ANGLIA RUSKIN UNIVERSITY

VISUAL INSPECTION TIME
AND SPECIFIC LEARNING DIFFERENCES

ANTONIA MARGARET JOHNSON

A thesis in partial fulfilment of the

requirements of Anglia Ruskin University

for the degree of Doctor of Philosophy

Submitted: 14.06.2019

Acknowledgements

My thanks go to all participants who so generously gave their time. In the early days of deciding on a way to investigate so-called *processing speed* in specific learning differences, the advice from my initial, first supervisor, Dr Peter Hills, was incisive and for that and for your patient, skilled supervision, Peter, I thank you. Dr Ruth Ford, who gamely took on the role after Peter, has been a gentle, clear thinking and patient first supervisor, so Ruth, thank you for your encouragement, shared knowledge and thoughtfulness. Dr Steven Stagg has had, in his role as second supervisor, provided key insights, thank you, Steven for helping me. Without the assistance of Dr Ian van der Linde, my third supervisor, this project would have foundered early on. Your computer wizardry, and sound advice, Ian, has been exceptional. Thank you so much. Finally, I want to thank my family. As always, you have been a joy, accepting my endeavours, always supportive in good measure, and more. Alice, Ben, Brendan, Bryony, Eddie, Emmett, Eti, Harris, Johnny, JoJo, Mil, Paula and Tom you make everything worthwhile.

ANGLIA RUSKIN UNIVERSITY

ABSTRACT

FACULTY OF SCIENCE AND TECHNOLOGY

DOCTOR OF PHILOSPHY

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ANTONIA MARGARET JOHNSON

JUNE 2019

Inspection time (Vickers, Nettelbeck & Willson, 1972), widely believed to evaluate processing speed (e.g., Anderson, 2008), is the time needed to discriminate between mirrored backward masked stimuli. Most children with developmental dyslexia have typical inspection times (e.g., McLean, Stuart, Coltheart & Castles, 2011), whereas in children with developmental coordination disorder (DCD) inspection times are atypically long (Piek, Dyck, Francis & Conwell, 2007). To date, there have been no comparative studies of inspection time or the shared variance between inspection time and other chronometric, psychometric or attainment measures in adults with these specific learning differences (SpLDs).

In the current investigation, the first aim was to compare inspection times in groups of adults: with typical development, dyslexia, DCD and co-occurring dyslexia/DCD. Participants (*N* = 141) completed inspection time tasks with standard, pi-figure stimuli and un-speeded versus speeded responses; and non-standard stimuli of left/right versus up/down discrimination. The second aim was to illuminate the nature of inspection time by exploring its relationships with alternative measures of information processing speed, namely, symbol-digit coding and decision time, as well as IQ, working memory, visual discomfort, and literacy attainment.

Results showed that standard inspection time was significantly longer than typical only in the group with dyslexia/DCD with this group difference remaining reliable after controlling for IQ, working memory and visual discomfort. In contrast, all the SpLD groups were slower than typical on inspection time from the non-standard stimuli, the symbol-digit coding test of processing speed and choice decision time. Whether the responses were speeded or un-speeded, or whether non-standard stimuli required and left-right or up-down discrimination, did not affect inspection time in any group but there was more variability between tests in the SpLD groups. All measures of processing speed shared significant variance with visual discomfort and, after controlling for group, there remained significant shared variance between standard and non-standard inspection time and visuospatial working memory.

Conclusions were that (1) among adults with dyslexia, DCD or both, slow standard inspection time is characteristic only of co-occurring dyslexia/DCD, not dyslexia or DCD alone, and (2) in diagnostic assessment, standard inspection time may be a more specific measure of processing speed than either symbol-digit coding or decision time.

Key-words: inspection time; developmental coordination disorder; dyslexia.

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Abbreviations and Symbols

2AFC	2 alternative forced choice
ADHD	attention deficit hyperactivity disorder
ASD	autistic spectrum disorder
b	regression coefficient
β	standardised *b* or bias in signal detection theory
BMP	bitmap
BRAT	Barrett algorithm, for measuring inspection time in three phases of a step-wise reduction in stimulus onset asynchrony
C	criterion level from signal detection theory
CDS	correct decision speed
CDT	choice decision time
CHC	Cattell-Horn-Carroll
CI	confidence interval
CRT	choice reaction time; cathode ray tube
CSOA	critical stimulus onset asynchrony
DAMP	disorder of attention, motor control and perception
DD	developmental dyslexia
DSM-5	Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition. Edited by American Psychiatric Association, 2013
DT	decision time
DCD	developmental coordination disorder
DPI	dots per inch
ECT	elementary cognitive task
EEG	electroencephalogram
ERP	event related potential
fMRI	functional magnetic resonance imaging

g	general intellect , the third order factor in the Cattell-Horn-Carroll theory of human abilities
Gc	crystallised intelligence, second order factor, Cattell-Horn-Carroll theory
Gf	fluid intelligence, second order factor in the Cattell-Horn-Carroll theory
Gs	speed assessed by pencil and paper tasks, second order factor in the Cattell-Horn-Carroll theory
Gt	speed assessed by elementary cognitive tasks reacting to stimuli, second order factor in the Cattell-Horn-Carroll theory
IT	inspection time
IQ	intelligence quotient
IQR	inter-quartile rnage
ITSD	inspection time standard deviation
I	stimulus light intensity
in.	inch
kb	kilobytes
LI	language impairment
LED	light emitting diode
LGN	lateral geniculate nucleus
ms	milliseconds (0.001 second)
M	magnocellular system
MA	mental age, mental ability
MABC	Movement Assessment Battery for Children
MATLAB	matrix laboratory
MEG	magnetoencephalography
MIS	Meares-Irlen Syndrome
MSa/S	mega-samples per second
MT	movement time

mv	millivolt
N	negative (in EEG)
N	noise (in signal detection theory)
NS	signal + noise (in signal detection theory)
P	parvocellular system
P	positive (in EEG)
p	probability
PCA	principal components analysis
PDD	pervasive development disorder
PGT	Pattern Glare Test (Wilkins & Evans, 2001)
PS	processing speed
PTB-3	Psychophysics Toolbox
r	coefficient of correlation Pearson's Product Moment Correlation
r_s	coefficient of correlation Spearman's coefficient of correlation, *rho*
R_{pb}	point biserial correlation coefficient
R	photochemical response in photo receptors, product of stimulus light intensity (I) and time (T; Bloch's Law).
R^2	coefficient of determination; the shared variance between a dependent and independent variable.
ΔR^2	change in R^2
RAN	rapid automatic naming
rate	number of items/time
RCPM	Raven's Coloured Progressive Matrices
RD	reading disability (disabled)
RELD	receptive and expressive language disorder
RGB	red: green: blue
RSPM	Raven's Standard Progressive Matrices

RT	reaction time
RTSD	reaction time standard deviation
SD	standard deviation
SD	secure digital
SDT	simple decision time
SLD	speech and language disorders
SLI	specific language impairment
SOA	stimulus onset asynchrony
speed	distance travelled/time
SpLD	specific learning difference
SPSS	Statistical Package for the Social Sciences
SRT	simple reaction time
STM	short-term memory
s	second
s	standard deviation of a sample
τb	Kendall's *tau-b*
T	duration of stimulus exposure
VBL	vertical blank
SVGA	super video graphics array
VDS	Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999)
WAIS	Wechsler Adult Intelligence Scale
WISC-III	Wechsler Intelligence Scale for Children; 3rd Edition
z	z-score (standard score for a sample)

Note. Abbreviations and definitions for chronometric variables follow Jensen (2006).

Symbols

λ	lambda, inspection time
η^2	eta squared for calculating effect size in ANOVA

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Copyright Declaration

CHAPTER 1

Introduction: Assessment of Specific Learning Differences and Processing Speed

Developmental dyslexia (hereafter referred to as *dyslexia;* e.g., Rose, 2009) affects the acquisition of literacy skills and developmental coordination disorder (DCD; commonly known as *dyspraxia;* American Psychiatric Association, 2013) affects the coordination of movements. Dyslexia sometimes co-occurs, in the same individual, with DCD and Meares-Irlen Syndrome (MIS; i.e., visual stress; Wilkins, 1995, 2016). A collective term for these neurodevelopmental differences and others beyond the scope of this thesis is *specific learning differences, difficulties, disabilities* or *disorders* (SpLDs).

1.1. Assessment of Specific Learning Differences

Individuals with SpLDs might have a diagnostic psychometric assessment to help them understand their differences compared to typical development (e.g., R. Kaplan & Saccuzzo, 2017). Such assessments show how their responses to diverse intelligence and cognitive psychometric tests relate to their performance in education and at work. Effective assessments are those that guide the provision of successful individual supportive intervention. Best would be if they contained tests that distinguished between aspects of SpLDs so that an “optimal educational plan” (Everatt & Reid, 2009, p. 10) can be constructed. Among commonly used assessment procedures are those that evaluate processing speed (e.g., Jones & Kindersley, 2017). There are reports of slow processing speed in individuals with DCD (e.g., Wilson & McKenzie, 1998), dyslexia (e.g., Beidas, Khateb & Breznitz, 2013) and MIS (Conlon, Lovegrove, Chekaluk & Pattison 1999). Effects of slow processing speed are unclear so it is difficult for educationalists to address consequent difficulties. Currently, a diagnostic assessment that reports on processing speed may not meet Everatt and Reid's (2009) requirements noted earlier to help distinguish between SpLDs and create an optimum plan.

1.1.1. Processing speed and its assessment. Stimuli from the physical environment act on our senses to initiate a course of action: *processing information* (e.g., G. A. Miller, 1956). A mental representation or process in the brain is evoked that may be encoded in short-term memory, or be related to information retrieved from memory (Buxbaum, 2016; Wood & Grafman, 2003). Decisions and responses follow. *Information processing speed* describes the speed of these cognitive processes (e.g., Posthuma & de Geus, 2008) but this is not easy to *index*, a term used to describe a process measured in order to make assumptions about another process, one or two steps removed. Kail (2000) suggested that information processing speed is an expression of a *global* biological mechanism. In contrast, some recognise processing speed as multi-faceted with specialisations in different parts of the brain (e.g., Danthiir, Wilhem & Roberts, 2012; McFarland, 2017). Terminology is confusing. Cepeda, Blackwell and Munakata (2013) even suggested that diverse, confusing terminology provides an argument for a multi-faceted mechanism for speed of processing. One might imagine that global biological mechanisms could limit information processing speed (Kail, 2000) but a global limiting *property* (McFarland, 2017, p. 354) does not preclude specific intra-individual, strengths and weaknesses in speed or efficiency of processes. This distinction between global and specific processes may be important when assessors wish to identify a specific weakness during psychometric assessment for SpLDs.

Tests of processing speed “assess how efficiently people can complete mental tasks that, if there were no time pressure, would rarely be answered incorrectly.” (Deary & Ritchie, 2016, p. 28). A fundamental requirement is for the task to be simple, overlearned and automatic to avoid problems that arise from higher-level processes that require conscious thought. Nevertheless, Stankov and Roberts (1997) suspected that timing gives an attractive dependent variable for an activity that may not have been suitably elementary to measure processing speed, for example handwriting tasks (e.g., R. Kaplan & Saccuzzo, 2017). Automaticity may utilise basal ganglia whereas tasks with greater complexity may require top-down prefrontal, or executive, control (Buschman & Miller, 2014, for a review). The decision about whether a task uses executive processes or is automatic is not straightforward. For example, level of education may influence automatic processes. Tests of processing speed that use identification of letters may not be automatic in new readers or in people with reading disabilities. Automatic processes for one individual or age group may not be automatic for another, particularly for very young or older people or those with marked cognitive differences. In recognition of this problem, Carroll distinguished “speed-of-performance” from “level-of-mastery” (Carroll, 1993, p. 440). Cepeda et al. (2013) explored automaticity and the contribution of executive control in a variety of tests of processing speed. They concluded that evaluations of processing speed largely correlate with tests of executive control and for more complex measures of processing speed, such as addition and subtraction, are virtually interchangeable with those of executive control, particularly in children and older adults.

Furthermore, similar functions do not necessarily describe the same neural pathways in different individuals. Circuitous, and hence slower, routes may be necessary in some individuals for particular tasks (Ball & Vance, 2008; Denckla, 1993). Specific abilities that support performance on different processing speed tasks probably develop and decline at different rates. Different groups of younger and older participants may employ different strategies for the same test (Geary & Wiley, 1991).

Development of additional aspects of cognitive processing, such as working memory, may influence age related changes in speed of processing (e.g., Anderson, Nettelbeck & Barlow, 1997). Patterns of changes in processing speed may be from developing, then aging, neurophysiological infrastructure but for example, speed of processing tasks with a verbal component have less age related decline than tasks with a spatial component (Salthouse, 2000). Consequent to unclear definitions, Deary (2001, p. 59) has challenged *processing speed* to be as a “quack-construct”. Nevertheless, during SpLD assessment, assessors continue to measure and report *processing speed*.

For example, the SpLD Assessment Standards Committee (SASC; 2016) regulates standards for assessors of students who are applying for a UK Government grant, the Disabled Student’s Allowance. SASC recommends a variety of paper-and-pencil tests as “Suitable” for “Speed of Processing” (SpLD Assessment Standards Committee, 2016, p. 40). They include rapid automatic naming (RAN) subtests of Comprehensive Test of Phonological Processing (CTOPP-2; Wagner, Torgesen, Rashotte & Pearson, 2013) and Detailed Assessment of Handwriting (DASH 17+; Barnett, Henderson, Scheib & Schulz, 2010). Also considered suitable are Symbol Digit Modalities Test (SDMT; Smith, 1982), a coding test in which symbols are quickly converted to digits; and Processing Speed Index which consists of digit symbol coding and symbol-search from Wechsler Adult Intelligence Scale Fourth UK Edition (WAIS-IVUK; Wechsler, 2010). In digit symbol coding, the person must convert digits to symbols as quickly as possible and for symbol-search, identify certain symbols from among others, in rows.

Another complication, processing speed also contributes to the assessment of intelligence (Appendix A). One definition of intelligence is of individual variation in mental competence (Hunt, 2005). The Processing Speed Index indexes Broad Cognitive Speediness (Gs), a second-order, group-level factor in the Cattell-Horn-Carroll (CHC) model of human cognitive abilities (Carroll, 1993). This hierarchical model, formed from Carroll’s analysis of 460 sets of data and composed of three tiers, provides a useful framework, used in this thesis. There are other models (e.g., W. Johnson & Bouchard, 2005). Constantly under revision, the CHC model has first order narrow cognitive abilities, often related to specific tests. It has second-order factors, each with its own set of first order factors. Second order factors are: Gf, fluid intelligence; Gc, crystallised intelligence; Gy, general memory and learning; Gv, broad visual perception; Gu, broad auditory perception; Gr, broad retrieval ability; and of particular interest, Gt and Gs. Gt, comprised of reaction time (RT) and decision speed, the time taken to make a decision or react to very simple stimuli presented singly, Gs as the fluency and speed at which easy, recurring cognitive tasks are accomplished. There is also Gps, psychomotor speed, which is speed and fluency of physical body movements (Carroll, 1976; Schneider & McGrew, 2012), which includes handwriting. Spearman (1904; 1927) proposed a *g factor*, equivalent to the third tier in the CHC model. Jensen (2005) described the g factor as “an aspect of individual differences that causes positive correlations between virtually all measurable cognitive abilities” (Jensen, 2005, p. 34): a *positive manifold*.

An example of positive manifold may be found in Deary’s (2000, p. 7) correlation matrix of 11 subtests of the Revised Wechsler Adult Intelligence Scale (WAIS-R; Wechsler, 1981) from a sample of the Scottish population. In the correlation matrix, there are significant, although far from perfect, positive correlations between the subtests. However, digit symbol, which is a test that contributes to the Processing Speed Index, correlates least strongly of any subtest to any other subtest in this Scottish sample. All digit symbols’ correlations with other subtests are between *r* (unpublished) = 0.25–0.36, compared to the other correlations in the matrix, which extend to *r* (unpublished) = 0.72. If this Scottish sample is representative of other populations, one could expect some individuals from any population to have average performance in some areas of intelligence, yet relatively slow or fast processing speed. Case History 1 (Appendix B) confirms and illustrates this expectation. This case history describes a young woman from East Anglia, KK, who had an assessment for

SpLD before going to university. Her profile is *spiky,* which is a characteristic feature of SpLDs. A spiky profile is one that has disparate standardised test scores. Although she has, among other attributes, average visual and verbal intelligence, assessed by visual and verbal puzzles from the Wide Range Intelligence Test (WRIT; Glutting, Adams & Sheslow, 2000), she has slow processing speed, evaluated by the SDMT. SDMT is not part of a standardised intelligence test, although it is similar to the coding test. That individuals can be, as is KK, selectively weak in one or more areas, in this case processing speed, contributes to lower correlations seen between the speed of processing subtest and the other subtests that assess intelligence in the example of the Scottish population sample. Thus, importantly, not all people with slow processing speed necessarily have weak intelligence overall.

Evidence for specific weaknesses in people with various SpLDs may come from processing speed test results from paper-and-pencil tests like the SDMT or the digit symbol. One might suppose that specific cognitive and motor abilities such as to: manipulate a pencil; visually track from the key with symbols and numbers to a grid to record them; evaluate or remember the shapes of the symbols; quickly manage serial tasks, or some other specific skill(s) influence performance on a digit symbol test. Slow processing speed as measured by paper-and-pencil tests may therefore have different aetiologies in different people and different SpLDs. Thus, paper-and-pencil tests of processing speed appear to be a blunt instrument. These tests provide scant in-depth illumination of the speed and efficiency of diverse, complex, cognitive and underlying neurophysiological processes that may be, or may not be, compromised specifically in people with SpLDs. They may be inadequate for the purpose of individual psychological diagnostic assessment or, importantly, to make recommendations for targeted intervention and effective management of SpLDs. An assessor may not be able to distinguish the underlying cause(s) of a weak result for a paper-and-pencil test, such as a coding test. As suggested by Demaree, Frazier and Johnson (2008), varied and specific tests of so-called processing speed need to reveal more closely functional outcomes from different neurological and psychological processes. They need to show which aspect is slow, or fast, and how these aspects relate to the development and execution of various skills in individuals. This would help clinicians to diagnose and teachers to design educational interventions that could relate to specific areas of weakness, such as reading or writing.

1.1.2. Elementary cognitive tasks. So-called *elementary* cognitive or chronometric tasks (ECTs), for example for RT, classed as Gt in the CHC model, are simpler than paper-and-pencil tests of speed. Performances for ECTs are calculated from repeated single trials each lasting milliseconds. Standardised ECTs and their implications are not yet readily available to assessors beyond the laboratory. Possibly the simplest ECT is the psychophysical test which measures inspection time (Vickers, Nettelbeck & Willson, 1972). Inspection time has been widely used by experimental psychologists to evaluate so-called *processing speed* (Nettelbeck, 2011; 2014). Crucially, inspection time trials exclude time for motor processes because the dependent variable is the duration of the stimulus image; it is not motor response time. Thus, inspection time assesses non-motor aspects of information processing speed. Inspection time has advantages over paper-and-pencil tests since these all employ motor skills. Such methodology obscures a distinction between efferent and input or cognitive processing stages of information processing, which may vary between SpLDs. Furthermore, inspection time does not rely on language, which could impinge on processing speed assessment in dyslexia. Inspection time is culture free.

1.2. The Present Investigation. In view of advantages that are offered by inspection time, this work set out to explore the value of inspection time as a more specific test of processing speed in the SpLDs of dyslexia and DCD than other ECTs or paper-and-pencil tests. Specifically, it was of interest to discover if standard inspection times are longer in groups of participants with certain SpLDs than in participants who are typically developing and if they are, whether this implies that inspection time could be used in the assessment of SpLDs or to help design appropriate intervention.

Chapters 2 and 3 contain reviews of inspection time and SpLDs, respectively. After these reviews, it became apparent that an investigation of inspection time in SpLDs might also shed light on the validity of the inspection time task as a test of processing speed. At the end of Chapter 3 is a full set of aims and hypotheses and a guide to the experimental work that forms the remaining chapters.

Throughout, dyslexia refers to developmental dyslexia—as opposed to dyslexia acquired from a neurological assault on a typically developing brain. The term inspection time refers to the metric obtained from the measurement of visual inspection time from a *two alternative forced choice* (2AFC; Macmillan & Creelman, 2004) inspection time test. Although auditory inspection time tasks have been devised (e.g., Deary, Caryl, Egan & Wight 1989), most research to date has been on visual inspection time. (Hereafter, *inspection time* refers to *visual inspection time)*. Gender refers to biological sex.

CHAPTER 2

Inspection Time

This chapter is about inspection time, its measurement; its psychophysical and physiological processes; psychometrics; and effects of gender, development and education. Inspection time has been reviewed by Deary (2000; 2001), Jensen (2006), Mackintosh (2011) and Nettelbeck (2011; 2014).

Gescheider (1997, p. ix) carefully described inspection time as a measure of "the relation between stimulus and sensation" and Schneider and McGrew (2012, p. 121) described it as "The speed at which differences in stimuli can be perceived." Nevertheless, inspection time has wide interpretation as "… one of the best current measures of speed of processing…" (Anderson, 2008, p. 123). This definition features in much of the literature on inspection time (e.g., Deary & Ritchie, 2016). Sometimes there is reference to *efficiency*, for example, "…efficiency of visual information processing…an assessment of central information processing speed." (Scotland, Whittle & Deary, 2012, p. 360). The inspection time task has already been proposed as a tool for assessing patients with Alzheimer's Disease (Gregory, Nettelbeck & Wilson, 2009; Nathan & Stough, 2001), Parkinson's Disease (A. M. Johnson et al., 2004) and depression (Tsourtos, Thompson & Stough, 2002).

2.1. Measurement

Simply, inspection time is an estimate in milliseconds of the time a person takes to identify a stimulus image before a mask image obscures it (Figure 1). It uses the procedure known as *two alternative forced choice* (2AFC), which reflects the fact that participants must select from between two response options. Fundamental requirements for the original inspection time test (Vickers et al., 1972) are that (a) given sufficient time, the majority of participants can decide which image was shown before it was masked and (b) response time is not the dependent variable. Unusually, results of the inspection time task align closely to Gs (e.g., N. R. Burns & Nettelbeck, 2003; Nettelbeck, 2011).

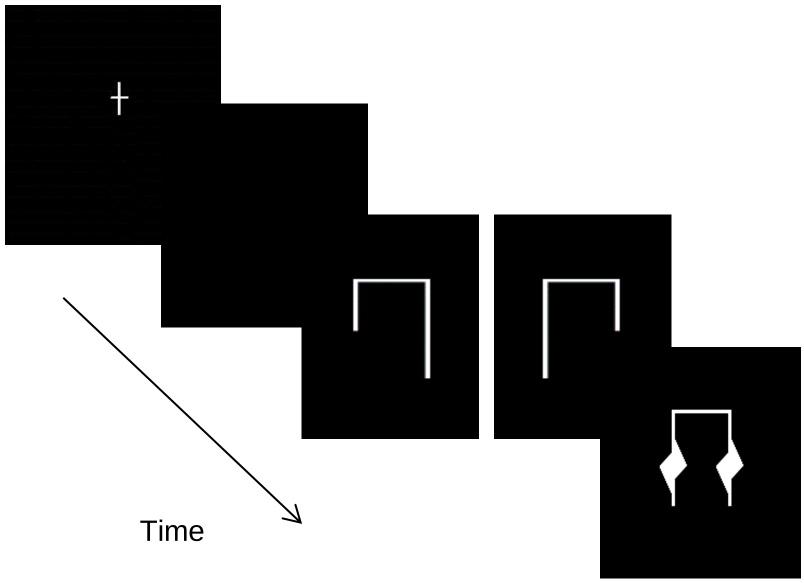


Figure 1. Inspection time task: locating cross, standard left/right mirrored pi-figure stimuli and a flash mask. *Note*. One pi-figure appears for each trial.

2.1.1. The standard method. In the standard method, each of several trials starts with the presentation of an attentional stimulus on a computer screen. After a blank interval, one, of two, left/right mirrored, two dimensional, pi-figures, white on a black background, chosen at random, is displayed for a variable number of milliseconds. Pi-figures have one vertical limb about half the length of the other. The participant identifies whether the short, or long, limb of the pi-figure was to left or right.

Immediately afterwards, a visual mask, that covers a greater area, physically replaces the pi-figure stimulus. The time between the start of the target and start of the mask is the *stimulus onset asynchrony* (SOA). SOAs range between sometimes less than ten to more than a hundred milliseconds. Without the mask, visible persistence, which is an after-image of the target stimulus (Coltheart, 1980), would extend the intended SOA.

