infants (8 months old) were faster than younger infants (5 months old) in accurately tracking the target (Nelson, 1971).

In the field of reading research, there is evidence to suggest that smooth pursuit (tracking) (Black, Collins, De Roach & Zubrick, 1984) and saccadic eye movements (Biscaldi, Gezeck & Stuhr, 1998; DeLuca, Di Pace, Judica, Spinelli & Zoccolotti, 1999; Jainta & Kapoula, 2011; Kapoula, Vernet, Yang & Bucci, 2008) are different in dyslexic readers (although see Brown, et al., 1983; Olson, Kleigl & Davidson, 1983 for alternative findings). For example, in a study by Bogacz and colleagues (1974), all 40 dyslexic readers demonstrated irregular smooth pursuit eye movements compared to a control group of good readers (Bogacz, Mendilaharsu & Mendilaharsu, 1974). To be clear, whilst the eye movements of dyslexic readers may be different in some studies, it is suggested that these eye movements are not the cause of the reading disability, but rather underlying deficits
in visual – spatial attention may impact saccadic programming, and subsequently the eye movements related to reading (Bellocchi, Muneaux, Bastien-Tonialzzo & Ducrot, 2013). Thus, a gamified tracking task that mimics the process of reading is yet to be explored within the field of reading research, but could have potential as a sensitive measure of dorsal stream performance. Given the importance of dorsal stream functioning in guiding the spotlight of attention during the reading process (Vidyasagar, 1999); a tracking task could be well placed to explore the performance of poor readers using eye movement actions similar to those observed during the reading process.

When reading, the visual – spatial attention system is required to engage and disengage attention frequently, as it shifts attention from one word to the next (Ruffino, Gori, Boccardi, Molteni & Facoetti, 2014). As well as intensifying resources within the focus of attention to perceive words, the spotlight of attention is required to reduce the effects of noise (or non relevant words) outside of the attentional focus (Facoetti, 2012). An impressive amount of literature has shown that dyslexic readers have demonstrated difficulties with engaging and disengaging visual spatial attention, as compared to their normally reading peers (Facoetti, et al., 2003). Evidence for impaired attentional deployment in dyslexic readers is found in a range of studies which have examined spatial cueing (Facoetti, et al., 2000; 2005; 2006; 2010; Roach & Hogben, 2007; Ruffino, et al., 2014), attentional blink (Buchholz & Aimola – Davies, 2007; Facoetti, Ruffino, Peru, Paganoni & Chelazzi, 2008; Hari, Valta & Uutela, 1999; Visser, Boden & Giaschi, 2004), temporal order judgement (Liddle, et al., 2009) and rapid multi – element presentations (Hawelka, Huber & Wimmer, 2006). Thus, a difficulty in orienting visual spatial attention, or sluggish attentional shifting (SAS), may selectively impair the sublexical level orthographic to phonological rapid processing ability that is essential for successful reading development (Facoetti, 2012; Hari & Renvall, 2001). A tracking task could be one way to test the ability of the visual – spatial attention system to engage and disengage attention, using a target designed to mimic some of the visual actions associated with reading. Designing a task to tap magnocellular/dorsal stream resources that aims to reproduce some of the visual actions of reading may also be advantageous in identifying a deficit that may be quite subtle or elusive.

According to Vidyasagar and Pammer (1999), the deficit in the magnocellular/dorsal stream in dyslexia may be a subtle one, not just apparent within the magnocells themselves, but could occur anywhere along the dorsal stream. If the deficit is within the magnocells where there is reduced density in
specific locations (e.g. one or two degrees either side of the fovea), this would be sufficient to cause a reading deficit (e.g. seriously impact the ability to sweep the focus of attention across along the length of each word). And whilst this deficit can be highly detrimental to reading ability, it would be difficult to identify using traditional tests of magnocellular /dorsal stream function (Vidyasagar & Pammer, 2010). Furthermore, given that dorsal stream deficits may be subtle, it is no surprise some researchers have failed to find significant differences between good and poor readers using similar tests of dorsal stream performance such as coherent motion (see Skottun, 2000 for a review). What is needed is a program that can target as closely as possible, the dorsal stream mechanism that is suggested to impact upon reading ability. The present study aimed to develop a completely new behavioural measure of dorsal stream functioning that would closely simulate the saccades, fixations and regressions that occur during the regular reading process, whilst also considering participant engagement, child friendliness and portability. Using a tracking type program, performance on this tracking task would be compared to each participant’s reading scores, to determine if tracking performance is correlated to reading accuracy or rate. It is suggested that passage reading accuracy and rate would correlate higher than single word performance, due to the increased spatial navigation resources required to read a sentence or paragraph of text. Consistent with other experiments in this project, a portable tablet computer was selected to present the gamified tracking program. The game itself was designed to simulate some of the actions associated with reading, including visually guiding attention across lines from left to right, fixating in one location, and also retracing previous parts of the line (regressions) during some stages of the task. If this new tracking task is able to mimic the process of reading and utilise dorsal stream resources, then it is hypothesised that performance on this visual tracking task would be correlated with reading performance, in particular, passage reading, with poor readers experiencing greater difficulty focussing visual spatial attention to track the target quickly and accurately.

6.2. Method

6.2.1. Participants

Sixty eight children, (forty two males), participated in the experiment. Children were aged between six and 12 years, with an average age of eight years.
and six months, and were tested within the school setting. Reading and intellectual ability was recorded using standardised tests, and tracking ability was measured using a gamified tracking program, administered to students in small groups. Data collected from one participant was removed due to not following instructions, and data from one participant was excluded due to low IQ (below 70). All parents provided written informed consent, and children also provided verbal consent prior to testing. Children wore corrective glasses during the experiment where this was required. All methods conformed to the Declaration of Helsinki and also had local ethics approval.

6.2.2. Stimuli

Tracking ability was measured using a task presented on a Samsung Galaxy Tab 10.1 touch screen tablet computer. Display size 10.1 inch widescreen, 1280x800 WXGATFT LCD, 149 pixels per inch (ppi). Processor was a 1GHz dual core NVIDIA Tegra 2 processor, with 1GB (RAM), 16GB (ROM). Video consisted of full HD video playback (1080p) @ 30 fps. The tablet utilised an android operating system (Honeycomb), Android Version 3.1, Kernel Version 2.6.36.3, root@DELL137#1. Model number GT-P7510. The stimuli were designed using a computer games engine called ‘Unity’, version 4.0 released in November 2012 by Unity Technologies. Unity is a cross platform game engine and Integrated Development Environment (IDE), and was selected for its ability to make the visual stimuli game like and enjoyable for the participant. Tracking ability was assessed by constructing a game called ‘Space Jump’, whereby children are asked to follow a small spaceman as he travelled through the galaxy. Children were instructed to watch the spaceman as he will change the colour of some of the planets as he passes, and when this occurs they were to tap on the planet as quickly as possible. The colours of the planets were yellow, red, green, orange, pink and blue, on a space themed background. If the child tapped the correct planet, it would jiggle back and forth twice. Children were directed to only tap on the planet that changed colour, or they may lose points. There were 16 trials in the experiment, and the speed of each level varied. Speed was calculated as the time taken for the spaceman to travel from the start of the left side of the screen and finish on the far right of each line. When the spaceman was at the end of each line, he would speed from right to left under the most recent line, and start again at the beginning of the next line. The spaceman took three seconds to travel across the line in five levels, five seconds in five levels and ten seconds in six trials. The height of the spaceman
was approximately 1 centimetre with a width of 0.5 centimetre, subtending a visual angle (VA) of 1.14 degrees, if the child was 50 centimetres from the screen, although, as intended viewing angle was variable in line with participant preference. There were six lines of planets in each trial (see Figure 13.6), and 15 changing planets each trial. The size of each planet was approximately 1 centimetre squared, subtending a visual angle of 1.14 x 1.14 degrees. The distance between each planet varied slightly from 1 centimetre (VA = 1.14 x 1.14 degrees) to 2 centimetres (VA = 1.14 x 2.29 degrees), with a border of approximately one centimetre from the last planet to the edge of the screen. The spaceman regressed (travelled forward, but then reversed back the distance of 2 – 5 planets) in three consecutive trials. Children generally finished the game in about 15 minutes.

Figure 13.6. Space Jump game. The spaceman (target) is located on the forth planet of the forth line

6.2.3. Procedure

Children were introduced to the study and asked if they would like to participate prior to commencement. Upon obtaining consent, participants were then given instructions to play the programs or ‘games’ provided. They were advised to rest their hands below the screen on the table between trials to minimise differences due to motor strategies (such as tracking the space man with their
finger). Following a short break, children were then administered the Woodcock – Johnson III Brief (B1A), the Neale Analysis of Reading Ability (NARA) (3rd Edition) and the Castles and Coltheart II (CC2) (2009). The Woodcock – Johnson III (BIA) was administered to ascertain intellectual functioning, and to rule out intellectual disability as a factor in reading and tracking performance. The NARA was administered to measure individual reading accuracy and rate. The CC2 battery was used to gain greater insight into the specific varieties of reading difficulties through presentation of 40 regular (e.g. bed), irregular (e.g. eye) and non-words (e.g. gop) (120 words total). Specifically, the non-words section of the CC2 was also used to assess phonological ability across participants. Children received a certificate or small reward (eraser or pencil) for their participation in the study. The children participated in a variety of settings, such as other classrooms, often with other children. Consistent with the experiment’s aims, the environment, lighting, and noise levels were not controlled.

6.3. Results

Data was screened prior to the commencement of analysis to check for outliers and errors in data entry. Homogeneity of variance and normality tests were conducted and there were no violations, therefore data analysis proceeded without the need for transformations. The visual dependant variables were tracking performance, in terms of accuracy (or how many planets they correctly identified as changing colour) and reaction time (how quickly the participant tapped the planet following colour change). Scores were collected for the three different tracking speeds. The cognitive dependant variables were NARA reading accuracy and rate discrepancy scores (the difference between their performance for their chronological age and actual performance), and CC2 single word reading scores (in terms of $z$ – scores, calculated based on their chronological age and actual performance). It was not useful to use raw scores for either reading test, as the same version is administered to all children aged 6 – 12 years, thus Australian standardised scores were used based on a specified age range.

6.3.1. NARA accuracy and rate results

The general relationship between tracking accuracy and reaction time (average) and reading ability was explored using a series of Pearsons correlation coefficients. There were no significant relationships between NARA reading
measures and tracking accuracy (Table 9.6 & Figure 14.6). Likewise, there was no correlation between NARA reading measures and tracking reaction time (see Table 9.6). When speed of the target was separated into the three different conditions (3s, 5s and 10s)(see Table 10.6), there was a significant result for tracking reaction time in the 3 second condition (M = 1.53 seconds, SD = .305 seconds) and reading accuracy (M = -5.65 months, SD = 23 months). However the strength of this relationship was considered small (r = .26) (Figure 15.6).

Table 9.6.

*Pearson correlations for NARA results and overall game performance*

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tracking Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NARA Accuracy</td>
<td>.040</td>
<td>.747</td>
</tr>
<tr>
<td>NARA Rate</td>
<td>.205</td>
<td>.094</td>
</tr>
<tr>
<td><strong>Tracking Reaction Time</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NARA Accuracy</td>
<td>.064</td>
<td>.606</td>
</tr>
<tr>
<td>NARA Rate</td>
<td>-.179</td>
<td>.143</td>
</tr>
</tbody>
</table>

*Note.* Tracking accuracy refers to how many targets were detected correctly. Tracking reaction time refers to how quickly participants tapped the correct target.
Figure 14.6. Pearson correlations for tracking accuracy (mean) and NARA rate.

Table 10.6.

Pearson correlations for different speeds of the target and relationships to NARA discrepancy (n = 68)

<table>
<thead>
<tr>
<th>Tracking Speed</th>
<th>3s</th>
<th>5s</th>
<th>10s</th>
</tr>
</thead>
<tbody>
<tr>
<td>NARA Accuracy</td>
<td>.264*</td>
<td>.030</td>
<td>-.045</td>
</tr>
<tr>
<td>NARA Rate</td>
<td>-.043</td>
<td>.728</td>
<td>-.200</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (two-tailed)

Note. s = seconds, and refers to the time taken for the target to get from the start of the line to the end (left to right).
To further explore the relationship between tracking reaction time for the 3 second condition (IV) and reading accuracy (DV), a standard multiple regression analysis was conducted. Results revealed that when IQ and age were factored into the model as independent variables, tracking reaction time no longer accounted for variance in reading accuracy. IQ was the only variable which made a unique contribution to the prediction of reading accuracy; explaining 18% of the variance in reading accuracy scores (see Table 11.6).

Table 11.6.

Summary of standard multiple regression analysis for variables predicting reading accuracy

<table>
<thead>
<tr>
<th></th>
<th>β</th>
<th>p</th>
<th>sr²</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ</td>
<td>.873</td>
<td>.000</td>
<td>.427</td>
</tr>
<tr>
<td>Age</td>
<td>-.799</td>
<td>.700</td>
<td>-.043</td>
</tr>
<tr>
<td>Tracking RT</td>
<td>5.20</td>
<td>.695</td>
<td>.043</td>
</tr>
</tbody>
</table>

Note: β for standardised coefficient; sr² = semi partial correlation; IQ = Woodcock Johnson III Brief Intellectual Ability score; Tracking RT = as measured by time taken to correctly tap the target.
6.3.2. Single word reading results

For single word reading, there were no significant relationships between tracking reaction speed and single word reading. For tracking accuracy, there were also no evident relationships with regular and non-word reading (see Table 12.6). However, there was significant relationship between tracking accuracy (M = 8.69, SD = 1.43) and irregular word reading (M = -.576, SD = 1.04) (Figure 16.6), however this effect was small (r= .261). When tracking conditions were grouped in terms of speed (3s, 5s, or 10s) there were also no significant relationships between tracking speed and accuracy, and reading abilities (see Table 13.6).

