# Visual-motor integration in developmental dyslexia

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**Acknowledgements: I would like to thank all the children and staff at Castleview Primary School for welcoming us into their wonderful school and for the children who were willing to participate in the project. I would like to thank Barbara Piotrowska for her continuous support and help with collecting data. I would like to offer the greatest thanks to Dr. Alex Willis for not only her constant support, but her useful comments and guidance, enthusiasm and helpful advice throughout.**

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## Abstract:

Despite the increasing interest in dyslexia in the literature, debates still surround theories about the causes of dyslexia and efficient methods of detection. One major theory of dyslexia is the General Sensorimotor Theory (Stein, 2001; Ramus, 2003), which hypothesises that visual and auditory processing, and motor/tactile aspects contribute to the causes of dyslexia. This study aims to test the “Dot-to-Dot” (DtD) task as a potential screening tool for primary school children. This study will address the visual-spatial-motor integration debate, testing for the notion that the general sensorimotor aspects are sufficient to identify dyslexia. The DtD task will be compared with an existing screening tool (LUCID Rapid), other phonological awareness tasks, and general intelligence measures. Participants were in the P1 and P3 classes of Castleview Primary School, recruited through City of Edinburgh Council. The 68 participants were between the ages of 4 years and 8 years. Testing took place at the school in two separate sessions. The first session tested children on the DtD and LUCID software, and the second session tested children on cognitive aspects using subtests from Wechsler’s Intelligence Tests (WPPSI & WISC) as well as the Dyslexia Early Screening Test (Version II, Fawcett & Nicolson, 2004). Correlational and regressional analyses revealed that generally, the DtD can be shown to add prediction to phonological awareness scores. The DtD can differentiate between ‘high’ and ‘low’ risk children with dyslexia, as classified by LUCID Rapid. Therefore, this suggests that this task could potentially be used to detect children at risk of developing dyslexia, with more detailed research.


KEY WORDS: VISUAL-MOTOR INTEGRATION, DEVELOPMENTAL DYSLEXIA, GENERAL SENSORI-MOTOR THEORY, DOT-TO-DOT TASK

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## 1. Introduction

In recent years, there has been an increasing interest in the area of developmental dyslexia (herein referred to simply as dyslexia). So much so, that it has been the subject of government investigations and initiatives (HMIE, 2008; Rose, 2009). The current major debates in the literature surround the definition of dyslexia, the theories of what causes dyslexia, and screening tools. Despite evidence showing that many factors shape a child's language and reading development before they start school (Lyytinen et al., 2006), many dyslexic children usually are diagnosed after they fail to learn to read at school. Many tests of phonological awareness are successful at differentiating between children with and without risk of dyslexia (Lyytinen et al., 2006). A phonological deficit is the defining feature of dyslexia, however alternative theories of dyslexia have provided evidence of a range of visual-sensorimotor deficits and view these visual-sensorimotor deficits as underpinning phonological deficits. Measuring visual-sensorimotor deficits is emerging as a significant, new approach for early identification of dyslexia (Franceschini, Gori, Ruffino, Pedrollo & Facoetti, 2012). This research therefore aims to test the general sensorimotor theory using a visual-motor ("dot-to-dot") task and comparing it to an existing screening tool (LUCID Rapid, Singleton, 2005), to see if the DtD task can predict phonological awareness scores. The aims of future longitudinal research are to determine whether sensorimotor deficits cause dyslexia or whether they co-exist with dyslexia, and to successfully develop a screening tool that identifies dyslexia in pre-reading age children.

### **1.1** Definitions of Dyslexia

The exact definition of developmental dyslexia continues to be debated in the literature. Many large institutions and associations give differing definitions. The DSM-IV definition differs from the DSM-V and from the definition given by the ICD-10.

The definition given by the DSM-IV is a discrepancy definition, meaning that the reading level has to be discrepant from the level expected for a child's IQ and age. The discrepancy definition assumes that IQ variations cause variations in the ease with which children learn to read (Stanovich & Siegel, 1994). This assumption can be seen as 'unproven at best' (Stanovich & Siegel, 1994). In agreement with Hulme & Snowling (2009) a satisfactory definition of dyslexia within the current understanding and research is:

> *"Dyslexia is a specific learning disability that is neurological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language"*

(International Dyslexia Association, 2007).

This definition favours the phonological theory of dyslexia but excludes a IQ discrepancy for diagnosis. In the debate surrounding the usefulness of a IQ discrepancy for a diagnosis of dyslexia, general research practice suggests it can aid distinction between different groups. By selecting groups of poor readers with average IQ, one can exclude more general learning difficulties, maximising the chance of highlighting a cause of reading problems (Hulme & Snowling, 2009). However, there are a number of concerns with using IQ when defining dyslexia or an ability-achievement discrepancy. These are, mainly, the conceptual understanding of IQ as a measure, the use of the group 'garden variety poor readers' and evidence supporting the nature of reading problems in these two groups, and the impact this definition has on interventions for dyslexics (Siegel & Himel, 1998; Stanovich, 1996; Rutter & Yule, 1975). This research project will test measures of cognitive skills in young children to predict a child's progress in learning to read, which may give some insight into the possible causes of variations in reading development.

Dyslexia and difficulties with phonological awareness are not a universal phenomenon. Dyslexia only strongly appears in irregular or 'opaque' orthographies, for example, the English language (Snowling, 2005). In more regular or transparent orthographies, for example Spanish or Italian, where the relationships between spellings and sounds are consistent, children learn to decode quickly and at the same time they rapidly acquire awareness of the phonemic structure of spoken words (Aro, 2004; Aro & Wimmer, 2003). This has implications for the further research of dyslexia, as this disorder can be seen to lack universality.

## **1.2** Deficits Observed in Children with Dyslexia

The deficits characterised by dyslexia manifest themselves in a variety of ways. Deficits include: "learning to read, phonological tasks, naming, speech development, balance, time estimation, memory, spelling, phonic skills, motion detection" (Department for Education and Skills, 2004, pg. 32).

**Table 1.1 A table of categorised tasks of phonological awareness (Adams, 1990 in Muter, 2005)**

| **Task** | | **Example** |
|---|---|---|
| Syllable & Phoneme Segmentation | Tap, count out, or identify syllables or phonemes within a word | "Cat," the child taps three times to indicate the three phonemes within word (Liberman, Shankweiler, Fischer, & Carter, 1974) |
| Phoneme Manipulation | Delete, add, substitute, or transpose phonemes within a word | In a consonant deletion task, "cat" without the "c" says "at" (Bruce, 1964) |
| Sound Blending | Examiner provides the phonemes of a word and child is asked to put them together | "c-a-t" blends to yield "cat" (Perfetti, Beck, Bell, & Hughes, 1987) |
| Rhyming | The identification of the non-rhyming word in a sequence of three or four words or knowledge of nursery rhymes | The odd word out in the series "cat, pat, fan" is "fan". Bradley & Bryant's sound categorisation task (1983) |

Phonological deficits are primarily measured using phonological awareness tasks which have been shown to successfully predict reading. These tasks can be categorised into four types, see table 1.1 (Adams, 1990, in Muter, 2005). These tasks are critiqued in terms of how well they collect data to support the Phonological

Deficit Hypothesis (Stanovich, 1988). Acquisition of these skills may depend on exposure to printed words or explicit reading instruction, which suggests a two-way interactive process between phonological skills and learning to read (Muter, 2005).

There is considerable debate about which types of tasks are most predictive of future reading abilities. Bryant (1998) argues that rhyming tasks best predict later reading success. Alternatively, Muter and Snowling (1998) suggest that segmentation tasks are influential in the initial stages of learning to read. Other evidence confirms that rhyming has relevance at later stages of reading development (Muter, Snowling & Taylor, 1994). There is therefore differing evidence for and against Goswami & Bryant's model (1990 in Goswami, 1993), that phonological skills relate to different levels of analysis of spoken word, and that awareness develops at different rates (Muter, 2005). Some phonological awareness tasks have been criticised for placing greater load on a child's phonological working memory ('Odd-word-out task, Bradley & Bryant, 1983 in Bryant, MacLean & Bradley, 1990), whilst other tasks appear to assess phonological memory but often tap into other phonological processes (e.g. non-word repetition) (Muter, 2005).

Apart from phonological deficits, children with dyslexia often present with difficulties in retrieving phonological information from long-term memory, as well as difficulties in accessing words, for example in studies using Rapid Naming tasks. These problems could stem from more basic deficits in speech perception, production, or temporal processing (Farmer & Klein, 1995). These deficits can be categorised in two main ways: verbal short-term memory and rapid automatised naming (RAN). Evidence suggests that dyslexics perform poorly on these tasks (Ramus & Ahissar, 2012; Abu-Hamour, 2009). Evidence for working memory reliance in speech perception comes from classic phonological studies (Conrad, 1964; Baddeley, Thomas & Buchanan, 1975 in Mather & Wendling, 2012), suggesting that these mechanisms work less efficiently in dyslexics. The importance of working memory (short-term verbal span) as a predictor of reading skill independently of phonological skills is hotly debated. Some studies suggest that working memory does not significantly predict reading skill after controlling for phonological abilities (Wagner et al., 1997), whilst other studies have found that phonological analysis and working memory account for unique variance (Hansen & Bowey, 1994 in Bowey, 1996). Whether working memory is viewed as phonological representations (Snowling, 1998; Wagner, Torgesen & Rashotte, 1994) or slow processing speed (Shankweiler, Crain, Brady & Macaruso, 1992), both sides see this as a core problem for poor-readers as a deficit in phonological processing.