For each trial at different SOAs, participants make a response, recorded as correct or incorrect when they press, in their own time, a left or right button on a response device. Then, the next trial starts and so the sequence repeats, trial after trial. Methods to vary the SOA are (a) *of constant stimuli* in which there is a prearranged selection of SOAs and (b) *of limits,* in which correct or incorrect responses prompt the reduction or increase in SOA (Gescheider, 1997, for a review). Reliability relates to the number of trials. Stimulus duration from many trials plotted on a graph against percent correct responses, typically produces a smooth sigmoid curve, or *ogive*. In Vickers et al.'s (1972) original test, inspection time was an estimate from this *psychometric function* obtained from the method of constant stimuli. Inspection time was the minimum time, lambda, λ, or *critical* SOA (CSOA), to give the sensory input required to make a correct decision about the stimulus for 97.5% of the trials. Now, halfway between guessing (50% correct) and total accuracy (100%), that is, 75% of the trials, is chosen, more commonly, as inspection time (e.g., M. White, 1996). This critical threshold reflects the time needed to identify the stimulus correctly and it is not sharply defined. According to classical threshold theory, the successive thresholds, tapped by successive trials, distribute normally around a notional mean threshold (Gescheider, 1997). A steep slope on a psychometric function indicates less variation in the response distribution than a shallow slope. Vickers et al. (1972) emphasised the importance of SOA variation, "the standard deviation of the best fitting normal ogive, …" (p. 263). They proposed that inspection time standard deviation (ITSD) indexes *noise* that could be from external variations in the stimulus and individually variable internal activity (e.g., Jensen, 2006). Regardless of origin, noise accompanies fluctuations in successive nerve cell firing that contribute to the normal distribution of inspection times around a mean value. Both inspection time and ITSD could be important for the assessment of specific learning differences (SpLDs).

2.1.2. Variability in method. Types of hardware, software and precise psychophysical methodology to obtain the CSOA: participant readiness; stimulus and mask types; response collection, and feedback for inspection time vary considerably in the 650 studies published since 1972 (search terms, Google Scholar, March, 2018, "*inspection time*", "*psychophysics*", "*ms*"; Appendix C). Procedural differences may affect validity or cause marked effects on inspection time values or both (e.g., Nettelbeck, 2011). Without standardisation, direct numerical comparisons between studies may not be valid or reliable. To use inspection time or ITSD in diagnostic assessment, standardised normative values, hardware and software would be necessary.

2.2. Physiology and Psychophysics

Vickers et al. (1972) believed that the inspection time task assessed the speed and accuracy of visual information processing. In their original work, they were mindful of quantal accumulator theories of perception. Thomson (1920) had proposed that units of information would accumulate in a short-term store or "urn" (p. 305). For a two-choice decision about the pi-stimulus, Vickers et al. (1972) suggested that eventually, after a critical duration, enough evidence had accumulated to make a decision about which stimulus had been seen. Noise in the system would influence the accumulation of information and, after signal detection theory a predetermined criterion (C), set by the participant, would affect the accuracy of response choice (Tanner & Swets, 1954). A low value of C allows more errors; less caution gives a less precise, more variable psychometric function. This original sampling theory assumed that inspection time depends upon post-sensory processing. One could theorise that these proposed post-sensory processes could limit visual processing speed, which may or may not reflect a global limiting mechanism for speed of all processes. In some people with SpLDs, weaknesses could be limited to post-sensory processes for visual processing speed or, even more specifically, just for inspection time. However, M. White (1993, for a review), particularly influenced by an evaluation of the masking procedure, argued that inspection time reflects sensory processes in the eyes and some early visual pathways.

2.2.1. Sensory processes. Sensory processes start with an image of the pi-stimulus falling on photosensitive cells in the retina. A photochemical response in various retinal photoreceptors is the product of exposure duration and light intensity. According to Bloch's Law (e.g., Scharnowski, Hermens & Herzog, 2007, for a review), temporal summation of light energy occurs during the first few hundred milliseconds. Bloch's Law applies because the SOA between pi-stimulus image and mask is mostly considerably less than 150 ms. As light intensity of the white pi-stimulus is constant, the photochemical response is directly proportional to duration of exposure. A critical level of photochemical response generates action potentials. Therefore, duration of exposure of the image controls this initial generation of action potentials. Appraisal of the pi-stimulus may depend on this critical level, which, although indexed by time, one can interpret as sensitivity (Hecker & Mapperson, 1996).

Importantly, this appraisal occurs within the period of one fixation between saccades. *Fixation* describes the state of the eyes when they train upon a stationary object and it must be efficient to evaluate a brief stimulus image. Fixation is a process that at once excludes saccades but includes microsaccades, controlled by the superior colliculus (Martinez-Conde, Macknik, Troncoso & Hubel, 2009, for a review). Microsaccades control visual processing, particularly after brief exposure to a visual stimulus, (Krauzlis, Goffart & Hafed, 2017), such as an inspection time stimulus. Target visibility in a fixation increases with increased number of microsaccades. It is not impossible that the activity of microsaccades affects temporal summation and in some instances could affect inspection time. Thus, one possible source of individual differences and individual variability in inspection time could arise from subtle changes of energy accumulation in photoreceptors in the retina, necessary to generate action potentials and transmit signals about the target stimulus. This peripheral aspect of individual differences in inspection time has hitherto been disregarded in the inspection time literature, as far as is known.

At least 17 categories of ganglion cells in the primate retina transmit information, for example about size and colour of the image, by action potentials from retinal photoreceptors and bipolar cells. These form pathways in the optic nerve, seven of which synapse in the lateral geniculate nucleus (LGN) of the thalamus. The LGN extends to the primary visual cortex (V1 Brodmann area 17) in the occipital lobe. Parallel pathways from the retina chiefly comprise magnocellular (M), parvocellular (P) and koniocellular systems, although this is an oversimplification (Field & Chichilnisky, 2007). Despite evidence that has emerged for more complex processes than simply M and P pathways, inspection time efficiency has been linked to the M system (e.g., McLean, Stuart, Coltheart & Castles, 2011). The M system, implicated in dyslexia (e.g., Stein, 2012), has high temporal resolution from cells that manage transient stimuli and it controls eye movements. The P system, believed to transmit colour and detail of objects, could also influence inspection time, but by how much is unknown.

After a critical point and subsequent generation of signals, individual differences in inspection time may also depend on nerve conduction velocity (NCV). Increased action potential firing rate does not necessarily equate to faster conduction along the nerve fibre. An important variable that governs NCV is the status of neurotransmitters at synapses. Acetylcholine performance in the cholinergic system underpins attentional processes (Soreq, 2015) and nicotine positively affects it. Nicotine has an enhancing effect on inspection time and conversely, when nicotine receptors are blocked there is a negative effect on inspection time (Parikh & Sarter, 2008; Stough, Thompson, Bates & Nathan, 2001, for a review). This suggests that acetylcholine is important for processes of inspection time. Conversely, neurotransmitters serotonin, noradrenaline and dopamine were not associated with inspection time levels (Nathan & Stough, 2001).

Apart from degree of excitation or inhibition at the synapses, neurodevelopmental differences may affect NCV from other properties such as axon diameter; number and size of synaptic connections; or myelin volume (e.g., Castelfranco & Hartline, 2016, for a review). There is evidence that development of myelin is important for inspection time (e.g., Chevalier et al., 2015; Kuznetsova et al., 2016; Wiseman et al., 2018).

To summarise, the ability to fixate on an image, sufficient to provide action potentials to register the signal, and the integrity of visual sensory pathways, sufficient to transmit the signal, could limit inspection time. Neurodevelopmental deficiencies associated with SpLDs may exacerbate the effects of these limitations. These could be from fixation instability, deficient activity of microsaccades, deficient M system, inefficient use of acetylcholine and consequent changes in attention, and myelin integrity.

Masks. Backward masks limit the duration of target stimuli. Two main theories are interruption and integration masking (Macknick & Martinez-Conde, 2007, for a review). Interruption masking theory proposes that the succeeding mask disrupts an already formed percept of the image at a post-sensory level of visual processing, before conscious perception “read [s] out” (M. White, 1996, p. 352) transmitted information, the experience of seeing an image. Alternatively, integration masking theory proposes that the mask image alters information from the target stimulus at an early stage, before it forms a percept. When two images are projected in quick succession to the same place on the retina, an image composite is formed–*feature fusion.* Integration theory also implies that a target stimulus-mask composite persists after, and may extend, the intended stimulus duration, although to what extent is unclear (e.g., Scharnowski et al., 2007). Integration theory of backward masking changed explanations for the inspection time construct from Vickers et al.'s (1972) original post-sensory explanations that employed interruption theory for backward masking. Inspection time may be the duration needed to resolve two images, target stimulus and subsequent mask, at a sensory level (M. White, 1996). M. White suggested that early temporal resolution between mask and target image limits inspection time. Later investigations supported this suggestion (e.g., N.R. Burns, Nettelbeck & White, 1998; N.R. Burns & Nettelbeck, 2003). N.R. Burns et al. (1998) used themselves as participants to test M. White's (1996) idea, and they believed to confirm, that standard inspection time relies on discrimination between the stimulus and the mask. As such, inspection time would measure the speed of identification of the first image against a subsequent mask image; importantly the decision is not only spatial—left or right feature, but sequential, that is, proficiency to resolve the difference between two images in time (N.R. Burns et al., 1998).

2.2.2. Post-sensory processes. Signals from the retina transmit to the primary visual cortex (VI) via the LGN in the thalamus and layered superior colliculus, by multiple types of connections and feedback systems. Encoding, which allows the extraction and then reconstruction of features such as angles and lines into a whole percept, starts in the visual cortex in the occipital lobe and assembles beyond, in the inferior temporal cortex. Whether integrated with the mask or not, this process allows a target stimulus to be discriminated by a comparison to memory (e.g., Bar et al., 2001). There are different models of cortical visual processing. One model used by researchers interested in reading is hierarchical with specialisation that increases along the way (Felleman & Van Essen, 1991; Wandell, 2011, for a review). Another highly influential model for cortical visual processes suggests two pathways or streams with different purposes, one for perception and one for action (Goodale & Milner, 1992; Milner & Goodale, 2008). In this model, the dorsal stream processes information for action that arises from sensory pathways, that is, for motor programing. The ventral stream may manage all conscious and unconscious perception of the same input but involves some planning. Actions dependent on remembering something perceived depend on the ventral system in the temporal cortex. This would apply to the inspection time stimulus in which the subsequent left/right action depends on memory of the left/right direction. However, Milner and Goodale also suggested that although the ventral system would monitor unpractised responses, with more practice the dorsal system would become preferentially involved so there could be some activity in the parietal cortex where this stream may operate. An interpretation that inspection time preferentially exploits the ventral pathway (e.g., Tachibana, Namba & Noguchi, 2014) may be at odds with the evidence of activation of both ventral and dorsal visual streams during an inspection time task (Deary et al., 2004). Functional magnetic resonance imaging (fMRI) evaluates the activity of neurones indirectly by measuring the relationship between oxygenated and deoxygenated haemoglobin in capillaries that supply the neural areas under investigation. In an fMRI study of inspection time in 20 young adults, Deary et al., (2004) tentatively concluded that there are different networks for different degrees of challenge between short and longer inspection times; different networks may activate if there is a degraded percept as opposed to one that is readily distinguishable. In another study, electroencephalograms (EEG) enabled calculation of the relative time taken to process an inspection time stimulus (Hill et al., 2011; Section 2.3.2). Both this and Deary et al.'s (2004) work imply that individual differences in post-sensory processes may occur during inspection time. A small, positive correlation between visual inspection time and auditory inspection time (AIT), measured with a spatial localisation task (r (78) = .30, p <.01), was *mean r* (2355) = −.32, s = .03, 95% C.I. = − .66 to .02; AIT *mean r* (389) = −.30, s = .04, 95% C.I. = − .69 to .09). A reason for this common relationship to intelligence could be a common fundamental neural physiology that influences both inspection time and AIT, which could be at a post-sensory level. Another reason for this small common relationship could be higher-level control.

Thus, there is some evidence from inspection time studies to support a two-stream hypothesis of post-sensory visual processing in which the ventral stream in the temporal cortex would manage the inspection time stimulus, at least initially. If neurodevelopmental differences affect inspection time at a post-sensory level, this could be either in the proposed ventral stream in the temporal region or in the dorsal stream in the parietal area, for more automatic responses. Top-down influences from strategy use may be present.

2.2.3. Top-down control. There is evidence to suggest that overarching processes influence the probability that an external stimulus provokes an impulse, conducts it along axons or transmits it across a synapse. Rhythmic oscillatory patterns of firing, formed by impulses in neural assemblages and networks of nerves working together, may limit the conduction of action potentials (Fell & Axmacher, 2011, for a review; VanRullen, 2016). Neural oscillation theory has that level of excitation forms a wave of electrical potential in neurones. Low frequency waves that peak less often would lead to less efficient information transfer (Jensen, 2011, Figure 1, p. 6). Waves with a higher frequency that peak more often would lead to more efficient signal transfer because of the temporal position of the stimulus in relation to the wave, hence more efficient information processing and potential for a higher resolution of adjacent signals. According to this theory, reaction time standard deviation (RTSD), which measures variability, would index neural oscillation rate, at least in part. This might also apply to ITSD. Greater variability would be due to fewer opportunities to respond due to slower oscillation rates. There is evidence for oscillation theory in temporal resolution of visual perception from a significant relationship (F (1, 16) = 11.45, p = .003) between finer-grained resolution of visual processes assessed by two-flash fusion thresholds and higher eyes-closed, scalp-recorded occipital alpha-band oscillations (7.5–12.5 Hz; Samaha & Postle, 2015). Furthermore, Samaha, Bauer, Cimaroli and Postle (2015) showed, in a series of investigations in which stimuli were preceded by a cue of varying intervals, that before target onset there was a “shift in the phase of alpha-band oscillations” to optimise and facilitate visual processes (p. 8439). This is evidence for top-down control by prediction of and precise early response to visual stimuli. There may also be gamma-band, 30–100 Hz, synchronisation of microsaccades in the primate striate cortex (Martinez-Conde et al., 2009). Although rhythmic oscillatory patterns of action potentials may contribute to ITSD, this variability might not be distinguishable from variability from experimental noise (P.A. White, 2018). Vickers and Smith (1986, p. 619) wrote that the original intention of the inspection time test was to provide a procedure to test for elementary information processing, “relatively immune from influence by higher cognitive activities” and they attributed ITSD to noise. They appeared not to anticipate that higher-level control of oscillation patterns of action potentials could contribute to variability.

Thus, theories drawn from experiments with reaction time (RT) and temporal resolution of visual perception might apply to inspection time. It may be that low frequency oscillations reduce performance and that weak control of oscillations leads to a lack of readiness to anticipate the inspection time stimulus. ITSD might evidence these behaviours as well as other sources of noise. In SpLDs, inefficient top-down control, as suggested by temporal sampling theory of dyslexia for example (see Appendix E), may contribute to increased inspection time, ITSD or both.

2.3. Psychometrics

There is evidence that inspection time is correlated with intelligence, processing speed, attention, memory and spatial skills (Nettelbeck, 2001). Tests, not necessarily well defined or directly related to specific neural processes or architecture, often evaluate and define these processes.

2.3.1. Intelligence and processing speed. Numerous studies, from diverse populations, have sought to illuminate relationships at a cognitive level between inspection time, processing speed, mental age, IQ, and g (e.g. W. Johnson & Deary, 2011, includes a review). Mental age is age that an intelligence test score would represent for an average performance, whereas IQ, a score from so-called intelligence tests, derives from average performance for that age. The CHC model of human cognitive abilities frames many of these studies (Chapter 1; Appendix A).

Intelligence. Nettelbeck and Lally's (1976) discovery of a large negative correlation between inspection time and performance IQ from the Wechsler Adult Intelligence Scale (WAIS; r_s (9) = .92, p = .001 and r_s (9) = .89, p = .001) generated considerable excitement (e.g., Deary & Stough, 1996). Since then, results of studies that aim to link inspection time to measures of intelligence have not always been so compelling. Moreover, there has been doubt whether inspection time causes variations in intelligence or vice versa or that there is a third unmeasured factor. For example, higher intelligence that can implement apparent movement between target image and mask, so-called *strategy-use,* may result in superior inspection time. Participants may be motivated to different extents that relate to their intelligence (Deary, 2001). Deary (2000) dismissed such suggestions, whereas Nettlebeck (2011) gave them credence. Moreover, results of a meta-analysis of inspection time's relationships to tests of intelligence did not support that strategy-use in inspection time was related to IQ. This meta-analysis estimated high correlations of inspection time with g (r (4196) = − .51) after corrections for range variation, measurement and sampling error (Grudnik & Kranzler, 2001). A later uncorrected meta-analysis showed that inspection time has a consistent, but weaker than previously calculated, significant relationship with intelligence: with Gf (r (44) = − .29), with Gc (r (44) = − .20), and with g overall (r (45) = − .36; Sheppard & Vernon, 2008). At a biological level, heritability may partly explain the relationship between inspection time and IQ. It could be that heritability influences myelination and myelin may affect both inspection time and IQ so that they covary (e.g., Luciano et al., 2005). Alternatively, there may be another common top-down influence, other than strategy-use, such as the ability to sustain attention (e.g., Edmonds et al., 2008).

Significant correlations between inspection time and visual and verbal intelligence raised the possibility that inspection time indexes physiological processes that affect all sensory modalities, and that underpin g (Nettelbeck, 2011). For example, in one analysis, inspection time predicted g through its connections to a latent *speed* factor formed from several ECTs as well as by a further unique route (Petrill, Luo, Thompson & Detterman, 2001). However, there are reasons to doubt a unique direct causal link between inspection time and g. Inspection time and intelligence, measured by IQ in young participants, change in parallel during development but mental age continued to develop after inspection time peaked in early adolescence, which could perhaps be from age-related learning strategies but also biological maturation (Anderson, 1986; Nettelbeck & Wilson, 1985). W. Johnson and Deary (2011) investigated the relationship to g of clerical speed tests and ECTs, in a study with 1091 participants aged between 68 and 71 years, which they acknowledged was a special group. Instead of the CHC model, they used an adapted Vernon's verbal-perceptual model, the *VP-R model* (W. Johnson & Bouchard, 2005). After they built several alternative solutions, their preferred model similarly related inspection time to g through spatial and verbal factors of the VP-R model.

Speed and efficiency. Nettelbeck (2001) cautioned against the hi-jack of inspection time as an intelligence test: *viz.,* a measure of IQ or g. His caveat may be particularly relevant for people with SpLDs. Since, research has suggested that inspection time likely relates to g or IQ, but through its relationship with second-order factors as in the VP-R model used by W. Johnson and Deary (2011) above or, in the CHC model, Gs. Evidence from sixth form students, aged 16–18 years (Mackintosh & Bennett, 2002), indicated that inspection time did not relate directly to g but related to intelligence because of its links with speed, labelled Gs in the CHC model. Moreover, O'Connor and Burns (2003), in a review and by investigation, found evidence that inspection time is linked to general speed of processing, Gs, rather than Gc or Gf. Therefore, it could be expected that inspection time can be long in people with strong

IQ overall. As seen in KK's case history (Appendix B), individuals may have a spiky profile of intelligence tests and long inspection times. The consistent relationship between inspection time and intelligence, albeit often small, need not necessarily deter the use of inspection time as an index of processing speed in diagnostic assessment of SpLDs. Someone can have long inspection time and better performance on tests of intelligence.

N.R. Burns and Nettelbeck (2003) replicated Mackintosh and Bennett's (2002) results in adults. "IT [inspection time], to be sure, somehow taps the same processes as those that contribute to performance on tests of clerical speed" (p. 249). In a later study, Nettelbeck and Burns (2010) found inspection time correlated with a digit symbol test in children and adults (r (239) = – .49, p < .001, r (237) = – .40, p < .001, respectively). That inspection time has an association with Gs is uncharacteristic of elementary cognitive tasks; other elementary cognitive tasks, those that measure RT and motor time (MT), and only sometimes inspection time (e.g., Schneider & McGrew, 2012), are located within Gt.

Results from inspection time's relationships with speeded cognitive tasks conflict in different studies. In their investigation of a group comprised largely of undergraduates, O'Connor and Burns (2003) factor analysed results of 18 measures of speed. Their results led them to choose four factors, which were perceptual speed, visualisation speed, DT and MT. Clerical tests such as digit symbol and cross out contributed to *perceptual speed. Visualisation speed* was "the time needed to perform tests requiring somewhat complex visualisation of stimuli" (O'Connor & Burns, 2003, p. 721) and included measures of odd-man-out decision time (OMO DT) and inspection time. Inspection time, in their study, shared more variance with OMO DT than it did with paper-and-pencil tests of processing speed such as symbol digits and cross out. OMO DT is a procedure during which three of eight lights light up. Always two are closer together than the third. In the task, the participant has to identify and press the third, OMO, which decision requires length discriminations. Similarly, the decision about a pi-stimulus requires a discrimination of length so affinities between OMO DT and inspection time appear plausible. Nevertheless, the relationship of inspection time to OMO DT is unclear because N.R. Burns and Nettelbeck (2003) inexplicably reported differently. Their analyses of 90 adults "unequivocally showed that IT [inspection time] and DT from OMO [DT] were independent" (N.R. Burns & Nettelbeck, 2003. p. 251). However, in their later study, Nettelbeck and Burns (2010) then showed that OMO DT correlated with inspection time, in children and in adults (r (239) = .34, p < .001; r (237) = .44, p < .001, respectively), which confirms O'Connor and Burns findings.

For O'Connor & Burns' (2003) third factor, DT, there were not significant relationships between inspection time and results of 2-, 4- and 8- DT choices (r (101) = .133, p > .05; r (101) = .110, p > .05; r (101) = .119, p > .05, respectively). Results from N.R. Burns and Nettelbeck (2003) reinforced these conclusions. In contrast, Deary and Ritchie (2016) found small and medium inspection time correlations with simple DT (r (949) = .17, p < .001) and choice DT (r (949) = .34, p < .001). W. Johnson and Deary (2011) concluded from their analyses that reaction time (meaning DT & MT) and inspection time represented elementary cognitive tasks equally well. This they attributed to the composition of tests, which were weighted towards RT. In their study, inspection time and simple RT (SRT) shared similar relationships to other cognitive abilities and "there was no reason that conclusions about CRT [choice reaction time] would be different" (W. Johnson & Deary, p. 415). That CRT requires a spatial decision whereas SRT does not, may be a reason, however.

There is less confusion about O'Connor and Burns' (2003) fourth factor, of MT. Although N.R. Burns & Nettelbeck (2003) found a small correlation (r (89) = .19, p < .01) between inspection time and MT in adults, MT, classed by Schneider and McGrew (2012) as a psychomotor speed, Gps, has generally been shown to be independent of inspection time. For example, in children, Mockler (2003) found that inspection time had negligible correlation with MT (r (56) = – .04, p = .77). These result accords with the absence of motor processes in inspection time (O'Connor & Burns, 2003, for a review).

Another point, Danthiir et al. (2012) made a direct comparison of single-item-computer-based speeded cognitive tasks, that did not include inspection time, derived from clerical paper-and-pencil tests and vice versa. There is an important but difference, the reason for which is unidentified, between tests attempted and evaluated one at a time, as with the computer-based tasks, and those performed in sequence, as for clerical tasks. The mode of delivery influenced the outcome.

Thus, factor analyses from different studies lead to different conclusions about relationships between inspection time, elementary cognitive tasks and paper-and-pencil tests of processing speed, possibly from a different composition of factors during analysis. There is, however, clarity that MT and inspection time are unrelated and this would be a useful property of inspection time when its use is considered for assessment of speed in SpLDs because in paper-and-pencil tests, MT is integral and cannot be distinguished from slow speed from other causes.