Table 12.6.

*Pearson correlation coefficients for overall tracking accuracy, reaction speed performance and single word reading ability (n = 68)*

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking Accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular Word Reading</td>
<td>.185</td>
<td>.132</td>
</tr>
<tr>
<td>Irregular Word Reading</td>
<td>.261*</td>
<td>.031</td>
</tr>
<tr>
<td>Non-Word Reading</td>
<td>.082</td>
<td>.505</td>
</tr>
<tr>
<td>Tracking Reaction Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular Word Reading</td>
<td>-.012</td>
<td>.921</td>
</tr>
<tr>
<td>Irregular Word Reading</td>
<td>-.104</td>
<td>.397</td>
</tr>
<tr>
<td>Non-Word Reading</td>
<td>-.010</td>
<td>.933</td>
</tr>
</tbody>
</table>

*Correlation is significant at 0.05 level
Figure 16.6. Tracking accuracy average and irregular word z – scores.

Table 13.6.

*Pearson correlations for different speeds of the target and relationship to single word reading (n = 68)*

<table>
<thead>
<tr>
<th>Speed</th>
<th>3s</th>
<th>5s</th>
<th>10s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>r</td>
</tr>
<tr>
<td>Regular Words</td>
<td>.129</td>
<td>.293</td>
<td>-.061</td>
</tr>
<tr>
<td>Irregular Words</td>
<td>.035</td>
<td>.774</td>
<td>-.174</td>
</tr>
<tr>
<td>Non - Words</td>
<td>.151</td>
<td>.218</td>
<td>-.087</td>
</tr>
</tbody>
</table>

*Note: s = seconds, and refers to the time taken for the target to get from the start to the end of each line (left to right).*

Tracking accuracy & irregular word reading

To further explore the relationship between irregular word reading and tracking accuracy, a standard multiple regression analysis was conducted. Results revealed that when IQ and age were factored into the model, tracking accuracy no longer predicted variance in irregular word reading scores. IQ was the only variable which made a unique contribution to the prediction of irregular word
performance, explaining 19% of the variance in irregular word reading (see Table 14.6).

Table 14.6.

<table>
<thead>
<tr>
<th></th>
<th>β</th>
<th>p</th>
<th>sr²</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ</td>
<td>.510</td>
<td>.000</td>
<td>.446</td>
</tr>
<tr>
<td>Age</td>
<td>.200</td>
<td>.147</td>
<td>.147</td>
</tr>
<tr>
<td>Tracking Accuracy</td>
<td>.062</td>
<td>.641</td>
<td>.641</td>
</tr>
</tbody>
</table>

*Note*: β for standardised coefficient; sr² = semi partial correlation; IQ = Woodcock Johnson III Brief Intellectual Ability score; Tracking accuracy = as measured by number of correct responses.

6.4. Discussion

The present study aimed to determine if there was a relationship between tracking performance and reading ability using a portable gamified tracking task in a relatively uncontrolled school based setting. The tracking program concept appeared to be new to this field, designed to mimic the dorsal stream controlled, spatial navigation aspect of reading. Based on the NARA scores, the findings revealed that there was not a strong correlation between reading accuracy and rate (for passages) and tracking performance, when analysed both in terms of both tracking speed and accuracy. When tracking speed was separated into conditions, the 3s condition was correlated with reading accuracy, however the relationship was considered weak, and the scatterplot did not show a convincing relationship. When a standard multiple regression was conducted with IQ and age added as independent variables, tracking speed no longer explained unique variance in reading accuracy. Poor readers were just as efficient as good readers at tracking the moving target and identifying the change in stimuli. There were also no significant correlations between regular and non-word reading and tracking accuracy or speed, as defined by the Castles and Coltheart II (2009). There was a small correlation between tracking accuracy and irregular word reading. However, again when IQ and age were added to a multiple regression model which included tracking accuracy, performance in tracking accuracy no longer explained variance in
irregular word reading, suggesting that tracking accuracy was unable to predict variability in irregular word reading ability.

Dyslexic readers may possess a deficit in the dorsal stream that impacts the ability of the spotlight of attention to move smoothly and sequentially across letters and words in an array (Vidyasagar, 1999). It was anticipated that if poor readers experience a deficit with the visual – spatial control of saccades and fixations during the reading process, they may also demonstrate difficulty ‘keeping up’ with the spaceman, and thus, failing to notice changes as it occur, or would respond more slowly to these changes. For example, when participants notice a change in a planet, they are required to tap on the target, and then reengage attention to the moving target (space man). It was anticipated that in the fastest (3 second) condition, the accuracy and speed performance differences between good and poor readers would be most evident, due to potential dorsal stream differences between these groups. Previous research has suggested that a deficit in the dorsal stream may result in difficulty focussing visual spatial attention (Facoetti, et al., 2000), and shifting attention quickly to a target (Brannan & Williams, 1987) which can both subsequently impact the ability to read efficiently (Franceschini, et al., 2012). There is also evidence to suggest that smooth pursuit (Black, Collins, Roach & Zubrick, 1984) and saccadic eye movements (Biscaldi, Gezeck & Stuhr, 1998; DeLuca, et al., 1999;) are abnormal in dyslexic readers, lending further support to the development of a tracking program that may differentiate good and poor readers. However, the specially designed tracking program was not correlated with passage or single word reading performance across the present sample, thus suggesting that traditional tests of visual – spatial attention (such as coherent motion and visual search) continue to be the best means by which to measure this deficit. Reasons why the tracking program was unsuccessful may include the nature of the tracking task, the speed of the stimuli and the surrounding distractors used in the task.

Reading is a self-guided task, with the speed of reading dictated by the reader, based on a variety of factors such as the length of words, familiarity and complexity of the text, and quality of the print (Rayner, 1998). However, in the tracking program, the eye movement was artificial, and guided by the computer programming. The participant was simply required to ‘keep up’ with a target of varying speeds. Therefore, the visual process of reading and visual process of tracking is different, whereby pursuit or tracking eye movement speeds are determined by the target, and are markedly slower than the visual speeds associated
with reading text (Rayner, 1998). The finding that tracking was not correlated to reading ability may be related to this difference. In the context of visual – spatial attention, tracking may not be sufficient to challenge the visual system in the way that reading can, particularly due to the complexity with which the visual system rapidly manages the saccades, fixations and regressions associated with successful reading. It may also be this self-guided/navigation element of the reading process, mediated by the dorsal stream, is the critical factor that is compromised that leads to reading disability. How close the tracking program was to (broadly) mimicking the reading process remains unknown. Presenting an updated version of this tracking with eye tracking technology could determine if the gamified program was close to mimicking the saccades, fixations and regressions associated with reading. Technology has come far since 1879 when Javal first noted (by observation) the saccades and pauses (fixations) that occur during reading (see Huey, 1908). Today, sophisticated eye movement recording systems that can record saccades, fixations and regressions can be used to collect reliable data on eye movement behaviour during the reading process (e.g. Apel, Henderson & Ferreira, 2012). According to Rayner and his colleagues (2006), this head mounted technology is a viable option to determine if particular students exhibit irregular eye movements compared to their normally reading peers. For the purposes on the present study, the aim was to determine performance in a naturalistic setting, without such equipment. However, with further advances in technology, early eye tracking models are being developed which can be administered through a computer tablet camera whilst the participant performs tasks on the same device (Wood & Bulling, 2014; Zhang, Di & Chen, 2014). Thus, using this type of tablet based, in-built technology, the present portable gamified task could be assessed to determine if it encourages eye movements similar to those exhibited during reading. By its very nature, the tracking program would be unable to mimic reading from a user – led perspective. However, if the eye tracking technology could be used to modify the program to more closely match the eye movement behaviour that occurs during the reading process, this may improve the ability of the test to detect visual – spatial attention differences between good and poor readers.

During the experiment, the astronaut moved across the screen in lines just above the planets, taking a total of 3, 5, or 10 seconds to travel from the start to the end of each line (which included the time taken for the space man to move backwards in the regression trials). Following a moving target is called a pursuit eye movement, which is different from fixations and saccades (Rayner, 1998). According to Rayner (1998) pursuit eye movements (that would have occurred
during the Space Jump game) are significantly slower than the saccades that occur during the regular reading process. It is possible that the speed at which the astronaut was moving was not fast enough to simulate the attentional demands placed on the dorsal stream that would occur during reading. Other studies with varied theoretical perspectives have also stressed the importance of a sufficiently rapid presentation of stimuli to capture sensory differences between good and poor readers (e.g. Tallal, 1980; Farmer and Klein, 1993; Nicolson & Fawcett, 1996). For example, in a study by Breznitz and Meyler (2003), dyslexic readers were compared to normal readers across a range of visual, auditory and cross modal tasks. The findings indicated that dyslexic readers demonstrated a significantly slower speed of processing across all three areas. The authors attributed these differences to potential physiological abnormalities such as deficits in the neural circuitry utilised during the reading process (e.g. Galaburda & Livingstone, 1993). Therefore, it appears vitally important that the visual system is challenged by tasks that can successfully tap these differences. Attempting to compare the 3 second tracking condition to reading a line of text is very difficult, as the time taken to read a line of text is influenced by many factors. The average fixation during reading is 225 – 250 milliseconds, but can vary from 50 milliseconds to 600 milliseconds. The average saccade length for English readers is 7 – 9 letter spaces during reading, but can be as short as one letter space and as long as 25 letter spaces (or longer). Time spent reading a sentence can also vary greatly depending on the skill of the reader and the text complexity (for complex texts, fixations are longer and saccades are shorter). Readers also skip high frequency words (such as ‘and’) during reading, and complex words are revisited (through regressions). Reading speed will also vary with age, with younger readers reading at a slower rate as they decipher new words (Rayner, 2009). Thus, given these factors, it could take 3 seconds to read a line of text, but it is very possible that it could take longer or indeed much less time (given that a saccade can span 500° in less than a second (Rayner, 1998)). As one example, texts (across 17 different languages) presented at a distance of 40 centimetres with 10 point Times New Roman font, can be read (aloud) at an average rate of 184 words per minute, or 3.06 words per second (Trauzettel – Klosinski & Dietz, 2012). If the planets were words in the tracking program, this would equate to almost 4 seconds per line, based on the reading speed findings presented by Trauzettel – Klosinski and Dietz, (2012). In contrast, during silent speed reading, rates around 600 – 700 words per minute can be achieved. However, it is noted that during speed reading, the reader is not actually reading every word of the text (Rayner & Pollatsek, 1989). In the context of the
tracking game, this would equate to much less than 1 second per line. It was critical
during the design phase to ensure that the game was not too difficult for the
participant. If the participant did not experience a sense of mastery and enjoyment
they may reject the game and refuse to play. However, there must be a balance
between ensuring participant engagement and challenging the visual system in a
manner that is similar to reading. Therefore, future designs should include levels
faster than the original 3 second condition (e.g. 2 seconds or 1.5 seconds), but also
intermix these levels with easier (e.g. 5 second) levels that the children can
continue to track successfully.

The lines of coloured circles (the planets in the game) were also very
different to sentences, in that words contain more complex parts (visual stimuli)
and could clutter the scene more so than the basic circles used in the tracking task.
Poor readers experience greater difficulty reading letters which are surrounded by
clutter (other letters). If letters are spaced further apart, it is suggested that poor
readers experience less difficulty focussing visual – spatial attention required to
read words successfully (Zorzi, et al., 2012). Likewise, dyslexic children perform
at similar levels to normally reading children in visual search tasks that involve
fewer distractors. However, as the number of distractors increase (more clutter),
dyslexic children find it more difficult to detect the target, compared to their
normally reading peers (Vidyasagar & Pammer, 1999). It is suggested that words
arranged in sentences would represent far more clutter, as compared to different
coloured circles/planets arranged in a line. Thus, poor readers may have found it
easier to complete this task, compared to reading sentences, because there is less
complexity or clutter in the stimuli (circles/planets). To overcome this, future
design could focus upon changing the planets to more complex objects (e.g.
multiple intersecting lines), and to make the objective to detect a change in the
configuration of the object (rather than a simple colour based change). By
increasing clutter, this could increase the demands placed upon the visuospatial
attention system, and more closely simulate the process that is associated with
reading words and sentences. It may also be worthwhile to return to a traditional
lab based approach, and carefully select elements such as luminance and colour, to
test the effectiveness of this new tracking program to differentiate good and poor
readers in a more controlled setting (where the contribution of the dorsal stream
can be more stringently determined).