Processing speed can be measured by Rapid Automatised Naming (RAN) tasks. This task typically involves naming pictorially represented objects, letters, or colours. Performance is measured by time (in seconds) taken to name all objects in the task. RAN is a well-documented linguistic measure that is correlated to reading. Some researchers think this reflects phonological memory or the retrieval process (Wolf & O'Brien, 2001 in Savage, 2004). RAN tasks are considered good tasks for children as they do not involve reading (Mather & Wendling, 2012), and are generally seen to contribute further towards the prediction of reading deficits beyond phonological awareness (Savage, Pillay & Melidona, 2007). Individual differences in RAN performance have been shown to predict reading development in 1st grade (Felton & Brown, 1990 in Wolf & Bowers, 1999) and in 3rd and 4th grades (Badian, McAnulty, Duffy & Als, 1990 in Badian, 1999). Naming speed tasks using digits and letters appear to be more predictive than naming of pictures, given the reading-related symbolic nature of the stimuli (Badian, 2005). This could either reflect ease of accessing phonological representation in long-term memory or the distinctness of representations. Wagner et al. (1997) suggests that individual differences in naming speed influences subsequent word level reading initially, but that these influences fade with development. They found that phonological awareness had a powerful and long-term bearing on reading progress. RAN could be a predictor of letter acquisition in younger children as well as phonological awareness.

There are different theories and perspectives on what these tasks are measuring and what they are tapping into. Snowling and Hulme (1994 in Muter, 2005; Wagner et al., 1994) view tasks of phonological awareness, verbal memory, naming speed, and speech rate as indirect tests of children's underlying phonological representations. Muter (2005) views these tests as tapping into the specificity of underlying phonological representations, and suggests that the quality of these representations affect children's ability to read. Alternative views are that naming speed, measures of working memory and speech rate may be tapping into processes that are separate from phoneme awareness, though still within the phonological domain. (Muter, 2005).

In addition to deficits in phonological awareness, verbal working memory, naming speed, and speech rate, children with dyslexia have also shown deficits in motor tasks. Motor impairments in children with developmental dyslexia have been reported for a long time (Denckla et al., 1985 in Kadesjo, & Gillberg, 1999). Dyslexic children often present with co-ordination, balance, or muscles tone impairments that are interpreted to be a consequence of cerebellar dysfunctions (Nicolson, Fawcett & Dean, 2001). Deficits in motor skills are reported at various rates. Some have reported sensory-motor symptoms in dyslexic children as low as 33% (Ramus et al., 2003), others have reported as high as 80% of cases (Nicolson et al., 2001), where others have reported between 40-57% (Chaix et al., 2007). Chaix and colleagues (2007) postulate that this variability across studies might relate to the methods used for assessing the motor disorders.

Furthering Nicolson and Fawcett's extensive work, some research has suggested that visual-spatial attention deficits in young children is an important risk factor for becoming a poor reader (Franceschini et al., 2012). Visual attention span can be measured using letter report tasks, a divided attention task (Bosse, Tainturier & Valdois, 2007), visual search tasks (Iles, Walsh & Richardson, 2000 in Valdois, Bosse, & Tainturier, 2004), speed of attention and disengagement (Facoetti, Ruffino, Peru, Paganoni & Chelazzi, 2008), spatial cueing (Roach & Hogben, 2004; Facoetti, Paganoni, Turratto, Marzola & Mascetti, 2000). Dyslexic childrens' performance on these tasks can account for substantial unique variance in reading performance after phonological skills is accounted for (Bosse et al., 2007; Moores, Cassim & Talcott, 2011). Visual attention has been shown to provide significant predictive information after language and naming scores were accounted for (Franceschini et al., 2012). Evidence of deficits in visual-spatial performance in dyslexic adults (Kevan & Pammer, 2008) further promotes the hypothesis that visual-spatial attention, independent of language could cause dyslexia (Vidyasager & Pammer, 2010).

In conclusion, a number of different deficits have been observed in dyslexic children. Research in this field generally agrees that a phonological deficit is key to defining dyslexia, however they theoretically disagree on the origin of the deficit and some see the phonological deficit as being underpinned by sensorimotor deficits. Theories that attempt to explain these observed deficits will be discussed below in section 1.4.

**1.3** Early Diagnosis & Intervention

From a western educational perspective, the ability to read is incredibly important. Without reading, an individual can quickly fall onto a negative path towards poor educational achievement. The literature is currently focussing on intervening early in a child's life, with the aim of reducing the negative effects of reading disorders on a child's learning success. (British Academy, 2013)

Successfully identifying an individual who is at risk of developing dyslexia with a screening tool can direct the child to further attention and the child can receive interventions to learn to read (Protopaps, Skaloumbakas & Bali, 2008). Interventions that help children who are having trouble learning to read (e.g. ABRACADABRA web-intervention, Lindamood Phonemic Sequencing, Read, Write & Type, Savage, 2004; Torgesen, Wagner, Rashotte, & Heron, 2003) appear to be most influential at the youngest ages (pre-reading, kindergarten - 5 years), before dyslexia is formally diagnosed (Gabrieli & Norton, 2012). The efficacy of individual interventions will not be discussed here due to the scope of this research (for a review see Torgesen et al., 2003). Recognising and identifying an individual's strengths and weaknesses in reading is beneficial as educational services can ensure that the individual receives the additional aid necessary, to ensure he or she achieves educational success.

Early identification can be very useful: however, it is important that schools have procedures in place to meet the needs of individuals. Aspects such as school policies, the role of professionals, and the role of parents should also be considered (Reid, 2009). Arguably, it can be near impossible to diagnose a child with a reading disorder before they can read, but if the aim is to identify risks of developing difficulties rather than to label, then this can lead to intervention, with a positive impact (Lynch, 2007). Formal diagnoses tend to be avoided by many schools and local authorities especially for pre-reading aged children, despite evidence showing that many factors shape a child's language and reading development before they start school (Lyytienen et al., 2006). For this reason, many dyslexic children usually are diagnosed after they fail to learn to read at school and are very behind in the educational system (Shu & Li, 2012).

**1.4** Theories of Dyslexia

There are many differing theories of dyslexia that aim to account for the various deficits observed in dyslexics. The major theories will be discussed here. Firstly, the phonological theory and the double-deficit hypothesis will be discussed. Secondly, the cerebellar deficit hypothesis, followed by a discussion of the transient processing theories, mainly the magnocellular theory and visual attentional theories. Finally, the 'umbrella' term, General Sensorimotor Theory, will be discussed.

### 1.4.1 The Phonological Theory.

The Phonological Theory of dyslexia has been the dominant theory within the field for some time. It postulates that reduced phonological awareness is associated with impaired reading skills (Beaton, 2004) and suggests that this phonological deficit “is directly and exclusively caused by a cognitive deficit specific to representations and processing of speech sounds” (Ramus, 2003, pg. 212). In light of recent research suggesting that there are many other contributing factors to dyslexia (White et al., 2006), this is perhaps a slightly simplistic understanding of dyslexia, as the phonological theory cannot account for any of the sensorimotor deficits often observed in dyslexics. Despite this, a phonological deficit remains the primary deficiency to account for when formulating hypotheses and theories of dyslexia. Other researchers seek to account for this phonological deficit as part of a broader framework.

One theory that has emerged from the original phonological theory is the Double-Deficit Hypothesis (Wolf & Bowers, 1999), which seeks to bridge the understanding between phonological deficits and naming speed deficiencies exhibited by dyslexics. Wolf and Bowers (1999) postulate that phonological and the underlying naming speed difficulties are two distinct sources of dyslexia and suggest that they contribute uniquely to the presence of different sub-types of dyslexia. Opinions surrounding the categorising of sub-types of dyslexia are also controversial. Castles & Coltheart (1993) classified children into ‘surface’ and ‘phonological’ subtypes of dyslexia using a non-word reading task. Snowling, Bryant & Hulme (1996 in Hulme & Snowling, 2009) critiqued this methodology, arguing that it did not include a reading-age matched control group, and thus group differences are harder to discern. Many subsequent studies that have included reading-age matched controls have found weaker results for this postulation (e.g. Stanovich, Siegel & Gottardo, 1997). Manis & Bailey (2001 in Bishop & Snowling, 2004) argue against such a classification, as these behavioural descriptors cannot be stable over time.

### **1.4.2 The Cerebellar Deficit Theory.**

The Cerebellar Deficit theory (Nicolson & Fawcett, 2007) from the Automatisation Deficit theory (Nicolson & Fawcett, 1990 in Nicolson & Fawcett, 1994) is one of the main alternative causal theories of developmental dyslexia. The Automatisation Deficit theory characterises difficulties in skill automatisation as behavioural symptoms of dyslexia (Nicolson, Fawcett & Dean, 2001). Skill automatisation deficits are typically expressed as difficulties with implicit types of learning, when a task becomes fluent with practice (Nicolson & Fawcett, 1994), in which dyslexics have documented deficits (Stoodley, Ray, Jack & Stein, 2008; Bennett, Romano, Howard & Howard, 2008). The Cerebellar Deficit theory postulates that the cerebellum of dyslexics is mildly dysfunctional and problems with automaticity lead to a number of cognitive difficulties, including reading (Sela & Karni, 2012). This theory arose from studies showing that dyslexic children had difficulty on dual tasks with motor skills (Nicolson, Fawcett, 1990 in Nicolson & Fawcett, 1994). In accordance with this theory, dyslexics should show deficits in RAN tasks, motor skills, and implicit learning learning tasks such as a serial reaction time task (Vicari, et al., 2005). Neuro-imaging evidence supports the Cerebellar Theory, showing abnormalities of activation, metabolic or structural signals in cerebellar regions in dyslexic adults (Rae et al., 1998; Menghini, Hagberg, Caltagirone, Petrosini, & Vicari, 2006). However, some subsequent meta-analysis suggests this theory is not as strong as first anticipated and that the data may reflect a sample with co-morbid ADHD (Rochelle & Talcott, 2006 in Hulme & Snowling, 2009). Other criticisms of the theory suggest that it lacks causality and that the cerebellum is merely correlated to dyslexic symptoms (Bishop, 2002 in Stoodley & Stein, 2011) and that if dyslexia is caused by a disordered cerebellum, one would expect more evidence of the classic cerebellar clinical syndrome (Zeffiro & Eden, 2001 in Beaton, 2004). Thus it can be said that the literature disagrees on whether cerebellar problems underlie or correlate with dyslexia.