2.3.2. Executive processes.

Inhibition or attention. Intuitively, one would expect the degree of attention paid to a stimulus would affect inspection time and ITSD. Loss of attention could be from overt distractibility or from subtler forms, which involve participant readiness or noise (Section. 2.2.3). Several studies link inspection time to attentional processes in a variety of ways. For example, evidence for the influence of some sort of attention on inspection time has come from a study in which a period varied before the stimulus, which required more attention than when the participants paced themselves, resulted in longer inspection times (Anderson, 1989). Edmonds et al. (2008) correlated inspection time in children with measures of attention and the largest correlation was with a test of visual attention (r (240) = .35, p < .01). In an fMRI study, Deary et al., (2001) noted that areas that support attentional and cognitive processes were active during an inspection time task. Some of these active areas related to processes for visuospatial and visual object information but there was also activity in the inferior parietal lobe and posterior cingulate, involved in non-specific attentional information processing. Furthermore, some studies suggest that attention influences the relationship between inspection time and IQ (e.g., Bors, Stokes, Forrin & Hodder, 1999; Fox, Roring & Mitchum, 2009) although some do not (e.g., Crawford, Deary, Allan & Gustaffson, 1998; Hutton, Wilding & Hudson, 1997). In a study that used event related potentials (ERPs) generated by an inspection time stimulus, Hill et al. (2011) concluded that inspection time evaluates attention rather than speed of processing. They divided university students into those with relatively high and low IQs, assessed by Raven's Advanced Progressive Matrices (RAPM). There were differences between the two groups in the amplitude, but not latency, of a subcomponent of visually evoked potential N1, which is greatest at 150–200 ms over parietal cortex and lateral occipital regions, thought to be involved with "*spatial attention*" (Luck, 2005, p. 37). The group with relatively high IQ performed inspection time more accurately and had larger amplitude of N1 after stimulus presentation but there was consistent latency of N1 across the two groups.

In summary, inspection time may depend, at least in part, on spatial attentional processes, rather than speed of processes, as suspected by Hill et al. (2011). If this is so, then evaluation of processing speed by inspection time may not be straightforward. Weaknesses in spatial attention may affect the use of inspection time for diagnostic assessment of SpLDs.

Memory. Concepts of attention and memory overlap (e.g., Alloway, 2012). Baddeley (2012) has described short-term memory as memory limited by both capacity and time, and working memory as the ability to save and manipulate the contents of short-term memory. Salthouse (1996) distinguished two ways that slow processing speed affects cognition: limited time and simultaneity. *Limited time* describes how time runs out for cognitive operations, whereas *simultaneity* describes how one operation does or does not coincide with another (Salthouse, 1996). Slow speed could affect inspection time (a) directly, speed → inspection time, in which case inspection time could directly index of speed of cognitive processes. Alternatively, (b) there could be an indirect relationship via memory; memory could be required for the inspection time process and that memory could depend on speed of encoding, speed → memory → inspection time.

Maintenance of the percept of an inspection time stimulus sufficient to make a correct response could depend on aspects of both visuospatial short-term and/or working memory, in which case one would expect inspection time to correlate significantly with one or both of them. A significant relationship between inspection time and both auditory and visuospatial memory would suggest that they ultimately depend on common fundamental or global cognitive processes. Results that suggest that there could be a fundamental common connection have come from Nettelbeck and Burns (2010), who obtained correlations between inspection time and digit span (r (239) = – .19; r (137) = – .424, in children & adults, respectively) and picture recognition (r (239) = – .22; r (137) = – .493, respectively). In older adults, aged 54–85 years, Nettelbeck and Rabbitt (1992) showed that the relationship between inspection time and memory measured by digit span forwards was (r (103) = – .40, p <.01). On the other hand, in their large study on The Lothian Birth Cohort 1936, W. Johnson and Deary (2011) found, in this older population, that inspection time correlated with spatial span forwards and backwards, and digit span (r (1092) = .17, .18, .14., respectively). These small but similar correlations also suggest a common mechanism that affects both auditory and visual domains. The differences in strength of the relationship between studies might not be significant or they may be due to different experimental procedures.

Again, after option (b), there may be a developmental cascade, in which speed increases and decreases with age, which amplifies and then reduces working memory capacity, thence reasoning and problem solving (Fry & Hale, 2000). Several studies indicate that memory and inspection time are linked developmentally. Sometimes in these studies, inspection time is used to index speed. In a longitudinal study of older participants over a total period of 3.5 years, Gregory, Nettelbeck, Howard and Wilson (2008) and Gregory, Nettelbeck and Wilson (2009) showed that a decline in working memory in older age predicted longer inspection times. Nevertheless, it may be that a further factor is responsible for shared trajectories; direct causal models are not the only reason for connections between memory and inspection time, in whatever direction. Developmental cascade theories of memory and speed are not always supported (e.g., Perlstein et al., 2004; Salmond et al., 2005).

Thus, memory processes may or may not be important for evaluation of inspection time stimuli. Confusingly, interpretations of investigations have sometimes relied on inspection time as an index of speed to explain processes. Speed of cognitive processes may influence relationships between memory and inspection time. Different aspects of poor memory or working memory, which may be auditory or visual, occur in people with SpLDs (Chapter 3). The proposed use of inspection time for diagnostic assessment, as laid out in Chapter 1, may be affected. Memory weaknesses associated with SpLDs may confound an inspection time assessment intended to index processing speed. Other variables that may confound inspection times are attention, discussed previously and/or spatial processing, discussed next. Ritchie, Tucker-Drob and Deary (2014, supplementary online discussion) suggested that, in older age, memory does not necessarily confound the relationship between decline in fluid ability and decline in inspection time, that is to imply option (b). They evaluated fluid intelligence by digit span backwards, matrix reasoning, block design and letter-number sequencing. To reinforce their theory of linked decline in processing speed – for which they used inspection time – and intelligence, they substituted a coding task, symbol search and CRT, with similar results. All these indices of intelligence and processing speed might also tap a decline in spatial skills.

2.3.3. Spatial processing. Spatial processing includes three abilities: bilateral integration, laterality and directionality (e.g., Scheiman & Rouse, 2006). *Bilateral* *integration* is the ability to be aware of and use the two sides of the body separately and simultaneously and *laterality* is the ability to be internally aware of and to identify left and right on oneself. It is likely that response to a pi-figure with an appropriate movement to the left or right requires skills of laterality and bilateral integration. *Directionality* is the ability to interpret right and left directions in external space – required to distinguish between pi-figures. Simultaneously, to evaluate the relative length of two vertical lines needs spatial ability.

In CHC theory, spatial ability is a second-order factor, Gv. Gv has 11 narrow abilities. These all appear too complex to answer for skills needed for the visual spatial identification of the pi-stimulus. Yet undoubtedly, evaluation of a pi-stimulus requires perception skills of discrimination, visuospatial memory and spatial directionality. A difficulty is that terminology in the literature is loose and encompasses a wide variety of tests and ideas. In this thesis unless qualified, the term *visuospatial* is used in the broadest sense: an ability to visually evaluate position and size of objects in relation to each other. In the Lothian Birth Cohort 1936, W. Johnson and Deary (2011, Figure 4) in their preferred interpretation of a factor analysis of the relationship of ECTs to second-order factors in the VP–R model of human cognitive abilities (Section 2.3.1), showed that inspection time loaded on spatial ability (r = .33), verbal ability (r = .25) and perceptual speed (r = .44). Tests of spatial span forward and backward, matrix reasoning and block design evaluated spatial ability. There are three interpretations for the medium loading on spatial ability: inspection time influenced spatial ability, vice versa, or there is a common influence to both.

Slight supporting evidence for the importance of visuospatial perceptual ability for the evaluation of inspection time also comes from Codorniu-Raga and Vigil-Colet (2003). These authors found a tiny difference in inspection time performance between 222 boys and girls aged 11–14 years. Boys had slightly better inspection times than did girls, which advantage disappeared when they covaried results of tests of visuospatial perceptual skills. Edmonds et al. (2008) found that, in children, inspection time did not share a significant proportion of variance with visuospatial tests of design copying and arrangement of arrows. In design copying, motor skills were required as well as visuoperceptual skills for copying. Arrows tested the ability to judge orientation of lines, not needed for standard inspection time. It may be that discrimination skills between one figure and another are an important limiting factor when an inspection time stimulus is evaluated and these were not evaluated in this study. In another study, Hegarty and Waller (2004) distinguished by factor analysis two types of spatial ability: *visualisation* and *orientation*. Visualisation included three dimensional image rotation tasks – the irrelevance of which to standard inspection time was supported by O'Connor and Burns' (2003) study in young adults, which correlated inspection time with a mental rotation task (r (101) = – .203, p > .05). Tachibana et al., (2014), also, found no significant correlations between inspection time and a 3-D computerised mental rotation task. Orientation has to do with visual patterns and their relationship to oneself, which also seems irrelevant to identify a pi-figure. Inspection time does not include movement time, and consequent spatial evaluations, which require skills for planning and executing movement. However, spatial, pre-motor planning is involved in inspection time tests. A left-hand pi-stimulus may generate a plan for a left-hand response, whether there is a response or not. According to Milner and Goodale (2008), such a plan before action happens in the ventral system of their model (Section 2.2.2). It is unknown how these processes involved with a plan, in the ventral stream, impact on the time of the perceived inspection time stimulus in the ventral stream.

To summarise, in addition to speed or efficiency of neural processes, the standard inspection time task obviously requires length and left/right position spatial discrimination skills, but there is little confirmatory detailed evidence. Identification of, and response to, left and right and comparison of line lengths, required for the pi-figure stimulus, is complex. Particular aspects of discrimination such as length discrimination or evaluation of left and right on a figure, left and right for a response or the translation of evaluation to response may limit inspection time in different SpLDs.

2.4. Gender, Development and Education

If inspection time was used for diagnostic assessment it would be important to know to what extent it is affected by gender, stage of development, and level of education.

Gender. N.R. Burns and Nettelbeck (2005) established in a large sample of 653 children, young and middle aged adults that there were no gender differences for inspection time. However, in a meta-analysis, Sheppard and Vernon (2008) noted that boys outperformed girls. Gregory et al. (2011) reported that men aged 76–89 years had superior inspection time to women of the same age.

Development and education. A study of twins provided evidence that levels of inspection time are heritable, at 45% (Edmonds et al., 2008). During development, inspection time decreases steadily up until early teens and then increases quite slowly from early adulthood (e.g., Nettelbeck & Wilson, 1985). It increases more sharply in older age (e.g., Ritchie, Tucker-Drob & Deary, 2014). Penke et al. (2012) showed that in older age inspection time, among other tests of processing speed, mediated a link between white matter integrity and IQ. Until early adulthood, age and educational status are interdependent and so effects on inspection time from increases in age may be difficult to disentangle from the influences of literacy and education or vice versa. It is unknown whether education influences inspection time in young people. In a study of older people, Ritchie, Bates, Der, Starr and Deary (2013) found that education influenced lifetime changes in IQ, but not inspection time, which suggests that at least an extended formal education does not influence basic processes indexed by inspection time. Processes associated with reading could affect visual processes for identification of letter-like pi-stimuli. However, although reading comprehension from the reading subtest of the Kaufman Test of Educational Achievement in typically developing children, 9–11 years of age, correlated significantly, albeit the correlations was small, with inspection time (r (56) = − .29, p <.05), reading fluency did not (Kranzler, Brownell & Miller, 1998). Mockler's (2003) study of typically developing children, 7–11 years old, also found no significant relationships between inspection time and untimed tests of letter-word identification, word attack or basic reading, from the Revised Woodcock-Johnson Tests of Reading Achievement (WJ-Ach; Woodcock-Johnson, 1989). Like Kranzler et al. (1998), Mockler found that inspection time correlated significantly with passage comprehension (r (56) = .28, p < .05) and skills of broad reading (r (56) = .30, p < .05). To date, evidence suggests links between inspection time and reading comprehension, and other factors, such as IQ may mediate this relationship.

In typically developing children, Mockler (2003) observed non-significant correlations between inspection time and elision. Tests of elision assess how phonemes are discriminated, a process that is integral to reading development, and is dependent, at least in part, upon speed of processing auditory information (Fitch, Miller & Tallal, 1997). The absence of a significant relationship between them suggests that any shared underlying neural processes are absent or obscured.

There are no reports of any links between inspection time and handwriting, as far as is known. Handwriting, along with MT, belongs in the CHC model to Gps, speed of body movements. In typically developing populations, given that inspection time is virtually orthogonal to MT, no correlations would be expected between inspection time and handwriting.

In another study, an undefined “comprehensive test of … scholastic achievement” (Stough & Bates, 2004, as cited in Jensen, 2006, p. 198) in secondary school students most closely correlated with inspection time (r (49) = −.74, p < .001) over three other tests, which were of IQ. Other evidence confirms the link between inspection time and educational achievement. Inspection time predicted success for MBA students (r (83) = − .33, p <.05), although claims that inspection time’s prediction value was superior to IQ and to a Graduate Admissions Tests were not validated statistically (Pesta & Poznanski, 2009). Inspection time may, in part, index an ability for perceptual learning – that is an ability to learn to discriminate between differences (N.R. Burns, Nettelbeck, McPherson & Stankov, 2007).

In later life, between 70–76 years, evidence from a longitudinal study showed a large link (r (627) = .78, p = .035) between changing inspection time and changing fluid intelligence (Ritchie, Tucker-Drob & Deary, 2014).

In summary, it appears that gender does not usually influence inspection time in children and younger adults. Inspection time shortens through childhood and adolescence but lengthens in older age, a pattern consistent with the development of white matter integrity. There is some evidence that inspection time is unaffected by education but there is a link between inspection time and educational achievement. Of literacy skills, to date only reading comprehension in children has been found to have clear links to inspection time.

2.5. Summary of Chapter 2

Inspection time is the outcome of a variably assessed process. Standardised hardware and software would be necessary for tasks that measure inspection time and ITSD in diagnostic assessment of SpLDs. Close to half a century after Vickers et al.'s (1972) seminal publication, psychophysical and physiological processes that underlie inspection time are not thoroughly understood, although there has been progress. The solid, but not large or always direct relationship between inspection time and IQ, has dominated the literature. Inspection time sometimes shares important variance with paper-and-pencil tests of processing speed, Gs in the CHC model of human cognitive abilities. For Gt, the strength of relationship between inspection time and DT varies between studies, but MT is unrelated to inspection time. Attention appears important. Relationships between memory and inspection time are of inconsistent strength.

Individual differences in inspection time in typically developing populations may reflect global efficiency or the presence of specific bottlenecks. Specific bottlenecks could compromise and cause differences in standard inspection time in SpLDs. Sensory processes may limit inspection time. These could be from the moment the pi-image falls on the retina, as sensitivity through stability of fixation and consequent generation of action potentials; response to and interactions with the mask; journey through the visual pathways, particularly the M system; acetylcholine activity and myelin integrity, which has emerged as a strong candidate to explain individual differences in inspection time. Overarching endogenous rhythms may be important. The inspection time task requires the ability to form an accurate percept of the stimulus image; spatial awareness; ability to relate spatial features to memory, to plan and to make a response, to left or to right. Nevertheless, it is less complex than repetitive complicated paper-and-pencil tests in that it only requires trial-by-trial recognition of one of two left/right mirrored images. The inspection time task is also simpler than all paper-and-pencil tests of processing speed and RT because it excludes efferent pathways.

CHAPTER 3

Specific Learning Differences

Sections 3.1 and 3.2 of this chapter briefly introduce dyslexia and developmental coordination disorder (DCD). Section 3.3 introduces co-occurrences of SpLDs and Meares-Irlen Syndrome (MIS). Reviews of inspection times in dyslexia and DCD are in Section 3.4. Aims and hypotheses for experiments are in Section 3.5. Assessors of SpLDs frequently encounter people with dyslexia, DCD and MIS. To make the investigation manageable, this study excluded other SpLDs, such as ADHD or autism.

3.1. Dyslexia

Unlike more generally recognised definitions of dyslexia, for example, “when accurate and fluent word reading and/or spelling develops very incompletely or with great difficulty” (British Psychology Society*,* 1999, p. 64), the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5; American Psychiatric Association, 2013*)* describes dyslexia as a *specific learning disorder* (SLD). SLD includes dyslexia and, and other learning differences, for example, dyscalculia. In dyslexia, other learning, apart from literacy, progresses or has progressed as expected and learning differences are not attributable to overt sensory impairment or socioeconomic and cultural background (DSM-5, 2013). Frequently there is a family history of SpLDs (e.g., Snowling & Melby-Lervag, 2016). Genes for dyslexia have been identified (e.g., Scerri & Schulte-Korne, 2010) but environmental factors are influential (e.g., Olson et al., 2013). Dyslexia manifests differently during the lifespan and is sensitive to the demands of everyday life, education or work, so that each person with dyslexia has a unique set of weaknesses and strengths. The Rose Report (Rose, 2009) reflects a view that, because levels of cognition and reading ability are normally distributed, dyslexia is part of a continuum and is inseparable from typical development (Shaywitz et al., 1992). Much of the scientific literature treats dyslexia as a distinct category and that is how it is treated in the main investigation presented here. However, as dyslexia is part of a continuum, there is potential to explore characteristics that are associated with it among so-called *typically developing* participants.

Environmental variability that interacts with complexities of the reading process (e.g., Norton & Wolf, 2012), diverse genetic origins (e.g., Raskind et al., 2013) and, co-occurring neurodevelopmental conditions could cause diverse signs and symptoms in dyslexia. Originally, dyslexia was called w*ord blindness;* implying a visual deficiency (Hinshelwood, 1917; Morgan, 1896). Although cognitive and behavioural profiles are diverse, many people with dyslexia have deficits in language processes (e.g., Ramus & Ahissar, 2012, for a review). After the work of Bradley and Bryant (1983), language and phonological theories dominated the scientific literature on dyslexia. Phonology is about abilities to distinguish different speech patterns. Differences in phonological processes may not be the only issue in dyslexia (e.g., Heim et al., 2008; but see White et al., 2006). Reviews of the main theories of dyslexia relevant to inspection time are in Appendix D. These theories suggest that dyslexia can be the result of visual or more general differences in cognition, not only language processing differences. Only 19% of children with dyslexia in one study had only phonological deficits and some had none (Bosse, Tainteurier & Valdois, 2007). There can be other differences in various combinations: allocation of attention, executive functioning and visuospatial perception (Menghini et al., 2010). Stein (2012) described dyslexia as “a general neurological syndrome" (p. 175). Associated signs and symptoms include left/right confusion; poor recall for sequences such as the alphabet and multiplication tables; and the atopic triad of eczema, asthma and hay fever (Stein, 2012).

Tafti, Boyle and Crawford (2014) have reviewed visuospatial processes in people with dyslexia and although they noted the evidence for compensatory visuospatial strengths, their meta-analysis supported other findings of a visuospatial attention deficit in participants with dyslexia. Distortions of text that many people with dyslexia experience have been attributed to deficits in the fast, transient magnocellular (M) system, which may affect eye movement control and binocular vision (Stein, 2018). There is also evidence for a parietal lobe dysfunction (e.g., Lobier, Peyrin, Pichat, Le Bas & Valdois, 2014). Multi-element processing, the ability to report an array of letters or digits, is deficient in some participants with dyslexia (e.g., Bosse et al., 2007). Deficits in the M system have been implicated and for which training has been shown to improve reading (Lawton & Shelley-Tremblay, 2017). In adults with dyslexia, Stenneken et al. (2011) used a verbal report of letters seen after different brief durations to test speed of their appraisal. They also tested varying number of letters for memory. They revealed that a reduction in speed of appraisal of the letters is more important in participants with dyslexia than memory, supporting other evidence for a deficit in the M system.

Investigation of a visual task, such as inspection time, may reveal more about non-language deficiencies in dyslexia, particularly as inspection time requires rapid appraisal of a stationary, centrally located, stimulus image but does not require those eye movements that are required for reading text or a verbal report on letters.

3.2. Developmental Coordination Disorder

Diagnosis of DCD may occur when, in the absence of physical, visual or intellectual impairments that would “better explain the symptoms”, there is a substantial deficiency in motor coordination and spatial awareness (American Psychiatric Association, 2013, p. 75; Purcell, Scott-Roberts & Kirby, 2015, for a review). Possible subtypes of DCD, incidence of symptoms from extreme prematurity, and co-occurrence of other SpLDs, complicate research and diagnosis (e.g., Alloway, 2012). Gomez and Sirigu (2015, for a review) report that cultural and perinatal circumstances are implicated in DCD, but up to 70% of cases are believed to be inherited (e.g., Lichtenstein, Carlström, Råstam, Gillberg & Anckarsäter, 2010). Among five and six-year-old children with DCD, there is weaker performance than typical across all motor and cognitive domains tested (Asonitou, Koutsouki, Kourtessis & Charitou, 2012). Weak motor coordination, organisation and social skills affect day-to-day living and education. A task that requires accuracy in time or space, that accompanies another, or is more complicated than is usual, can accentuate the impairment (Wilson et al., 2017). Handwriting, motor coordination, planning, organisation, self-esteem, relationships and emotional health are affected (e.g., Tal-Saban, Zarka, Grotto, Ornoy & Parush, 2012; Wilson, Ruddock, Smits-Engelsman, Polatajko & Blank, 2013).

As adults have DCD, there are suggestions that associated difficulties are the result of disordered neural arrangements rather than developmental immaturity (Wilson et al., 2017, for a review). Diagnosis of DCD in adults rests on a history of DCD as a child (American Psychiatric Association, 2013). Adults with DCD have deficits for navigation (Wilmut, Du & Barnett, 2015); motor imagery (Hyde et al., 2014); attention (Tal-Saban, Ornoy & Parush, 2014); ”organisational skills, memory, forward planning, … and processing speed” (Purcell et al., 2015, p. 298).

In children, simple decision time (SDT), choice decision time (CDT) and motor time (MT) predicted DCD (e.g., Henderson, Rose & Henderson, 1992). Children with

DCD had longer reaction times (RTs) for a go/no-go task (Querne et al., 2008). RT was relatively longer than MT, which suggested deficiencies in implementing actions (Cousins & Smyth, 2003; Piek & Skinner, 1999). RTs related to degree of motor deficit (Piek, Dyck, Francis & Conwell, 2007). A cross-out task took longer for participants with DCD but there were no group differences for visual scanning or trail making (Leonard, Bernardi, Hill & Henry, 2015).

Children with DCD are impaired in tasks of verbal working memory, verbal short-term memory, visuospatial short-term memory and particularly visuospatial working memory (Alloway, Rajendran & Archibald, 2009). Weak visuospatial working memory was accompanied by weak neurocognitive performance in the parietal area in DCD (Wang, Tseng, Liu & Tsai, 2017). Children with DCD exhibit more attentional problems than typical and less inhibitory control (Dewey, Kaplan, Crawford & Wilson, 2002).

In children with DCD, recent studies show differences in oculomotor control that would affect ability to sustain attention on a visual target such as an inspection time stimulus. These were of fixation stability (Sumner, Hutton, Kuhn & Hill, 2016); accommodation, linked to motor control and believed associated with reading difficulties (Rafique & Northway, 2015, for a review); risk of refractive error and binocular inefficiency (Creavin, Lingam, Northstone & Williams, 2014). Also, there were vertical and horizontal smooth pursuit eye movements, in which horizontal movements were as normal but vertical movements were developmentally delayed (Robert, Ingster-Moati, Albuisson, Cabrol, Golse & Vaivre-Douret, 2014).

Visual spatial information processing is impaired in children with DCD. They cannot easily discriminate shape, area, slope, line length and size (Gomez & Sirigu, 2015; Wilson et al., 2013). In a visually guided pointing task (Sirigu et al., 1996), the time taken to reach different size target boxes from a starting point a few centimetres distant should increase as the size of the target decreases. This is Fitts's Law (Fitts, 1954). In participants with parietal lesions, actual movement to the target decreases in speed with decreased target size, but in an imagined movement, the speed does not decrease as it would typically. Maruff, Wilson, Trebilcock and Currie (1999) found the same in children with DCD, MT over all was slower and imagined movements did not follow Fitts's Law. Handwriting, believed to be a main educational difficulty in DCD, requires complex planning and organisation in time and space (Rosenblum, 2013, for a review). Overall copying speed is slower in children with DCD, as well as weak quality of letter formation and difficulties with spatial organisation on the paper (Wilson et al., 2017, for a review).

Numerous brain regions are implicated in DCD (e.g., Reynolds, Licari, Elliott, Lay & Williams, 2015). Areas under suspicion for DCD are the parietal lobe (e.g., Cummins et al., 2005); frontal-parietal circuitry (e.g., Sumner et al., 2016); basal ganglia and cerebellum (e.g., Zwicke, Missiuna & Boyd, 2009, for a review). Neuroimaging studies of children with DCD suggest that white matter is different compared to typically developing children (Brown-Lum & Zwicker, 2015, for a review). Diffusion tensor imaging is a variant of fMRI that uses diffusion of water molecules to trace tissues such as myelin. In a diffusion tensor imaging study, reduced white matter integrity was shown in parietofrontal and corticospinal tracts, particularly the superior longitudinal fasciculus (J. Williams, Kashuk, Wilson, Thorpe & Egan, 2017; Zwicker, Missiuna, Harris & Boyd, 2012). As has been shown (Chapter 2), white matter integrity could influence inspection time. Again, in children, Debrabant et al. (2016), with fibre tractography, exposed relatively deficient myelin in visual tracts, which could affect inspection time. Fibre tractography constructs 3D images from diffusion tensor images. Task related fMRI in children with DCD has confirmed less neural activity than is typical in the parietal region, cerebellum and dorso lateral prefrontal cortex, the latter being implicated in attentional networks (Zwicker, Missiuna, Harris & Boyd, 2011; Wilson et al., 2017). The differences in brain organisation shown by neuroimaging studies, both of activation patterns and of white matter structure, are not necessarily causal.