Overall, speed or accuracy performance in the gamified tracking program
was not correlated with passage or single word reading skills. There are a number
of reasons why the program may have been unable to detect dorsal stream
differences. Firstly, reading is a user led process, which is different from tracking a moving object of a set speed. In order to determine if the tracking program encouraged similar eye movements associated with reading, eye tracking technology could be used to record eye movements whilst participants engage in the (updated) program. Secondly, the dorsal stream may require a greater challenge by increasing the speed at which the target travels across the lines of planets, to more closely mimic normal reading behaviour. Lastly, the effects of clutter should be more closely considered, in order to reflect the process of reading. This could include replacing the planets with more complex objects, and making the changes that occur in the scene object based changes as opposed to colour based differences. It is possible that if these adjustments are made, this would result in a program that is more effective in challenging the visual – spatial attention system in a manner which is more reflective of the reading process, and thus have more utility in exploring the visual qualities of dyslexia.
6.5. References


Chapter 7.

Game Based Training to Improve Visual Attention and Reading: A Clinical Pilot Study

7.1. Introduction

The aim of the three previous studies was to determine if performance on portable game-like magnocellular/dorsal stream tests was correlated with reading ability, when administered in a school-based setting. Results revealed that performance on visual search and change detection games, but not the tracking game, was correlated with reading ability. That is, visual search speed accounted for 7% of unique variance, and change detection accounted for 9% of unique variance in reading rate over and above IQ, age and phonological ability. Change detection ability was also able to predict single word phonological and orthographic reading performance. These results contribute to a growing body of evidence that suggest performance on visual search (e.g. Moores, Cassim & Talcott, 2011; Casco, Tressoldi & Dellantonio, 1998; Sireteanu, et al., 2008; Vidyasagar & Pammer, 1999) and change detection (Rutkowski, Crewther & Crewther, 2003) programs may be used as an index of reading ability. Additionally, the present findings also make an additional contribution to the reading research field in providing evidence that portable gamified versions of these classic tasks can be administered in a practical school-based setting, and still predict reading ability. Performance on the tracking program (Chapter 6), a new type of dorsal stream test, was not correlated with reading ability. It is proposed that the speed of the tracked item was insufficient to challenge the dorsal stream in a manner similar to the reading process. As performance on the specially designed visual search and change detection games was significantly correlated with reading ability, the next step here was to explore whether such tasks could have utility as part of a clinical intervention.

The most widely accepted current clinical intervention for dyslexia is phonological training (Shaywitz, Morris & Shaywitz, 2008). This involves training children to identify individual letters and their corresponding sounds, combinations of letters and their sounds, same/different sounds, rhyming, phoneme deletion, segmenting and blending sounds, and practice of non-words (Alexander,
Anderson, Heilman, Voeller & Torgesen, 1991; Schneider, Ennemoser, Roth & Kuspert, 1999; Torgesen, Morgan & Davis, 1992). The theory associated with this intervention is the phonological theory of dyslexia, which contends that dyslexia is exclusively and directly caused by a cognitive deficit in the area of the brain responsible for the representation and processing of speech sounds. Over the past two decades it has been the most prominent theory in dyslexia research, forming the basis for many intervention studies (Ramus, 2003). For example, in a study by Elbro and Petersen (2004), at-risk readers were provided with an intensive 17 week program in phonemic awareness. Following treatment, the trained group outperformed at-risk controls in both non-word and regular word reading measures. Furthermore, the trained group continued to demonstrate these gains in grades 2, 3 and 7 (Elbro & Petersen, 2004). Likewise, a multitude of intervention programs with a phonological training component have also experienced success in improving phonological awareness and early level reading skills (Aboras, Elbanna, Abdou, & Salama, 2012; Bianco, et al., 2012; Brady, Fowler, Stone, & Winbury, 1994; Ecalle, Magnan, Bouchafa, & Gombert, 2009; Falth, Gustafson, Tjus, Heimann, & Svensson, 2013; Gustafson, Ferreira & Ronnberg, 2007; Hindson, et al., 2005; Lovett, et al, 1994; Lundberg, Frost & Petersen, 1988; Lyster, 2002; McArthur, et al., 2013; Schneider, Ennemoser, Roth & Küspert, 1999; Schneider, Roth & Ennemoser, 2000). Whilst it is recognized that early intervention in programs such as phonological training can result in short term gains in reading ability, not all children improve their phonological skills, or return to normal reading levels in the long term (Byrne, Fielding – Barnsley & Ashley, 2000; Hurry & Sylvia, 2007). Approximately 2% to 6% of children will continue to experience significant reading deficits, despite intensive phonological interventions (Torgesen, 2000). In a randomized controlled trial of reading and language intervention for six year old children at risk of dyslexia, daily intervention (e.g. phonological awareness and reading skills) resulted in small to moderate improvements in letter knowledge and phonemic awareness. However, 18 weeks post – intervention, there were no reliable effect of the intervention on word – level reading abilities (Duff, et al., 2014). Given that a proportion of children fail to benefit (or receive only minor benefit) from phonological interventions, it is reasonable to examine additional causal factors and subsequent training programs which may improve the literacy outcomes for poor readers, in addition to the phonological training programs currently administered.
In determining if there is a causal link between a process, such as magnocellular/dorsal stream processing and reading ability, a few important issues should be considered (Castles & Coltheart, 2004). Firstly, dorsal stream abilities should be measured in children before they learn to read. This way, if dorsal stream deficits precede reading ability, this suggests that dorsal stream differences may influence the development of reading skills (as opposed to reading exposure subsequently impacting dorsal stream development). Kevan and Pammer (2008) have established that children at risk for dyslexia demonstrate deficits before they learn to read, with dorsal stream performance continuing to uniquely predict reading ability when IQ, age and phonological ability are also taken into account (Kevan & Pammer, 2009). This result was later supported by the work of Facoetti and colleagues (2010) who also confirmed visual spatial attention deficits were present in at-risk pre-schoolers before they commenced reading tuition, and Franceschini and colleagues (2012), who confirmed that pre-reading visual attention deficits are predictive of reading ability in grades one and two. Secondly, to support a causal hypothesis, in this case, for visual-spatial attention training to improve reading ability, there must be a non-spurious relationship between biology and behavioural outcomes. In the area of vision research, mounting evidence suggests that dyslexic readers also demonstrate deficits on tasks that rely on magnocellular/dorsal stream functioning (Buchholz & McKone, 2004; Casco and Prunetti, 1996; Conlon, Lilleskaret, Wright & Power, 2012; Cornelissen, Richardson, Mason, Fowler & Stein, 1995; de Boer-Schellekens & Vroomen, 2012; Kevan & Pammer, 2008; Lovegrove, Bowling, Badcock, & Blackwood, 1980; Pammer & Wheatley, 2001; Rutkowski, Crewther & Crewther, 2003; Witton, et al., 1998). Specifically, it has been demonstrated that poor readers demonstrate impairments in their ability to visually focus attention (Facoetti, et al., 2000, 2001, 2003, 2006, 2010; Hari & Renvall, 2001; Hari, Valta & Uutela, 1999), which may impact the spatial navigation function that assists in reading accurately and fluently (Vidyasagar and Pammer, 2010). Finally, criteria for causality should also include training, where visual training should not only result in visual-attention improvements, but also transfer to reading improvements (Castles & Coltheart, 2004). In a study by Franceschini and colleagues (2013), training of visual-spatial attention improved not only visual-spatial attention in poor readers, but also transferred to improvements in reading ability. Thus, this finding meets some of the criteria for a causal relationship between visual-spatial attention performance and reading ability. However, there is still much work to do in establishing visual-spatial attention as one of the potential causal factors of
dyslexia, and in building an evidence base for visual – spatial attention training as an effective treatment to improve reading abilities in poor, and at – risk, readers. Whilst studies exploring action video games training and reading are in the early stages, there exists a strong evidence base suggesting action video games training can improve visual attention in a variety of domains.

With the increasing popularity of computer games in modern culture (Jansz & Martens, 2005), researchers have begun to explore the impact of video game play on the functioning of the visual system. For example, video game players (VGP) and non – video game players (NVGP) have been compared across a range of areas to determine if differences in performance exist between these two groups. From these investigations, researchers have suggested that gamers are indeed different in a number of ways including; VGP’s have faster reaction times when detecting targets (Castel, Pratt & Drummond, 2005), enhancement of visual abilities both in the central and periphery regions (Green & Bavelier, 2006a; Wu, et al., 2012), are able to track more targets simultaneously (Green and Bavelier, 2006b), and are better at successfully dividing their visual attention (Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994). To test the visual impacts of training NVGP’s, participants were provided with training in video games, and following this training demonstrated improvements in the areas of visual reaction speed and tracking (Green & Bavelier, 2006a), enhanced useful field of view, and faster recovery from attentional blink (Green and Bavelier, 2003). Additionally, portable visual training using a hidden object type game for one hour per day (5 days per week) for 20 hours improved visual search and spatial working memory in participants who had little previous gaming experience (Oei & Patterson, 2013). Video game players can also outperform non-video game players on change detection tasks, thought to be the case due to a broader scanning range when searching the scene for the difference (Clark, Fleck & Mitroff, 2011).

More specifically related to dyslexic readers, studies have shown that visual training can improve visual performance on tasks that some dyslexic readers had previously performed poorly. For example, in a study by Conlon, Sanders and Wright (2009), participants were provided with a coherent motion task. This task involved viewing two black panels with white dots, and indicating which panel contained the coherent motion. Dyslexic readers were significantly less sensitive to global motion compared to a control group of normally reading participants, when baseline measures were taken. Each participant took between 35 and 40 trials following this initial assessment, which acted as practice. The effects of this
practice session were measured by taking a second threshold estimate for coherent motion performance. After just one round of practice, the dyslexic readers, but not normal readers, showed a significant improvement in their sensitivity to global motion. Whilst dyslexic readers improved, they were still impaired in their visual motion sensitivity compared to normal readers following this training. This improvement in visual ability is consistent with previous research, which has demonstrated that dyslexic participants can increased their sensitivity on complex motion processing tasks (e.g. identifying the direction of dots or lines) following practice with similar tasks (Cornelissen, et al., 1995). Furthermore, training that uses tasks thought to rely on magnocellular/dorsal stream processing has also been correlated with improvements in reading ability in poor to moderate readers (Lawton, 2007, Solan, et al., 2004), although in both studies the extent of the unique contribution of visual training is somewhat unclear. For example, in the study by Solan and colleagues (2004), participants were provided with a ‘guided reading’ task to improve reading fluency. This entailed reading (at their own reading level) using a viewing system that moved from left to right exposing three words at a time. Thus, separating the contribution of the visual versus reading training to subsequent reading and visual improvements is complex, and requires further research with separate experimental conditions. Importantly, however, the work of Cornelissen (1995), Conlon (2009), and their colleagues have demonstrated that visual abilities are not fixed, and with appropriate training, dyslexic readers can improve their performance on visual tasks in which they had previously performed poorly.

Development of the dorsal stream is an ongoing process in early childhood, and is suggested to mature at around age eleven (Crewther, Crewther, Barnard, & Klistorner, 1996). Parrish and colleagues (2005) concur that the human visual system is not fixed from birth, but rather continues to develop throughout early childhood. In a series of studies they confirmed that motion defined form matures in children by age 7-8, global motion detection by age 3-4, texture defined form by age 11-12, and global arrow texture by age 3-4. They concluded that both the dorsal and ventral streams continue to develop from infancy to adulthood, with different aspects of visual performance maturing at different developmental stages (Parrish, Giaschi, Boden & Dougherty, 2005). Early experiences can greatly alter both the structure and function of the developing brain (although neural plasticity has been demonstrated throughout the lifespan) (Nelson, 2000). As deficits in visual attention are detectable in children at risk for dyslexia before they learn to
read, early targeting/training of visual attention deficits could result in substantial gains (and reduce the impact of secondary psychological and social consequences). The results from the visual search and change detection experiments (Chapter 4 & 5) support the use of portable games in detecting visual attention differences in poor readers from 6 – 12 years, thus the use of games may also be useful in the treatment of visual – spatial attention deficits. Action video game play has also been suggested to be related to higher levels of neural plasticity, as desire driven dopamine levels might support neural changes, especially in the right dorsolateral prefrontal cortex (e.g. reaching from object and spatial information) (Kuhn, Gleich, Lorenz, Lindenberger, & Gallinat, 2014).

Given that reading impairment is associated with difficulties in focussing visuo – spatial attention (e.g. Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000), early research has begun into the impacts of game - like training on visual attention and reading abilities. Franceschini and colleagues (2013) successfully demonstrated that visual attention can be trained to improve reading abilities in an action video games training task. They asked ten dyslexic children to play an action based Nintendo Wii Rayman Raving Rabids game, and ten to play a game which did not have action components (mini games that were assessed as being less reliant on the dorsal stream). Each child played this game individually for a total of 12 hours (9 sessions, 80 minutes each), and did not receive additional phonological or orthographic training during this training schedule. Data was collected from each participant regarding spatial attention (by way of a cueing experiment), as well as decoding of non-words and word text reading skills, before and after training in video games was administered. In the focused spatial attention task, participants were asked to focus on a fixation point, and following a red dot (cue), a string of six symbols appeared, from which the participant had to identify the target. In the distributed spatial attention task, the red dot appeared after the symbols disappeared. In the cross modal attention task, two circles were displayed on the left and right side of the fixation point. An auditory cue was presented on the left, right or to both ears prior to the presentation of the target (stylized dog). In this task both reaction times and accuracy were recorded. When performance was compared from time 1 to time 2, non-word and word text reading ability significantly improved for the action video game players, but not for the non-action video game players. The authors suggested that the improvements made for this group were equivalent to 12 months of spontaneous improvement of reading ability. Additionally, action video games players also improved their spatial and
temporal attention (from time 1 to time 2). Impressively, when students were retested two months later, it was found that the action video game training gains were retained. They concluded that action video games training may be optimal to improve reading due to the demands placed on the magnocellular/dorsal pathway. Specifically, these type of games are fast, utilise peripheral information and require the spotlight of attention to be engaged under high load, all of which could be useful in ‘working out’ or strengthening the visuo-spatial attentional system (Franceschini, 2013). This study provides the first evidence that the system can be strengthened through training and consequently improve reading ability.