**1.4.3 Transient Processing Theories.**

A large body of evidence has investigated the visual and auditory transient processing deficits which are thought to lead to phonological deficits (Lallier & Valdois, 2012; Stein & Talcott, 1999; Stein & Walsh, 1997; Tallal, 1980 in Wydell, 2012). Visual processing deficits can be understood in terms of deficits in the magnocellular system, as well as in terms of attentional deficits. The main understanding of auditory deficits is from an attentional perspective.

The Magnocellular theory hypothesises that the magnocellular system is responsible for timing visual events during reading (Stein, 2001). Evidence suggests that dyslexics are less sensitive to dynamic visual stimuli and have deficits in processing rapid sequences of visual stimuli (Witruk & Wilcke, 2010). This theory originated from the understanding of the visual pathways and the magnocells in the lateral geniculate nucleus (LGN) being responsible for contrast and movement perception (Livingstone et al., 1991 in Skottun, 2000). The magnocellular pathway receives input from cones and rods in the retina, and stretches from the primary visual cortex (V1) in the occipital lobe into the parietal lobe (Stein & Talcott, 1999). Reading can be seen as an interaction of magno- and parvocells, where the magnocellular pathway is suppressed during saccades (Burr, Morrone, Ross, 1994; Skottun, 2000), contrary to previous understanding of magnocellular and parvocellular pathways (Lovegrove et al., 1986 in Skottun, 2000). It is thought that the magnocellular system is responsible for timing visual events during reading (Stein, 2001). Research supporting this theory suggests that dyslexics have fewer and more deviantly structured magnocells (Witruk & Wilcke, 2010), coherent motion deficits (Cornelissen, Richardson, Mason, Fowler & Stein, 1995), visual motion deficits (Talcott, Hansen et al., 2000), and spatial frequency doubling (Kevan & Pammer, 2008; Pammer & Kevan, 2009).

Some researchers suggest that the magnocellular temporal processing deficit extends to other systems, such as the motor domain, causing impairments (Stein and Walsh, 1997). Dyslexics also present with reduced tactile sensation, consistent with impaired magnocellular dorsal column function (Grant, Zangaladze, Thiagarajah, & Sathian, 1999; Stoodley, Talcott, Carter, Witton & Stein, 2000), as well as subtle motor impairments consistent with cerebellar deficits within the Cerebellar Deficit hypothesis understanding (Sela & Karni, 2012).

Farmer & Klein (1995) postulate that temporal processing difficulties lead to speech processing impairments, which detrimentally impact on reading development. Generally, dyslexics are found to be less sensitive to dynamic sensory stimuli (Talcott, Witton, et al., 2000) and show poor performance on visual and auditory tasks, verbal and non-verbal (Stein & Talcott, 1999; Joanisse et al., 2000). Processing deficits observed in dyslexics can also be understood from an attentional perspective. Visual attention, which can also be seen to be mediated by the magnocellular system (see above), has been shown to be important in the development of phonological and orthographic representations necessary for learning to read (Facoetti, Turatto, Lorusso & Mascetti, 2001) as demonstrated by emerging theories, the Sluggish Attentional Shifting (SAS) hypothesis (Hari and Renvall, 2001), and the Visual Attention (VA) Span deficit hypothesis (Bosse et al., 2007). The SAS hypothesis assumes that a deficit at the attentional level would lead to developmental reading disorders. The SAS hypothesis views dyslexia as resulting from phonological disorder, which would result from auditory sluggish attentional shifting and also associated with additional visual attentional deficits (Hari & Renvall, 2001; Tallal, 1980 in Wydell, 2012). The SAS hypothesis can be seen as a crossroad between the rapid sequential processing deficit hypothesis and the magnocellular deficit hypothesis. However a magnocellular deficit is not sufficient to observe dyslexia although still associated with reading difficulties (Skoyles & Skottun, 2004). The exact role of visual attention deficits in reading difficulties is still unclear (Lallier & Valdois, 2012), therefore more research is needed to establish more precisely the role of visual attention in dyslexia. The Visual Attention (VA) Span deficit hypothesis (Bosse et al., 2007) views dyslexia as a cognitive multifactorial disorder. According to the VA Span hypothesis, dysfunctional reading developmental can either originate from a visual attention deficit or a phonological deficit, which affects the simultaneous processing of multiple visual stimuli (Lallier & Valdois, 2012). The VA Span deficit hypothesis postulates that a reduction or deficit in visual attention span should prevent normal encoding of the orthographic sequence of most words (Bosse et al. 2007). Both theories assume that a parietal dysfunction is the cerebral origin of reading disorder (Lallier & Valdois, 2012). Despite evidence supporting these theories (Vidyasager & Pammer, 2010; Moores, et al., 2011), contradicting evidence suggests that the auditory and visual rapid sequential deficits may not be sufficient to detect dyslexia (Lassonen et al., 2001, in Lallier & Valdois, 2012).

The cerebellar theory and the magnocellular theory, as well as visual attention hypotheses are not contradictory but simply propose different origins of dysfunction within the brain (Stoodley & Stein, 2011). Both the magnocellular and cerebellar theory attempt to explain why and how cognitive-level deficits in phonology and fluency arise (Stoodley & Stein, 2011). The magnocellular visual system feeds into the cerebellum (Stein & Glickstein, 1992 in Stoodley & Stein, 2011), thus cerebellar output may be abnormal because of receiving compromised input (Stoodley & Stein, 2011).

### 1.4.4 The General Sensorimotor Hypothesis.

The General Sensorimotor Hypothesis has been proposed as an ‘umbrella term’ (Stein, 2001; Ramus 2003) to include the lower-level auditory processing theories (Tallal, 1980 in Wydell, 2012), the visual processing theories (Lovegrove et al., 1980 in Nicolson & Fawcett, 1994; Livingstone et al., 1991, in Skottun, 2000; Stein &

Walsh, 1997) and motor deficits incorporated in the cerebellar theory (Nicolson & Fawcett, 2004). The General Sensorimotor Hypothesis postulates that a phonological deficit is underpinned by more basic deficits in visual and sensorimotor processing. The general sensorimotor hypothesis does not exclude the presence of a phonological deficit, but views it as secondary to an auditory/visual impairment (Ramus, 2003). Ramus argues that there is no one theory that can explain the phonological deficit observed in dyslexia. Ramus advocates the need to look at all the factors and theories affecting dyslexia in order to gain a broader understanding and more complete theory of dyslexia.

**1.4.5 Summary.**

In summary, there are differing theories of developmental dyslexia which can broadly be grouped into phonological and sensorimotor underlying understanding. The current main causal theory is the phonological deficit theory. Other cognitive causal theories include Cerebellar Deficit-based theories and the Magnocellular Theory, which can be grouped into a general sensorimotor understanding. Disagreements surround the biological level of explanation, differing views as to what occurs in the brain that accounts for deficits seen at a cognitive level. To date, a few current studies have attempted to assess all major theories of dyslexia (Ramus et al., 2003; White et al., 2006). Ramus and colleagues (2003) conducted a multiple case study using adult dyslexic university students on psychometric, phonological, auditory perception, visual perception, and cerebellar tasks. They concluded that a phonological deficit is sufficient to cause dyslexia in the absence of any sensory or motor deficits, thus supporting the Phonological theory of dyslexia. They found little evidence for motor deficits in keeping with a Cerebellar hypothesis. White and colleagues (2006) compared groups of autistic and dyslexic children to a control group on a variety of literacy, phonological, auditory, visual, and motor tasks. They concluded that there is a double dissociation between sensorimotor and reading impairments, and that although sensorimotor impairments do not seem to cause dyslexia, they can be seen as markers for this disorder.

It can be said that they have some methodological limitations and criticisms (Bishop, 2006; Nicolson & Fawcett, 2006; Tallal, 2006). These two studies can be criticised for the tasks they have chosen. The tasks chosen to assess the different cognitive abilities were not uniformly distributed (Menghini et al., 2010). The Phonological theory was extensively tested, whereas the Cerebellar theory was only investigated with a few basic tasks. The hypothesis of attentional-parietal deficits was not evaluated (Menghini et al., 2010). This discrepancy in understanding has most likely arisen from the researchers' initial interests and thus subsequent research direction and findings. However, it is likely that dyslexics differ in that they have deficits in one, two or all of the areas in the brain associated with dyslexia. As of yet, no theory of dyslexia is robust. As Castles and Coltheart articulate;

> *"it can be concluded that no study has provided unequivocal evidence that there is a causal link between the competence in phonological awareness to success in reading and spelling acquisition"*
>
> (Castles & Coltheart, 2004, pg. 77).

The major theories of dyslexia generally propose different origins for the dysfunction and this affects how dyslexia is understood and has repercussions on the types of assessments and interventions offered. Therefore more research is needed in order to gain a better understanding of how these deficits contribute to dyslexia.