Observed differences might have arisen from lack of physical activity, thus be a consequence rather than a cause of DCD (Wilson et al., 2017).

Reviews of main theories of DCD are in Appendix D. These theories are based chiefly on evidence from motor performance. The internal forward modelling theory of DCD implicates weak predictive control of limbs from deficiencies, possibly additional neural noise to usual, in the parietal cortex and cerebellum. Weak predictive control might introduce error into inspection time responses by effects on the response accuracy when, for example, left response is matched to left pi-figure, especially at speed. The neural noise theory arises from the presence of more intra-individual variability in motor systems of children with DCD (Smits-Engelsman & Wilson, 2013). Noise in the sensory system could affect inspection time trials and influence a final inspection time. Another theory implicates weak procedural learning from a deficit in the cerebellum, basal ganglia or both. As with dyslexia, in participants with DCD, a procedural-cerebellar deficit might affect inspection time by the need for more practice trials, but any further differences in inspection time from a procedural deficit seem less probable and therefore inspection time would be a preferable measure of processing speed than a paper-and-pencil test. Huau, Velay and Jover (2015) found evidence to support a procedural learning deficit; in a task in which participants wrote unfamiliar letter-like shapes, participants with DCD learnt the task more slowly. This could confound the outcome of a test intended to evaluate processing speed as in some coding tests.

Deficits in processing speed, memory, attention, visuospatial and oculomotor skills are all features of DCD that could influence inspection time or vice versa.

3.3. Co-occurrence

Co-occurrence, a term that neither implies or denies shared causality between SpLDs, is common and can be a challenge to diagnosis (e.g., Boada, Willcutt, & Pennington, 2012*;* B. Kaplan, Crawford, Cantell, Kooistra & Dewey, 2006). Gomez and Sirigu (2015) described four models to explain co-occurrence in SpLDs. First, types could arise independently, have separate aetiologies and overlap by coincidence; an individual would exhibit characteristics of separate SpLDs. Second, one type could cause another, the direct causation model, exemplified by attention deficit hyperactivity disorder (ADHD), in which difficulties of attention can affect reading instruction (Willcutt, 2018). Third, types could have a common aetiology, which leads to the separate SpLDs, as suggested by the cerebellar deficit hypothesis (e.g., Nicolson & Fawcett, 2007). Fourth, like the first type, two conditions could have unrelated aetiologies and there is a further cause for their co-occurrence.

Co-occurrence may be confused with subtypes of SpLDs (Visser, 2003). Co-occurring DCD is found in over half of all children with dyslexia and an estimated 55% of children with DCD have dyslexia (Biotteau, Albaret, Lelong & Chaix, 2015, for a review). B. Kaplan et al. (2006) found evidence that children with co-occurring ADHD, DCD or dyslexia had greater severity of a range of symptoms. This supports a theory that there is a continuum, graded for severity, with more co-occurrence between SpLDs with increased severity of effects. Biotteau et al. (2015) did not find that there was increased severity of symptoms among children with both dyslexia and DCD. Characteristics of people who have co-occurring SpLDs may not be the sum of characteristics for the individual SpLDs (Willcutt, 2018).

3.3.1. Meares-Irlen Syndrome (MIS). When a person has visual discomfort of sensory, rather than ocular, origin, it may be MIS or *visual stress*. Symptoms of MIS are sometimes associated with, but distinct from, dyslexia (e.g., Evans & Allen, 2016; Kriss & Evans, 2005). Saksida et al. (2016) did not find visual stress more often in dyslexic children. MIS in DCD has not received attention in the scientific literature to date, as far as is known.

Symptoms of MIS are sometimes somatic but more usually are of uncomfortable visual distortions of colour, shape and motion. Symptoms have an adverse effect on reading (Wilkins, 1995, 2016). A questionnaire that forms a Visual Discomfort Scale (VDS) evaluates the degree of visual discomfort (Conlon et al., 1999). The Pattern Glare Test (PGT; Wilkins & Evans, 2001) provides effective diagnosis when the symptoms are unexplained by visual anomalies (Hollis & Allen, 2006). Diagnostic assessment of MIS by visual search, hence by tests of reading, is questionable (Allen, Hollis & Gilchrist, 2008).

Visual discomfort from MIS is provoked by physical properties of the image - such as certain wavelengths of radiation; glare spots on overhead projectors; patterns that repeat at medium spatial frequencies; lights that flicker with regularity; and an image centrally placed in the field of view adds risk of visual discomfort (e.g., Wilkins, Veitch & Lehman, 2010). Square wave patterns with a duty cycle of 50% subtended from the eye at 2–8 cycles/degree, or other patterns that have high contrast, cause discomfort in people with MIS (e.g., Fernandez & Wilkins, 2008). Patterns that may provoke discomfort are similar to those that provoke photosensitive epileptic seizures in some people (Wilkins, 1995; Yoshimoto et al., 2016). Lines of text (Wilkins et al., 1984) affect readers with MIS, although not for monocular reading, which raises suspicions of binocular effects (Jainta, Jaschinski, & Wilkins, 2010).

When viewing uncomfortable images, people with MIS show a large haemodynamic response in the visual cortex (Coutts, Cooper, Elwell & Wilkins, 2012). Wilkins et al., (1984) suggested that the visual cortex is hyper-excitable from deficient gain control mechanisms; neurones may fail to manage sensory impulses outside certain limits. Stein and Walsh (1997) suspected disordered magnocellular cells.

The digit symbol test from the Wechsler Intelligence Scale for Children–Revised (WISC–R; 1974) has a square-wave pattern of stripes and boxes that contain digits and letter-like symbols that repeat. Performance for this test, which forms part of the Processing Speed Index, correlated highly in groups of university students with high scores on the VDS (r (38) = − .83, p < .05; Conlon et al., 1999). Speed of reading was slower in participants with more visual discomfort assessed by the VDS. The degree of pattern glare to assess visual stress did not add variance to predictions for literacy tests in hierarchical regression analysis (Saksida et al., 2016).

Images that depart from spatial and temporal patterns found in the natural environment, which would include inspection time images, may cause visual discomfort (Wilkins, 2016; Yoshimoto et al., 2016). Thus, visual inspection time stimuli might provoke MIS-related discomfort. The potential influence of, or relationships between, MIS and inspection time have not been investigated in the literature to date, as far as is known. Discomfort could be from the stimulus design – a spatial provocation, or a temporal provocation from pulsed stimuli from some display devices.

3.4. Inspection Time in Specific Learning Differences

3.4.1. Inspection time in dyslexia. There have been three investigations of inspection time in participants with dyslexia at the time of writing (Kranzler, 1994; McLean et al., 2011; Whyte, Currie & Hale, 1985). These investigations are briefly described below, but expanded in Table D1, Appendix D.

First, Whyte et al. (1985) compared inspection time between seven boys with dyslexia, 9−11 years old and the same number of typically developing boys of that age. Boys with dyslexia had significantly longer mean inspection times than boys without (F (1, 13) = 11.28, p = 0.01; Table D2). There were markedly long inspection times in four of seven participants with dyslexia; consequently, greater variability between participants with dyslexia than in the participants without. In participants with dyslexia, mean inspection time and variance tended to reduce with practice. Intelligence, assessed by Raven's Progressive Matrices, did not correlate significantly with inspection time in either group.

In this small study, which used age-matched rather than reading age-matched controls, there was an unusual requirement to use separate hands for left and right responses. This required different co-ordination skills than does a response with one hand. The stimulus was a pi-figure, but the differences in length between left and right stimuli were tiny, 1 mm in the whole stimulus length of 31 mm, viewed at a distance of 45 cm. There was a long 20 ms lower limit on stimulus duration, nevertheless Barrett and Kranzler (1994) questioned the ability of the computer programing language to resolve this duration accurately. Notably, the test routine was lengthy: 200 trials; the test session lasted approximately 2 hours. The authors claimed evidence that "speed of intake rather than generalised perceptual deficit" is the crucial factor in dyslexia (Whyte et al., 1985, p. 427).

Second, Kranzler (1994) compared inspection time between 18 children with reading difficulties and 23 children without reading difficulties, matched on age and gender. Investigational details and results contrasted to Whyte et al.'s (1985) study of inspection time in dyslexia. Kranzler used, against a black background, two parallel rows of red light LEDs, 6 in. (15.24 cm) in length, with a 1.5 in. (3.81 cm) difference on one side or the other to provide the choice for left or right short side, interfaced with an IBM-AT computer. Red light could preferentially activate the parvocellular (P) system. In a comparison between tasks that used a computer screen and an LED, N.R. Burns and Nettelbeck (2003) reported the two tasks had a small correlation (r (89) = .29, p <.01). There were no significant differences between mean inspection times in the two groups of children, after nonverbal intelligence had been controlled (Table D2). However, 7 out of 18 participants with reading difficulties were excluded from the analysis compared to 2 out of 23 participants without reading difficulties (φ = 0.26 (40), p <.05, one-tailed). These children had *timed out.* Timing out occurred if the participant did not respond correctly to 9 out of 10 consecutive trials in a final phase of the algorithm for inspection time resolution. Final stimulus durations were in increments of only 2 ms. Timing out indicates that these participants had more variable responses. Kranzler proposed that the children with reading difficulties were unable to maintain their attention perhaps because the computer controlled the start of each trial. In a later publication he concluded "results of this study, which have yet to be replicated and at present are poorly understood, suggest that inspection time may be importantly related to RD [reading difficulties]" (Grudnik & Kranzler, 2001, p. 528).

In a third study of inspection time in participants with dyslexia, inspection time was one of a battery of tests to investigate magnocellular deficits in dyslexia. Stimuli were space invaders that had antennae of overall length 27 mm, with 5 mm difference in length (McLean et al., 2011). As with the two previous studies, responses to left or right were compatible with the stimulus. The difference between mean inspection times in groups with and without dyslexia was not significant (*t* (80) = 1.493, *p* = >.05, *d* = .327; Table D2). However, four of 40 children with dyslexia and one child without dyslexia had extremely long inspection times, more than 120 ms, and while the "Dyslexia Group was positively skewed (Kolmogorov-Smirnov, $p < .05$), the Control Group was not (Kolmogorov-Smirnov, $p > .05$)" (G.M.T. McLean, personal communication, 19 March 2016). The authors concluded from exploratory factor analysis that in some poor readers the results of inspection time, combined with a go/no-go RT test, a flicker perception task in the magnocellular condition, and a single target rapid serial visual presentation, contributed to a "Perceptual Speed" factor (McLean et al., 2011, p. 1971). This factor was independent of phonological processing, rapid automatic naming (RAN) and general performance skills, and uniquely, but weakly, predictive of irregular and non-word reading (*r* (79) = .222 and .214 respectively, p <.05). The authors postulated that, although there were significant correlations between perceptual speed and reading, this relationship was not a direct consequence of magnocellular deficiencies but that another factor, possibly memory, could be a mediator. Another possibility is that a difference in intelligence may have contributed to the slightly longer inspection time and the larger standard deviation observed in the dyslexia group. The mean of Raven's Progressive Matrices for the group without dyslexia was higher than for the group with dyslexia (percentile ranks: controls: *mean* 72.50, *SD* = 22.60; dyslexia, *mean* = 63.00, SD = 22.70).

Summary of investigations in dyslexia. Participants from three studies into inspection time were from diverse populations in time: spanning 25 years, geographical location and selection criteria for dyslexia. These and different test conditions, stimuli and investigational procedures probably account for differences in inspection time values between the different studies. Nevertheless, in all studies there were subtle response differences that may signify differences in neurocognitive processes associated with inspection time, in some participants with dyslexia. Excluding Whyte et al.'s (1984) study, groups of children with dyslexia and age-matched children without dyslexia had similar mean inspection times but there were group differences in practice effects, within-participant variability and between-participant variability. In Kranzler's study, many children with dyslexia timed out and in McLean et al.'s study there was a proportion of children with very long inspection times. Standard deviations were always greater in the group of participants with dyslexia (Table D2) thus some participants performed more poorly in inspection time tasks than other peers with or without dyslexia. Possible explanations for these results are a subtype of dyslexia in which participants had long inspection times or co-occurrence with another SpLD.

3.4.2. Inspection time in developmental coordination disorder. There have been two investigations of inspection time in DCD (Dyck & Piek, 2010; Piek et al., 2007). First, Piek et al. (2007) measured inspection time and RT in 18 children with DCD, aged between 6.6–13.1 years, 39 children with ADHD, aged 7–14.1 years, and 138 typically developing children, aged 6.1–13.11 years (Table D3). Because ADHD and DCD occur together so often, the aim of the study, that explored the possibility of a common neurocognitive mechanism, was to identify similarities or differences between the groups in working memory, set-shifting and processing speed—for which was used inspection time and RT. When age and intelligence were controlled, there were significant group differences between DCD, ADHD and typically developing children. Children with DCD had significantly longer inspection times than in the other groups (F (3, 188) = 3.81, p = .01, η^2 = .07) after age and IQ were controlled. The authors concluded that the cerebellum is “most likely” implicated in DCD because of the evidence provided by long inspection times and RTs (Piek et al., 2007, p. 682). Subsequently, it has been confirmed that inspection time is not significantly affected in participants with ADHD (Galloway-Long & Huang-Pollock, 2018).

Although the conclusions drawn from the inspection time results by these authors are not without question, one could have expected the results, because of the known visuospatial processing deficits in people with DCD (Wilson & McKenzie, 1998); inspection time requires visuospatial analysis that could render this task particularly difficult for affected children. However, there were also important differences in the investigation procedure that could have influenced children with DCD more than other children. As with McLean et al. (2011), lines were on space invader stimuli, but the difference was smaller, antennae were either the same height of 5 mm or different heights of 2.5 and 5 mm, at a close viewing distance of 25 cm, visual angle 0.57 º. The investigational procedure, developed by Anderson (1988), was unusual. Following Anderson (1988), they used a visual patterned mask, called a *wall,* and, because the method of constant stimuli evaluated inspection time there were a considerable number of presentations (120). Children pressed a blue key for lines of the same length and a red key for lines of unequal length. This stimulus and response, different from the typical left/right response that is congruent with left/right difference in stimulus, could capture aspects of working memory. Alloway and Archibald (2008) showed that working memory is impaired in children with DCD. Furthermore, in Anderson’s method, when the space invader was correctly identified, the screen lit up to simulate an explosion. This raises concerns about visual discomfort from feedback from a screen that has been lit up. Also unusually, the method was to collect RT simultaneously to inspection time. Children had to respond to the inspection time stimulus as quickly as possible. These authors do not precisely define RT in their study, and it is not clear whether it included MT or not. Furthermore, inspection time duration influences RT; as the stimulus time for inspection time decreases, RT increases (Jensen, 2006).

Furthermore, RT and inspection time collected simultaneously could lead to a differential effect from speed-accuracy trade-off in participants who have unconfident movement skills. This could have led to exaggerated inspection times; a participant aware of their movement disability may have been more inclined to opt for speed over accuracy with simultaneous collection of RT, which may have included motor time. This could have led to longer than *true* inspection times from a shift in the criterion, C as defined in signal detection theory (Tanner & Swets, 1954).

Second, inspection time in which methods were again after Anderson (1988), was one test in a range of cognitive tests given to 20 children with DCD, 5–13 years, and which Dyck and Piek (2010) compared to children chosen from the lower end of the normal distribution of abilities who had poor motor skills but no diagnosis. Children with weak motor skills had longer inspection times than those with DCD but there were typically developing participants to compare in this study.

Summary of inspection time in developmental coordination disorder. In DCD, the results of investigations published to date deserve replication and further scrutiny because they used unusual test conditions. Inspection time in these investigations may not have been as pure a measure as the authors had intended. A number of methodological issues could have confounded the inspection time results. These could have been by methods of response collection that might have captured working memory; the requirement of a speeded response; the amalgamation of RT and MT, if indeed this happened; or participants' susceptibility to MIS. Difficulties of attentional processes, visuospatial processing, weaker visuospatial working memory, fixation stability and accommodation, together or separately, might have affected inspection times in these children with DCD. Furthermore, spatial processing requirements of the inspection time task could confound it as an assessment of speed in DCD.

3.4.3. Inspection time in Meares-Irlen Syndrome. There have been no studies of inspection time in MIS, as far as is known.

3.5. The Present Investigation: Aims

Previous investigations of inspection time in participants with dyslexia and DCD have been limited to children and have used non-standard stimuli. There have been no investigations of inspection time in participants with co-occurring dyslexia/ DCD. The cognitive and attainment profiles of participants with long inspection times are not clear. The methods used to investigate children with dyslexia and DCD differed in several important ways so they are not directly comparable, particularly the use of a speeded response in the investigations into DCD. Although poor spatial awareness is a main feature of DCD, it is unknown how visuospatial awareness relates to inspection time. Hence, the first broad aim of the current study was:

***Q*1. To explore inspection time in groups of adult participants with typical development and SpLDs of dyslexia, DCD or both.**

In particular, to answer these questions:

Q1.1. Is standard inspection time in adult participants with dyslexia, DCD or both longer than inspection time in participants with typical development?

To shed light on the validity of inspection time measures in previous studies in SpLDs, questions were:

Q1.2. Do quick responses required of adult participants with dyslexia, DCD or both influence their inspection times more than in typical development?

Q1.3. In participants with typical development, dyslexia, DCD or both, do left/right spatial decisions and responses influence inspection times?

Second, as demonstrated in reviews in Chapters 2 and 3, there is uncertainty about inspection times' relationships to cognitive processes of speed, memory and literacy attainment. Previous inspection time studies have ignored visual stress. Could inspection time data from participants with SpLDs add to the current body of knowledge about the validity of the inspection time task? Features characteristic of SpLDs that have larger than typical correlations with inspection time may illuminate what it is that inspection time evaluates. Hence, the second broad aim of the current study was to answer the question:

Q2. Within groups of adult participants with typical development, dyslexia, DCD or both, what are inspection time tasks really measuring?

How does inspection time relate to:

Q2.1. visual discomfort?

Q2.2. auditory and visual memory?

Q2.3. information processing speed as gauged by (a) paper-and-pencil tests (b) simple decision time (SDT), (c) choice decision time (CDT) and (d) simple motor time (SMT)?

Q2.4. literacy attainment: (a) rapid automatic naming (RAN) of digits, letters, colours and objects, (b) sight word and phonemic decoding efficiency and (c) handwriting speed?

Q2.5. What are the cognitive and attainment profiles of adult participants with long standard inspection times?

3.6. Hypotheses

Question 1.

H1.1. Standard inspection time. Given that dyslexia and DCD continue into adulthood, and based on previous research in children, it was hypothesised that standard inspection time would be longer in adults with DCD or dyslexia/DCD than in participants with typical development.

H1.2. Speeded inspection time. Given weaknesses of motor prediction in participants with DCD, a demand for speed may influence decisions that require spatial coordination more than it would in participants without DCD due to speed-accuracy trade-off. Previous studies of inspection time in DCD included a speeded response

(Section 3.4.). It was hypothesised that participants with DCD would have longer inspection times under speeded conditions than those without DCD.

H1.3. Directionality and other spatial decisions. Spatial awareness may be important for inspection time (e.g., Nettelbeck, 2001). In participants with dyslexia, DCD or both, to date, the question of whether the requirement for decisions and responses about left and right, evaluation of relative line-lengths, or more general spatial awareness affects inspection time measured with pi-figure stimuli has not been explored. Commonly, in dyslexia, there is confusion between left and right (Section 3.1) and other visuospatial deficits have been observed (e.g., Giovagnoli, Vicar, Tomassetti, & Menghini, 2016). Visuospatial deficits are characteristic of DCD (Blank et al., 2019). As general visuospatial deficits may influence inspection time in DCD it was not possible to predict the outcome of removing the left/right decision in this group. When stimulus design relieves them of a decision and response about left and right, participants with dyslexia, or both have shorter inspection times than from a standard pi-figure stimulus.

Question 2.

H2.1.Visual discomfort. It is not known if visual discomfort from anomalies, such as of fixation instability and accommodation insufficiency, affect inspection time. Another cause of visual discomfort is from MIS. MIS (Section 3.3) is characterised by visual discomfort caused by certain visual stimuli, particularly those with repeating spatial or temporal patterns. It was possible that inspection time stimuli might provoke MIS-related discomfort either by its spatial design or temporally by pulsed stimuli from some monitors. Although the limbs of pi-figure stimuli are parallel, they are not gratings of a repeating pattern and are well spaced. However, they have high Weber contrast between the small white pi-figure on a large black background. Weber contrast is calculated from the Weber fraction where contrast = $\frac{I - Ib}{Ib}$ in which I = luminance of the pi-figure and I_b luminance of the background. Stimuli are also central to the screen, which increases the risk of visual stress. Pulsed stimuli from a small image on a large contrasting background delivered on a monitor (Section 4.1 & Appendix E) may provoke sufficient discomfort to distract from the inspection time stimulus in some participants who are susceptible to MIS, so it was hypothesised that inspection time would correlate positively with levels of visual discomfort in participants with and without SpLDs.

H2.2. Memory. Previous research into typical relationships between inspection time and memory suggests that inspection time and some tests of memory have medium, significant correlations in children and young adults but smaller correlations in older age (Section 2.3.2). Memory may be required for inspection time task processes, or inspection time performance may link to speed of processes that are also fundamental to memory. Expectations were that participants with dyslexia would have weaknesses in auditory memory relative to those with typical development (Section 3.1) and that participants with DCD would have weaknesses in visual memory, particularly visuospatial working memory (Section 3.2). Because different SpLDs may be characterised by different memory deficits, larger than usual correlations between inspection time and some aspects of memory, specific to different SpLDs, could highlight if aspects of memory have specific links with inspection time or if inspection time reflects fundamental aspects of memory. It was hypothesised that inspection time would relate significantly to both tests of auditory and visual memory in all groups; that the relationships between inspection time and memory would be significantly larger in groups that exhibit memory deficiencies, that is, the SpLD groups; that inspection time would relate more strongly to visuospatial memory than auditory memory, particularly in DCD.

H2.3. Information processing speed (to include motor time). Previous research into relationships between inspection time and information processing speed has been in participants with typical development (Section 2.3.1). In these participants, inspection time has hitherto shown no relationships with MT but has shown significant small relationships with other tests of speed. Hypotheses were that inspection time would significantly correlate with a paper-and-pencil test of coding in all groups; there would be significant but small correlations between inspection time and DTs in all groups; and it was not expected that there would be significant correlations between inspection time and MT. Furthermore, while all SpLD groups would show deficiencies of paper-and-pencil coding compared to the typical group, this would not follow for inspection time.

H2.4. Inspection time and literacy attainment.

Rapid automatic naming. RAN has close parallels with reading. It has sometimes been categorised as a processing speed task (e.g., Jacobson et al., 2011) but, strictly, such a classification assumes that the procedure is automatic; in CHC theory for example, a description of Gs is “once a task is mastered” (Schneider & McGrew, 2012, p. 119). In participants without difficulties with language processes, as both RAN and inspection time tasks index single item rapid visual processing they might share significant variance with inspection time. Participants with dyslexia have not always attained mastery of the digits, letters, colours or object names, so, as the measure of automaticity is a purpose of RAN, its position as a processing speed task is contradictory. In this study, it was hypothesised that if the orthographic nature of inspection time were important for its evaluation, there would be more shared variance between inspection time and alphanumeric RAN than with objects, colours or both in non-dyslexic participants. Furthermore, if spatial processes influence inspection time, then there would be a significant relationship between inspection time and RAN objects but not necessarily with RAN colours. In participants with dyslexia, but not in participants with DCD, difficulties with language processes would override an expected relationship due to spatial awareness between inspection time and RAN objects. Another expectation was that in participants with typical development but not in participants with dyslexia, inspection time would correlate significantly with all RAN tasks due to their shared reliance on speed. In participants with DCD, inspection time would correlate significantly with alphanumeric and colours RAN but the relationship between inspection time and RAN objects would be greater due to weaknesses in visuospatial processes in DCD.