Like Franceschini and colleagues (2013), the aim of the present experiment was also to explore training of visual spatial attention in poor readers, to determine if this training can subsequently improve reading ability. Whilst it has been established that performance on portable computer tablets, using specially designed visual search and change detection games, is correlated with reading ability (see Chapters 4 & 5), it is yet to be determined if these similar portable methods and game-like tasks can be used in an effective intervention program. That is, for portable visual search and change detection games to be used in everyday settings such as the school, to improve visual spatial attention and subsequent reading ability. Visual search and change detection tasks are certainly good candidates for training the dorsal stream to improve reading ability, as both require the fast visual spatial coding of a complex and cluttered scene (like reading) – and is an action that is specifically the domain of the dorsal stream (Pammer, 2012). Furthermore, it has been demonstrated that both visual search abilities can significantly improve following action video games training (Oei & Petterson, 2013; Wu & Spence, 2013), and change detection abilities are superior in participants with regular action video game exposure (Clark, Fleck & Mitroff, 2011; McDermott, Bavelier & Green, 2014). If portable games are also successful within a school setting, this would have exciting implications for a comprehensive training program which could include visual attention based games training in schools, alongside traditional phonological interventions that are presently provided to poor readers. Additionally, the current study was designed to assess reading ability across the spectrum, from very poor to very good readers. That is, to assess if portable games training has the potential to improve reading across all ranges, or just improve skills for poor readers. Thus, an unselected sample was utilised to explore the potential benefits of portable computer tablet games training, in a pilot study, across all levels of reading ability. It was hypothesised that training in visual
search and change detection games would improve passage reading (reading accuracy and rate) more so than single word reading, due to the higher levels of spatial navigation that is required to negotiate the clutter (other words), compared to single word reading.

7.2 Method

7.2.1. Participants

Forty children (24 males) participated in the training study. The training group (or experimental group) consisted of 25 participants, and this group were provided with visual search and change detection games. Nine children were allocated as controls, and were provided with puzzle type games, thought to be less reliant on dorsal stream processing. Both experimental and control groups were administered reading tests prior to, and upon conclusion of, the study. Dyslexic readers were classified as individuals with reading accuracy or rate scores which were two or more years below their expected levels for their chronological age. This was calculated using the Neale Analysis of Reading Ability (3rd Edition) (NARA), and was based upon NARA scores obtained prior to training. Analysis of the Woodcock Johnson III Brief Intellectual Ability scores indicated that there was no significant difference between dyslexic (M = 95.5, SD = 8.9) and normal readers (M = 101.4, SD = 8.3) in their intellectual abilities (t (32) = -.199, p = .060). In the control group, four participants were classified as dyslexic readers, and in the experimental group 12 participants were classified as dyslexic. Children were aged between six and 12 years, with an average age of nine years, and were tested and trained within their school. NARA results from two participants were unable to be collected post training due to technical difficulties, two were excluded due to low IQ scores (below 80), and data from two participants were excluded due to performing 2.5 standard deviations below the mean for reading rate following training.
Demographic information for combined and separate groups

<table>
<thead>
<tr>
<th></th>
<th>Training Group</th>
<th>Control Group</th>
<th>Total Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Participants</td>
<td>25</td>
<td>9</td>
<td>34</td>
</tr>
<tr>
<td>Average Age (years)</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Average IQ</td>
<td>100.4</td>
<td>93.6</td>
<td>98.6</td>
</tr>
<tr>
<td>Dyslexic Readers (number)</td>
<td>12</td>
<td>4</td>
<td>16</td>
</tr>
</tbody>
</table>

7.2.2. Stimuli

Following the significant correlations detected between visual search and change detection performance (Chapter 4 & 5) and reading ability, commercial games for visual attention training were selected based on these search and detection elements. It was anticipated that if these types of games are capable of detecting dorsal stream differences in poor readers, these games could likewise be utilised in training dorsal stream mediated visual attention. Like the previous studies (Chapter 4 & 5), these games were presented on the same computer tablets, in similar school based settings. For the visual search games the participant was required to find specific objects in a complex cluttered array by tapping on the hidden item on the screen where it is located. For change detection, the participant was required to identify differences between two images and tap where the differences are located on the screen (see Figure 17.7). A total of five different themed visual search and change detection games were provided to participants, to allow for variety during game play and reduce the effects of boredom (e.g. under the sea, in the garden, in the house etc). For the control group, commercial tablet computer games were selected that involved completing a series of static puzzles (see Figure 18.7) such as Cut the Rope, Naughts and Crosses and Jewel Hunter. A total of six different types of puzzle games were provided to participants, similarly to increase variety in game play and maintain interest. During these games, the participants had opportunities to achieve level upgrades, collect points and receive
special items for their performance. All games started at a basic (early school age) level, and increased in complexity as the participant improved (e.g. more items, increased level of concealment).

7.2.3. Procedure

Approximately four months prior to training, all participants were tested by the author (Clinical Psychology Registrar) on a series of psychometric tests and specially designed portable games. The Woodcock Johnson - III (Brief Version) was administered to gain a brief measure of intellectual ability. Two participants scored lower than 80, and their data was subsequently removed from the analysis. All other participants tested were within low average to high average ranges. The Neale Analysis of Reading Ability (3rd Edition) (NARA) is an Australian standardised reading test, and was used to gather information on reading performance in the areas of word accuracy, reading rate and comprehension of material. Children were timed whilst reading short stories of increasing difficulty, and errors were coded. Once stories were read aloud, the comprehension component of testing was assessed by asking set questions related to the story. The Castles and Coltheart II (Castles, et al., 2009) was also administered to obtain performance scores in the areas of regular, irregular and non-word reading. For this test, children were asked to read aloud single words that gradually increased in difficulty. These words alternated between all three word types (regular, irregular and non-words). After five consecutive errors in a single category (e.g. irregular words), presentation of that word type was discontinued. Number of correct responses for each word category were tallied and matched to z - scores to indicate reading performance relative to age.

Participants in both the experimental and control conditions underwent a minimum of five and a half hours of game play over the course of seven weeks (M = 333.925 minutes). The timing and frequency of these training sessions varied due to the needs of the school and availability of students. Students participated in 1 – 6 sessions per week, for a total of 10 – 70 minutes per session. Training occurred both inside in a well-lit, relatively quiet room, and also outside in undercover spaces, in groups of up to five students. This variability in environment and noise was purposely intended, to test if training can be provided in practical environments that are less controlled. Prior to commencement, all students
received instruction on how to play the games, and students wore corrective glasses where this was required.

Post training literacy testing was administered by Provisional Psychologists in a university training program, who were unfamiliar to the students. The Provisional Psychologists were also unaware as to each students’ group allocation (experimental or control). These testers were allocated in this manner to reduce the potential for experimenter bias during the retesting phase. Literacy testing occurred in a quiet, well lit space, close to the students’ classroom. Students were retested on the NARA, using the supplementary version of the test (new stories that were not previously read by the students). They were also administered the first edition of the Castles and Coltheart test (1993) to gather information regarding regular, irregular and non-word reading. This first edition was used to reduce retest effects which may have occurred if the second edition of the Castles & Coltheart was used (2009) repeatedly. Intellectual abilities (IQ) were not retested as this was not an area of interest in the present study.

*Figure 17.7. Examples of visual search and change detection games used for the purpose of training*
Figure 18.7. Example of puzzle games administered to the control group

7.3. Results

Data was first screened to ensure no missing values or outliers were present. This screening revealed that there were two outliers that were more than 2.5 standard deviations above the mean (at time 2), and data from these participants were subsequently removed from the analysis. Data from 34 participants remained, and was subsequently analysed. Time 1 refers to reading scores prior to training. Time 2 refers to reading scores following training (or following puzzle games for the control group). Discrepancy refers to the difference between the participants expected score based on age, and their actual score obtained during testing. For example, if a participant’s NARA accuracy score was four months behind their peers, then their NARA accuracy discrepancy would be -4 months. There were no significant differences in intellectual ability between the training and control group in the present experiment (t(32) = 2.013, p = .060). At both time 1 and time 2, reading comprehension and rate were normally distributed. However, reading accuracy was positively skewed. This suggests that the majority of the sample was below average levels for reading accuracy, and this remained the case following training (see Table 15.7). No transformations were applied to this analysis.
7.3.1 NARA scores

Overall, visual attention games training did not significantly improve reading accuracy, comprehension or rate, as measured by independent samples t-tests based on NARA discrepancy scores. Prior to training, there were no significant differences between groups for reading accuracy or comprehension. There was a significant difference between groups for reading rate at time 1 (t(32)= -2.412, p = .023), with the experimental group performing better than the control group in their reading rate at the commencement of the training. However, following training, the groups were no longer significantly different (t (32) = .220, p = .827), with both the experimental group and the control group performing on average 12 months worse, post program (see Table 15.7).
Table 15.7.

Summary of independent samples t-test to measure the effect of training on reading accuracy, comprehension and rate (in months)

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>Training</th>
<th>Control</th>
<th>Training</th>
<th>Control</th>
<th>T(32)</th>
<th>p</th>
<th>CI</th>
<th>Mean Difference</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1</td>
<td>-17.04</td>
<td>-12.56</td>
<td>12.81</td>
<td>16.81</td>
<td>.828</td>
<td>.414</td>
<td>.828</td>
<td>.414</td>
<td>-6.54</td>
<td>4.48</td>
<td>0.14</td>
</tr>
<tr>
<td>Time 2</td>
<td>-16.92</td>
<td>-16.67</td>
<td>12.48</td>
<td>18.88</td>
<td>.045</td>
<td>.964</td>
<td>.045</td>
<td>.964</td>
<td>-11.11</td>
<td>.253</td>
<td>0.00</td>
</tr>
<tr>
<td>Difference</td>
<td>.120</td>
<td>-4.11</td>
<td>8.19</td>
<td>7.80</td>
<td>.957</td>
<td>.188</td>
<td>.957</td>
<td>.188</td>
<td>-10.64</td>
<td>-4.23</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>Comprehension</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1</td>
<td>-12.16</td>
<td>-16.00</td>
<td>12.03</td>
<td>17.23</td>
<td>-.730</td>
<td>.470</td>
<td>-.730</td>
<td>.470</td>
<td>-14.54</td>
<td>-3.84</td>
<td>0.12</td>
</tr>
<tr>
<td>Time 2</td>
<td>-7.48</td>
<td>-10.56</td>
<td>14.03</td>
<td>18.64</td>
<td>-.516</td>
<td>.609</td>
<td>-.516</td>
<td>.609</td>
<td>-15.20</td>
<td>-3.07</td>
<td>0.09</td>
</tr>
<tr>
<td>Difference</td>
<td>4.68</td>
<td>5.44</td>
<td>10.23</td>
<td>8.45</td>
<td>.200</td>
<td>.843</td>
<td>.200</td>
<td>.843</td>
<td>-7.01-</td>
<td>.764</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>Rate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1</td>
<td>3.56</td>
<td>-9.00</td>
<td>19.63</td>
<td>10.25</td>
<td>-1.81</td>
<td>.023</td>
<td>-1.81</td>
<td>.023</td>
<td>-26.62</td>
<td>-12.5</td>
<td>0.30</td>
</tr>
<tr>
<td>Time 2</td>
<td>-9.60</td>
<td>-20.67</td>
<td>20.06</td>
<td>18.76</td>
<td>-1.44</td>
<td>.159</td>
<td>-1.44</td>
<td>.159</td>
<td>-26.70</td>
<td>-11.0</td>
<td>0.24</td>
</tr>
<tr>
<td>Difference</td>
<td>-13.16</td>
<td>-11.66</td>
<td>18.78</td>
<td>12.77</td>
<td>.220</td>
<td>.827</td>
<td>.220</td>
<td>.827</td>
<td>-12.34</td>
<td>1.49</td>
<td>0.03</td>
</tr>
</tbody>
</table>
7.3.2. Single word scores

For the Castles and Coltheart single word reading test, findings were mixed, however overall, the participants did not improve their single word reading ability following visual attention training. For regular word reading, there were no differences between groups at time 1 or time 2. However, there was a significant difference between groups in the difference between the time 1 and time 2 regular word scores. The magnitude of the difference in the means (mean difference = .57, 95% CI: .069 to 1.07) was large (eta squared = .143). This indicates that the discrepancy between time 1 and time 2 became larger, with the training group performing worse and control group performing better in regular word reading following the experiment. For non-word reading, groups were not significantly different pre training, however post training; there was a significant difference between groups. The magnitude of the difference in the means (mean difference = .65, 95% CI: .007 to 1.28) was moderate (eta squared = .117). These results suggest that post training the control group was performing significantly better in their non-word reading compared to the experimental group. There was no significant differences at time 1, time 2 or in the difference between time 1 and time 2 for irregular word reading (see Table 16.7).
Table 16.7.