**1.5** Aims & Objectives

Aim: To test the general sensorimotor theory, a visual-motor (“dot-to-dot”, Willis, Piotrowska, Bannach-Brown, MacLean & Kerridge, 2014) task will be compared to an existing screening tool (LUCID Rapid, Singleton, 2005) to see if the DtD task can predict phonological awareness scores. The aims of future longitudinal research are to determine whether sensorimotor deficits cause dyslexia or co-exist, and successfully developing a screening tool that identifies dyslexia in pre-reading age children.

The research questions of the study will include ascertaining the following:

1. Is there a relationship between performance on the DtD task and performance on an existing computer-based dyslexia screening tool (i.e. LUCID Rapid)?
2. Does the performance on DtD relate to other cognitive skills, such as working memory, rapid automatised naming and phonological awareness, all of which are believed to predict reading skills?

## 2. Methods

### 2.1 Design

Correlational design.

#### 2.1.1 Participants.

All participants attended the Castleview Primary School, Edinburgh in classes P1 and P3. 38 Children in the P1 class, 20 females and 18 males, with average age at the start of data collection in November 2013 of 5 years, 3 months. 31 Children in the P3 class, 16 females, 15 males, with average age at the start of data collection in November 2013 of 7 years, 3 months, 24 days.

### 2.2 Materials

#### 2.2.1 The Dot-to-Dot (DtD) Task.

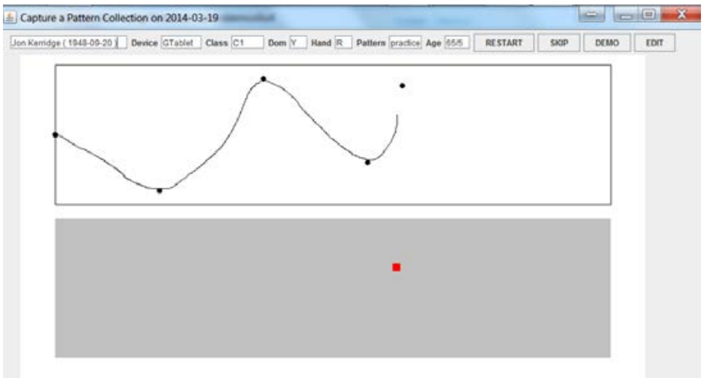


Fig. 2.1 A Computer Screen Shot of the Dot-to-Dot task

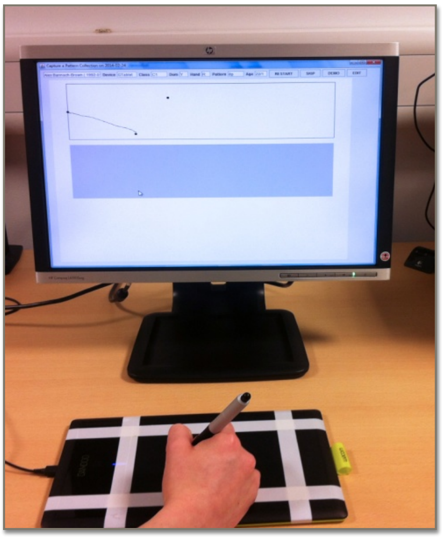

Fig 2.2 Set-Up of the DtD Task

The Dot-to-Dot (DtD) task was administered as a measure of visual-motor integration, (Willis et al., 2014). This computer and tablet-based screening tool measures hand-eye coordination and visual spatial attention. The task involves a series of short tasks which involve joining up a sequence of dots together with a straight line. The dots are shown on a computer screen and participants join the dots by drawing on a tablet underneath with an electronic stylus (see figure 2.1 and figure 2.2). Initially, only two dots are displayed, but as participants start to draw the line and get closer to the second dot, a third dot appears and so on until the end. The participant's attention must be split between two display areas on the screen and the tablet. A new trajectory needs to be planned as each new dot appears. Measures are taken from the task performed with the dominant and non-dominant hand, and different numbers of dots in the task. The main measures from this task were Average Points (average number of pixels 'coloured in' per trials), Average Time (average time taken to complete each trial, in seconds), Average SAD (average deviation from the perfect fit line over the whole pattern), and

Average First Section error (Average deviation from the perfect fit line between the first and the second dot).

### 2.2.2 LUCID Rapid.

LUCID Rapid (Singleton, 2005) was administered as a correlate with the DtD task. This widely used screening tool taps into auditory sequential memory and visual-verbal integrated memory, as well as phonological processing in children ages 4 years to 7 years 11 months, phonic decoding in children aged 8 years to 12 years, and lexical access in age 18 years and above.

These two dyslexia screening tools were correlated with measures of phonological awareness, rapid automatised naming, manual dexterity, working memory, verbal comprehension and perceptual reasoning.

### 2.2.3 Cognitive Measures.

DEST-II (Dyslexia Early Screening Tool: Nicholson and Fawcett, 2004, Pearson Assessments), DST-J (Dyslexia Screening Tool - Junior: Nicholson and Fawcett, 2004, Pearson Assessments), WPPSI (Wechsler's Preschool and Primary Scale of Intelligence, Wechsler, 2012), and WISC-IV (Wechsler's Intelligence Scale for Children, Wechsler, 2004) tools were used. Table 2.1 shows which subtests were used for which age group.

**Table 2.1 A Table to Show the Subtests Used, Depending on Age, and Indicating the Origin of Test.**

| | **DEST-II** | **WPPPSI** | **DST-J** | **WISC-IV** |
|---|---|---|---|---|
| Class | P1 | P1 | P3 | P3 |
| Similarities | | ✓ | | ✓ |
| Block Design | | ✓ | | ✓ |
| Matrix Reasoning | | ✓ | | ✓ |
| Forwards Digit Span | | ✓ | | ✓ |
| Backwards Digit Span | | | | ✓ |
| Bead Threading | ✓ | | ✓ | |
| RAN | ✓ | | ✓ | |
| Rhyming/First Letter | ✓ | | | |
| Phonological segmentation | | | ✓ | |
| School Baseline Literacy Assesments | ✓ | ✓ | ✓ | ✓ |

The Dyslexia screening tools and the Wechsler's intelligence tests were chosen because of the similarity of the subtests between ages, wide age-range applicability, and their ability for the same subtest to be administered to children of a large range of ages. Tasks were chosen based on their high validity and evidence-based correlation/relationship to phonological deficits and predicting future reading ability. All subtests were administered under strict guidelines from the accompanying Administration Manuals.

From the Dyslexia Screening Test Range (Fawcett & Nicolson, 2004) the Bead, RAN (Rapid Automatised Naming) and phonological awareness subtests were used. A bead threading task was used as a measure of manual dexterity to test the Cerebellar Deficit Hypothesis (Nicolson & Fawcett, 2007), as well as measure the relationship between motor skills and the DtD task. The task consisted of threading 13 beads onto thread. A measure was taken of how many beads were threaded in 30 seconds. The measure of RAN consisted of 8 rows of 5 objects. The objects are pictured in Figure 2.3 were displayed twice. These were presented in black and white on an A4 piece of white paper.

Fig. 2.3 Objects in RAN Task

The measure of phonological awareness, the 'Rhyming/First Letter' subtest and 'Phoneme Segmentation/Spoonerisms' subtest was used. The 'Rhyme/First Letter' subtest consisted of two parts; firstly the 'Rhyme' task where participants judged whether two words rhymed, and secondly, the 'First Letter' task where participants were asked to say the sound of the first letter of a word. The 'Rhyme' task consisted of a practice round and then 8 word pairs. The 'First Letter' task consisted of a practice round and 5 words. Thus the 'Rhyming/First Letter' subtest was collectively scored out of 13. The phonological segmentation task in the DST-J asks participants to say a word, and then to repeat the word without a phoneme. The task consists of 3 practice items and 12 test words. The 'Spoonerisms' task asks participants to swap the first phonemes in first and last names. The task consisted of 2 practice items and 3 test names. Thus the 'Phoneme Segmentation/Spoonerisms' subtest was scored out of 15.

All children were tested on baseline reading and literacy assessments by Castleview Primary school at the start of each academic year.

### 2.3 Procedure

The tests were administered by two different psychology researchers from Edinburgh Napier University, Alexandra Bannach-Brown and Barbara Piotrowska, on two separate occasions at Castleview Primary School. The testing was carried out in a separate room, which was quiet and away from the classroom to minimise distractions. Each testing session lasted no longer than 30 minutes, so the child did not miss too much of the curriculum, lose concentration, or get fatigued.

In the first session, participants were tested on the DtD and LUCID Rapid. The order in which these two tests were administered was randomised. The second session tested participants on the cognitive measures. These tests were split in two blocks. Block 'A' consisted of measures from the Wechsler's Range. These tasks were administered in the order suggested in the Wechsler's Administration Manuals; Block

Design, Matrix Reasoning, Similarities, Digit Span. Block ‘B’ consisted of measures from the DEST-II and DST-J. These tasks were administered in the order of RAN, Bead Threading and Phonological awareness. The order in which Block ‘A’ and Block ‘B” were administered was randomised.

### 2.4 Ethics

Ethical Approval was gained from the City of Edinburgh Council. Ethical Approval was granted by the Head Teacher of Castleview Primary (See Appendix 1) *in locus parentis*, on behalf of the parents, who received information regarding the study and the option to withdraw their children from the study (See Appendix 2). Before testing, the children were verbally taken through the principles of informed consent and their right to withdraw and consented to participating in the study by writing their name (See Appendix 3). Procedures were developed In accordance to the Declaration of Helsinki. The project was approved by Edinburgh Napier Ethics Committee.