Reading. Other than with reading comprehension (Section 2. 4), as far as is known, any significant relationships between inspection time and attainments in reading have not been exposed. In dyslexia, reading theory is dominated by the presence of weak phonological processes but some visual processes have been implicated (Section 3.1.3). There is less documentation about effects of DCD on reading performance, although some evidence points to visual anomalies that affect reading in this group. Reading efficiency is classed as Gs in the CHC model. Consequently, it was hypothesised that there would be significant negative correlations between inspection time and sight word reading efficiency in all groups of participants.

Handwriting. Handwriting speed is impaired in some people with dyslexia (e.g., Barnett, Henderson, Scheib & Schulz, 2010) but the reasons for this are not always clear. The causes of impairments in handwriting observed in people with dyslexia may be from deficits in language and literacy, fine motor control, motor speed or spatial awareness (Section 3.2). Typically, inspection time does not correlate with motor processes such as MT and as both MT and handwriting belong in Gps, it was not expected that inspection time would correlate with measures of handwriting.

H2.5. Cognitive and attainment profiles. Based on previous research of inspection times in SpLDs, it was hypothesised that participants with long standard inspection times would be those with signs and symptoms of DCD.

3.7. Plan for experimental work

There had been no previous investigations of inspection time in the laboratories of Anglia Ruskin University, so it was first necessary to solve the technical problems associated with accurately measuring inspection time. Chapter 4 describes how inspection times and RTs were measured and refers to two pilot studies, reported in Appendix G, for task development. These pilot studies relied on a small convenience sample of children from a secondary school with mostly neuro-typical development (hereafter referred to as *typical development*). It was important to preserve volunteers with SpLDs for participation in the subsequent main experiment; anticipations that they would be difficult to recruit were correct. Chapter 4 also describes the methodology of the main experiment, which tested a large sample of adults divided into four groups (namely, with typical development, dyslexia, DCD and both dyslexia and DCD: dyslexia/DCD). Results of the main experiment, addressing Questions 1 and 2, are in Chapters 5 and 6, respectively. Chapter 7 is intended as a 'stand-alone' chapter that presents an omnibus analysis of the results from adult participants, addressing the most important aims and hypotheses. This chapter extracts the principal findings from Chapters 5 and 6 then, with the addition of some new analyses, considers the implications for theory and practice. The general discussion is in Chapter 8.

CHAPTER 4

Task Development and Method for Studies 1, 2 and 3.

Section 4.1 of this chapter contains descriptions of hardware, software and procedures for the accurate measurement of inspection time and reaction time (RT). Details of hardware, software and explanations for how an oscilloscope verified (a) image duration and (b) image persistence are in Appendix E. Also in Appendix E are the results of two small studies of children mostly with typical development, which explored variations of the standard inspection time test to evaluate spatial influences on it. These are summarised in Section 4.2.

4.1. Hardware and Software

4.1.1. Hardware. A personal computer delivered stimuli displayed on a CRT monitor and recorded responses from a response box. The Dell computer operated with Windows 7 Professional and displayed images on a Sony Trinitron, 16 × 12 in. (406 x 305 mm) monitor, spatial resolution 1024 × 768 pixels; temporal resolution 85 Hz and consequent interframe interval (IFI) of 11.76 ms. Responses were collected by a customised Black Box Toolkit Company response box (The Black Box ToolKit Ltd, Sheffield, UK). The response box had horizontally aligned, 2 cm buttons, one green button flanked by two white, with 3 cm between the centres of the buttons. One finger of the participants' choice operated the buttons.

4.1.2. Software. Computer programs were developed in MATLAB R14a (The Mathworks Inc. Natick MA, USA) with Psychophysics Toolbox extensions, Version

3.0.11 (PTB-3; Brainard, 1997; Kleiner et al., 2007). Generic programs were: 1) instructions with practice trials and 2) main trials.

Computer Program 1 for instructions with practice trials. Instructions and introductory stimulus sequences, which formed Program 1, were adapted from a program written in Visual Basic (Microsoft Corp., Redmond WA, USA) kindly supplied by Preiss and Burns (2012). Introductory trials, which used a left-hand stimulus (Figure 1, left-hand stimulus image) only, shown each time for 165 ms (14 × IFI), followed a sequential overview of the whole sequence. In each trial, participants were shown a cross, and after 1058 ms, the stimulus image in the same position. Then, the mask immediately replaced the stimulus image. Up to 20 trials showed left- or right-hand stimuli randomly for 165 ms until participants made five consecutive correct responses. MATLAB generated the pseudorandom numbers. Participants received further oral explanation when necessary.

Computer Program 2 for main trials, adaptive staircase and resolution. Main trials used generic Program 2 to resolve each participant's inspection time. In Program 2, as in Program 1, instructions to initiate the routine were "Keep going. Press the middle button." Participants pressed and kept pressing, with their chosen finger, the centre button of the three-button response box. If they lifted their finger from the centre button before the target stimulus appeared, a *false start* was recorded and the sequence began again. The main trial sequence was a blank black background (1058 ms; 90 x IFI); the cross (353 ms; 30 X IFI); blank black background (1058 ms); one of two randomly chosen target stimuli (predetermined duration from an adaptive staircase procedure); mask (353 ms); blank black background. On indication of their response by a button press to the left- or right-hand button, the screen displayed the instruction "Keep going. Press the middle button." A direction change in the adaptive staircase was a *reversal.* Sets of trials ended after 10 reversals.

The adaptive staircase, method of limits, procedure started at stimulus duration 165 ms. A *two-down, one-up* staircase was always used. Two correct responses, two-down, were required before the stimulus duration was reduced and after one incorrect response the stimulus duration increased, *one-up*. Step size, dictated by the IFI, was calculated and recorded for each trial. The ratio of the down-step size to up-step size is important. The two-down, one-up rule has been shown to work best with a ratio of 0.59 between up-step to down-step size (García-Pérez, 1998). The step size for the inspection time investigation, limited by the IFI, was a ratio of 0.50 or down one IFI, 11.76 ms, after two correct responses and up two IFIs, 23.52 ms, upon an incorrect response. If there was an incorrect response after a correct response, the duration increased and the staircase direction reversed. If, after a wrong response, there was a second correct response the direction reversed. To reduce unnecessary trials, initial step sizes down were two IFIs until below 80 ms or a reversal, and one IFI thereafter. The procedure continued until the IFI imposed a lower limit on inspection time, at which point the stimulus duration remained as one IFI unless there was an incorrect response.

Computer recorded events. Event times were measured by the **`GetSecs()`** function from PTB-3. There were individual results for all trials. These were: requested **`STIMULUS_DURATION`** and actual duration **(`thisDuration = (maskOnset – stimOnset)`)** of each image from the start of the first frame to the start of the mask; false starts–release of the centre button before appearance of the target image; left- or right-hand target stimulus; correct or incorrect response; and cumulated number of reversals. Inspection time was the average stimulus duration of the last eight reversals.

Reaction, decision and motor time. Decision time (DT) and motor time (MT) together make up reaction time (RT). DT is the time needed to release a home key on a response box after the start of the stimulus whereas MT is the time needed to press another button after release of the home key (Jensen, 2006). When a record of DT was the main object of the trials, as in simple DT (SDT) and choice DT (CDT), programs were without a staircase and there was no mask. To maintain participants' attention, target cross and decision stimulus interval varied randomly, between 0.5–2 seconds. The image remained on the screen until participants pressed the appropriate response button, with verbal and on-screen instructions to do so “as fast as possible”. For CDT, DTs were recorded as correct or incorrect. The mean and standard deviation of SDT and CDT were from 20 trials.

Inspection and decision time stimulus images.

Cross. The white, 9.5 mm, cross on a black background aligned with the centre of each stimulus image.

Target stimuli. Target stimuli were 8-bit (greyscale) bitmap images, of size 676 kB, 720 × 960 pixels. Stimulus images were a fraction of the screen area. Presentations were central, 203 mm or 502 vertical scan lines, to the centre of the stimulus, on horizontal scan line 213. They were 90 mm below the top of the otherwise black screen and did not start to be visible until 3.25 ms into the frame refresh cycle of 11.76 ms. Target stimulus images were constructed in Paint (Microsoft Corp., Redmond WA USA). Target stimulus designs were different between investigations and are described in the method for each investigation. The mean value in image matrices for all white target images were standardised to 0.3999 (frame buffer values were zero = black and 255 = white RGB) by the MATLAB function: **`mean2().`** Only black (0) and white (255) pixels were used by GNU Image Manipulating Program 2.8.14 (GIMP), used to convert the images to 8-bit greyscale.

Masks. Construction for mask images was as for stimulus images.

4.1.3. Accuracy.

Optimal performance. Program performance speed and accuracy was optimised by OPENGL (Silicon Graphics Inc.), an application program interface; 8-bit bitmaps; the use of the highest **`Priority`** settings in PTB-3, which suspend background operations and thus optimise selected sections of code: **`Drawing finished`** after **`PutImage ()`**, a function that sends graphical information to the buffer. Unnecessary MATLAB windows were closed; **`for`** loops were avoided to reduce execution time; preloaded variables and stimuli were shown at least once before each set of trials.

The frame cycle. The monitor frame cycle is fundamental to accurate stimulus delivery. In Programs 1 and 2, at the start of each trial, PTB-3 measured and reported the time between two successive vertical blanks (VBL), the IFI, which dictated the refresh rate. Refresh rate, in frames per second, is the rate at which frames appear. Stimulus durations were in multiples of the IFI, average 11.76 ms. The PTB-3 function: **`PutImage()`** loaded or drew an image onto the back buffer and the function **`Flip()`** delivered an image to the screen from this buffer, which synchronised the VBL with the buffer swaps. Important code is in Appendix E. Tables E1 and E2 explain the meanings of input and output arguments for the delivery of a target stimulus and mask (Kleiner et al., 2007). *C*hecks for timing accuracy are in Appendix E.

4.2. Summary for Studies 1 and 2

Two studies, reported fully in Appendix E, piloted procedures and image designs. In Study 1, it proved a challenge to design adequately masked stimulus pairs for a fair test of individual spatial issues: length, direction or both. Unexpectedly short inspection times and higher correlations with memory might be attributable to inadequate masks and invalidated the results. In Study 2, the random dot mask was more effective with the new stimuli, but the variable degree of difficulty between circles designs thwarted a fair comparison. Additionally, gestalt processes may have been involved. This would involve the perception of the image as a whole rather than an evaluation of its parts and thus not be directly comparable to letter-like stimuli such as the pi-figure. Small numbers and the absence of participants with SpLDs limited the use of Studies 1 and 2 to answer questions advanced in Section 3.5 but they served to hone experimental techniques for Study 3 and highlight potential pitfalls.

4.3. Study 3

In Study 3, participants with diagnosed SpLDs were adults because adults had not received attention in the literature to date. To address the aims and hypotheses set out at the end of Chapter 3, Study 3 used a standard pi-figure stimulus and flash mask. This reversion to letter-like stimuli was to avoid the possibility that gestalt processes would be involved, as was the likelihood with the abandoned circles stimuli. Furthermore, comparisons with previous work would be more meaningful if the stimuli were closer in design to the standard pi-figure and flash mask, more generally used. Therefore, tests for line-length discrimination, which in Study 1 used dotted stimuli that were difficult to mask, were postponed for a future investigation and replaced by a simple comparison of speeded and un-speeded responses to the pi-figure. Letter-like stimulus figures and mask tested for the effects of directionality, but they had a slightly altered design from the pi-figure to compare discrimination between left/right and between up/down discrimination and responses. A range of cognitive and attainment tests were administered so that they (a) could be used to confirm diagnoses of dyslexia and DCD and (b) be compared to inspection time.

4.4. Method: Study 3

4.4.1. Participants. Participants were students or staff from Anglia Ruskin University and from the wider community, who had responded to advertisements and word of mouth. Advertisements were with the Department of Psychology's research participation scheme, disability forums, a doctors' surgery, lectures, local colleges, a newspaper, social media, and the university website. Psychology students earned class credit and, for all participants, there was a draw for vouchers: one first prize of £100; three second prizes of £50; and five third prizes of £20. Data was collected over 12 months. Participants with English as a second language did not participate because of possible confounds to verbal and phonological tests. In schizophrenia, masking of visual stimuli is exaggerated (Green, Lee, Wynn, & Mathis, 2011), so volunteers with schizophrenia or a family history of schizophrenia were asked not to volunteer. Several volunteers declared on the questionnaire that they had autism, bipolar disorder, cerebral palsy, foetal alcohol syndrome or multiple sclerosis. Data from these participants were set aside. Participants reported either normal or corrected-to-normal vision. Power calculations for the adult study were made with G*Power (Faul, Erdfelder, Lang & Buchner, 2007; 2009).

Prospective power calculations. First, calculations were based on three groups matched for age and intelligence with a repeated-measures ANOVA anticipated as the analytical method, an effect size of .25, power of .80; α error probability of .05. The recommended sample size was 159. Recruitment attained 141 participants. However, hierarchical regression was used eventually instead of more straightforward ANOVA and a fourth group of participants with dyslexia/ DCD emerged.

Retrospective power calculations*.* Retrospective power calculations for a hierarchical regression analysis with six predictors showed that for effect size of 0.25; power of .80; and α error probability of .05; sample size needed to be 65.

Groups. Finally, there were 141 participants, 18–56 years. All had 12 or more years of formal education. Four unequal, unmatched groups were constructed by diagnostic methods described below. Table 1 displays ages and standard scores for Wide Range Intelligence Test (WRIT) verbal analogies and matrices (Glutting et al., 2000) in these four groups. Participants with dyslexia/DCD scored less on WRIT verbal analogies and matrices. Fewer men than women volunteered, mean age and ranges of the different groups were similar. Psychometric profiles of three groups with SpLDs are in Tables H1 and H2. Participants without a history of SpLDs formed one group for typical development. Three groups contained participants with formal diagnoses of either dyslexia, DCD or both by an educational psychologist or specialist teacher with a Practicing Certificate validated by the Specialist Assessment Standards Committee (SASC; www.sasc.org.uk).

Table 1

Study 3: Ages and Intelligence Test Standard Scores in Four Groups of Participants

N = 141		Typical	Dyslexia	DCD	Dyslexia/DCD
n (men)		50 (17)	40 (14)	33 (13)	18 (4)
Age (years)	median	23	26	24	27
	mean	29	31	30	31
	range	18–55	18–56	20–54	19–53
WRIT verbal analogies	median	102	98	101	89
	mean	100	97	100	90
	range	68–114	58–121	71–118	68–114
WRIT matrices	median	108	103	103	94
	mean	105	101	102	95
	range	74–125	67–127	73–125	68–127

Note. DCD = developmental coordination disorder; dyslexia = developmental dyslexia; WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000).

Results of several tests of cognition and attainment (Table H1) provided further evidence to the official individual diagnoses as follows:

Typically developing participants. Fifty participants did not have a diagnosis of SpLDs.

Developmental dyslexia. For inclusion in the group of participants with dyslexia, tests were: elision and rapid automatic naming, Comprehensive Test of Phonological Processing (CTOPP-2; Wagner et al., 2013); sight words and phonemic decoding, Test of Word Reading Efficiency (TOWRE-2; Torgeson et al., 2012); digits forward, Test of Memory and Learning (TOMAL-2; Reynolds & Voress, 2007). Thus, besides a formal diagnosis, all participants with dyslexia had either:

- two standard deviations below the mean for 50 typically developing participants (typical mean; $z = \pm 1.96$) in at least one of the above tests; or
- one standard deviation below the typical mean ($z = \pm 0.98$) in two of the tests.

Developmental coordination disorder. For inclusion in the group of participants with DCD, tests and questionnaires were: handwriting or graphic speed subtests from the Detailed Assessment of Handwriting (DASH 17+, Barnett et al., 2010); choice reaction time (CRT, Chapter 4) that was separated into decision (CDT) and motor times (CMT); rapid automatic naming (RAN) from CTOPP-2 and the Adult Developmental Coordination Disorder/Dyspraxia Checklist for Further and Higher Education (ADC; Kirby & Rosenblum, 2008). Thus, besides a formal diagnosis, all participants with DCD had either:

- a score of more than 56 on the ADC, indicating a risk of DCD, or
- two standard deviations below the typical mean ($z = \pm 1.96$) in at least one of the above tests of motor coordination; or
- one standard deviation below the typical mean ($z = \pm 0.98$) in two of the tests.

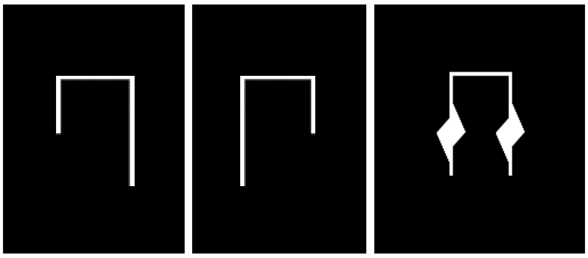
Developmental dyslexia with developmental coordination disorder. Eighteen volunteers had formal diagnoses of both dyslexia and DCD (dyslexia/DCD). They fulfilled the additional requirements described above for both dyslexia and DCD.

4.4.2. Materials.

Questionnaire. Age, gender, hand, SpLD, family history of SpLD, prematurity, corrected-to-normal eyesight, computer gaming and smoking habits were recorded by questionnaire (Appendix H). Participants were questioned about conditions, illnesses or medications that might affect tests. Some of these data were to examine the characteristics of participants with long inspection times (Section 6.13).

***Sussex Near Vision Reading Test Type Chart*.** All participants could read type size N10 of the Sussex Near Vision Reading Test (Sussex Vision International, 2015) held at arm’s length of about 60 cm.

Inspection time. Section 4.1 describes measurement of inspection time. Standard inspection time Test IT1 for adults used the well-known, standard pi-figure stimuli with a lightning flash mask (Figure 2).

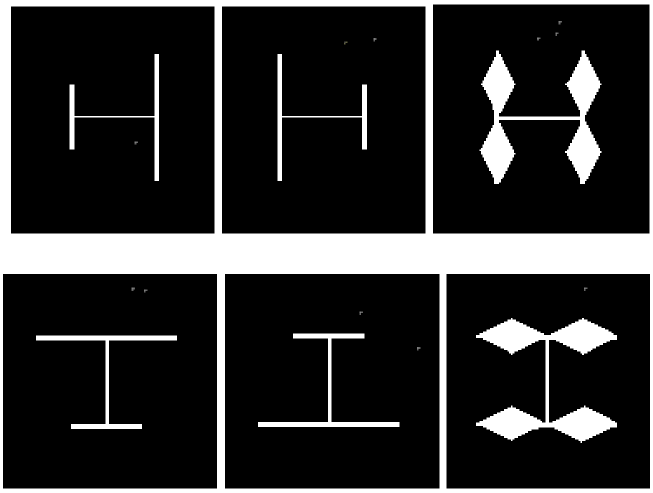


Test IT1, un-speeded response

Test IT2, speeded response

Figure 2. White left and right inspection time stimulus, mask and response condition for standard inspection time (Test IT1) and speeded inspection time (Test IT2) on black background.

The vertical limbs were of different lengths, normally easily distinguishable from each other. The response was un-speeded. Due to results from Study 1, in Study 3, to increase difficulty of the task, lines of target stimuli were as thin as possible. Standard inspection time, Test IT1, generated the variable standard inspection time (IT1) in milliseconds. Speeded inspection time, Test IT2, generated the variable speeded inspection time (IT2). Test IT2 was the same as Test IT1 in every way except participants responded as fast as possible. To test for difficulties with directionality, previous stimulus designs were abandoned in favour of rotation of the stimulus through 90 °. Rotation of a pi-figure causes a laterally asymmetrical stimulus. Due to results of Study 1, it was apparent that random dots were not effective for letter-like stimuli, so to test laterality, non-standard stimulus images for Tests IT3 and IT4 used the same linear elements as in the pi-figure for Test IT1, rearranged to permit rotation through 90 ° without asymmetry (Figure 3). Left/right inspection time Test IT3 was to establish inspection time while retaining the left/right decision and response. Rotation of left/right inspection time Test IT3 stimulus generated the stimulus for up/down inspection time Test IT4, and required an up/down decision and response—on a response box also rotated through 90 ° — rather than the usual left/right response. Responses for left/right and up/down Tests IT3 and IT4 were un-speeded.



Left/right, un-speeded inspection time Test IT3

Up/down, un-speeded inspection time Test IT4

Figure 3. White left and right; and up and down non-standard stimuli, mask and response conditions for left/right and up/down Tests IT3 and IT4 on black background.

Comparatively long left/right inspection times would result in longer left/right inspection time IT3s than up/down inspection time IT4s. As the left/right decision is more familiar, an up/down decision could be more difficult for people with poor spatial awareness, such as participants with DCD, in which case left/right inspection time IT3 would be longer than in typically developing participants, but not as long as up/down inspection time IT4. Table 2 has details of dimensions for stimuli.

Table 2

Study 3: On-Screen Dimensions and Viewing Angles of Stimuli

Stimulus	Dimension (mm)		Pixels	Viewing angle (º)
Locating cross	Height	9.53	24	0.90
	Width	9.51	24	1.06
	Line thickness	0.06	2	0.08
Stimuli	Height of long limb	30.58	77	2.88
	Height of short limb	15.89	40	1.49
	Width	17.87	45	1.68
	Difference between the two limbs	14.69	37	1.38
	Line thickness	1.19	3	0.11

Note. Viewing distance = 60 cm.

Psychometric tests of intelligence. There was an assessment for intelligence because of its expected shared variance with inspection time (Section 2.3.1) and its likely shared variance with other measures of cognition and attainment. However, it could be that visuospatial processing deficiencies in DCD could affect performance on tests of visual intelligence (Section 3.2). An alternative method of assessing participants' intelligence is to use a verbal intelligence test. In DCD, there is no reason to believe that verbal ability is selectively deficient. However, people with dyslexia regularly have verbal ability less well developed than visual ability (Section 3.1). Therefore, both visual and verbal tests evaluated intelligence.

V*erbal analogies* (WRIT; Glutting, Adams & Sheslow, 2000). This untimed test of oral language understanding and knowledge requires an appropriate verbal response and assesses crystallised, verbal ability. An example analogy is "Eagle is to bird as vellum is to ___". The metric was number of correct analogies until five consecutive errors. WRIT assessments are similar across gender and ethnicity.

Visual matrices. (WRIT; Glutting, Adams & Sheslow, 2000). WRIT visual matrices individually assess analytical, visual fluid ability. It tests the ability to "visualise relationships between elements such as perceiving the similarity between complex visual patterns" (Glutting, et al., 2000, p. 58). Participants have 30 seconds to choose one of 3–6 pictures that best completes a matrix. Items that are more difficult have 45 seconds and a score weighted to two points compared to the easier items that have one point. The test discontinues after four errors in five matrices. The metric is total score.

Tests for visual discomfort. Two tasks evaluated symptoms of visual discomfort. These were The Visual Discomfort Scale (VDS; Conlon et al., 1999) and The Pattern Glare Test (PGT; Wilkins & Evans, 2001). Ocular rather than psychophysiological conditions can cause symptoms similar to Meares-Irlen Syndrome (MIS), so reported symptoms of visual discomfort from the VDS, the PGT or both do not equate to a diagnosis of MIS. To diagnose MIS requires a suitably qualified optometrist.

The Visual Discomfort Scale(VDS). The VDS has 23 questions, which "addressed possible somatic, perceptual, and performance difficulties experienced with exposure to different light sources or when reading" (Conlon et al., 1999, p. 641). Responses, graded on a Rasch scale between zero and three (0 = never; 1 = occasionally; 2 = often; 3 = almost always), were summed to give values between 0–69. During scale development, the authors demonstrated that a single continuum derived from the scale represents degree of discomfort. Total score provides continuous data. Conlon et al. (1999, p. 649) defined *low visual discomfort* as a score of less than 24 positive answers on the VDS.

The Pattern Glare Test (PGT). Participants answered questions about visual distortion and discomfort that they had experienced, after they had looked at low, medium, and high frequency (0.5, 3 & 12 cycles per degree), square wave monochrome gratings for five seconds. Questions were about impressions of colour, how lines bent or blurred, shimmered or flickered, faded, or there were other effects such as shadowy shapes. Pattern glare has occurred if there are more than three positive answers to the questions for the medium grating (B. Evans, personal communication, October 8, 2017). Pattern glare correlates with age but not gender (Evans & Stevenson, 2008). Nominal data were susceptibility to pattern glare (1), or not (0). Participants with a history of epilepsy cannot take the PGT.