Summary of independent samples t-tests to measure the effects of training on regular, irregular and non-word reading (z-scores)

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>Training</th>
<th>Control</th>
<th>Training</th>
<th>Control</th>
<th>T(32)</th>
<th>p</th>
<th>CI</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regular Words</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1</td>
<td>-0.683</td>
<td>-0.636</td>
<td>0.887</td>
<td>0.532</td>
<td>0.148</td>
<td>0.883</td>
<td>-0.597 - 0.691</td>
<td>0.046</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 2</td>
<td>-0.926</td>
<td>-0.307</td>
<td>0.818</td>
<td>0.983</td>
<td>1.68</td>
<td>0.116</td>
<td>-0.177 - 1.41</td>
<td>0.618</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>-0.243</td>
<td>0.328</td>
<td>0.636</td>
<td>0.628</td>
<td>2.31</td>
<td>0.027</td>
<td>0.069 - 1.07</td>
<td>0.572</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Irregular Words</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1</td>
<td>-0.844</td>
<td>-0.757</td>
<td>0.922</td>
<td>0.631</td>
<td>0.258</td>
<td>0.798</td>
<td>-0.593 - 0.766</td>
<td>0.086</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 2</td>
<td>-0.926</td>
<td>-0.380</td>
<td>0.761</td>
<td>0.700</td>
<td>1.95</td>
<td>0.069</td>
<td>-0.046 - 1.13</td>
<td>0.545</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>-0.082</td>
<td>0.377</td>
<td>0.778</td>
<td>0.674</td>
<td>1.56</td>
<td>0.127</td>
<td>-0.137 - 1.05</td>
<td>0.459</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Non- Words</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1</td>
<td>-0.858</td>
<td>-0.466</td>
<td>0.940</td>
<td>0.916</td>
<td>1.07</td>
<td>0.289</td>
<td>-0.348 - 1.13</td>
<td>0.391</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 2</td>
<td>-0.820</td>
<td>-0.174</td>
<td>0.831</td>
<td>0.742</td>
<td>2.06</td>
<td>0.047</td>
<td>0.007 - 1.28</td>
<td>0.646</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>0.037</td>
<td>0.292</td>
<td>0.504</td>
<td>0.474</td>
<td>1.31</td>
<td>0.197</td>
<td>-0.139 - 0.648</td>
<td>0.254</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.3.3. Initial reading level and subsequent improvement

It is suggested that children with the greatest reading deficits may benefit most from visuo – attentional training. To test this prediction, a correlational analysis was conducted between pre – training reading levels and post training.
improvement for experimental and control groups. The correlational analysis revealed that level of reading discrepancy at time 1 is negatively correlated with the amount of change between time 1 and time 2, but only for reading rate within the experimental group. That is, for the training group, those who were fastest in their reading speed at time 1, were more likely to have the largest discrepancy in their reading speed post training (i.e. the fastest participants were significantly slower in their reading rate)(see Table 17.7).

Table 17.7.

_Correlation analyses between pre-training reading levels and post training discrepancy (in months)_

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group, N = 25</th>
<th>Control Group, N = 9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
</tr>
<tr>
<td>Accuracy</td>
<td>-.360</td>
<td>.077</td>
</tr>
<tr>
<td>Comprehension</td>
<td>-.214</td>
<td>.305</td>
</tr>
<tr>
<td>Rate</td>
<td>-.455</td>
<td>.022*</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level

7.3.4. Impact of age on level of reading improvement

A general consensus within the reading research community exists regarding the importance of early intervention on reading outcomes. It is suggested that if poor readers are provided with appropriate intervention early in their development, they will achieve much better reading outcomes over the longer term (Nelson, et al., 2005). To test this prediction in the context of visual training, a correlational analysis was conducted to measure the relationship between age before training and post training improvement in reading ability. Results suggested that there was not a significant relationship between age and post training improvement for the experimental group. However, for the control group, age was negatively correlated with time 2 discrepancy for accuracy and rate (see Table 18.7). Examination of scatterplots for the control group indicate that older participants tended to perform worse in accuracy and rate from time 1 to time 2, with less discrepancy for younger participants (see Figure 19.7 & 20.7). This result
must be interpreted with caution due to the limited number of older participants in this study.

Table 18.7.

*Correlation between age and level of reading discrepancy from time 1 to time 2*

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group</th>
<th></th>
<th>Control Group</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>r</td>
<td>p</td>
</tr>
<tr>
<td>Accuracy</td>
<td>-.017</td>
<td>.936</td>
<td>-.691</td>
<td>.039*</td>
</tr>
<tr>
<td>Comprehension</td>
<td>-.002</td>
<td>.993</td>
<td>.289</td>
<td>.451</td>
</tr>
<tr>
<td>Rate</td>
<td>-.336</td>
<td>.101</td>
<td>-.714</td>
<td>.031*</td>
</tr>
</tbody>
</table>

* Significant at the .05 level

*Figure 19.7. Accuracy discrepancy between time 1 and time 2 by age for participants in the control group*
7.4. Discussion

Previous studies have suggested that video games training can improve not only visual attention (Green & Bavelier, 2006a), but also reading ability (Franceschini, et al., 2013). Performance on portable game – like visual search and change detection tasks that are administered in relatively uncontrolled school settings, have also been correlated with reading ability (Chapter 4 & 5). It was hypothesized that providing visual training using game like portable technology would result in improvements in reading skill, due to an enhanced ability to focus visual – spatial attention during the reading process. The experimental group was provided with over five hours of training in change detection and visual search type portable games. The control group were provided with static puzzle type games that were not thought to heavily rely on the dorsal stream. The present study did not support the suggestion that training improves reading accuracy, comprehension or rate. Training also failed to improve regular, irregular and non-word reading. Intriguingly, reading rate significantly slowed, not only for the experimental group, but also to the control group, who were not exposed to visual training. Implications for these findings, potential limitations, and future directions are discussed.

Administration of the training program did not result in any significant gains for the experimental group in terms of their reading accuracy, when measured with the NARA. There was also no differences detected between the
experimental and control group, post training. This is contrary to the findings by Franceschini and colleagues (2013), who did achieve an improvement in reading accuracy post training. However, there are important differences between his study and the present study, which may have influenced the effectiveness of the present training program.

The present study was a clinical pilot, designed to test the viability of training within ‘real world’ settings, and was administered with flexibility in cooperation with the teachers of the school. Children participated in the training during days and for durations that best suited the school curriculum. Franceschini and colleagues (2013) provided 12 hours of game play, which consisted of nine sessions of 80 minutes per day over two weeks. This is contrasted with the present study whereby children received five hours of game play, consisting of varied sessions (10 – 70 minutes) over seven weeks. It is possible that in the present study, the training was ineffective because it was not intensive enough, and too ‘spread out’ across the training timeframe. That is, because it was not as intensive (was not administered every day or most days, and for a significant amount of time); it may not have challenged the dorsal stream beyond its limits in a way that could result in meaningful change for visual attention abilities and subsequent reading accuracy. Other studies that have found visual system improvements due to computer gaming have generally tested established gamers (Dye, Green & Bavelier, 2009; Green & Bavelier, 2006b; West, et al., 2008), who play video games regularly for minimum amount of time (e.g. 5 hours per week in a study by Green and Bavelier (2007); 7 hours per week on a study by Boot and colleagues (2008)). In a study which examined the impact of action video games on the visual system of non–gamers, it was discovered that one hour per day over ten consecutive days resulted in improvements in the capacity of visual attention, its temporal resolution and spatial distribution (Green & Bavelier, 2003). This finding was later replicated by Feng, Spence and Pratt (2007) who also found ten hours of action video game play improved both visual – spatial attention and mental rotation abilities in participants who reported no previous experience with action video games. In the present study, children were only able to be released from class to participate in training for approximately half this time (5 hours).

The present study also utilised commercial change detection and visual search games, based upon the findings that performance on these types of programs can detect dorsal stream differences between good and poor readers (Chapter 4 & 5). However, whilst these games required fast response times, they would not be
considered action based. In a study by Clark, Fleck and Mitroff (2011), individuals who played action video games required less time to notice changes between two images. They concluded that playing action video games enhanced the ability to visually scan more broadly across images. Therefore it appears that change detection performance can predict reading ability (Chapter 5), but action video games may be required to improve change detection performance (Clark, Fleck & Mitroff, 2011). In the study by Franceschini and colleagues (2013), it was discovered that only action video games have the ability to improve visual spatial attention and subsequent reading ability; regular games that require less input from the dorsal stream did not influence reading ability. This is consistent with other vision studies which have also found that fast paced action games are best placed to change visual attention abilities (Dye & Bavelier, 2004; Hubert – Wallander, Green & Bavelier, 2011). In the present study, whilst the games were based on the visual search and change detection deficits that were previously detected in poor readers, they did not contain the all the action elements provided in the game by Franceschini and his colleagues (2013) such as; extraordinary speed, a high level of cognitive, perceptual and motor load, spatial and temporal unpredictability, and a high demand for peripheral processing of information. Therefore, whilst visual search and change detection programs can detect dorsal stream differences, they may not be sufficient to challenge the visual system to influence change in the dorsal stream. Green, Li and Bavelier (2010) explain that action video games demand extraordinary speed of response from the visual system, and high cognitive, perceptual and motor demands. Games with these elements which demand a high amount of resources appear critical to improving the functioning of the visual system, as evidenced by non-action based games which have not elicited the same visual attention benefits in its players during experimental training.

Prior to training, the control group was significantly slower than the experimental group in their reading rate. When groups were compared post training, there were no significant differences because the experimental group had significantly slowed their reading rate from +3.5 months pre training to -9 months post training. The control group also experienced slower reading speeds (from -9 months to -20 months at the end of 7 weeks), which resulted in a significant difference from time 1 to time 2. It is somewhat puzzling that the experimental group dropped to almost exactly the level of the control group in reading rate (9 months behind expected level), and even more puzzling that the control group also experienced such a sharp decrease in reading rate. When examining performance in
terms of initial reading rate and time 2 scores, the fastest readers in the experimental group demonstrated the largest decreases in reading rate performance. This finding is opposite to Franceschini and colleagues (2013) who recorded an increase in reading rate for the action video games group, post training. The results of the present study are also counter intuitive, as one may expect reading rate to improve, due to an increased ability to focus visual attention that visual training could provide. A slowing of reading rate could be beneficial to the accurate processing of words and sentences; however the present results do not support this finding. It appears that whatever factor or combination of factors influenced the experimental group also impacted the control group. When assessed in terms of variability, age of the participant, but not the influence of training, could explain variability in reading rate from time 1 to time 2. Older readers demonstrated larger discrepancies between time 1 and time 2 (with larger drops in reading rate performance). Younger readers may not demonstrate such large discrepancies because these are simply not possible, such that early reading standardised measurement starts at six years of age for the NARA. As students’ get older there is more room for error, thus the discrepancy has the potential to be larger at older ages. One potential factor could be the way in which the NARA was administered at time 2. A team of Provisional Psychologists were used at time 2, as compared to one Clinical Psychology Registrar at time 1. This was purposely implemented to reduce potential experimenter bias. If the group of psychologists at time 2 emphasised the importance of reading slowly and accurately in the instructions phase, the children may have taken a slower approach to the reading of passages. It is also possible that during the testing itself, the psychologists waited longer before providing the answer for more complex words (when the child paused) compared to the psychologist at time 1. As the games presented were very different in their visual properties, it is most likely that the similar differences (between experimental (13 month decrease) and control group (11 month decrease)) detected were a result of experimenter measurement, as compared to the type of treatment administered. Although this is somewhat puzzling given that the reading examiners at time 2 were trained in the use of the tests by the examiner at time 1.

For NARA comprehension, the experimental group improved significantly from time 1 to time 2, by an average of 16 months. The control group also improved from time 1 to time 2, by an average of 21 months. When the experimental and control group were compared, there were no significant differences between groups for reading comprehension improvement. It may be
suggested that improvements in comprehension are a result of a general improvement with age. However this is not the case, as improvement is calculated by the students’ current age in months and their expected reading rate. Improvements across both groups suggest that visual training did not have a specific impact upon reading comprehension abilities, although it is curious as to why such a large improvement occurred. One possibility concerns the rate at which participants were reading. As both groups were reading on average 12 months slower than their expected level, it is possible that slower reading resulted in more time to process the information presented. Another, more likely possibility, is that because the students were familiar with this type of testing (due to previous testing with a different version of the NARA); they were practiced in the process of attending to the passage in order to answer the questions provided, and were thus more efficient.

When single word reading was examined post training, the only significant change was an improvement in the control group for regular and non-word reading from time 1 to time 2. There were no differences between groups for irregular word reading. This suggests that visual training does not improve single word reading for good or poor readers, and is in contrast to previous findings which have suggested that single word training can be improved with visual training (e.g. Franceschini, et al., 2013). As discussed, this non-significant finding could be due to one or a combination of factors including the frequency or training sessions, the intensity (i.e. action video game play has been established as providing good outcomes) and duration of training sessions. Another suggestion, however very unlikely, is that puzzle type games may improve non-word reading skills, although there appears to be little evidence to support this claim.