## 3. Results & Discussion

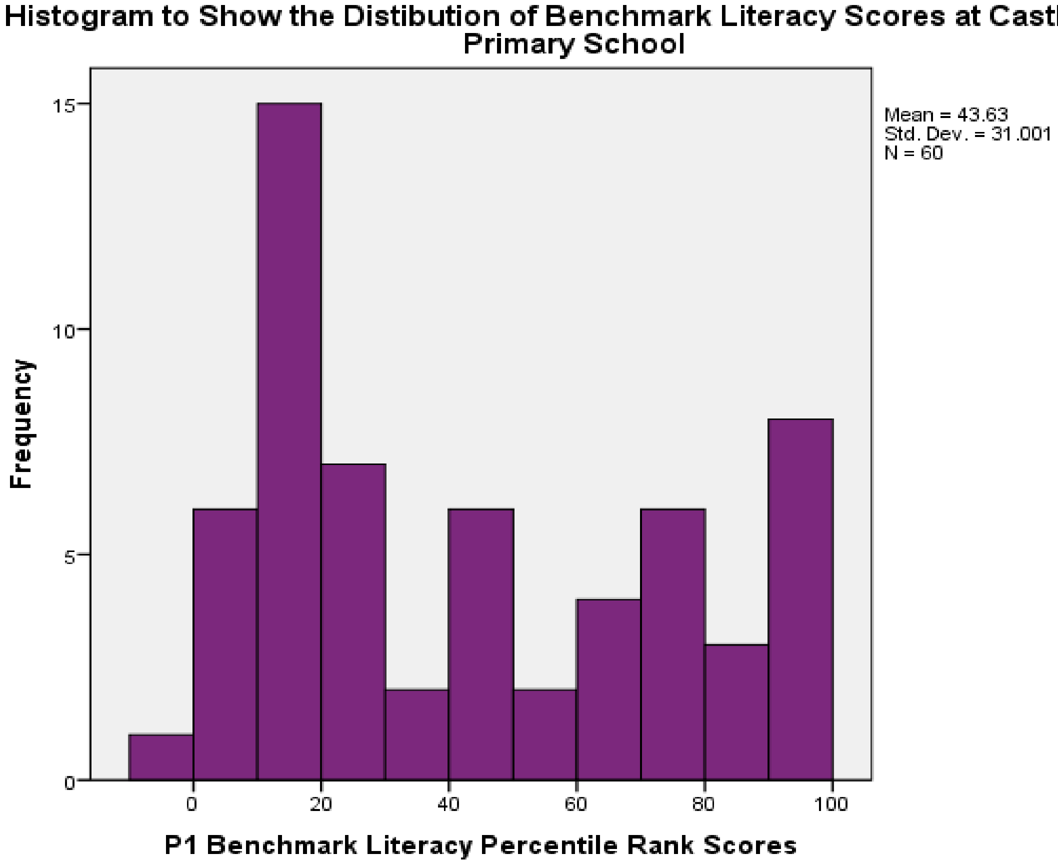


Figure 3.1 A Histogram to show the distribution of Benchmark Literacy Scores in this sample at Castleview Primary School

Note that the baseline literacy assessments carried out by the school showed that one third (N = 21) of children scored in the bottom 20% centime rank of national scores. Thus this sample does not have a normal distribution of reading performance. 21.1% of the children were non-native speakers (N = 15). 47.7% of children were currently receiving some form of additional support (language, behavioural etc) from the school (N = 31). This sample is not representative of primary aged children nationally. The catchment area for this school is currently

**Table 3.0 A Table to show the Level of English with Risk Group of Dyslexia as Classified by LUCID Rapid.**

| **Risk Group** | **Low** | **Moderate** | **High** | **Very High** | **Total** |
|---|---|---|---|---|---|
| **Level of English** | | | | | |
| **Native** | 14 | 17 | 14 | 4 | 50 |
| **Non-Native; Good** | 5 | 2 | 0 | 3 | 9 |
| **Non-Native; Poor** | 0 | 0 | 2 | 3 | 5 |
| **Total** | 19 | 19 | 16 | 10 | 64 |

ranked in the 3rd centile for deprivation in Scotland (Scottish Index of Multiple Deprivation, 2012). 60.7 % of pupils at the school receive free school meals; 33% of families in the area are rated as “income” and / or “employment” deprived.

Table 3.0 shows the numbers of English as a Second Language (ESL) and how these children were classified by LUCID Rapid in terms of risk of dyslexia. Note that all ESL children were classified as either ‘high’ or ‘very high’ risk.

### 3.1 Does performance on the DtD correlate with other cognitive abilities?

A correlation was run to test the research question; Does performance on the DtD correlate with other cognitive abilities? Mainly, the data violated normality, linearity and homoscedasticity assumptions, therefore a Spearman’s correlation was run. All effect sizes were small or medium.

Phonological Skills also significantly positively correlated with Block Design (rho(65) = 0.375, p = 0.002), Matrix Reasoning (rho(65) = 0.432, $p < 0.0005$), Similarities (rho(65) = 0.437, $p < 0.0005$), Digit Span (rho(65) = 0.427, $p < 0.0005$), and negatively correlated with RAN (rho(65) = -0.355, $p = 0.004$).

**Table 3.1 Correlations of the Dominant Hand Scores on the DtD task with Other Cognitive Measures**

| | Average Points | Average Time | First Section Error | Average SAD |
|---|---|---|---|---|
| **Bead Threading** | rho(65) = -0.423 *** | rho(66) = -0.337 ** | rho(66) -0.362** | rho(66) = -0.469 *** |
| **Phonological Skills** | rho(65) = -0.256 * | rho(65) = 0.044 | rho(65) = -0.341 ** | rho(65) = -0.352 ** |
| **RAN** | rho(66) = 0.300 *** | rho(66) = 0.221 | rho(66) = 0.357 ** | rho(66) = 0.504 *** |
| **Matrix Reasoning** | rho(65) = -0.220 | rho(65) = -0.229 | rho(65) = -0.351 ** | rho(65) = -0.315 * |
| **Similarities** | rho(65) = -0.155 | rho(65) = -0.054 | rho(65) = -0.259 * | rho(65) = -0.213 |
| **Digit Span** | rho(65) = -0.236 | rho(65) = -0.044 | rho(65) = -0.385 ** | rho(65) = -0.508 *** |
| **Block Design** | rho(65) = -0.024 | rho(65) = -0.016 | rho(65) = -0.216 | rho(65) = -0.303 * |

*** $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$**

The results in Table 3.1 suggest that DtD measures significantly correlate with tasks that predict reading ability (Phonological skills, RAN, Digit Span, bead threading), but also non-verbal reasoning abilities (Matrix Reasoning and Block Design) and verbal comprehension tasks (Similarities). As there were many more significant correlations for the dominant hand in comparison with the non-dominant hand (See Table 3.2), especially with tasks that predict later reading ability, this could suggest that non-dominant hand is a less effective measure.

Arguably phonological skills are one of the most predictive measures of later reading success, along with RAN (Muter, 2005). DtD Dominant Hand Average Points negatively correlated with phonological skills, which suggests that there is a relationship between accuracy on the DtD and phonological skills. DtD Dominant Hand Average Points, First Section Error, and Average SAD positively correlated with RAN, the lower accuracy from the first dot to the second, as well as overall, and the more time spent on DtD, the higher RAN in seconds score. The slower the children were at retrieving phonological information from memory, the slower the processing speed (in terms of the cerebellar theory). RAN arguably adds prediction to later reading success (Savage et al., 2007). DtD Dominant Hand First Section error and Average SAD also negatively correlated with Digit span, another measure which is thought to be predictive of later reading success. As expected, the DtD Dominant Hand Average Points, Average Time, Average SAD and First Section Error were negatively correlated to Bead threading. This suggests that poor dexterity affects accuracy on the DtD. This suggests that both tasks are tapping into similar aspects of motor skills.

DtD measures also negatively correlated with Matrix Reasoning, a non-verbal comprehension measure of fluid intelligence. This could suggest that there is a relationship between the DtD and approaching novel tasks. As both the matrix reasoning and DtD are novel tasks, implicit learning could play a part. The fact that Similarities, Matrix reasoning subtests are highly correlated with the DtD as well as phonological awareness scores is in keeping with previous results (Bosse et al., 2007) that suggest that cognitive deficits could be linked to or possibly responsible for dyslexia. Further research could look at whether the DtD specifically supports the multitrace memory model of reading, that hypothesises a causal relationship between the VA span disorder and reading difficulties (Bosse et al., 2007), by comparing it to tasks that solely measure visual attention.