Visuospatial, sequential short-term and working memory. The standardised Corsi Block-Tapping Task from The Psychological Investigation Building Language (PEBL) tested visuospatial memory by computer (Corsi, 1972; Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000; Mueller, 2010). The program also recorded details about participant responses. Nine large squares of colour were on the screen during each trial. The squares lit up briefly, initially two and for each successive trial the number increased by one square. Increases were up to seven squares. After the sequence had appeared on the screen, participants clicked the squares with a mouse-controlled cursor in the same and then reversed order of presentation. Total correct score forward and total correct score backward indexed visuospatial short-term memory and working memory, respectively.

Forward and backward digit span. In digit spans from the Test of Memory and Learning-2 (TOMAL-2; Reynolds & Voress, 2007), participants repeat numbers of increasing string length read out at intervals of one second, in the same or reverse order. The tests, that evaluate sequential auditory and working memory, respectively, are believed to reflect levels of attention and concentration (Reynolds & Voress, 2007). Forward digit span uses the left hemisphere and relates to intelligence (e.g., Gignac & Weiss, 2015). Backward span taps an aspect of the Baddeley and Hitch's (1974) visuospatial sketchpad, linked to the right hemisphere (Reynolds & Voress, 2007).

Abstract visual memory**.** Abstract visual memory (TOMAL-2) assessed nonverbal memory from "immediate recall for meaningless figures" (Reynolds & Voress, 2007, p. 16). Participants had to recognise an abstract geometric figure displayed for five seconds from a subsequent display of six similar figures. There was increased figure complexity each trial until two of three consecutive items were incorrect. This test evaluates visual processes, attention to detail, ability to match an abstract figure and aspects of right hemisphere processing (Reynolds & Voress, 2007)**.**

Symbol Digit Modalities Test. A paper-and-pencil test, the Symbol Digit Modalities Test (SDMT; Smith, 1982) assessed coding skill. The participant converted with a key, in 90 seconds, as fast as possible, meaningless geometric symbols into digits, 1–9. The symbols use visual processes and numbers include verbal processes. The ordinal test variable was number of times a participant matched a digit to a symbol correctly. The SDMT was chosen rather than similar coding tests because it requires participants to write familiar numbers rather than unfamiliar symbols, a task that makes additional demands on cognitive processes. Moreover, specialist teachers routinely use the SDMT to assess so-called processing speed. Coding tests are among tests that measure Gs in the Cattell-Horn-Carroll (CHC) model of human cognitive abilities.

Decision time. Section 4.1 describes methods for measuring SDT and CDT. The SDT test employed the short right-hand standard, pi-figure stimulus used in Test IT1, without a mask. Both left and right standard pi-figure stimuli (Figure 1), unmasked, were in the CDT task. Participants pressed the centre button of a response box to initiate a sequence of a cross followed by the stimulus at random intervals. The duration between the appearance of the stimulus and the moment the participant released the home button recorded on a continuous scale as DT. CDT was of correct DTs. There were 20 trials each for tests of SDT and CDT. In CHC theory, Gt includes SDT and CDT (Table C2; Schneider & McGrew, 2012).

Motor time. Section 4.1 describes the method for motor time (MT) measurement. MT is the time taken for a participant to move a finger from a home button to a response button. CMT included time for some participants to waver over the response box while they chose which button to press, so SMT was the preferred measurement for MT, recorded on a continuous scale. In CHC theory, Gps includes SMT.

Tests of literacy. They were two subtests from Test of Word Reading Efficiency (TOWRE-2; Torgeson et al., 2012) and four subtests from Detailed Assessment of Handwriting (DASH-17+; Barnett et al., 2007).

Sight word reading and phonemic decoding efficiency. The Test of Word Reading Efficiency (TOWRE-2; Torgeson, Wagner & Rashotte, 2012) measured word-level reading *efficiency*, which encompasses speed and accuracy. After a brief practice, vertically arranged words in two subtests were read for 45 seconds. Examples of sight words are “is” and “phenomenon”. Examples of phonemic decoding words are “ip” and “prilingdorfent” *(*Torgeson et al., 2012, Test Materials).

Rapid automatic naming of digits, letters, colours and objects. There are four RAN tests in the Comprehensive Test of Phonological Processing (CTOPP -2; Wagner et al., 2013). Each task consists of 36 randomly arranged items, named as rapidly as possible from left to right. There is a short practice trial for each set. Items are (a), digits 2, 3, 4, 5, 7 and 8; (b) letters a, c, k, n, s and t; (c) coloured blocks of black, blue, brown, green, red and yellow; and (d) objects which are small pictures of a boat, chair, fish, key, pencil and star. Numbers of seconds to read each array provided four continuous variables.

Copy fast, copy best, alphabet writing and graphic speed. Subtests of the Detailed Assessment of Handwriting (DASH; Barnett, Henderson, Scheib & Schulz, 2007) measured copy fast, copy best, alphabet writing and graphic speed. Participants copied: 'The quick brown fox jumps over the lazy dog.' The alphabet-writing task reflects (a) if the participant has remembered this common sequence accurately and (b) the speed of writing these letters. The time a participant takes to place a cross between successive sets of two concentric circles records fine motor, hand movement speed. These subtests express speed in items completed per minute. Fast legible handwriting requires perceptual, cognitive, kinaesthetic and motor skills for the formation of each letter. To put letters in the appropriate place in words and on a page requires skills of spatial awareness. Fast legible handwriting may link to academic success (Dinehart, 2015).

Adult Developmental Coordination Disorder, Questionnaire. The Adult Developmental Coordination Disorder/ Dyspraxia Checklist (ADC) for Further and Higher Education (ADC; Kirby & Rosenblum, 2008) evaluates signs and symptoms of DCD in adults. There are ten questions in Section A that evaluate characteristics of DCD as a child, for example, "As a child, did you have difficulty eating without getting dirty?". There are 30 questions in Section B. These evaluate further details of DCD, for example, "Do you currently have difficulty with self-care tasks such as shaving or putting on make-up?" Positive answers to the questionnaire, weighted differently for each question, are on a scale of 1–4. Variables were: (a) nominal data of at risk of

DCD or not, in which at risk required a score of 17 in Section A and 56 for Sections A and B together; (b) total score for Section A; (c) total score for Section B.

4.4.3. Design. The independent variable was participant group. Participant groups test scores served as a dependent variable. To confirm diagnoses and to address the questions, participants took chronometric, cognitive and attainment tests and questionnaires, in a consistent order (Table 3). The exceptions were chronometric tests: Tests IT1–4, Tests for Simple and Choice Reaction Time (SRT; CRT), which were in a rotation, counterbalanced by a Latin Square. To maintain participants' attention, the type of activity varied regularly between reading, oral, screen and writing tests.

Statistical analyses. Analyses were with raw scores, unless stated otherwise, in IBM SPSS Statistics for Windows, Version 20 (IBM Corp., Armonk, NY, USA) and MATLAB R14a (The Mathworks Inc. Natick MA, USA). A nonparametric one-way repeated-measures ANOVA evaluated differences between ITs 1–4. Correlation analyses were between ITs1–4, and between summed z-scores of IT1–4, cognitive and attainment tests. Statistical analyses used .05 as the decisive significance value of alpha. Cohen's standard (Cohen, 1988) evaluated effect sizes with value 0.10 to 0.29, a small association; 0.30 to 0.49, medium; 0.50 or over, large. Statistically significant differences between correlations were compared by Cocor (Diedenhofen & Musch, 2015), an on-line statistical tool. No adjustments for multiple correlations were made, to make sure that significant results were not overlooked. At an exploratory stage, to include all possible covariates, it is expedient to tolerate possible Type I errors (e.g., Streiner & Norman, 2011). Accordingly, although there are one or two exceptions, discussion about significant effects was confined to medium and large correlations.

Analyses included descriptive statistics of the variables in the four groups, correlational analyses between variables and hierarchical regression analyses. Hierarchical regression analyses compared inspection times in the groups because inspection times were not distributed normally, thus the more obvious ANOVA was inappropriate. Controls were made for age, gender and WRIT matrices, where appropriate.

Table 3

Study 3: Order of Tests and Questionnaires

1. Sussex Near Vision Reading Test (Sussex Vision International, 2015)
2. Adult Questionnaire (Appendix H)
3. Adult Developmental Coordination Disorder/Dyspraxia Checklist (ADC) for Further and Higher Education (Kirby & Rosenblum, 2008)
4. Corsi Block-Tapping Task (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000)
5. Verbal analogies, Wide Range Intelligence Tests (WRIT; Glutting, Adams & Sheslow, 2000)
6. Elision and rapid automatic naming, Comprehensive Test of Phonological Processing (CTOPP-2; Wagner, Torgeson, Rashotte & Pearson, 2013)
7. Visually guided pointing task (Sirigu et al., 1996)
8. First three inspection time and decision time tests (Sections 4.1 & 5. 1. 2)
9. Sight words and phonemic decoding, Test of Word Reading Efficiency (TOWRE-2; Torgeson, Wagner & Rashotte, 2012)
10. Digits forward, Test of Memory & Learning (TOMAL-2; Reynolds & Voress, 2007)
11. Digits backward, TOMAL-2
12. Abstract visual memory, TOMAL-2
13. Remaining three inspection time and decision time tests (Sections 4.1 & 5. 1. 2)
14. Symbol Digit Modalities Test (Smith, 1982)
15. Copy best, alphabet writing, copy fast, graphic speed, Detailed Assessment of Speed of Handwriting 17+ (DASH 17+; Barnett, Henderson, Scheib & Schulz, 2010)
16. Visual matrices, WRIT
17. Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999)
18. Pattern Glare Test (Wilkins & Evans, 2001)

4.4.4. Procedure. The Departmental Research Ethics Panel of the Department of Psychology of Anglia Ruskin University approved the study. The researcher is a specialist teacher qualified to assess for dyslexia, and DCD in adults. Participants signed a consent form that expressed their willingness to participate before they took the tests individually. Tests were in a laboratory that had an overhead fluorescent, Crompton 3500K/35 58W White FT58W, CAT2 Diffuser tube. Participants sat to the left of the researcher. Participants took all the tests at one sitting. Tests took about 100 minutes, of which chronometric tests took about 25–30 minutes. After they had completed all tasks, participants received thanks and a debriefing.

4.4.5. Group differences. Table 1 includes group values for age, numbers for men and women, WRIT verbal analogies and WRIT matrices. Apart from investigations proposed at the end of Chapter 3, the data collected afforded a unique opportunity to examine profiles of adults with dyslexia, DCD and both (Tables H1 & H2). Table H2 shows a summary of the βs from hierarchical regression analyses that appear in Appendices L–R. All groups of participants with SpLDs showed differences in cognitive and attainment profiles to participants with typical development.

4.5. Plan for Results and Discussion

Results and discussion of Study 3 are in the following chapters. Chapter 5 addresses Questions 1.1 to 1.3: it reports and discusses standard inspection time, speeded inspection time and results of the non-standard test to explore directionality. Chapter 6 addresses Questions 2.1–2.5: it reports and discusses relationships between standard inspection time and visual discomfort, memory, chronometric and coding tasks, literacy attainment and cognitive profiles associated with inspection time. In Chapter 7 is an omnibus analysis of the data from Study 3. The general discussion is in Chapter 8.

CHAPTER 5

Study 3: Results and Discussion

Standard and Speeded Inspection Time and Directionality

This chapter addressed the first aim of this work, which was to explore inspection time in groups of adult participants with typical development and SpLDs, phrased as Questions 1.1–1.3 as set out at the end of Chapter 3. It presents results of inspection time Tests IT1-4: standard (IT1), speeded (IT2), left/right (IT3) and up/down (IT4) inspection times, with four groups of adult participants, namely with typical development, dyslexia, DCD or dyslexia/DCD. Descriptive statistics for IT1–4 are presented in Table 4 and in Table 5 are correlations of inspection times (IT1–4) with age, gender and WRIT tests of intelligence for the separate groups. Hierarchical regression analyses with inspection times as dependent variables established differences between groups. Supplementary tables and analyses for Chapter 5 are in Appendices I–K.

Table 4

Study 3: Descriptive Statistics for Inspection Times in Four Groups

Inspection time (IT) *N* = 141		Skewness	*SE* Skewness	Kurtosis	*SE* Kurtosis	Shapiro-Wilk Test statistic	Median (ms)	Interquartile range (ms)	Mean (ms)	Standard Deviation
Typical *n* = 50	IT1	0.98		0.99		.93**	50	14	53	14
	IT2	1.89		5.06		.84***	51	16	55	19
	IT3	1.51		2.77		.87***	46	24	53	23
	IT4	0.53	0.34	− 0.21	0.66	.96	49	69	52	18
	(IT2 − IT1)	0.61		0.20		.97	− 0.80	2.10	2.20	1.61
	(IT3 − IT4)	1.26		3.12		.91.	− 1.45	1.84	0.80	2.20
Developmental dyslexia *n* = 40	IT1	1.39		3.80		.91**	54	23	57	17
	IT2	0.85		0.29		.94*	51	20	56	16
	IT3	0.87		− 0.09		.91**	56	35	63	27
	IT4	1.49	0.37	3.36	0.73	.89**	57	36	64	28
	(IT2 − IT1)	− 0.15		4.34		.90**	− 2.93	1.33	− 0.60	1.73
	(IT3 − IT4)	− 1.07		2.92		.94*	1.41	4.13	− 0.50	3.34
Developmental coordination (DCD) disorder *n* = 33	IT1	1.59		3.35		.85***	59	21	60	19
	IT2	0.18		2.89		.96	60	34	59	18
	IT3	1.02		0.57		.92*	60	37	67	30
	IT4	1.26	0.41	3.49	0.80	.91**	62	26	64	28
	(IT2 − IT1)	− 1.87		7.02		.85***	2.90	2.21	− 0.60	1.98
	(IT3 − IT4)	0.57		0.29		.95	2.90	29.42	7.54	31.92
Developmental dyslexia/DCD *n* = 18	IT1	2.03		5.46		.81**	66	19	69	24
	IT2	1.86		2.89		.75***	56	45	79	49
	IT3	0.77		0.74		.95	66	34	68	23
	IT4	0.61	0.54	− 0.89	1.04	.90	68	59	75	40
	(IT2 − IT1)	1.21		0.42		.84**	− 9.60	3.79	− 1.40	3.41
	(IT3 − IT4)	− 0.60		0.43		.95	− 0.80	5.33	− 7.60	3.34

Note. IT1 = standard inspection time; IT2 = speeded inspection time; IT3 = left/right inspection time; IT4 = up/down inspection time. *p* <.05; ** *p* <.01; *** *p* < 001, two-tailed.

Table 5

Study 3: Spearman and Kendall Correlation Analyses of Inspection Time Tests 1–4*, Age, Gender, Visual and Verbal Intelligence in Four Groups*

Typical *n* = 50	IT1	IT2	IT3	IT4	Matrices	Analogies
IT2	**.45***	1.00				
IT3	.26	**.37**	1.00			
IT4	.12	**.30***	**.45***	1.00		
Matrices (WRIT)	**− .29***	− .24	− .14	−.18	1.00	
Analogies (WRIT)	− .01	− .07	.04	.12	**.30***	1.00
Age	− .17	− .14	− .17	.01	.14	**.65***
Gender	.20	.21	.17	.09	**– .38**	– .25
Dyslexia *n* = 40						
IT2	**.65***	1.00				
IT3	**.43**	**.40***	1.00			
IT4	**.32***	**.57**	**.33***	1.00		
Matrices (WRIT)	.06	.05	.05	−.26	1.00	
Analogies (WRIT)	.11	.10	− .05	.04	**.35***	1.00
Age	−.01	− 10	− .16	.09	− .17	**.47**
Gender	−.04	.05	.21	–.03	– .12	**– .29***
DCD *n* = 33						
IT2	**.55***	1.00				
IT3	.28	**.40***	1.00			
IT4	.08	.07	.12	1.00		
Matrices (WRIT)	.13	.06	− .11	− .19	1.00	
Analogies (WRIT)	− .24	− .06	.27	− .20	− .12	1.00
Age	.14	**.37***	**.42***	.14	− .25	.00
Gender	**.40**	.13	– .01	– .04	.01	**.38***
Dyslexia/DCD *n* = 18	IT1	IT2	IT3	IT4	Matrices	Analogies
IT2	.34	1.00				
IT3	.41	**.65**	1.00			
IT4	.420	**.57**	.42	1.00		
Matrices (WRIT)	− .29	− .17	.02	− .12	1.00	
Analogies (WRIT)	.07	− .27	.15	− .30	.42	1.00
Age	.45	.46	.15	.40	− .45	− .18
Gender	.09	.37	.39	**.43***	– .14	– .13

Note. Statistically significant values are in bold. Age in months; gender: 0 = men, 1 = women (Kendall's correlation). DCD = developmental coordination disorder; dyslexia = developmental dyslexia; IT = inspection time; WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). * $p < .05$; ** $p < .01$; *** $p < .001$, two-tailed.

5.1. Results: Standard Inspection Time

Section 6.1 addressed Question 1.1, which asked if standard inspection time (IT1) in adult participants with dyslexia, DCD or dyslexia/DCD was longer than in participants with typical development?

5.1.1. Descriptive statistics. Standard inspection time (IT1; Table 4) distributions were positively skewed. Results of the Shapiro-Wilk test for assessing the normality of distributions in all groups confirmed a need for nonparametric statistical methods. A box plot (Figure 4) of IT1 shows the distributions, median standard inspection time and outliers in the four groups. Outliers are further out (Figure 2) and interquartile ranges are greater (Table 4), in the groups of participants with SpLDs compared to the group of participants with typical development.

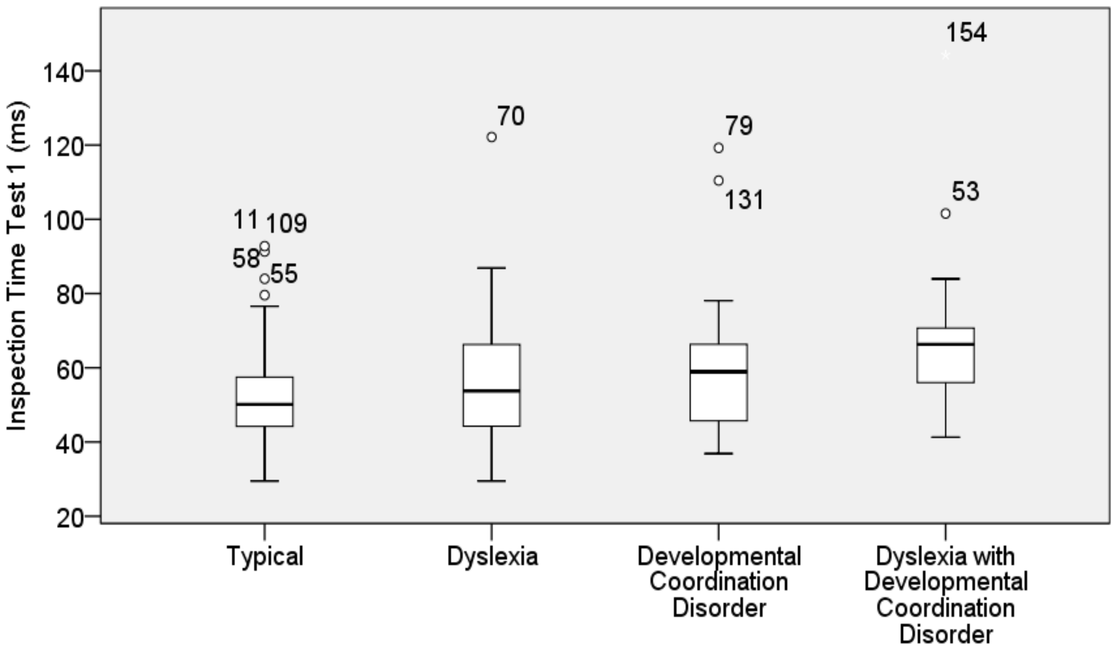


Figure 4. Box plot for standard inspection times (IT1). *Note.* Groups were participants with typical development, dyslexia, developmental coordination disorder or both (*n* = 50, 40, 33 & 18, respectively) and were unmatched for age, gender or intelligence. Whiskers at 1.5 x interquartile range. Participant numbers: ºoutliers, with inspection times extending beyond 1.5, *extreme outliers beyond 3, box-lengths from box edge.

5.1.2. Correlation analyses.

Age. Age was not significantly correlated with standard inspection time (IT1) in any participant group (Table 5).

WRIT analogies and matrices. WRIT analogies was not correlated significantly with standard inspection time (IT1) in any group. In participants with typical development, there was a small, significant, negative correlation between standard inspection time (IT1) and WRIT matrices (r_s (49) = − .29, p = .043).

Gender. In participants with DCD, inspection time (IT1) correlated to a medium, significant degree with gender (τ_b = .40, p = .006).

5.1.3. Regression analysis. Standard inspection time (IT1) was the dependent variable in a hierarchical regression analysis. Based on correlation analyses described above and information in the literature on inspection time, age, gender and WRIT matrices were controlled in Step 1. For Step 2, the four categorical, nominal variables for the participant groups, recoded to three dummy variables: dyslexia (100), DCD (010) and dyslexia/DCD (001) were each compared against the group of participants with typical development (000). This format for the hierarchical regression analysis for standard inspection time was followed for all regression analyses in Chapter 6, for consistency. Variables were “entered” (SPSS, regression) in each step. The regression analyses did not violate assumptions. *Q–Q* plots indicated that the distributions of residuals were approximately normal. Variance inflation/ tolerance values were less than 10/greater than 0.1, which indicated an absence of multi-collinearity. Homoscedasticity was acceptable, checked from visual inspection of plots of standardised residuals against standardised predicted values. Linearity was acceptable, established by visual inspection of scatterplots of outcome against predictor variables. Outliers with studentised residuals of value beyond ±3 *SD* were retained. There were no leverage values above .2 or Cook’s Distances above 1.0, to indicate unwanted influences from some participants.

Table 6

Study 3: Hierarchical Regression Analysis to Predict Standard Inspection Time (IT1)

	Model 1			Model 2			95% CIs	
N = 141	*b*	*SE b*	*β*	*b*	*SE b*	*β*	*LL*	*UL*
Step 1 Constant	63.52	11.13		53.72	11.55			
Age in months	0.01	0.01	.09	0.01	0.01	.09	− 0.01	0.03
Gender	**6.47**	**3.24**	**.17***	**6.47**	**3.18**	**.17***	**0.13**	**12.72**
WRIT matrices	− 0.39	0.24	− .14	− 0.24	0.24	− .09	− 0.71	0.24
Step 2 Dyslexia				2.92	3.70	.07	− 4.40	10.25
DCD				6.42	3.91	.15	− 1.32	14.16
Dyslexia/DCD				**13.83**	**4.90**	**.26****	**4.13**	**23.54**
R^2 = .13**; *Step 1* ΔR^2 = .07*; *Step 2* ΔR^2 = .06*								

Note. Statistically significant values are in bold. Coding: 0 = men, 1 = women, specific learning differences group against typically developing group, code 0000**.** CI = confidence interval for *b* in Model 2, LL = lower limit, UL = upper limit; dyslexia = developmental dyslexia; DCD = developmental coordination disorder; IT = inspection time in milliseconds; WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). * $p < .05$, ** $p < .01$, *** $p < .001$, two-tailed.

Results in Table 6 showed that the full model, of age, gender, WRIT matrices and SpLDs to predict standard inspection time (IT1) was significant ($R^2 = .13$, $F(6, 134) = 3.28$, $p = .005$). In Step 2, only the group with dyslexia/DCD compared to the group with typical development significantly predicted standard inspection time ($p = .006$).

5.2. Discussion: Standard Inspection Time

The results show hitherto unreported standard inspection times in three groups of adults with SpLDs compared to adults with typical development. That there was no significant difference between the group with dyslexia and the group with typical development, is consistent with the results of McLean et al. (2011) for group analyses of inspection time in children with dyslexia. In the group with dyslexia, there was just one outlier with exceptionally long standard inspection time, Participant 70 (Figure 2; Appendix I).