This visual attention training pilot study, whilst unsuccessful in improving reading ability, does provide valuable insights into time and content considerations for designing future games based training programs in the area of reading remediation. Due to the needs of the students and teachers within the school environment, the present study administered five hours of training in a varied format to students. Five hours of training, of varying intervals, over seven weeks appears insufficient to influence meaningful change in reading ability. Based on the literature, one hour blocks of training, preferably over 10 consecutive days (10 hours in total)(Green & Bavelier, 2003) is minimum amount of time required to improve visual – spatial attention, and a minimum of 12 hours is required for these attentional improvements to translate to reading gains (Franceschini, et al., 2013).
Gaggi and colleagues (2012) have suggested that a minimum of 20 – 30 minutes per day of visual training for at least one month is required to support meaningful change in reading ability. Thus, future training programs, which also utilise more rigorous testing procedures, could explore the administration of training programs that exceeds five hours, and optimally, consistent (daily) training of at least ten hours or more. Content of the games provided also appears critical to the success of the training provided. The current studies suggest that visual search and change detection games can detect differences between readers (Chapter 4 & 5), but these types of programs are unsuccessful in improving reading ability when provided as a short term training program. This supports the proposition that action video games are most effective type of program in altering visual attention abilities, compared to slower, less demanding games (Franceschini, et al., 2013, Green & Bavelier, 2012). There is also much to learn regarding the long term effects of visual training on reading ability. Following action video games training, improvements in reading skill were retained two months later (Franceschini, et al., 2013), but it is unknown if participants retained these improvements over the longer term. Future experiments that examine the effects of different doses of training (e.g. one month, two months, six months) on retention of reading improvements longer term (one month, one year, two years) would be valuable to determine if certain hours of training are more (or less) valuable in sustaining reading improvements. It would also be useful to take measures of visual search and change detection performance following video games training, to determine if training improved these skills in addition to reading ability. Of particular interest would be the relationship between early visual performance and subsequent influence of the treatment program. Along these lines, comparing video game performance from pre to post training, as well as the relationship between changes in visual search and change detection skill, with changing game skill could be worthwhile. Using classic visual tasks such as visual search and coherent motion to determine if performance on these tasks could predict game performance would also be an intriguing avenue for future research.

Overall, the findings of the present study were mixed, with results revealing more questions than answers. Visual training with portable change detection and visual search games did not improve NARA scores, as both groups experienced an improvement in comprehension skills and decrease in reading rate. Training also did not improve single word reading ability. This highlights the needs for future research in this field, to ascertain the effects of visual attention training
on reading ability, both its benefits and limits. Specifically, more research is needed into the type of games needed to best challenge the dorsal stream, how often these games would need to be administered to ensure a therapeutic dose, and additionally, how long training effects could continue post treatment.
7.5. References


Neuropsychologia, 50(7), 1672-1681.

Neuropsychologia, 47(3), 907-915.

Vision Research, 35(10), 1483-1494.


de Boer-Schellekens, L., & Vroomen, J. (2012). Sound can improve visual search in developmental dyslexia. 
Experimental Brain Research, 216(2), 243-248.


Neuropsychologia, 47(8), 1780-1789.

Dyslexia, 15(3), 218-238.


Chapter 8.

Discussion and Conclusions

Each chapter and manuscript in this thesis contains its own discussion relating to the specifics of each experiment; therefore this chapter will focus on the results as a whole, as well as future directions. The aim of this project was to determine if visual-spatial attention can be assessed and trained outside of the tightly controlled laboratory environment, using magnocellular/dorsal stream visual tasks that were gamified versions of classic tests. The main outcomes were: performance on specially designed portable visual search and change detection games was significantly correlated with reading performance (Chapter 4 & 5), but not a specially designed tracking game (Chapter 6), and training intervention using commercially made visual search and change detection games did not appear to positively influence the reading skills of the participants tested (Chapter 7). Clinical and theoretical implications of these findings will be discussed below.

8.1. Clinical implications for the future assessment of dyslexia

Results from the present studies suggest that certain types of portable game-like dorsal stream tests can predict good and poor reading performance within everyday, relatively uncontrolled settings such as primary schools. Specifically, visual search and change detection tasks (Chapter 4 & 5), but not a newly developed tracking program (Chapter 6), could predict reading speed and single word reading abilities in good and poor readers. The finding that performance on portable gamified change detection and visual search tasks is correlated with reading ability, has considerable implications for the development of portable visual assessment tools which could be used to screen young and at-risk children for reading disability. It has been established that visual-attentional deficits, controlled by the dorsal stream, can be detected in at-risk children before they learn to read (Facoetti, Corradi, Ruffino, Gori, & Zorzi, 2010; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Kevan & Pammer, 2009). As early intervention is a critical element in successful reading outcomes in at-risk populations (Coyne, Kame‘enui & Simmons, 2001), implementation of a portable early screening assessment tool, which includes visual-attention testing, could be extremely valuable in identifying poor readers in the earliest stages of their reading
development, and also in screening genetically at-risk children, to provide timely interventions to target these deficits.

At present, children are usually identified as dyslexic when they are at least two standard deviations or two years below their expected reading level (in addition to other criteria such as access to adequate educational opportunities and absence of medical cause) (American Psychiatric Association - DSM – 5, 2013). Given our current reading tests, children may need to be at least eight years of age before a diagnosis can be confidently given. For example, the Neale Analysis of Reading Ability (3rd Ed.) has a testing age range of 6 – 12 years. Thus, in the context of education, diagnosis may not be provided until after the child has completed two or three years of primary school. And, this is assuming that children are identified as delayed in reading skills, and a proper diagnostic assessment is available and attainable by the family/school. In one cross-sectional study of 1774 children, 3.2% met the criteria for a diagnosis, yet two out of three children with dyslexia had not been previously diagnosed (Barbiero, et al., 2012). The age at which children may be diagnosed, and the rate at which diagnosis occurs, is unacceptable, given that early intervention is paramount, and secondary effects (such as reduced self-esteem and bullying) may manifest in these early years (Bryan, Sonnefeld, & Grabowski, 1983; Chapman, Tunmer & Prochnow, 2000; Glazzard, 2010; Hellendoorn & Ruijssenaars, 2000; Humphrey & Mullins, 2002; Margalit & Levin – Alyagon, 1994). Traditional phonological and reading tests, such as the Phonological Assessment Battery (PhAB), the Neale Analysis of Reading Ability (NARA), or the word reading component of the Wechsler Individual Achievement Test (WIAT – III), will always be critical to a proper diagnostic assessment of dyslexia. However, the use of a visual – attentional measurement tool could be a valuable addition to a comprehensive assessment battery used by clinicians. This visual tool may be especially valuable as a screening test in the earlier stages of development, to detect possible visual deficits when standardised scores at very young ages are unavailable. If a general screening of visual – spatial attention abilities, or testing of genetically at-risk children were to reveal a deficit, this could prompt an intensive attention-based intervention training program alongside traditional phonological intervention, before the gap in reading ability widens.

Future studies would need to explore not only the reliability of the screening tool to detect dorsal stream deficits, but also to ascertain how effective this screening tool would be in the context of comorbid disorders. Over 60% of children with dyslexia meet the criteria for one additional diagnosis, the highest of
which is Attention Deficit Hyperactivity Disorder (ADHD), with dyslexic readers having an 18% (females) to 42% (males) probability of also meeting the criteria for this disorder (Willcutt & Pennington, 2000). If a child has both dyslexia and ADHD, it would be important to determine how ADHD would impact upon an impaired visual – spatial attention system, and subsequently the development of a screening tool. ADHD and dyslexia share some areas of brain abnormality (Seidman, Valera & Makris, 2005), such as reduced activation of the dorsolateral prefrontal cortex (Seidman, et al., 2006; Sun, et al., 2011), and in the temporal lobes (Shafritz, Marchione, Gore, Shaywitz, & Shaywitz, 2004; Shaywitz, et al., 2002). It is suggested that comorbid dyslexia and ADHD may have an ‘additive effect’ which results in more severe deficits in cognitive functioning (Germano, Gagliano & Curatolo, 2010). Thus, disentangling how an impaired visual – spatial attention system may be impacted by additional abnormalities in the same or neighbouring regions of the brain is a complex task that requires further investigation. One way to evaluate this possible interaction would be to administer a visual – spatial attention screening tool to normal readers, dyslexic readers, children with ADHD (distinguishing both the inattentive and/or hyperactive type) and children with both dyslexia and ADHD to determine the correlations between each of these groups in relation to their visual abilities.

8.2. Clinical implications for future dyslexia intervention programs

Firstly, it is important to restate the view that intensive literacy skills programs with phonological components (such as Reading Recovery – see D’Agostino & Murphy (2004) for a meta-analysis of reading recovery studies) are an important and well evidenced element in the treatment of dyslexia, and should continue to be provided to poor readers in school and home settings. To explore the hypothesis that visual training may be a valuable additional treatment in reading remediation programs, by improving visual spatial attention skills and subsequently reading ability, two gamified dorsal stream programs were provided to students in schools utilising a portable format. Whilst there was promising evidence elsewhere to suggest that visual training can improve both visual attention (Castel, Pratt & Drummond, 2005; Green & Bavelier, 2006; Gopher, Well & Bareket, 1994; Okagaki & Frensch, 1994; Quaiser – Pohl, Geiser & Lehmann, 2006; Trick, Jaspers – Fayer & Sethi, 2005; Hubert - Wallander, Green, Sugarman & Bavelier, 2011), and reading abilities (Franceschini, et al., 2013), the present pilot study failed to find positive effects of visuo – attentional/dorsal stream training on
reading abilities. Five hours of game play using portable visual search and change detection type games did not improve reading accuracy or rate. It is suggested that this result may have occurred due to the type of games and frequency at which these were provided to the participants. Specifically, the games provided may not have been sufficiently challenging for the dorsal stream, to a level which would facilitate change.

Action type video games may be a better candidate for visual training, due to their fast paced properties and ability to significantly challenge the visual system (Clark, Fleck & Mitroff, 2011; Dye & Bavelier, 2004; Franceschini, et al., 2013; Hubert – Wallander, et al., 2011). Designing an action based video game which provides mini – games, modelled from tasks such as visual search and change detection would be a worthwhile avenue for future research. Determining which tasks, or indeed elements of the task (such as the visual and sound properties) are most effective in improving visual – spatial performance, would be important in constructing an effective games based intervention program. Investigation into such mini games has recently commenced by Gaggi and colleagues (2012) who have developed a series of specially designed games to train visual – spatial attention, as well as speech segmentation. For example, the Paths game was designed to train the participants’ capacity to rapidly discriminate between images in the fovea and surrounding ocular area. Participants are instructed to navigate through an array of C – like shapes, by guiding their attention through each opening of the C – shape, onto the next shape. The opening of the C is oriented in one of four directions (up, down, left, right). This game relies upon effective visual search, in engaging, focussing and disengaging attention on each stimulus, as well as the ability to focus upon relevant information whilst disregarding irrelevant information (crowding). The participant is trained by gradually increasing the difficulty of the ‘path’ with each successful ‘match’. A total of five matches are proposed for each day of training. It is anticipated that this training will assist in improving visual – spatial attention and subsequently, reading ability (Gaggi, Galiano, Palazzi, Facoetti & Franceschini, 2012). The frequency at which training is presented is also an important element of a training program, and for the present study, it is suggested that the frequency of the training provided may not have been sufficient to encourage significant improvements in visual – spatial attention.

Availability of participants within the school setting resulted in challenges and limitations in the frequency and duration of training provided. To allow for minimal disruptions to teaching, students were collected from class and taken for
training at the discretion of the class teacher. Therefore, children underwent a mixed schedule of training which varied in terms of time and frequency. Ideally, children would be engaged in training sessions of at least one hour in duration, for at least ten consecutive days (Green & Bavelier, 2003), to ensure that the dosage of training was sufficient to influence the visual system. In the present study, 10-70 minute training sessions were provided at varying intervals over the final two months of one school term. The importance of consistency in training has been reported in a number of papers. For example, in one study, participants played an action video game consistently for 30 minutes per day, every day, over a two month period. Following the training, scans revealed a significant increase in grey matter for the game players compared to the control group, which resulted in structural neural changes in multiple brain areas including the prefrontal cortex (e.g. important for working memory, behavioural flexibility, future planning and attention) and the right dorsolateral prefrontal cortex (e.g. reaching from object and spatial information) (Kuhn, Gleich, Lorenz, Lindenberger & Gallinat, 2014).

Likewise, in a randomised controlled trial of older adults, 20 sessions of one hour video game training (puzzle based activities), over 10-12 weeks, significantly improved multiple areas of cognitive functioning including processing speed, attention and visual recognition memory (Ballesteros, et al., 2014). In contrast, a study which administered five sessions (2 hours each) of action video games to its participants, failed to find significant differences between the video game players and control group, when measuring performance on a coherent motion task (van Ravenzwaaji, et al., 2014). When the hours of game play was doubled (4 hours each session) but frequency remained at five sessions, the training continued to provide little benefit to action video game players, compared to non – game players (van Ravenzwaaji, Boelkel, Forstmann, Ratcliff & Wagenmakers, 2014). In a meta-analysis of twenty experimental training studies, it was concluded that shorter, more frequent video game training sessions (1-6 weeks), produce greater benefits in improving cognition compared to longer training durations (7-12 weeks), when working with older adults (Toril, Reales & Ballesteros, 2014). Thus, it is proposed that there may be an optimal training ‘treatment dose’ that is specific to improving reading ability in children and adults. Therefore, future training experiments would benefit from investigating the optimal frequency and duration at which training should be provided, such as multiple experimental groups that are provided with training at varying intervals (e.g. twice daily, daily, twice weekly, weekly and for 10 minutes, 30minutes, 1 hour etc.), using participants of varied ages, and that have availability to participate in these specified schedules. Such an experimental design
should also include a condition containing phonological training only, and combined phonological and visual training program. It may be the case that a combination of phonological and visual training results in the strongest gains for young struggling readers.