**Table 3.2 Correlations of the Non-Dominant Hand Scores on the DtD task with Other Cognitive Measures**

| | Average Points | Average Time | First Section Error | Average SAD |
|---|---|---|---|---|
| **Bead Threading** | rho(62) = -0.266* | rho(62) = -0.144 | rho(62) = -0.417*** | rho(62) = -0.429*** |
| **Phonological Skills** | rho(62) = -0.202 | rho(62) = 0.005 | rho(62) = -0.181 | rho(62) = -0.311* |
| **RAN** | rho(62) = 0.311* | rho(62) = 0.239 | rho(62) = 0.324** | rho(62) = 0.321* |
| **Matrix Reasoning** | rho(62) = -0.186 | rho(62) = -0.019 | rho(62) = -0.214 | rho(62) = -0.307* |
| **Similarities** | rho(62) = -0.222 | rho(62) = -0.130 | rho(62) = -0.212 | rho(62) = -0.164 |
| **Digit Span** | rho(62) = -0.245 | rho(62) = -0.177 | rho(62) = -0.315* | rho(62) = -0.378** |
| **Block Design** | rho(62) = 0.042 | rho(62) = 0.098 | rho(62) = -0.251* | rho(62) = -0.296* |

*** $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$**

The results from this analysis show that DtD correlates with Similarities which is a verbal comprehension subtest, a measure of crystallised intelligence. Scores on the Similarities subtest also correlated with phonological awareness measures. This could suggest that poor scores on phonological measures could also reflect things like access to print and knowledge, which could be linked to the fact that the school was located in catchment area with a low socioeconomic status. Somewhat surprisingly, phonological awareness scores were also correlated to Block Design, a measure of perceptual reasoning, which is surprising as these are two subtests are conceptually measuring very different abilities. This result could also reflect the skewed sample in terms of ability. In relation to an IQ-discrepancy definition of dyslexia, this could reflect a large sample of ‘garden variety poor readers’.

### 3.2 Is there a relationship between performance on the DtD task and performance on the LUCID Rapid?

To test whether there was a relationship between performance on the DtD task and performance on an existing dyslexia screening tool (i.e. LUCID Rapid), two separate types of analyses were carried out. Firstly, measures of phonological awareness were used as a predictor variable in a multiple regression to measure the contribution of the cognitive measures in explaining the variance in phonological awareness. Secondly, LUCID grouped children into four risk categories based on their scores on the phonological and working memory subtests. The four risk categories are; ‘low’, ‘moderate’, ‘high’, and ‘very high’. A multivariate analysis of variance was carried out to determine if there was a relationship between scores on the DtD and LUCID scores.

#### 3.2.1 Phonological Awareness & Multiple Regression.

Firstly, the measures of phonological awareness were used as an indicator of potential risk of dyslexia. Two different outcome measures of phonological awareness were used, firstly phonological awareness as measured by DEST-II and DST-J, and secondly, the phonological subtest by LUCID Rapid. Therefore, two multiple regressions were conducted with the separate measures.

A multiple regression was run to determine the main predictors of phonological awareness (as measured by DEST-II and DST-J Raw Score) from the Wechsler’s Intelligence Tests (Similarities, Matrix Reasoning, Block Design, and Digit Span), RAN, and bead threading, along with measures from the DtD task (Dominant Hand average SAD, Dominant Hand average time, Dominant Hand first section error, Dominant Hand Average Points). Using the enter method, a significant model emerged: Similarities, Matrix Reasoning, DtD Dominant Hand Average Time and DtD Dominant Hand Average Points scores statistically significantly predicted phonological awareness $F(10,54) = 6.900$, $p < 0.0005$. The model explained 48% of the variance of phonological awareness (Adjusted $R^2 = 0.480$). Fig 3.3 shows the predictor variables entered into the model.

Using the second measure of phonological awareness, as measured by the LUCID Rapid Phonological Subtest, produced a slightly different outcome. A multiple regression was run to determine the main predictors of phonological awareness from the Wechsler’s Intelligence Tests (Similarities, Matrix Reasoning, Block Design, and Digit Span), RAN, and bead threading, along with measures from the DtD task (Dominant Hand average SAD, Dominant Hand average time, Dominant Hand first section error, Dominant Hand Average Points). Using the enter method, a significant model emerged: Matrix Reasoning, and Digit Span significantly predicted phonological awareness; $F(10, 52) = 4.762$, $p < 0.0005$. The model explained 38% of the variance in phonological awareness scores (Adjusted $R^2 = 0.378$). Fig 3.4 shows the predictor variables entered into the model.

**Table 3.3 The unstandardised and standardised regression coefficients for the variables entered into the model.**

| Variable | B | SE B | β |
|---|---|---|---|
| **Similarities** | 0.312 | 0.104 | 0.306** |
| **Block Design** | 0.263 | 0.112 | 0.256* |
| **DtD DomHand AvTime** | 0.164 | 0.063 | 0.335* |
| **DtD DomHand AvPoints** | -0.011 | 0.004 | -0.442* |
| **Digit Span** | 0.337 | 0.098 | 0.437*** |
| **RAN** | 0.016 | 0.016 | 0.111 |
| **Bead Threading** | -0.326 | 0.249 | -0.151 |
| **Matrix Reasoning** | 0.220 | 0.116 | 0.207 |
| **DtD DomHand AvFSerr** | -0.006 | 0.030 | -0.030 |
| **DtD DomHand AvSAD** | 0.000 | 0.000 | 0.194 |

***$p$ < 0.05, **$p$ < 0.005, ***$p$ = 0.001**

**Table 3.4 The unstandardised and standardised regression coefficients for the variables entered into the model.**

| Variable | B | SE B | β |
|---|---|---|---|
| **Digit Span** | 3.572 | 1.164 | 0.432* |
| **Matrix Reasoning** | 4.739 | 1.347 | 0.423** |
| **Similarities** | 1.736 | 1.211 | 0.160 |
| **RAN** | -0.014 | 0.189 | -0.010 |
| **Block Design** | 0.561 | 1.314 | 0.052 |
| **Bead Threading** | -3.400 | 2.884 | -0.148 |
| **DtD DomHand AvPoints** | -0.003 | 0.047 | -0.011 |
| **DtD DomHand AvTime** | 0.037 | 0.740 | 0.007 |
| **DtD DomHand AvFSerr** | 0.065 | 0.355 | 0.030 |
| **DtD DomHand AvSAD** | 0.00 | 0.001 | -0.026 |

***$p$ = 0.003, **$p$ = 0.001**

Using the DEST-II and DST-J Phonological Awareness Score as a predictor, the multiple regression showed that DtD Dominant Hand Average Time and DtD Dominant Hand Average Points scores significantly added to the prediction of phonological awareness. Assuming that the Dot-to-dot task correctly measures visual-spatial attention, this result suggests that visual-spatial attention significantly adds to the prediction of phonological awareness. Based on this result, the DtD might be a useful tool for identifying and predicting poor phonological skills. This can be followed up with future research. The DtD still needs to be tested as to whether it correctly measures visual-spatial integration, thus conclusions at this stage are preliminary. That a visual-spatial integration task adds to the prediction of phonological awareness scores, does not support the VA Span hypothesis. This hypothesis postulates that visual attentional deficits do not correlate to any other type of phonological or verbal deficit, and that dyslexia is solely correlated to visual attention deficits (Bosse et al., 2007).

Digit span was shown to significantly contribute to the prediction of phonological scores. This finding is in keeping with previous research which suggests that phonological deficit is primary in dyslexia, and that measures of working memory can add to the prediction of phonological scores (Muter, 2005). This finding adds further weight to the integration of working memory into many recent definitions of dyslexia (e.g. British Dyslexia Association). Similarities and Block Design scores also significantly contributed to prediction of phonological scores. This suggests that processes being measured in Block Design and Similarities, verbal comprehension and fluid intelligence measured by motor skills, also contribute to phonological skills. Surprisingly, RAN did not add to the prediction of phonological scores, which contradicts research suggesting that rapid processing adds to the prediction of phonological scores, which contradicts the double-deficit hypothesis (Wolf & Bowers, 1999) as well as the General Sensorimotor Theory which hypothesis that processing speed deficits are seen in addition to phonological deficits in dyslexia (Ramus, 2003). Also, this model only predicts 48% of the variance in phonological awareness. This suggests that there must be other factors that contribute to a further 52% of variance in this measure of phonological awareness which haven’t been measured in this study.

When the LUCID Rapid Phonological subtest centile scores was used as a predictor, only Digit Span and Matrix Reasoning significantly predicted performance on this phonological awareness task. This is consistent with previous findings which suggest non-verbal comprehension correlates with phonological comprehension (Bishop & Adams, 1990). That non-verbal comprehension contributes to the prediction of phonological awareness might reflect that the national reading performance scores in this sample were extremely skewed towards the lower end (See section 3.1). Phonological measures correlating to measures of non-verbal comprehension has implications for the use of an IQ-discrepancy definition of dyslexia. The model predicting scores on LUCID phonological awareness score only predicted 38% of the variance in phonological awareness, even less than the previous model which predicted 48% of variance in phonological scores, further suggesting that that there must be other factors that contribute to phonological awareness which have not been measured in this study. This model regression, using LUCID, does not support our hypotheses that DtD can predict scores of phonological awareness.

Using two different measures of phonological awareness and the regressions yielding such different results suggests that LUCID phonological subtests and the DEST-II and DST-J sub-tests of phonological awareness might be measuring slightly different abilities, if the only variable that adds to prediction in both models is Digit

Span. This confirms the finding that verbal working memory is a large contributing factor to predicting phonological awareness, which as previously mentioned supports using working memory as a significant addition to the definition of dyslexia (British Dyslexia Association, 2007).

### 3.2.2 LUCID Risk Classification & Multivariate Analysis of Variance.

Using the second measure of dyslexia, the risk level that LUCID Rapid produced for each child as an independent variable, a between-subjects multivariate analysis of variance (MANOVA) was conducted to see if there was a relationship between scores on the DtD task and the LUCID rapid.