Between the group of adults with DCD and the group with typical development, a difference in *b* for inspection time did not reach significance. This result is in contrast to the unequivocal difference found in children reported by Piek et al. (2007) and Dyck and Piek (2010). Contrary to the statistical power analysis software G*Power (Faul et al., 2007; 2009), Miles and Shevlin (2001) estimated that, to detect a small effect size, 600 participants would be required for regression analysis that had five or six predictors and power value of .80. For a medium effect size, 100 participants would be required. Their estimate suggests that the participant number of 141 used in this study is not sufficient to show whether there was a *small* effect in any group, although the number in the current study was sufficient to show a medium or large effect had there been one. It has to be said that small differences are hard to distinguish from noise with the accuracy and resolution of measurements of inspection time in this number of participants. Moreover, the results of this investigation do not compare directly to investigations with children because of differences in procedures. In previous investigations with children with DCD, specific confounds from speeded responses or other procedural differences may explain differences between the groups of children and adults, so it is now important to confirm results in children with DCD with the standard method, without a simultaneous measurement of reaction time (RT) and with the same stimulus image as was used here. Nevertheless, results from adult participants with DCD presented an opportunity to consider the question of whether long inspection times in children with DCD are from a deficit that continues into adulthood or a developmental immaturity in younger participants that diminishes upon reaching maturity. Although the present results do not resolve this question, they do suggest that, if the results in children with DCD can be trusted, maturation lessens the difference in inspection time between participants with DCD and typically developing participants; long inspection times in children could be the result of a developmental delay, which is at least partly resolved upon maturity. This idea is contrary to that of Wilson et al. (2017), which considered that differences associated with DCD were the result of disordered neural arrangements rather than developmental immaturity. There may be at least partial resolution upon maturity of some deficits, in this instance a deficit that affects inspection time. An alternative explanation is that the stimulus image was relatively easy for participants with DCD compared to the one used in previous experiments with children. This, partly due to size and partly due to the requirement to remember an image, of equal and unequal antennae, that was not compatible with the response as in a direct left/right choice, used here.

Only the group of participants with dyslexia/DCD significantly predicted longer standard inspection times compared to the group of participants who were typically developing. The results of inspection time in the present study are inconsistent with conclusions drawn by Biotteau et al. (2017) who observed no additive effects from dyslexia and DCD found together for a range of intellectual, attentional and psychosocial parameters that included the Processing Speed Index from WISC-IV in children with dyslexia, DCD and dyslexia/DCD. Although they observed distinctly different aspects of profiles for participants with either dyslexia or DCD, there were many similarities so they proposed that a common neurological deficit was responsible for all three SpLDs. This may be true, but the results for inspection time show that any common deficit does not encompass inspection time. It appears that non-significant differences in dyslexia and DCD are in contrast to very significant differences in the group with combined SpLDs, at least for inspection time. Bellocchi et al., (2018) in a study of children with DCD, dyslexia and both, noted that among children with both dyslexia/ DCD the only increase in severity of symptoms was in a test for oculomotor control measured by a test of vertical and horizontal pursuit. Other possibilities are that there is synergy; compensatory mechanisms may not be possible for participants with both dyslexia and DCD; dyslexia/DCD may be a separate, third SpLD; or a combination of these reasons. The exaggerated results for the dyslexia/DCD group support the proposal by Willcutt (2018) for co-occurrence of SpLDs. He hypothesised that effects are greater when there is co-occurrence because there are more severe influences, which produced more than one SpLD.

Moving on to correlates of inspection time in the separate groups, age did not significantly affect inspection time but given the small median difference previously found in inspection times across this age range (Preiss & Burns, 2012) this is unsurprising. Results for the typically developing group in the present study are consistent with Grudnik and Kranzler's (2001) meta-analysis of the correlation between inspection time and visual intelligence (r (2356) = – .32, s = .02); there is correlational evidence for a small relationship between IT1 and visual intelligence assessed by WRIT matrices. That the links between inspection time and intelligence are less obvious in participants with SpLDs signals that different attributes, that obscure the relationship, contribute to either one or both of these measures in these groups. The absence of a significant correlation between inspection time and verbal intelligence evaluated by analogies in the current study is in contrast to that found by W. Johnson and Deary (2011) in older participants with typical development, for example. This absence may reflect the educational range of the participant groups used here as they were restricted to tertiary educated participants, that is those that had studied at college or university,16 years old and above. This may attenuate the correlation, compared to the sample of older participants with a wider variation in formal educational level. For gender, N.R. Burns and Nettelbeck (2005) found no gender differences in adults between 18–78 years and results from adults in the current study reflect this, except for participants with DCD. An explanation for DCD may lie in gender bias for diagnosis. Rivard, Missiuna, Hanna and Wishart (2007) have suggested that more boys with suspected DCD are referred for assessment than girls because motor weaknesses in males are more likely to attract the attention of teachers. Thus, the women in this study may be more severely affected because they were identified more readily than women who had less severe DCD.

There were limitations for Study 3. The generalisability of the results is limited because participants were educated to tertiary level, although in older participants, inspection times become longer independently from educational influence (Ritchie, Bates, Der, Starr & Deary, 2013). At the lower end of the distribution, the technical constraint of frame duration to determine inspection time may have obscured potentially short inspection times. Consequently, larger differences between groups would be necessary to reach significance. The positively skewed distribution was, in part, because of the technically imposed lower limit of inspection time but this is unlikely to be the whole explanation. The skewed distributions also indicate that a few participants had exceptionally long inspection times. Section 6.11 presents a search for a subset composed of participants with long inspection times. A further point was that the groups of participants were unequal. These groups were in preference to the original intention, which had been to analyse participants in three equal groups, matched for age, gender and intelligence. This choice was because that design, of 99 (3 X 33) participants in groups of participants classed as typically developing, with dyslexia or with DCD, posed difficult decisions about who to choose or exclude without bias (e.g., Jarrold & Brock, 2004). Importantly, the matched design also would have excluded not only much valuable data from unmatched participants but also the interesting further group of 18 participants with both dyslexia and DCD (dyslexia/DCD).

At the end of Chapter 3, a hypothesis suggested that inspection time would be long in participants with DCD or dyslexia/DCD. This hypothesis was supported only for dyslexia/DCD.

5.3. Results: Speeded Inspection Time

Question 1.2 asked if quick responses influence inspection times. Difference scores between speeded (IT2) and standard inspection time (IT1) were calculated for each participant. Difference scores were inspected graphically (Appendix J). Higher difference scores indicated longer speeded inspection times. Hierarchical regression analyses were run with (a) speeded inspection time (IT2) and (b) difference scores (*IT2 – IT1*), as dependent variables.

5.3.1. Descriptive statistics. Table 4 shows descriptive statistics for standard inspection time (IT1), speeded inspection time (IT2) and difference scores (IT2 − IT1). IT1, IT2 and (IT2 – IT1) mostly failed the Shapiro-Wilk test.

5.3.2. Correlation analyses. There were medium, significant correlations between age and speeded inspection time (IT2) in the group of participants with DCD (r_s (32) = − .37, p = .033). Speeded inspection time (IT2) did not correlate significantly with gender, WRIT analogies or WRIT matrices in any group (Table 5).

5.3.3. Regression analyses. Regression analyses were conducted as for standard inspection time (IT1; Section 6.1.3).

Inspection time Test 2. Table 7 displays results for a hierarchical regression analysis with speeded inspection time (IT2) as the dependent variable.

The full model, of age, gender, WRIT matrices, and SpLD to predict speeded inspection time (IT2) was significant (R^2 = .15, F (6, 134) = 3.92, p = .001). Speeded inspection time (IT2) was longer in women than in men. The group of participants with dyslexia/DCD compared to the group of participants with typical development significantly predicted speeded inspection time (IT2; p = .003).

Table 7

Study 3: Hierarchical Regression Analyses to Predict Speeded Inspection Time (IT2)

N = 141	Model 1			Model 2			95% CIs	
	b	*SE b*	*β*	*b*	*SE b*	*β*	*LL*	*UL*
Step 1 Constant	67.34	15.16		56.68	15.63		37.36	97.31
Age in months	0.02	0.02	.10	0.02	0.02	.10	– 0.01	0.05
Gender	**9.51**	**4.41**	**.18***	**9.00**	**4.31**	**.17***	**0.79**	**18.23**
WRIT matrices	− 0.57	0.32	− .15	− 0.36	0.32	− .10	– 1.20	0.08
Step 2 Dyslexia				− 0.12	5.00	.00	– 10.03	9.79
DCD				3.57	5.30	.06	– 6.90	14.04
Dyslexia/DCD				**20.23**	**6.64**	**.27****	**7.10**	**33.36**
R^2 = .15***; *Step 1 Δ* R^2 = .08**; *Step 2 Δ* R^2 = .07*								

Note. Statistically significant values are bold. Coding: 0 = men, 1 = women, specific learning differences group against typically developing group, code 0000**.** CI = confidence interval for *b* in Model 2, LL = lower limit, UL = upper limit; dyslexia = developmental dyslexia; DCD = developmental coordination disorder; IT = inspection time in milliseconds; WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). * *p* < .05, ** *p* < .01, *** *p* < .001, two-tailed.

Difference scores: inspection time from Test 2 minus Test 1 and change scores: Test 2/Test 1. Table 8 displays results for a regression analysis with (IT2 – IT1) as the dependent variable. The full model of age, gender, WRIT matrices, and SpLD to predict (IT2 – IT1) was not significant (R^2 = .03, *F* (6, 134) = .79, *p* = .581). The addition of SpLD groups in Step 2 did not significantly increase the coefficient of determination, R^2. No group compared to participants with typical development significantly predicted (IT2 − IT1). Bar charts of individual difference scores are in Figure J1. The chart stimulated the question: Is general variability of inspection time performance a feature of any SpLD group? investigated with *change scores.* Change scores were defined as the overall variability of a group regardless of the direction of that variability. They were obtained by removing the negative sign from the difference score. A difference score can be either positive or negative and reflects whether standard (IT1) was longer or shorter than speeded inspection time (IT2) whereas change scores were sign-less. A regression analysis of change scores for IT1/IT2 (Table 9, details in Appendix K) showed that the dyslexia/DCD group, but not the dyslexia or DCD groups, had significantly more variable results between tests than the group of participants with typical development.

Table 8

Study 3: Hierarchical Regression Analysis to Predict Inspection Time Difference (IT2 − IT1)

	Model 1			Model 2			95% CIs	
	b	*SE b*	*β*	*b*	*SE b*	*β*	*LL*	*UL*
Step 1 Constant	3.82	12.90		2.95	13.67			
Age in months	0.01	0.01	.04	0.01	0.01	.04	– 0.02	0.03
Gender	3.04	3.75	.07	2.58	3.77	.06	– 4.87	10.03
WRIT matrices	− 0.17	0.28	− .06	− 0.12	0.28	−.04	– 0.68	0.44
Step 2 Dyslexia				− 3.04	4.38	− .07	– 11.71	5.63
DCD				− 2.86	4.63	− .06	– 12.02	6.31
Dyslexia/DCD				6.40	5.81	0.11	– 5.09	17.88

R^2 = .03*; Step 1: Δ* R^2 = .02; Step 2: *Δ* R^2 = .02. There were no significant R^2 *or βs.*

Note. *Note.* Coding: 0 = men, 1 = women, specific learning differences group against typically developing group, code 0000**.** CI = confidence interval for *b* in Model 2, LL & UL= lower & upper limits; dyslexia = developmental dyslexia; DCD = developmental coordination disorder; IT = inspection time (ms); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000).

Table 9

Study 3: Hierarchical Regression to Predict Change Score (IT2/ IT1)

	Model 1			Model 2			95% CIs	
N = 141	*b*	*SE b*	*β*	*b*	*SE b*	*β*	*LL*	*UL*
Step 1 Constant	24.12	9.43		19.06	9.76		– 0.24	38.35
Age	− 0.01	0.01	.05	− 0.01	0.01	− .05	– 0.02	0.01
Gender	0.94	2.70	.03	0.55	2.69	.02	– 4.77	5.87
WRIT matrices	− 0.23	0.20	.20	− 0.12	0.20	− .05	– 0.52	0.28
Step 2 Dyslexia				− 1.35	3.13	− .04	– 7.54	4.83
DCD				0.67	3.31	.02	– 5.86	7.21
Dyslexia/DCD				**11.36**	**4.14**	**.26****	**3.17**	**19.55**

R^2 = .08; *Step 1:* ΔR^2 = .01; Step 2: ΔR^2 = .07*.

Note. Statistically significant values are bold. Coding: 0 = men, 1 = women, specific learning differences group against typically developing group, code 0000**.** DCD = developmental coordination disorder; IT = inspection time (ms); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). * $p < .05$, ** $p < .01$.

5.4. Discussion: Speeded Inspection Time

The results described above showed that, with a speeded response, only inspection times of participants in the group with dyslexia/DCD were significantly longer, compared to participants from the typically developing group. Regression analysis for the difference in each adult participant between speeded and standard inspection time (IT2 – IT1) showed that none of the groups with SpLDs, compared to the typically developing group, significantly predicted longer or shorter inspection times under speeded conditions. The possibility remains for children that the speeded nature of the task in Piek et al.'s (2007) study resulted in the long inspection times noted for children with DCD.

Variability between standard and speeded inspection time is reported in more detail in Appendices J and K. From a visual examination of a comparison of individual differences scores (Figure J1), there were extreme differences between standard and speeded inspection times in some individuals from all groups. More extreme difference scores were obvious in groups with SpLDs, particularly in four participants in the dyslexia/DCD group whose un-speeded inspection time was shorter than speeded. Although inspection time variability (ITSD) is known to be greater in participants with weaker intelligence scores (Deary, 2000), intelligence was not correlated significantly with any (IT2 – IT1) difference or change score. Change scores also indicated that the dyslexia/DCD group had more overall variability than was typical. Test-retest reliability has been noted to be less secure in some psychophysical tasks in participants with dyslexia (Heath, Bishop, Hogben & Roach, 2006), so it is possible that the variability would be present between two tests in the current study regardless of whether they were standard or speeded. A reason for the pattern of change scores could be the effects of additional noise in the detection of the signal from the stimulus. This depends on the source of the noise but the variability may be either because the noise enhances the stimulus, so that the participant is more sensitive to the signal from the stimulus, or alternatively it can obscure the signal from the stimulus, which results in less sensitivity. The outcome therefore is a greater ITSD. With many trials, positive and negative variability would even out to produce a more reliable overall inspection time. However, in a limited number of test trials, as was with the method of limits, this variability could increase or decrease the resolved inspection time. With a limited number of trials, the difference between two resolved inspection times may be negative or positive. If the noise is present for one test and not another, the resolved outcome for the test without noise may be more reliable than that for the test in which there is noise.

In summary, a hypothesis at the end of Chapter 3, that inspection times under speeded conditions would be longer in participants with DCD than without, was unsupported. In comparison to the group of participants with typical development the participant group with dyslexia/DCD had overall more variability, expressed as a change score, between standard and speeded results.

5.5. Results: Directionality

Question 1.3 asked if left/right directional aspects of the stimulus evaluation and response influenced inspection times in participants with SpLDs compared to typically developing participants. Difference scores (IT3 – IT4) between left/right (IT3) and up/down (IT4) inspection time stimuli were calculated for each participant. These were inspected graphically (Figure J2). Higher difference scores indicate a longer inspection time response for inspection time collected with the left/right figure. Correlation analyses were between left/right (IT3), up/down (IT4), age, gender, results of WRIT analogies and WRIT matrices (Table 5). Hierarchical regression analyses were conducted for (a) left/right (IT3) and up/down (IT4) (b) difference scores (IT3 – IT4) as dependent variables. Change scores, defined in Section 5.4, were calculated for IT3/ IT4.

5.5.1. Descriptive statistics. In four groups, most IT3, IT4 and (IT3 – IT4) distributions failed the Shapiro-Wilk normality test (Table 4).

5.5.2. Correlation analyses.

Age. In DCD, age correlated significantly with left/right inspection time (IT3; r_s (32) = − .42, p = .015).

WRIT analogies and matrices. In no group did IT3 and IT4 correlate significantly with WRIT analogies or matrices.

Gender. Gender correlated significantly with up/down inspection time in dyslexia/DCD (IT4; r_s (17) = − .43, p = .034).

5.5.3. Regression analyses.

Inspection time Test 3, left/right. Table 10 displays results for a hierarchical regression analysis with left/right (IT3) as the dependent variable.

Table 10

Study 3: Hierarchical Regression Analysis to Predict Left/Right Inspection Time (IT3)

	Model 1			Model 2			95% CIs	
N = 141	*b*	*SE b*	*β*	*b*	*SE b*	*β*	*LL*	*UL*
Step 1 Constant	65.06	16.73		50.15	17.46		15.62	84.68
Age (months)	0.01	0.02	.06	0.01	0.02	.06	– 0.02	0.05
Gender	6.03	4.87	.11	6.62	4.81	.12	– 2.89	16.14
WRIT matrices	− 0.17	0.36	− .04	− 0.17	0.36	− .04	0.55	– 0.12
Step 2 Dyslexia				10.08	5.60	.17	– 0.99	21.16
DCD				**14.26**	**5.92**	**.23***	**2.56**	**25.96**
Dyslexia/DCD				13.31	7.42	.17	– 1.35	27.98
R^2 = .09*; Step 1 Δ* R^2 = .05; *Step 2 Δ* R^2 = .05								

Note. Statistically significant values are in bold. Coding: 0 = men, 1 = women, specific learning differences group against typically developing group, code 0000**.** CI = confidence interval for *b* in Model 2, LL & UL = lower & upper limits; DCD = developmental coordination disorder; IT = inspection time (ms); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). * $p < .05$, two-tailed.

The full model, of age, gender, WRIT matrices, and SpLD, to predict left/right inspection time was not significant, $R^2 = .08$, $F(6, 134) = 1.90$, $p = .086$). The group of participants with DCD significantly predicted left/right inspection time ($p = .017$).

Inspection time Test 4, up/down. Table 11 displays results for a hierarchical regression analysis with up/down inspection time as the dependent variable.
The full model of age, gender, WRIT matrices and SpLD to predict up/down (IT4) was significant ($R^2 = .13$, $F(6, 134) = 3.18$, $p = .006$). Age, gender and WRIT matrices did not significantly influence the outcome. The group of participants with dyslexia compared to the group of participants who were typically developing significantly predicted up/down (IT4) inspection time ($p = .046$) as did the group with dyslexia/DCD ($p = .004$).

Table 11

Study 3: Hierarchical Regression Analysis to Predict (Up/Down) Inspection Time (IT4)

	Model 1			Model 2			95% CIs	
N = 141	*b*	*SE b*	*β*	*b*	*SE b*	*β*	*LL*	*UL*
Step 1 Constant	67.79	16.16		51.82	16.71		18.77	84.88
Age (months)	0.03	0.02	.07	0.03	0.02	.07	0.00	0.06
Gender	1.71	4.70	.03	1.57	4.60	.03	– 7.54	10.68
WRIT matrices	− 0.57	0.35	− .14	− 0.33	0.35	− .08	– 1.01	0.36
Step 2 Dyslexia				**10.79**	**5.36**	**.19***	**0.20**	**21.39**
DCD				7.03	5.66	.11	– 4.17	18.23
Dyslexia/DCD				**21.10**	**7.10**	**.27****	**7.06**	**35.14**
R^2 = .13**; *Step 1* ΔR^2 = .07*; *Step 2* ΔR^2 = .07*								

Note. Statistically significant values are in bold. Coding: 0 = men, 1 = women, specific learning differences group against typically developing group, code 0000**.** CI = confidence interval for *b* in Model 2, LL = lower limit, UL = upper limit; DCD = developmental coordination disorder; IT = inspection time (ms); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000).* $p < .05$, ** $p < .01$, *** $p < .001$, two-tailed.

A further regression analysis was made with combined *z*-scores scores for IT3 and IT4 (IT3 + IT4; Table 12) for the dependent variable, because the group with dyslexia predicted IT4 and the *ß* value was high for IT3 in this group. Results showed that the full model, of age, gender, WRIT matrices, and SpLD to predict (IT3 + IT4) was significant (R^2 = .13, F (6, 134) = 3.31, p = .005). All groups of participants with SpLDs were significantly different to the group of typically developing participants. In case formation of z-scores affected the result because the distributions of IT3 and IT4 were not normal, another analysis was run with the dependent variable formed from raw scores of IT3 and IT4 but exactly the same standardised *b*s were obtained.

Table 12

Study 3: Hierarchical Regression Analysis to Predict Inspection Time (IT3 + IT4)

	Model 1			Model 2			95% CIs	
N = 141	*b*	*SE b*	*ß*	*b*	*SE b*	*ß*	*LL*	*UL*
Step 1 Constant	0.46	1.03		– 0.71	1.06		– 2.80	1.39
Age (months)	0.00	0.00	.14	0.00	0.00	.14	0.00	0.00
Gender	0.29	0.30	.08	0.31	0.29	.09	– 0.27	0.88
WRIT matrices	− 0.04	0.02	− .14	– 0.02	0.02	− .07	– 0.06	0.03
Step 2 Dyslexia				**0.79**	**0.34**	**.22***	**0.12**	**1.46**
DCD				**0.80**	**0.36**	**.21***	**0.10**	**1.51**
Dyslexia/DCD				**1.30**	**0.45**	**.26****	**0.42**	**2.19**

R^2 = .13**; *Step 1* ΔR^2 = .06*; *Step 2* ΔR^2 = .07*

Note. In Step 2, statistically significant values are in bold. Coding: 1 = women, 0 = men. CI = confidence interval for *b* in Model 2, LL/ UL = lower/upper limits; DCD = developmental coordination disorder; IT = inspection time; WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). * $p < .05$, ** $p < .01$, *** $p < .001$, two-tailed.

Upon close examination of the raw data (Figure J3), a possible bimodal distribution for the dyslexia group was discernible, which suggests a subtype of dyslexia comprised of eight participants with longer combined (IT3 + IT4) than others.

Difference scores: inspection times from Test 3 minus from Test 4.

Difference scores were calculated to show if the left right inspection time was more difficult than the up/down. A hierarchical regression analysis was made with the difference score (IT3 − IT4) as the dependent variable (Table J1). The full model of age, gender, WRIT matrices, and SpLD groups to predict (IT3 − IT4) was not significant (R^2 = .04, F (6, 134) = 0.92, p = .486). The addition of SpLD groups in Step 2 did not significantly increase R^2 and no group compared to the group of typically developing participants significantly predicted (IT3 − IT4). Individual difference scores were examined (IT3 – IT4, Figure J2) and a visual inspection of these supported the regression analysis.

Change scores: inspection times from Test 3 minus from Test 4. A hierarchical regression analysis of change scores for IT3/IT4 showed that all the groups of participants with SpLDs were significantly more variable than the group of participants with typical development (Table 13; Appendix K).

Table 13

Study 3: Hierarchical Regression Analysis to Predict Change Score (IT3/ IT4)

	Model 1			Model 2			95% CIs	
N = 139	*b*	*SE b*	*β*	*b*	*SE b*	*β*	*LL*	*UL*
Step 1 Constant	11.03	11.79		– 0.43	12.27		– 27.68	27.13
Age	0.01	0.01	.05	0.01	0.01	.05	– 0.01	0.04
Gender	5.27	3.46	.13	5.56	3.40	.14	– 3.34	11.77
WRIT matrices	0.64	0.25	.02	0.20	0.25	.07	– 0.39	0.75
Step 2 Dyslexia				**8.11**	**3.97**	**.20***	**0.36**	**17.93**
DCD				**10.19**	**4.17**	**.23****	**– 0.50**	**18.08**
Dyslexia/DCD				**10.44**	**5.22**	**.19***	**– 2.60**	**20.68**

R^2 = .08; *Step 1: Δ* R^2 = .02; Step 2: *Δ* R^2 = .06.

Note. Statistically significant values are in bold. Coding: 0 = men, 1 = women, specific learning differences group against typically developing group, code 0000**.** CI = confidence interval for *b* in Model 2, LL & UL = lower & upper limits; DCD = developmental coordination disorder; IT = inspection time (ms); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000); * *p* < .05, ** *p* < .01, *** *p* < .001.

5.6. Discussion: Directionality

A non-standard stimulus design was used to explore if directionality affected inspection time in any group of participants with SpLDs compared to a group with typical development. For the group with dyslexia, difference scores did not show that participants with dyslexia found left/right inspection time significantly more difficult than up/down. However, unlike the commonly used, standard pi-figure stimulus, results were significantly different to the typical group for up/down (IT4) and the group with dyslexia significantly predicted an amalgamation of IT3 and IT4. Thus, an unexpected, additional finding was that the stimulus type was important for participants with dyslexia. The non-standard stimulus had two points of focus at which a decision could be made, which were at either end of the short line on the stimulus figure compared to just one on the standard pi-figure. A speculation is that it was the two points of focus that affected inspection times for at least some participants with dyslexia, as the distribution looked bimodal. The two points of focus may require serial search, recognised to be deficient in dyslexia (see Section 3.1), whereas the single point of focus for a pi-figure 'pops out' more readily as it requires parallel search. If this idea is correct, the results support the visual attention span deficit hypothesis (Bosse et al., 2007). The visual attention span hypothesis is a proposal that in some participants with dyslexia there is difficulty with processing multi-element arrays. These difficulties have been attributed to a deficit in the magnocellular system in dyslexia (e.g. Stein, 2018). Also, there has been particular interest in crowding effects, related to reading in dyslexia, supported by observations that spacing letters more widely helps a subgroup of poor readers (e.g., Joo, White, Strodtman & Yeatman, 2018). Lateral masking is believed to be responsible and may be determined partly by distance of stimulus from fixation. Causal theories are that there is high lateral inhibition, an attention deficit, or maybe less reading practice. That the two points of focus for the non-standard stimulus were edging away from the fovea may have affected recognition in dyslexic participants. Investigations of visual attention in dyslexia have exposed a tendency to perform less efficiently for stimuli in the left visual field (e.g., Hari, Renvall & Tanskanen, 2001) but that the stimulus in the up/down position was similarly affected suggests that left neglect was not the reason for the results for the non-standard stimulus in dyslexia.