The aim of the present studies was to determine visual performance across the continuum of reading abilities (standard classrooms of students), without excluding specific children from the analysis (with the exception of data from children with low cognitive ability). In terms of providing a treatment intervention within the context of comorbid disorders, it is possible that a visual – spatial attention intervention program based on the principles of action video game play may be beneficial, not just for dyslexia, but also for comorbid disorders such as ADHD. Dyslexia and ADHD are two of the most common disorders diagnosed in childhood (Sexton, Gelhorn, Bell & Classi, 2011). Furthermore, these disorders are the most likely to occur together, especially dyslexia and the ADHD inattentive type (Germano, Gagliano & Curatolo, 2010). Therefore, it is reasonable to question if visual – spatial attention training would also have an impact on the symptoms of ADHD. In the area of ADHD research, a pilot study has commenced which is investigating if a specially designed computer action video game can improve alertness, sustained and selective attention, working memory, impulse control and the ability to suppress distracting information in children with ADHD (Mishra, Merzenich & Sagar, 2013). Given that established studies suggest that action video games can improve general attentional processes (e.g. Castel, Pratt & Drummond, 2005; Green & Bavelier, 2003), and reading ability (Franceschini, et al., 2013), another possible avenue for future research would be to determine if action video games have the potential to improve both reading ability and attentional capacity in comorbid dyslexia and ADHD participants.

8.3. Theoretical implications of the present studies

The results of the present experiments support the suggestion that dorsal/magnocellular stream performance, specifically visual – spatial attention, is significantly correlated with reading accuracy and rate (Brannan & Williams, 1987; Facoetti, et al., 2000; Stein & Walsh, 1997; Lovegrove, Bowling, Badcock & Blackwood, 1980; Vidyasagar & Pammer, 2010). The proposition that phonological deficits alone cannot fully explain the variance in reading abilities is also supported by the current study (Kevan & Pammer, 2009). However it is
somewhat unexpected that phonological performance did not account for significant variance in reading rate. Here, the non–word reading test used as a measure of phonological processing (non–word list of the Castles & Coltheart – II) did not correlate with reading speed. This finding contradicts the suggestion that phonological ability is a strong predictor of reading abilities (for example, see Torgesen, Wagner and Rashotte (1994) for longitudinal studies of phonological awareness and reading). One explanation for these findings could be the influence of school based interventions on phonological skill. It was noted that many of the children who were delayed in their reading were receiving intervention at the time of the study. This intervention entailed weekly sessions in a small group setting (ratio of approximately two teachers and 4-5 students) specifically focussing on phonological skills and reading comprehension. In an Australian study of ten schools in New South Wales (Center, et al., 1995), it was found that the Reading Recovery program was an effective short term intervention for reading difficulties, with the students in the experimental (intervention) group demonstrating significant gains compared to the control group. Over the longer term, 35% of students continued to maintain normal reading levels, whereas 35% continued to experience significant reading difficulties 12 months post – program (Center, Wheldall, Freeman, Outhred & McNaught, 1995). Therefore, it is possible that due to this concurrent reading assistance, participants did not demonstrate the correlation between reading accuracy and rate (lower accuracy and slower rate) that would usually be seen in this population. This finding although unexpected, is not unique. In a longitudinal study by Franceschini and colleagues (2012), they also found that visuo– spatial attention performance was a better predictor of text reading variance compared to phonological skill, IQ and age. Visuo spatial attention predicted 28% of the variance in text reading for dyslexic readers, as compared to phonological skill which explained 9%, and age and verbal IQ which explained approximately 4% of the variance in text reading ability. To better understand the predictive power of visual performance on reading ability, further research is needed. This could include comparisons between phonological and visual assessment methods to detect reading difficulties at differing ages and stages of reading exposure. For example, the predictive power of visual testing with regards to reading outcomes may be strongest during the emerging literacy stage, before the student has developed unusual neural connections or alternative coping strategies that support a struggling reading network (Kevan & Pammer, 2009).
8.4. Conclusion

Some gamified and portable versions of classic visual search and change detection tasks can differentiate good and poor readers within the school setting in relatively uncontrolled and natural environments. This significant finding is consistent with the visual – spatial attention theory of reading disability, and will have important implications for the future development of portable/accessible comprehensive assessments and early intervention programs. In contrast, training poor readers using similar, commercially available games did not result in reading improvements. The training results may have been influenced by frequency/duration and type of games provided. A critical next step in this field is to develop a comprehensive and reliable screening tool, which includes visual – spatial attention tasks that can be administered to all children at the commencement of their schooling. If this tool were effective, it would have exciting implications for the ability to identify at-risk students early, and to provide targeted and timely intervention programs to minimise or even eliminate the direct impacts of dyslexia and its indirect consequences.


cortex volumetric abnormalities in adults with attention-deficit/hyperactivity disorder identified by magnetic resonance imaging. *Biological Psychiatry, 60*(10), 1071-1080.


Appendix 1. Consent form for assessment study

Participant and Parent Information Sheet
Visual Performance & Reading Study

Researcher: My name is Kayla Tulloch and I am a Doctor of Clinical Psychology student from the Department of Psychology, College of Medicine, Biology and Environment, Australian National University.

Project Title: The role of visual performance and reading ability in school age children

General Outline of the Project: This research forms part of a three year project investigating the role of visual performance and reading ability in children. We are interested in determining how varying performance on search and motion visual tasks may be linked to varying levels of reading ability. In particular, we would like to create a collection of visual tasks which may, in the future, contribute towards an early intervention tool for children with a reading disability.

For this research, we will be seeking approximately 100 Canberra students between the ages of 9 and 12 years to participate. Along with parental consent, the verbal consent of the student will also be sought prior to participation. Data collection will occur in two one hour sessions, where students will be asked to complete some basic reading tests and game like visual activities. Results will not be shared with participants; however parents are welcome to contact us should they wish to discuss their child’s results, or the outcome of this research. Additionally, the researcher (Kayla Tulloch) may contact parents should they be required to discuss the results of their child further. Data obtained during these tasks will be kept completely confidential, and may be used as part of a broader journal publication or future vision research studies.

Participant Involvement: Participants will be asked to participate in two sessions, which should take approximately one hour each. These sessions will be conducted at the students’ school, during the school day. Participants will be tested in a room separate to the classroom, and will engage in some reading activities, and visual game like tasks (such as “Spot the Difference” and “Find the Zebra”). Between tasks, students will be encouraged to take regular breaks as required. If it appears that the student becomes bored or tired, breaks will also be encouraged. There are no known adverse effects of participating in this study. Participation is completely voluntary and students will be free to withdraw at any time. If a student withdraws from the study, data collected will be destroyed. At the end of the second session, students will be rewarded with a certificate for their participation.

Exclusion criteria: None. All students will be eligible to participate in this study.

Confidentiality: All data collected will be treated with confidentiality, as far as the law allows. Access to collected data will be restricted to ANU Department of Psychology researchers only. Participant details and results will be de-identified. The results of this study will be reported in thesis form and potentially academic journals. Data will be stored in a locked filing cabinet, password protected computer, and kept for 5 years from publication, then destroyed. Individual participant details and results will be kept separate.

Queries and Concerns: For further information regarding this study, please feel free to contact Ms Kayla Tulloch, Primary Researcher, on (02) 6125 0788 or Kayla.Tulloch@anu.edu.au. Alternatively, Dr Kristen Pammer, Research Supervisor, may also be contacted on (02) 6125 0499 or Kristen.Pammer@anu.edu.au.

Ethics Committee Clearance: The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee and The Department of Education Ethics Committee.

If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: 6125 3427
Email: Human.Ethics.Officer@anu.edu.au
Consent Form

Visual Performance & Reading Study

Researchers: Ms Kayla Tulloch – Primary Researcher/Doctor of Clinical Psychology Candidate
Dr Kristen Pammer – Research Supervisor/Associate Professor ANU

1. I ................................................................. (please print) consent for my child to take part in the visual performance and reading study, conducted by Ms Kayla Tulloch, ANU. I have read the Participant and Parent Information Sheet for this project and understand its contents, and my consent is freely given.

2. I understand that my child will participate in two sessions, which will take approximately one hour each, and involve both reading and visual task activities.

3. I understand that while information gained during the research project may be published in reports, academic journals, and further examined by ANU Department of Psychology Researchers, my child’s name or personal details will not be published or identifiable.

4. I understand that my child’s personal details such as name and school will be kept confidential as far as the law allows. This form and any other identifying materials will be stored separately in a locked office at the Australian National University. Data entered onto a computer will be kept in a computer accessible only by password by a member of the research team.

5. I understand that my child may withdraw from the research project at any stage, without providing any reason, and that this will not result in any adverse consequences. If my child withdraws, their information will not be included in the research project.

6. I consent to be contacted by telephone should the researchers in this study (Ms Kayla Tulloch or Dr Kristen Pammer) wish to discuss my child’s reading results with me confidentially.

Parents Name.................................................................
ParentSignature......................................................
Date.................................................................
Parents Contact Telephone Number..............................

Researcher to complete: I, Kayla Tulloch, certify that I have explained the nature and procedures of the research project to ................................................................. (student) and consider that he/she understands what is involved, and that they are free to withdraw at any time without penalty.

Signed...........................................................................................
Date .................................................................
Appendix 2. Consent form for training study

Participant and Parent Information Sheet

Visual Training & Reading Remediation Study

Researchers: This project will be conducted by Kayla Tulloch, a Doctor of Clinical Psychology student from the Department of Psychology, College of Medicine, Biology and Environment, Australian National University, and Shei Pei, an Honours student. Both students are under the supervision of Associate professor Kristen Pammer.

Project Title: The role of visual performance and reading ability in school age children: Training study

General Outline of the Project: For many years researchers have demonstrated that poor readers have difficulties in specific sorts of visual tasks such as searching cluttered arrays, processing quickly moving stimuli, or detecting differences between similar pictures. This forms part of what is known as the “magnocellular deficit theory of dyslexia”. As part of her clinical PhD research, Kayla has been looking at whether we can take these tasks out of the laboratory and turn them into games, and whether they will still then discriminate between good and poor readers. Our research thus far is encouraging, and it looks like the tasks we have been using are just as successful as our lab-based tasks. We would now like to take this project to the next level and see if such game-like task can actually improve reading ability, by training children on these tasks.

You are being contacted now because your child participated in the first stage of this project. We would like to invite your child to participate in this next stage. Having participated in the first stage of the project, you are under no obligation to participate in this next stage, and you may withdraw your permission at any time through the project.

Participant Involvement: Children will engage in 10-12 hours of ‘training’ through Term 4. In this case ‘training’ actually refers to engaging in carefully selected computer games, so as far as the children are concerned, they will be asked to play computer games for about 30mins a few times a week for approximately a month. The children will then again be retested on a shortened version of the reading tests that they have already done. There are no known adverse effects of participating in this study. Participation is completely voluntary and students will be free to withdraw at any time. If a student withdraws from the study, data collected will be destroyed.

Exclusion criteria: None. All students who participated in the first stage of the project will be eligible to participate in this study.

Confidentiality: All data collected will be treated with confidentiality, as far as the law allows. Access to collected data will be restricted to ANU Department of Psychology researchers only. Participant details and results will be de-identified. The results of this study will be reported in thesis form and potentially academic journals. Data will be stored in a locked filing cabinet, password protected computer, and kept for 5 years from publication, then destroyed. Individual participant details and results will be kept separate.

Queries and Concerns: For further information regarding this study, please feel free to contact Ms Kayla Tulloch, Primary Researcher, on (02) 6125 0788 or Kayla.Tulloch@anu.edu.au. Alternatively, Dr Kristen Pammer, Research Supervisor, may also be contacted on (02) 6125 0499 or Kristen.Pammer@anu.edu.au.

Ethics Committee Clearance: The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (2011/628).

If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: 6125 3427
Email: Human.Ethics.Office@anu.edu.au
Consent Form – Please return to class teacher
Visual Training & Reading Remediation Study

Researchers: Ms Kayla Tulloch – Primary Researcher/Doctor of Clinical Psychology Candidate
Ms Pei Shi – Honours candidate
Dr Kristen Pammer – Research Supervisor/Associate Professor ANU

I ........................................................... (please print) consent for my child to take part in the visual performance and reading study, conducted by Ms Kayla Tulloch, and Ms Pei Shi, from the ANU. I have read the Participant and Parent Information Sheet for this project and understand its contents, and my consent is freely given.

I understand that my child will participate in a total of no more than 12 hours of sessions, which will consist of a sequence of 20 minute sessions. The sessions will involve my child playing visual computer games under the supervision of the researchers. I also understand that my child’s reading performance will be reassessed at the end of the 4th school term, 2013.

I understand that while information gained during the research project may be published in reports, academic journals, and further examined by ANU Department of Psychology Researchers, my child’s name or personal details will not be published or identifiable.

I understand that my child’s personal details such as name and school will be kept confidential as far as the law allows. This form and any other identifying materials will be stored separately in a locked office at the Australian National University. Data entered onto a computer will be kept in a computer accessible only by password by a member of the research team.