**Table 3.5 A Table to Show the Means, ANOVA results and follow-up post-hoc tests results for cognitive measures and LUCID Risk Groups.**

| | **Low** [mean (SD) N = 17 | **Moderate** [mean (SD)] N = 18 | **High** [mean (SD)] N = 16 | **Very High** [mean (SD)] N = 10 | **One-way ANOVA** [F(Df); *p*] | **Tukey Post-hoc** (*p*) |
|---|---|---|---|---|---|---|
| **DtD FSerr** | 30.13 (3.71) | 36.44 (3.62) | 46.62 (3.82) | 44.78 (4.98) | 3.833 (3,60); .014 | .015[e] |
| **DtD AvPoints** | 1106.6 (38.98) | 1113.1 (37.94) | 1141.5 (40.12) | 1176.2 (52.31) | 0.473 (3,60); .702 | - |
| **DtD AvTime** | 20.82 (1.65) | 20.04 (1.60) | 19.64 (1.69) | 19.54 (2.21) | 0.109 (3,60); .954 | - |
| **DtD AvSAD** | 9428.48 (1262.11) | 12295.19 (1228.45) | 13685.71 (1298.70) | 14796.55 (1693.30) | 2.828 (3,60); .046 | - |
| **Phonological Awareness** | 12.176 (0.666) | 9.444 (0.647) | 7.941 (0.666) | 6.333 (0.915) | 11.12 (3,57); <.005 | .036$_{b}$;<.005[c];<.005[e];.024[f] |
| **RAN** | 43.765 (4.861) | 44.444 (4.724) | 63.294 (4.861) | 78.900 (6.338) | 9.156 (3,58); < .005 | <.005[b];<.005[c];.036[d];.031[e] |
| **Digit Span** | 12.235 (.927) | 8.944 (.901) | 7.765 (.927) | 5.222 (1.274) | 7.584 (3,57); <.005 | <.005[c];.006[e] |
| **Bead Threading** | 4.882 (.383) | 4.5 (.372) | 4.471 (.383) | 3.7 (.499) | 1.181 (3,58); .325 | - |
| **Similarities** | 11.111 (.671) | 9.611 (.671) | 8.706 (.69) | 6 (.948) | 6.783 (3,58); .001 | .015[b];<.005[e] |
| **Block Design** | 20.167 (1.7) | 18 (1.7) | 13.235 (1.749) | 17 (2.404) | 2.803 (3.58); .048 | .031[e] |
| **Matrix Reasoning** | 10.389 (.745) | 9 (.745) | 7.529 (.767) | 7.778 (1.054) | 2.766 (3,58); .05 | .047[e] |

**[a]very high vs high, [b]very high vs moderate, [c]very high vs low, [d]high vs moderate, [e]high vs low, [f]moderate vs low**

Box's test of assumption of equality of co-variance matrix is significant, meaning that the co-variance matrices are not equal. Using Wilks's lambda, there was a significant difference between the 'risk' groups on different phonological and cognitive tests. Wilk's $\Lambda = 0.285$, $F(33, 139.175) = 2.239$, $p = 0.001$. The MANOVA was followed up with one-way ANOVAs. See Table 3.5 for the summary.

There were significant differences between LUCID risk groups in DtD First Section Error scores, Phonological Awareness, RAN, Digit Span, Similarities, Block Design and Matrix Reasoning. These significant differences were followed up with Tukey post-hoc tests which revealed that differences between high and low risk groups were the most common. It is acknowledged that this method increases the chance of Type 1 error. However the MANOVA test is robust for type 1 error, despite normality being violated. Conducting multiple ANOVAs does not take into account the dependant variable interrelationships, however the MANOVA conducted proved significant. MANOVA assumes linear relationships among all dependant variables.

A direct discriminant analysis was run to evaluate the LUCID Risk classifications. The three LUCID subtest centile scores were entered as predictors of membership in the four risk groups; low, moderate, high, and very high. Of the original 68 cases, 7 were dropped from analysis due to missing data from the predictors variables. Out of 61 cases, 73.8% of cases were correctly classified. The 'high' risk group prediction was just above chance levels with 56.3% correctly classified, 31.3% of cases are suggested to be reclassified as 'very high' risk. The highest group that was successfully predicted was the 'very high risk' group with 90% of cases successfully predicted, which suggests that these subtests are best at predicting children at a very high risk of dyslexia. The lowest group of successfully predicted cases was the 'high risk' group with only 56.3%. This could suggest that different factors are responsible for differentiating between more extreme and less extreme cases of dyslexia, which supports the theory that there are perhaps different subtypes of dyslexia (Bosse et al., 2007; Lallier & Valdois, 2012).

The finding that Dot-to-dot First Section can significantly differentiate between low and high risk groups as classified by LUCID Rapid confirms the hypothesis that there is a relationship between the DtD task and LUCID Rapid. It also suggests that the DtD task, measuring visual-spatial attention, can differentiate between children at a high and low risk of dyslexia and that visual-spatial attention can significantly add to this prediction. It is unknown whether or not visual-spatial attention is independent of phonological awareness, and thus it cannot be determined whether this research is in keeping with the VA Span hypothesis or the SAS hypothesis (Lallier & Valdois, 2012). However, follow-up research could be conducted to determine this.

Other measures, such as phonological awareness and RAN could significantly differentiate between all four risk groups. This is in keeping with the general understanding of dyslexia, that phonological awareness and processing speed are the best predictors for future reading success (Muter, 2005). Digit span scores also significantly differentiated between the risk groups very high and high, and high and low. This suggests that working memory adds to the prediction of risk of dyslexia, also in keeping with the general understanding of dyslexia. Bead threading scores could not significantly differentiate between groups. This finding is not in keeping with the literature surrounding motor skills and dyslexia, which suggests that this measure can independently add to the prediction of future reading success (Nicolson & Fawcett, 2007).

LUCID sub-tests only accounted for 73.8% of cases, and in the ‘high’ risk group, the classification success was only just above chance. This could also suggest that the LUCID Rapid is perhaps not the most reliable at categorising risk. ESL children were classified as ‘high’ or ‘very high’ risk, which could just reflect their poor English skills, not an underlying deficit in phonological awareness. Previous research suggests that ESL children do ‘catch-up’ to their native peers with time, around 3rd Grade (Lesaux & Siegel, 2003). This suggests that it may be useful to use the DtD on children who have not yet caught up to their peers, where traditional tools such as the LUCID, which, because they rely so heavily on language, have a high rate of false positives. As Lesaux and Siegel (2003) suggest, early identification and intervention is beneficial for ESL children at risk of dyslexia.

## 4. General Discussion

### 4.1 Limitations

This study can be said to have a number of limitations: firstly, the skewed sample in terms of literacy scores and phonological performance; and, secondly, the limitations of the tests and tasks used will be discussed.

#### 4.1.1 Sample Limitations.

The sample used in this study was from a school with a low socioeconomic catchment area (5% of most deprived in Scotland, SIMD Rank, 2012). The National Literacy scores of the children in this study were severely skewed towards the lower end of National Literacy Scores. Histograms (see section 3.0) show that the reading performance for this sample is poor. The P1 Benchmark literacy scores showed a median of 35.5 with a mean score of 43.93. There was a proportion of English (21.1%) as a second language speakers in this sample, which could have affected the data as the LUCID Rapid was administered in English, whenever possible the testing was translated to Polish by the experimenter, Barbara Piotrowska, the main second language minority group in this school. Non-native speakers were not removed from analyses as this study aimed to collect data from a representative sample. Socioeconomic status (SES) was not controlled for to get a broader understanding of reading difficulties and socioeconomic status, and to maintain ecological validity. Many other studies use middle SES and assume that this can be generalised (Duncan & Seymour, 2000). The results could also have reflected the previous finding that low SES groups display a delay in development in comparison with high SES groups. However the two samples ultimately develop in very similar ways (Duncan & Seymour, 2000). This developmental delay could also reflect less exposure to print in books and less experience of reading at home (Siegel & Himel, 1998). 47.7% of children were currently receiving some form of additional support, 7% of the sample were specifically receiving support for speech and language, with 21.1% of the sample receiving two of more support programmes. This could have affected the distribution of the data and thus their scores on cognitive and phonological subtests. However, as with language, this sub-sample was not removed from analyses in order to gain understanding of a representative sample.

This study used young children, who have not yet been diagnosed with dyslexia, thus the LUCID rapid categorisation of risk is purely based on the LUCID scores and no other. Further, as LUCID scores were greatly affected by the non-native speaking children this could have skewed the data. As the sample in this study was an unselected cross-section, a reading-matched control group could not be used as a comparison of scores. The use of age and reading matched groups can be used to establish direction of causality (Bradley & Bryant, 1985 in Bryant, MacLean & Bradley, 1990). However the use of reading and age-matched controls has been criticised as certain conditions must be present before causality can be approached, and event then, causality should be approached very carefully (Shankweiler et al., 1992).

### 4.1.2 Methodological Limitations.

LUCID Rapid can be criticised from a number of perspectives. It can be argued that the phonological subtest ‘rhymes’ to some extent also measures short term and/or long term memory because there are four words to remember. For some younger children, some or all of these words are new to them. Although there are pictures presented, it is not necessarily the case that the picture accurately represents the word enough so as to act as a memory aid. From carrying out the testing, it is evident that the standard instructions were not clear enough, very few of the youngest children (Age 4 years - 5 years 11 months) understood the instructions, and often needed to have them repeated or explained more than once. When LUCID was conducted in Polish, the instructions were repeated in Polish and thus LUCID took longer to administer, which could have affected the child’s attention span and performance, as they had to concentrate for longer. Some parts of LUCID Rapid were entertaining and distracting for children who already had low levels of concentration, which could have affected the data. For example, in the sub-test ‘Zoid’s Friends’, deselecting a friend makes a ‘funny’ noise. LUCID provided positive reinforcement for correct answers during the ‘Rhymes’ task but not for any of the other tasks. For a young child this could significantly affect their engagement with the tasks. Technical issues were encountered. The LUCID programme sometimes froze or quit unexpectedly without saving the data, thus the children were asked to repeat the task, which could have caused learning effects, or the opposite, lack of interest or boredom

The DtD task also had a number of limitations. The DtD software had trouble with freezing and quitting unexpectedly, causing the programme to need restarting, often loosing the data that had previously been acquired. As with the LUCID programme, the children were asked to repeat the trials that were lost, which could have caused learning effects or the opposite, boredom and lack of interest. From administering the tasks, it became apparent that accuracy of the lines created on the DtD task greatly depends on how the child holds the pen and whether their hand or wrist is resting on the tablet. This was corrected as much as possible by the researchers. Some children actively chose to hold the pen in a way that disadvantages their accuracy. A further limitation of the DtD task is that the task always tested the dominant hand first. This was not randomised, therefore further research can investigate the effects of randomising the order, or alternatively the non-dominant hand can be dispensed with altogether in order to make the task shorter.

WISC & WPPSI can also be critiqued for not providing reinforcement to the children throughout the test. Some children became very discouraged without any engagement or reply from the administrator, which could have affected the results due to attention span, or lack of interest.

### 4.2 General Discussion

Overall the DtD can be said to add to the prediction of phonological scores, as evident from the regression analyses. Scores on the DtD task did correlate with other cognitive abilities. The DtD task correlated with cognitive abilities which typically predict later reading success, such as phonological awareness, RAN, and working memory, The DtD did also correlate with tests of verbal comprehension, and perceptual reasoning. That DtD and phonological awareness scores correlate with measures from the Wechsler's range, is not in keeping with a discrepancy definition of dyslexia, and could signal a large proportion of 'garden variety poor readers' in this particular sample. The DtD did not add to prediction of scores on the LUCID measure of phonological awareness when analysed with a regression. The DtD First Section Error measure did significantly differentiate between LUCID risk groups. All findings are generally in keeping with the current understanding of dyslexia. Generally, the DtD can be shown to add prediction to phonological awareness scores. Therefore, this suggests that this task could potentially be used to detect children at risk of developing dyslexia, with more detailed research.

### 4.2.1 IQ-Discrepancy Definition.

There are concerns over using IQ when defining dyslexia or an ability-achievement discrepancy. These are primarily: the conceptual understanding of IQ as a measure, the use of the group 'garden variety poor readers' and evidence supporting the nature of reading problems in these two groups, and the impact this has on interventions for dyslexics. There is considerable debate surrounding the idea that IQ measures learning aptitude, or innate ability, an idea upon which the discrepancy definition is founded. This assumes that there is a maximum level of performance at which children are capable in relation to age. Evidence suggests that IQ is not a pure measure of innate ability and often reflects both genetic influences and nutritional and environmental factors (Siegel & Himel, 1998; Rutter & Yule, 1975). It can be argued that dyslexia classification may depend on socioeconomic status (SES) (Siegel & Himel, 1998). They argue that children from lower SES background are less likely to be exposed to environmental experiences that result in higher IQ scores, despite not being able to draw causal conclusions. Rutter and Yule argue that this concept, in practice is invalid, and IQ should not be used due to the confounding with SES (1975; Siegel & Himel, 1998).

> *"There is no logically or empirically interpretable sense in which we can say that low intelligence (intelligence being a panoply of cognitive processes) causes poor reading."*
>
> (Stanovich, 1996, pg 155)

Siegel and Himel advocate for the use of detailed analyses of reading, writing, spelling, and arithmetic skills to replace the use of IQ, in order to help all children achieve their potential in reading. The IQ discrepancy definition rests on the assumption that the causes of reading problems are not similar in dyslexics and 'garden-variety poor readers', and subsequent interventions.

There is both evidence for and evidence against the notion that dyslexics significantly differ from poor readers. Share argues that these assumptions have largely remained untested, perhaps due to the influence of the idea that IQ measures a somewhat fixed capacity to learn (1996; Stanovich, 1991). Siegel & Himel (1998) argue that studies of reading disabled individuals have found no difference between dyslexics and poor readers (Wolf, 1999; Stanovich & Siegel, 1994). What proportion of the children in this sample are dyslexia and how are these children different from 'garden variety poor readers'? Stanovich (1988) would argue that both groups present with a phonological deficit but that ‘garden variety poor readers’ have more generalised deficits in vocabulary, memory and general knowledge, which may play a causal role in their reading difficulties. Stanovich argues that the superior cognitive status of the IQ discrepant poor readers enables them to compensate for poor word recognition so that differences should be apparent in reading comprehension when the two groups are matched for word recognition. However, Share (1996) questions the idea that these two groups really have differing causes and nature of reading problems. Share finds evidence against the notion that there are no qualitative differences in the nature of reading between specific when compared with non-specific reading disability.

The IQ-discrepancy definition has significant consequences for interventions for children who have difficulty reading. Rooted in the discrepancy definition is the view that reading failure in low IQ children can be explained solely by limited capacity (Stanovich, 1996), and that these children were thus considered ‘irremediable’ (Rutter & Yule, 1997). Poor readers with average or above normal IQ, on the other hand, are seen as not living up to their potential, and that there is another cause of their reading difficulties (Stanovich, 1996). The type of help a child receives will depend on their IQ. Children who score higher are more likely to receive the intervention they need (Siegel & Himel, 1998). Both groups however require additional support in order to achieve academic success. Through further research, it can be determined whether ‘garden variety poor readers’ and dyslexics differ significantly in performance and the cause of reading disorder.

Prevalence of ‘garden variety poor readers’ varies with samples. The implications of this need to be taking into consideration, especially for interventions. For the sample in this study, it is likely that there is a high proportion of ‘garden-variety poor readers’. Further research could look at creating these groups through the use of a Full Scale IQ test. However, the efficacy of the use of this differentiation can be questioned, as there is varying evidence as to whether these two groups differ significantly. Further research is required firstly to pinpoint a cause of dyslexia, and secondly, whether dyslexics are significantly different than ‘garden variety poor readers’.

### 4.2.2 Ecological Validity.

This study can be seen as an ecologically valid study in that the sample was an unselected cross-section of children at a school. This research will be followed up as part of longitudinal research, thus a longitudinal, unselected cross-section of data will be gathered from children, not only from this school, but other schools from a range of socio-economic catchment areas. In-depth research in dyslexia has previously been rare but is increasing in popularity (White et al., 2006; Ramus et al., 2003). With a longitudinal study, children at a pre-reading age can be tested for an array of cognitive tests and followed up over the years, to determine the main predictors of reading success and failure, and ultimately, causal relationships.

## 4.3 Future Research & Implications

The measures from the DtD that provided the most robust correlations to measures typically thought to relate to reading skills (e.g. phonological skills, working memory, RAN) are First Section Error and Average SAD. Therefore these measures should be followed up more vigorously to determine their predictability of dyslexia. First Section Error showed as being one of the more confident measures. This could be due being able to judge the initial angle of the line and rapidly correcting this. This possibly is due to the motor learning or perceptual novel problem solving aspect of the task. In order to gain a more in-depth understanding of the mechanisms behind the task, and the extent to which the DtD specifically measures visual-spatial attention, the task should be compared to other specific tasks that measure visual-spatial attention (e.g. visual search tasks).

Future research could also look at improving the DtD task in order to make it more efficient. One possible improvement for the task could be removing the Non-dominant hand and only collecting data from the dominant hand. The non-dominant hand correlated less with cognitive measures. This would make the task much quicker and could improve concentration on the task, especially in very young children, who demonstrate higher levels of distractibility. Also it could be easier to administer for children who also suffer from Attention-Deficit-Hyperactivity-Disorder and other co-morbidities. Alternatively, future research could investigate the effect of randomising the dominant and non-dominant order of the task to see if this has an effect on the DtD correlating with cognitive measures.

Future research can look into comparing low socio-economic areas with middle and high socio-economic areas to get a spread of data and to see how socio-economic status might affect scores on the Dot-to-Dot task. In order to test the IQ-discrepancy definition and the DtD task, further research could be undertaken using a measure of full scale IQ and comparing this to reading performance. This could be one method to successfully differentiate 'garden variety poor readers' from dyslexics. As the scope and duration of this study was limited to just under a year, an avenue for future research will be to follow up with these children yearly and map their progress and their scores on DtD (i) to test the predictive validity of the DtD task, (ii) to see whether this task can predict future reading success, (iii) to see how many children ultimately are formally diagnosed with dyslexia. This research is part of a longitudinal project to see if the DtD task can successfully discriminate between children with and without dyslexia. This project will also collect data from other schools in varying socioeconomic catchment areas. Before longitudinal research has been carried out, findings cannot be generalised to a wider sample.

## 5. Conclusion

This study has provided evidence which suggests that a visual-motor task is correlated to and can predict scores on a phonological awareness task. The novel task, the dot-to-dot, is related to a standard dyslexia screening tool and can significantly differentiate between ‘high’ and ‘low’ risk groups. These results are in keeping with previous research that suggests that visual-sensorimotor tasks add to the prediction of future reading success. Future testing is required before the dot-to-dot task can be used for identifying children that might be at risk of developing dyslexia. A key issue in dyslexia research rests on determining a cause and effect relationship for establishing the origins of this reading disability. Further research is needed to determine whether a sensorimotor deficit is causally linked to dyslexia or merely correlated. If sensorimotor deficits are causally linked to dyslexia, and previous research has shown that these skills develop prior to formal language abilities (Franceschini et al., 2012), then a sensorimotor task will be useful for identifying children before they fail to learn to read.

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