I understand that my child may withdraw from the research project at any stage, without providing any reason, and that this will not result in any adverse consequences. If my child withdraws, their information will not be included in the research project.

I consent to be contacted by telephone should the senior researchers in this study (Ms Kayla Tulloch or Dr Kristen Pammer) or the school wish to discuss my child’s reading and cognitive results with me confidentially.

Parents Name (Please print).......................................................................................................................

Parent Signature.................................................................................................................................
Date........................................

Parents Contact Telephone Number...................................................................................................

Researcher to complete: I, certify that I have explained the nature and procedures of the research project to ................................................... (Student) and consider that he/she understands what is involved, and that they are free to withdraw at any time without penalty.

Signed..............................................................................................................................................
Date ........................................
Appendix 3. Visual Search Computer Programming and Design

**Design** – Number next to trial indicates the number of bugs on screen. Position of target bug is in each of the grid squares at least once

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Trial 21</th>
<th>Trial 41</th>
<th>Trial 61</th>
<th>Trial 81</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>36</td>
<td>73</td>
<td>12</td>
<td>36</td>
</tr>
<tr>
<td>Trial 2</td>
<td>Trial 22</td>
<td>Trial 42</td>
<td>Trial 62</td>
<td>Trial 82</td>
</tr>
<tr>
<td>36</td>
<td>36</td>
<td>73</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Trial 3</td>
<td>Trial 23</td>
<td>Trial 43</td>
<td>Trial 63</td>
<td>Trial 83</td>
</tr>
<tr>
<td>12</td>
<td>36</td>
<td>12</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Trial 4</td>
<td>Trial 24</td>
<td>Trial 44</td>
<td>Trial 64</td>
<td>Trial 84</td>
</tr>
<tr>
<td>24</td>
<td>36</td>
<td>36</td>
<td>12</td>
<td>73</td>
</tr>
<tr>
<td>Trial 5</td>
<td>Trial 25</td>
<td>Trial 45</td>
<td>Trial 65</td>
<td>Trial 85</td>
</tr>
<tr>
<td>24</td>
<td>12</td>
<td>36</td>
<td>12</td>
<td>73</td>
</tr>
<tr>
<td>Trial 6</td>
<td>Trial 26</td>
<td>Trial 46</td>
<td>Trial 66</td>
<td>Trial 86</td>
</tr>
<tr>
<td>36</td>
<td>73</td>
<td>12</td>
<td>36</td>
<td>73</td>
</tr>
<tr>
<td>Trial 7</td>
<td>Trial 27</td>
<td>Trial 47</td>
<td>Trial 67</td>
<td>Trial 87</td>
</tr>
<tr>
<td>73</td>
<td>36</td>
<td>36</td>
<td>73</td>
<td>24</td>
</tr>
<tr>
<td>Trial 8</td>
<td>Trial 28</td>
<td>Trial 48</td>
<td>Trial 68</td>
<td>Trial 88</td>
</tr>
<tr>
<td>73</td>
<td>36</td>
<td>12</td>
<td>36</td>
<td>73</td>
</tr>
<tr>
<td>Trial 9</td>
<td>Trial 29</td>
<td>Trial 49</td>
<td>Trial 69</td>
<td>Trial 89</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>36</td>
<td>36</td>
<td>73</td>
</tr>
<tr>
<td>Trial 10</td>
<td>Trial 30</td>
<td>Trial 50</td>
<td>Trial 70</td>
<td>Trial 90</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>73</td>
<td>73</td>
<td>24</td>
</tr>
<tr>
<td>Trial 11</td>
<td>Trial 31</td>
<td>Trial 51</td>
<td>Trial 71</td>
<td>Trial 91</td>
</tr>
<tr>
<td>36</td>
<td>24</td>
<td>73</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Trial 12</td>
<td>Trial 32</td>
<td>Trial 52</td>
<td>Trial 72</td>
<td>Trial 92</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>24</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>Trial 13</td>
<td>Trial 33</td>
<td>Trial 53</td>
<td>Trial 73</td>
<td>Trial 93</td>
</tr>
<tr>
<td>24</td>
<td>73</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Trial 14</td>
<td>Trial 34</td>
<td>Trial 54</td>
<td>Trial 74</td>
<td>Trial 94</td>
</tr>
<tr>
<td>36</td>
<td>12</td>
<td>73</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Trial 15</td>
<td>Trial 35</td>
<td>Trial 55</td>
<td>Trial 75</td>
<td>Trial 95</td>
</tr>
<tr>
<td>12</td>
<td>36</td>
<td>24</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Trial 16</td>
<td>Trial 36</td>
<td>Trial 56</td>
<td>Trial 76</td>
<td>Trial 96</td>
</tr>
<tr>
<td>73</td>
<td>73</td>
<td>73</td>
<td>36</td>
<td>12</td>
</tr>
<tr>
<td>Trial 17</td>
<td>Trial 37</td>
<td>Trial 57</td>
<td>Trial 77</td>
<td>Trial 97</td>
</tr>
<tr>
<td>73</td>
<td>73</td>
<td>24</td>
<td>73</td>
<td>24</td>
</tr>
<tr>
<td>Trial 18</td>
<td>Trial 38</td>
<td>Trial 58</td>
<td>Trial 78</td>
<td>Trial 98</td>
</tr>
<tr>
<td>24</td>
<td>36</td>
<td>24</td>
<td>36</td>
<td>24</td>
</tr>
<tr>
<td>Trial 19</td>
<td>Trial 39</td>
<td>Trial 59</td>
<td>Trial 79</td>
<td>Trial 99</td>
</tr>
<tr>
<td>12</td>
<td>36</td>
<td>12</td>
<td>36</td>
<td>24</td>
</tr>
<tr>
<td>Trial 20</td>
<td>Trial 40</td>
<td>Trial 60</td>
<td>Trial 80</td>
<td>Trial 100</td>
</tr>
<tr>
<td>73</td>
<td>36</td>
<td>12</td>
<td>36</td>
<td>12</td>
</tr>
</tbody>
</table>
Appendix 4. Change Detection Computer Programming and Design

Program was designed to present a mixture of line and photographic drawings, of varying difficulty. Easy (E) is defined as single objects, as compared to (H) harder which refers to multiple objects or complex backgrounds. Two “extra hard” trials were added to the end of the experiment to extend the older participants.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Picture Description</th>
<th>Trial</th>
<th>Picture Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Photograph – Tractor &amp; Cart (E)</td>
<td>21</td>
<td>Drawing – Sheep (E)(Pop Out)</td>
</tr>
<tr>
<td>2</td>
<td>Drawing – Shark (E)</td>
<td>22</td>
<td>Photograph – Temple (H)</td>
</tr>
<tr>
<td>3</td>
<td>Photograph – Train (E)</td>
<td>23</td>
<td>Drawing – Snake (E)</td>
</tr>
<tr>
<td>4</td>
<td>Drawing – Teddy Bear (E)</td>
<td>24</td>
<td>Photograph – Ten Pins (E)</td>
</tr>
<tr>
<td>5</td>
<td>Photograph – Bucket and Spade (E)</td>
<td>25</td>
<td>Drawing – Cow (E)</td>
</tr>
<tr>
<td>6</td>
<td>Drawing – Chicken (E)</td>
<td>26</td>
<td>Photograph – Toy Soldiers (H)</td>
</tr>
<tr>
<td>7</td>
<td>Photograph – Shells (E)</td>
<td>27</td>
<td>Drawing – Chicken (E)</td>
</tr>
<tr>
<td>8</td>
<td>Drawing – Lion (E)</td>
<td>28</td>
<td>Drawing – Snake (E)</td>
</tr>
<tr>
<td>9</td>
<td>Drawing – Dog (E)</td>
<td>29</td>
<td>Drawing – Mouse (E)</td>
</tr>
<tr>
<td>10</td>
<td>Photograph – Cow (H)</td>
<td>30</td>
<td>Photograph – Dominoes (H)</td>
</tr>
<tr>
<td>11</td>
<td>Photograph – Putter &amp; Ball (E)</td>
<td>31</td>
<td>Drawing – Cow (E)</td>
</tr>
<tr>
<td>12</td>
<td>Drawing – Pig (E)</td>
<td>32</td>
<td>Photograph – Ferris Wheel (H)</td>
</tr>
<tr>
<td>13</td>
<td>Photograph – Blocks (E)</td>
<td>33</td>
<td>Photograph – Block Tower (H)</td>
</tr>
<tr>
<td>14</td>
<td>Drawing – Monkey (E)</td>
<td>34</td>
<td>Drawing – Mouse &amp; Cheese (E)</td>
</tr>
<tr>
<td>15</td>
<td>Photograph – Dice (H)</td>
<td>35</td>
<td>Photograph – Toy Store (H)</td>
</tr>
<tr>
<td>16</td>
<td>Drawing – Rabbit (E)</td>
<td>36</td>
<td>Drawing – Boy &amp; Plant (H)</td>
</tr>
<tr>
<td>17</td>
<td>Photograph – Block Building (E)</td>
<td>37</td>
<td>Photograph – Building (H)</td>
</tr>
<tr>
<td>18</td>
<td>Drawing – Dragon (E)</td>
<td>38</td>
<td>Drawing – Bus (H)</td>
</tr>
<tr>
<td>19</td>
<td>Photograph – Vegetables (H)</td>
<td>39</td>
<td>Photograph – Dolls (H)</td>
</tr>
<tr>
<td>20</td>
<td>Photograph – Boats (H)</td>
<td>40</td>
<td>Drawing – Building (H)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41</td>
<td>Drawing – Building (Extra H)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>42</td>
<td>Drawing – Canal (Extra H)</td>
</tr>
</tbody>
</table>
Appendix 5. Visual Tracking Computer

Programming and Design

Programming for the design of ‘Space Jump’. Planet 1 – 11 represent the order of the planets from left to right. Line 1 – 6 represents the line of planets from top to bottom. N = not a target. Numbers in the table represent the order that the targets appeared in each trial.

<table>
<thead>
<tr>
<th>Trial 1 – Speed 3s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Line 3</td>
<td>7</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>10</td>
<td>11</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 2 – Speed 10s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>1</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>N</td>
<td>4</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 3</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>N</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>11</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 3 – Speed 5s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 2</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>4</td>
<td>N</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>N</td>
<td>6</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>10</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>11</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 4 – Speed 3s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Line 3</td>
<td>6</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>N</td>
<td>10</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>11</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

197
<table>
<thead>
<tr>
<th>Trial 5 – Planet Speed 10s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>N</td>
<td>3</td>
</tr>
<tr>
<td>Line 2</td>
<td>4</td>
<td>N</td>
<td>5</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>10</td>
<td>N</td>
<td>N</td>
<td>11</td>
</tr>
<tr>
<td>Line 5</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>13</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 6 – Planet Speed 5s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>3</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>N</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>11</td>
<td>12</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 7 – Planet Speed 3s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>1</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>4</td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>10</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>11</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>13</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 8 – Planet Speed 10s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>6</td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>10</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>11</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 9 – Planet Speed 5s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>10</td>
<td>N</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>11</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Trial 10 - Speed 3s</td>
<td>Planet 1</td>
<td>Planet 2</td>
<td>Planet 3</td>
<td>Planet 4</td>
<td>Planet 5</td>
<td>Planet 6</td>
<td>Planet 7</td>
<td>Planet 8</td>
<td>Planet 9</td>
<td>Planet 10</td>
<td>Planet 11</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Line 1</td>
<td>N</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>6</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>10</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>11</td>
<td>N</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 11 - Speed 10s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>4</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 4</td>
<td>9</td>
<td>N</td>
<td>10</td>
<td>11</td>
<td>N</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 12 - Speed 5s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>Y</td>
<td>2</td>
<td>N</td>
<td>Y</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>6</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 4</td>
<td>9</td>
<td>N</td>
<td>10</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>10</td>
<td>N</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>11</td>
<td>N</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td>14</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 13 - Speed 3s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>8</td>
</tr>
<tr>
<td>Line 4</td>
<td>9</td>
<td>N</td>
<td>10</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>12</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 14 - Speed 10s</th>
<th>Planet 1</th>
<th>Planet 2</th>
<th>Planet 3</th>
<th>Planet 4</th>
<th>Planet 5</th>
<th>Planet 6</th>
<th>Planet 7</th>
<th>Planet 8</th>
<th>Planet 9</th>
<th>Planet 10</th>
<th>Planet 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>1</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>N</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>9</td>
<td>N</td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>10</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>11</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>13</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Trial 15 - Planet</td>
<td>Speed 5s</td>
<td>Planets</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>------------------</td>
<td>----------</td>
<td>---------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>----</td>
</tr>
<tr>
<td>Line 1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>6</td>
<td>N</td>
<td>7</td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>10</td>
<td>N</td>
<td>11</td>
<td>N</td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td>N</td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 16 - Planet</th>
<th>Speed 3s</th>
<th>Planets</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 2</td>
<td>N</td>
<td>3</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>7</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>9</td>
<td>N</td>
<td>N</td>
<td>10</td>
<td>11</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>14</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 17 - Planet</th>
<th>Speed 10s</th>
<th>Planets</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>N</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>2</td>
<td>3</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 2</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 3</td>
<td>N</td>
<td>N</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Line 4</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>8</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line 5</td>
<td>N</td>
<td>N</td>
<td>11</td>
<td>12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td>N</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line 6</td>
<td>N</td>
<td>15</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>