In the group of participants with DCD, left/right inspection time (IT3) was significantly longer, and therefore more difficult, than in the group with typical development, whereas up/down (IT4) was not. But, there is no firm evidence from difference scores that the group of participants with DCD as a whole found left/right inspection time with the non-standard stimulus more difficult than up/down.

In the group with dyslexia/DCD, up/down inspection time (IT4) from the up/down decision was significantly longer than in the group with typical development but inspection time left/right (IT3) was not, although it trended towards being more difficult for this group. Why left/right Test IT3 should have been less problematic than the three other stimuli in the dyslexa/DCD group is not clear. Left/right Test IT3 had nothing singular about it in comparison to any of the other three tests. The difference scores between IT3 and IT4, (IT3 – IT4), did not generate a significant result for the group of participants with dyslexia/DCD overall.

In summary, a non-standard stimulus design was used but no SpLD group as a whole showed a significant difference from the typical group for the differences to distinguish and respond between left/right (IT3) and up/down (IT4) inspection times (IT3 – IT4). The hypothesis that when stimulus design relieves them of a decision and response about left and right, compared to participants with typical development, participants with dyslexia, DCD or dyslexia/DCD would have shorter inspection times than from a standard pi-figure stimulus was therefore unsupported. Consequently, there is no firm evidence that left/right requirements of the task explains long inspection times found in children with DCD by Piek et al. (2007).

Hierarchical regression analyses for the overall change scores between IT3/ IT4, showed that there was significant overall variability, regardless of direction, in all groups of participants with SpLDs compared to participants who were typically developing. This, if the arguments laid out for variability between Tests 1 and 2 apply, suggests that participants with SpLDs experience more noise than is typical.

A potential limitation of this study is that some participants, perhaps those with less spatial confidence, may have found that a response was awkward when the response box was in a rotated position, as it was in Test 4. Although theoretically this should have made little difference to inspection times, as no speed was required for the response, the slope of the response box turned through 90 ° was a potential distraction. Moreover, there was only one set of results and no repeat testing. Although there was variability between tests, it was not possible to know whether on another occasion this may have resulted in variability in the opposite direction. Had there been variability more consistent in one direction across participants it would have been possible to attribute this to a directional difficulty.

5.7. Summary for Chapter 5

Standard inspection time was significantly longer than typical only in a group with dyslexia/DCD. Speeded response requirements did not significantly affect the inspection times of SpLD groups compared to typical. There was no evidence that a left/right stimulus challenged participants more than the top/bottom stimulus or vice versa in any group. Incidental findings were that non-standard stimulus figures generated significantly longer inspection times in the dyslexia and DCD group compared to the typically developing group. Individual variability, between standard and speeded tests, measured as change scores, was significantly more than typical in the group with dyslexia/DCD. All SpLD groups had more variable change scores to typical between inspection times from left/right and up/down tests.

In stand-alone Chapter 7, there are further analyses that confirm that speed and directionality had little consequence on inspection time but that there are implications of using a more complex stimulus figure. In the following Chapter 6, are further results to address Question 2 about what inspection time tasks are really measuring. Analyses in Chapter 6 use results from inspection time Test 1, that had a pi-figure stimulus and un-speeded response.

CHAPTER 6

Study 3: Results and Discussion

Visual Discomfort, Memory, Chronometric and Coding Tasks, Literacy Attainment

This chapter addressed the second aim of this work, which was to answer the question: Within groups of adult participants with typical development, dyslexia, DCD or both, what are inspection time tasks really measuring?, phrased as Questions 2.1–2.5 as set out at the end of Chapter 3. Unless otherwise stated, inspection time was from the standard method of inspection time Test 1 (IT1): with pi-figure stimuli and un-speeded responses, as it was the simplest inspection time task. Descriptive statistics and correlations of standard inspection time (IT1) with age, gender and WRIT tests of intelligence for the separate groups are in Tables 4 and 5, respectively. Similar to analyses in Chapter 5, distributions were largely not normal thus warranting nonparametric analysis.

As explained in Section 4.4.3., throughout Chapter 6 there were no adjustments for multiple correlations. Consequently, as there is an inflated possibility of Type I errors, discussions about significant effects were confined to medium and large correlations that were relevant to the hypotheses. Throughout Chapter 6, the approach has been to analyse separate tests and typically developing, dyslexia, DCD and dyslexia/DCD groups separately. A criticism of this detailed, in-depth approach is that by using such methods it is difficult to extract an overview of the results and conclusions. Consequently, in Chapter 7, there is an omnibus, whole participant sample analysis to extract the main results and conclusions.

6.1. Results: Visual Discomfort

First, Question 2.1 asked about the relationship between inspection time and visual discomfort. Descriptive statistics for the Visual Discomfort Scale (VDS; Conlon et al., 1999) and the Pattern Glare Test (PGT; Wilkins & Evans, 2001) are in Tables 14 and 15, respectively. Group differences were explored. Correlation analyses established if age, gender and WRIT matrices were covariates of these tests. Further correlation analyses were between IT1, VDS and PGT; and between speeded (IT2), left/right (IT3), up/down (IT4) inspection times, VDS and PGT. In Appendix L are additional hierarchical regression analyses, with four inspection times (IT1–4) as dependent variables and participant groups as the predictors, with results from the VDS controlled.

6.1.1. Descriptive statistics. Participants with a score of more than 24, those with more than low visual discomfort, were 6%; 69%; 63%; and 78% of participants with typical development, dyslexia, DCD and dyslexia/DCD, respectively. In the group of typically developing participants, due to three participants who reported more than usual visual discomfort, Shapiro-Wilk tests indicated that the distribution of results of the VDS was not normal.

Table 15 shows frequencies of positive and negative responses to the PGT. Four participants were omitted after an administrative oversight, another had epilepsy.

Table 14

Study 3: Descriptive Statistics for Visual Discomfort Scale in Four Groups

N = 141	*n*	Skewness	*SE* skewness	Kurtosis	*SE* kurtosis	Shapiro–Wilk Statistic	Median	IQR	Mean	Standard Deviation
Typical	49	2.00	0.34	5.55	0.66	.83***	7	8	8.34	7.16
Dyslexia	38	− 0.24	0.37	− 0.37	0.73	.98	32	20	30.25	14.12
DCD	31	0.34	0.41	− 0.91	0.80	.96	27	30	29.70	17.60
Dyslexia / DCD	18	− 0.41	0.54	− 0.64	1.04	.96	36.5	24	36.33	16.19

Note. Typical = typical development; DCD = developmental coordination disorder; IQR = interquartile range; Visual Discomfort Scale (VDS; Conlon, Lovegrove, Chekaluk & Pattison, 1999). *** *p* <. 001, two-tailed.

Table 15

Study 3: Frequency of Positive and Negative Responses for the Pattern Glare Test

Group *N* = 136	*n*	Negative	Positive	% Positive
Typical development	49	33	16	32
Dyslexia	38	14	22	55
DCD	31	11	20	61
Dyslexia/developmental coordination disorder	18	3	15	83

Note: Pattern Glare Test (Wilkins & Evans, 2001).

6.1.2. Inferential statistics.

Covariates. VDS correlated significantly with age (r_s (32) = .41, *p* = .018) and gender (τ_b = .34, *p* = .022) in the DCD group. There were no significant correlations between visual discomfort and WRIT tests of intelligence. In no group did age, gender, WRIT analogies or WRIT matrices correlate with the PGT.

Group differences for Visual Discomfort Scale. Hierarchical regression analyses were made for group differences for results of the VDS (Table 16). Consistent with previous regression analyses (e.g., Section 6.1.1), age, gender and

WRIT matrices were in step 1. As before, step 2 used dummy variables for SpLD groups set against the group with typical development. The full model to predict the VDS was significant (R^2 = .44, *F (6, 129)* = 17.16, *p* < .001). In Model 2, gender predicted results of the VDS (*p* = .008). R^2 in step 2 significantly increased; all SpLD groups were significant (*p* < .001).

Group differences for Pattern Glare Test. The PGT was the dependent variable in a one-way ANOVA, which used the Welch statistic and Games-Howell post hoc tests. There was a significant difference between the four groups (Table 17; *F* (3) = 6.28, *p* = .001, η^2 = .13). Games-Howell post hoc tests confirmed that there were more participants with pattern glare in the SpLD groups than in the group of participants with typical development.

Table 16

Study 3: Hierarchical Regression Analysis to Predict Visual Discomfort Scale(VDS)

N = 136	Model 1			Model 2			95% CIs	
Step 1	*b*	*SE b*	*β*	*b*	*SE b*	*β*	*LL*	*UL*
Constant	24.97	10.87		− 2.87	8.95		3.47	46.47
Age	0.01	0.01	.09	0.01	0.01	.07	− 0.01	0.03
Gender	6.06	3.19	.17	**6.74**	**2.49**	**.18****	**− 0.26**	**12.37**
Matrices	− 0.28	0.23	− .11	0.09	0.19	.03	− 0.75	0.18
Step 2 Dyslexia				**21.13**	**2.94**	**.54*****	**15.31**	**26.96**
DCD				**21.66**	**3.04**	**.53*****	**15.65**	**27.67**
Dyslexia/DCD				**27.43**	**3.78**	**.53*****	**19.95**	**34.90**
*R^2 = .44***; Step 1 Δ R^2 =.06; Step 2 Δ R^2 =.39****								

Note. Significant correlations are in bold. Coding: 0 = men, 1 = women, specific learning differences group against typically developing group, code 0000**.** CI = confidence interval for *b* in Model 2, LL & UL= lower & upper limit; DCD = developmental coordination disorder; Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000).* *p* < .05, ** *p* < .01, *** *p* < .001, two-tailed.

Table 17

Study 3: One way Analysis of Variance for Pattern Glare Test (PGT)

Test	Welch Test $F(3)$	Sig.	Games-Howell (1964) post hoc tests: typically developing (n = 49) vs. SpLD group mean difference			
				Test statistic	*p*	95% CIs
PGT	6.28	**.001**	Dyslexia (n = 38)	– .33	**.009**	– .60– – .06
			DCD (n = 31)	– .36	**.004**	– .63– – .09
			Dyslexia/DCD (n = 18)	– .41	**.009**	– .72– – .11

Note. DCD = developmental coordination disorder; dyslexia = developmental dyslexia; Pattern Glare Test (PGT; Wilkins & Evans, 2001); SpLD = specific learning differences.

Correlations between inspection time, results for Visual Discomfort Scale (VDS) and Pattern Glare Test (PGT). Spearman partial correlational analyses were made between IT1 and results of the VDS in the four participant groups, with and without controls for age and WRIT matrices (Table 18).

Table 18

Study 3: Spearman and Kendall Correlations Between Standard Inspection Time (IT1), Visual Discomfort Scale (VDS) and Pattern Glare Test (PGT) in Four Groups

Typically developing (n = 49)	1	2	3
1. IT1	-	.14	-
2. VDS	.16	-	-
3. PGT	.21	**.38****	-
Dyslexia (n = 38)	1	2	3
1. IT1	-	– .03	-
2. VDS	– .05	-	-
3. PGT	.10	**.42****	-
DCD (n = 31)	1	2	3
1. IT1	-	**.54 ****	-
2. VDS	**.54 ****	-	-
3. PGT	.01	.08	-
Dyslexia/ DCD (n = 18)	1	2	3
1. IT1	-	– .17	-
2. VDS	– .18	-	-
3. PGT	- .16	**.54 ***	-

Note. Below diagonal: no control; above diagonal: control for age and matrices, Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). Significant values in bold. DCD = developmental coordination disorder; dyslexia = developmental dyslexia; Pattern Glare Test (Wilkins & Evans, 2001); Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999). * p < .05, ** p < .01, *** p < .001, two-tailed.

Controls were because of correlations between VDS and age in participants with DCD, and between IT1 and WRIT matrices in the group of participants with typical development. In the group of participants with DCD, Spearman correlation between results for IT1 and VDS was significant, positive and large ($r_s(30) = .54$, $p = .001$) and remained so when covariates of age and WRIT matrices were accounted for ($r_s(30) = .54$, $p = .002$). Figures L1–3 show scatter graphs of IT1 plotted against VDS in the DCD group and the effects of splitting these data by gender. The relationship between results for IT1 and the VDS was visible for both men and women. IT1 did not significantly correlate with results for the VDS in the other groups. A comparison of correlations (Cocor; Diedenhofen & Musch, 2015) showed that there was a significant difference between the correlations for DCD ($r_s(30) = .54$, $p = .001$) and dyslexia/DCD ($r_s(17) = –.18$, $p = .473$). The null hypothesis was rejected (Fisher's $z = 2.51$, $p = .006$).

Kendall's *tau-b* correlation coefficient assessed the degree of association between the PGT and VDS in different participant groups (Table 18). In the group of participants with DCD, there is a noteworthy absence of large or significant correlation between results from the PGT and the VDS, compared to the medium and large, significant correlations in the three other groups. Fisher's *z* to compare Spearman correlations is a robust procedure (Myers & Sirois, 2006). There is less documentation for comparisons between Kendall's *tau-b*. After transformation of *tau-b* to Spearman's *rho* (Walker, 2003), the correlations of DCD ($\tau_b = .08$, $p = .616$) and dyslexia/DCD ($\tau_b = .54$, $p = .008$) were compared with Cocor (Diedenhofen & Musch, 2015) for the possibility that the correlations were the same. The correlations were significantly different because the null hypothesis was rejected (Fisher's $z = – 2.68$, $p = .004$, one-tailed).

IT1 and PGT results did not correlate significantly in any group.

Correlations: inspection time from Tests 2, 3 and 4 with results for Visual Discomfort Scale (VDS) and Pattern Glare Test (PGT). Only in DCD were the correlations between VDS and speeded inspection time (IT2; $r_s(32) = .40$, $p = .024$) and left/right inspection time (IT3; $r_s(32) = .53$, $p = .001$) significant. However, up/down inspection time (IT4) did not correlate significantly with the VDS: ($r_s(32) = -.03$, $p = .854$) in DCD. As with IT1, there were no significant correlations between IT2–4 and the PGT in any group.

The patterns of results in the different groups for the relationships between VDS and IT1, speeded inspection time (IT2) and left/right inspection time (IT3), prompted the question: Is visual discomfort, as assessed by the VDS, different in DCD? This idea is explored in Appendix L.

Analyses for cognitive and attainment characteristics with Visual Discomfort Scale (VDS) controlled. It was important to establish to what extent visual discomfort, evaluated by the results of the VDS, which occurs in all the SpLD groups in this investigation, related to the test results used to establish the cognitive profiles of SpLDs. Details of group differences of a range of variables, described in Chapter 4, and their relationships to results of VDS formed from hierarchical regression analyses, with and without the VDS in step 1 are summarised in Table H2. After control for results of VDS, selectively deficient test results were, in DCD, Corsi block-tapping task backward and CDT; and in dyslexia and dyslexia/DCD, no tests. The full supplementary details obtained differences between groups for cognitive and attainment tests and were as follows: memory: Appendix O; Symbol Digit Modalities Test (SDMT) and chronometric tests: Appendix P; rapid automatic naming (RAN): Appendix Q; reading and writing tests: Appendix R.

6.2. Discussion: Visual Discomfort

Visual Discomfort Scale (VDS). A smaller proportion of the group of participants with typical development reported more than usual symptoms of visual discomfort, as assessed by the VDS, than in Conlon et al.'s (1999) study. All three groups of participants with SpLDs had significantly more participants than was typical with more than low visual discomfort, evaluated by the VDS.

Pattern Glare Test (PGT). One-third of participants with typical development reported pattern glare, more than has been previously reported (Evans & Stevenson, 2008) and possibly a function of the lighting conditions in the testing room. There were more participants with pattern glare in SpLD groups than in the group with typical development. These results are contrary to those of Saksida et al. (2016) who did not find unusual levels of pattern glare in French children with dyslexia. In participants with dyslexia, susceptibility to pattern glare has sometimes been noted (Section 3.3) but pattern glare in participants with DCD or dyslexia/DCD has not received attention in the scientific literature, as far as is known. Pattern glare, considered to be a perceptual anomaly, is diagnostic of Meares-Irlen Syndrome (MIS) when there are no visual anomalies. Although participants claimed normal or corrected to normal vision, in the absence of thorough eye examinations, visual anomalies cannot be discounted, so the presence of pattern glare in the current investigation is not diagnostic of MIS. Eye examinations were beyond the scope of this study, limited by reliance on questionnaires to assess visual discomfort.

Visual Discomfort Scale (VDS) and Pattern Glare Test (PGT). In the groups of participants with typical development, dyslexia and dyslexia/DCD, results from the VDS correlated significantly with those of the PGT. This suggests that they assessed some similar aspects of visual discomfort or a similar latent variable that controlled both sources of visual discomfort. A significant relationship between the reports of visual discomfort from the VDS and PGT in most groups is consistent with the findings of Conlon et al. (1999) for participants with typical development. In contrast, in the group of participants with DCD, there was no significant correlation. If there is an underlying relationship between VDS and PGT in this group, it has been obscured by an additional influence, perhaps visual anomalies.

Inspection time. Pattern glare did not correlate significantly with inspection time in any group suggesting that inspection time stimuli did not provoke pattern glare. A significant relationship between IT1–3 and results of the VDS was only evident in participants with DCD, not in the other groups. Some aspects of visual discomfort exclusively tapped by the VDS in DCD relate to performance for IT1–3 or a common factor influences both IT1–3 and VDS.

As shown in Section 5.1, inspection time in DCD was not significantly different to that from participants with typical development. However, the medium significant relationship between inspection time and results of the VDS in DCD raises questions about inspection time measurement in participants with DCD. The results cannot evidence a causal relationship between visual discomfort and inspection time in DCD but a causal relationship is possible. Nevertheless, as the visual discomfort experienced by participants with DCD in the present study with adults does not correlate significantly with pattern glare, one explanation for these results is of accommodation or fixation differences. Rafique and Northway (2015) showed a link between reading disabilities, accommodation and motor skills in children with DCD. Furthermore, in children with DCD, Sumner, Hutton, Kuhn and Hill (2016) noted fixation instability. Hitherto, visual confounds in inspection time measurement have been disregarded in the literature but the assumption that there are no visual confounds relies on appropriate coordination of both eyes and that inspection time occurs within one saccade. Deficiencies of accommodation and fixation stability could affect performance within one saccade; hence, they could affect inspection time. Alternatively, another factor could moderate results for both inspection time and accommodation and/or fixation stability.

Thus, long inspection times, as were found in children by Piek et al. (2007), may be attributable to visual deficiencies. Eye examinations in participants, both children and adults with DCD, in experiments with inspection time are required to illuminate further the extent of any visual effects on inspection time. On the other hand, that the relationships described above were restricted to participants with DCD is reassuring for the assessment of inspection time in participants with typical development, dyslexia and dyslexia/DCD.

At the end of Chapter 3, it was hypothesised that inspection time would correlate positively with levels of visual discomfort, which can be optical or perceptual in origin, in participants with and without SpLDs. The results shown and discussed above do not support this hypothesis for all groups; standard inspection time correlated significantly only with the results of the VDS in participants with DCD. The performance for inspection time appears not to correspond to instances of pattern glare.

Finally, in analyses of variables used to establish profiles of dyslexia, DCD and both, control for results of VDS affected all tests, except abstract visual memory and backward digit span. These results include digit span forward and SMT that do not require vision. Again, this suggests that the VDS and these tests share a more general and perhaps underlying factor, in addition to visual discomfort. Thus, in some circumstances of statistical analysis its discriminant validity may be in question.

6.3. Results: Memory

Question 2.2, asked about relationships of inspection time to measures of auditory and visual memory. Descriptive statistics for two tests of auditory memory: digit span forwards and backwards, and three tests of visual memory: abstract visual memory, Corsi block-tapping tasks forwards and backwards are in Table 19. Correlation analyses established if age, gender and WRIT matrices were covariates of these tests of memory. Further correlation analyses explored relationships between standard inspection time (IT1) and all memory tests results, controlled by identified covariates.

6.3.1. Descriptive statistics. Distributions of most test results for memory were not normal.

6.3.2. Inferential statistics. Age, gender, WRIT matrices, results of VDS all correlated significantly with some tests of memory in some groups. Supplementary details that include details of covariates for five tests of memory and differences between groups for these tests are in Appendix O (Tables O1–O5). In subsequent correlation analyses, potential covariates included age and VDS. These analyses were with and without WRIT matrices because the choice of whether to control for them was not straightforward. There were two significant correlations with gender. Sample size was insufficient to analyse men and women separately.

Correlations: inspection time with memory. Spearman partial correlations between IT1 and results of tests of memory, with different covariates controlled are in Table 20. In the groups of typically developing participants, participants with dyslexia and dyslexia/DCD, there were no significant correlations between IT1 and any of the memory tests after control for age, VDS and WRIT matrices. In the group of participants with DCD, when age and visual discomfort were controlled (Table 20, below the diagonal), there were significant correlations for IT1 with Corsi block-tapping task forward (r_s (32) = – .60, p < .001) and backward (r_s (32) = – .39, p = .035). Partial correlations with added covariate of WRIT matrices made little difference to the results (Table 20, above the diagonal). There was a significant difference in the correlations of Corsi block-tapping task forwards and IT1 between the dyslexia and DCD groups (Fisher's z = -2.33, p = .01, one-tailed, Diedenhofen & Musch, 2015).

Table 19

Study 3: Descriptive Statistics for Five Tests of Memory in Four Groups

Group	Test	Skewness	SE skewness	Kurtosis	SE kurtosis	Shapiro-Wilk Test statistic	Median	Interquartile Range (ms)	Mean	Standard Deviation
Typical *n* = 50	Corsi f	1.00		0.69		.87***	54	42	62	26
	Corsib	0.47		− 0.76		.92**	52	34	62	21
	AVM	− 0.75	.34	− 0.75	.66	.88***	30	13	26	9
	Digits f	− 0.39		− 0.65		.94*	52	18	51	16
	Digitsb	0.79		0.66		.95*	28	14	29	12
Dyslexia *n* = 40	Corsi f	0.62		0.43		.92**	40	22	49	20
	Corsib	0.40		− 0.04		.94	54	23	52	21
	AVM	− 0.29	.39	− 1.16	.76	.93*	27	16	25	9
	Digits f	0.25		− 0.84		.97	47	23	48	14
	Digitsb	1.13		0.88		.85***	19	16	25	15
DCD *n* = 33	Corsi f	0.70		− 0.22		.92*	48	25	49	19
	Corsib	− 0.10		0.06		.95	48	25	43	19
	AVM	− 1.20	.41	0.77	.80	.87**	31	7	28	7
	Digits f	− 0.24		− 0.86		.96	54	18	52	13
	Digitsb	0.61		− 0.79		.92*	22	22	28	14
DCD with dyslexia *n* = 18	Corsi f	0.26		− 0.76		.89*	41	26	46	22
	Corsib	0.32		0.59		.97	45	30	46	22
	AVM	− 0.51	.34	− 0.84	.66	.94	27	15	25	9
	Digits f	0.59		− 0.60		.93	32	22	37	15
	Digitsb	0.68		− 0.41		.93	21.5	19	24	11

Note. Corsi = Corsi block-tapping task, b: back; f: forward; *(*Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000; The Psychological Investigation Building Language, PEBL; Mueller, 2010); DCD = developmental coordination disorder; dyslexia = developmental dyslexia; digit span and abstract visual memory (AVM) Test of Memory & Learning-2 (TOMAL-2; Reynolds & Voress, 2007). * *p* < .05; ** *p* < .01; *** *p* < .001.

Table 20

Study 3: Spearman Partial Correlations for Standard Inspection Time and Memory

Typical *n* = 50	1	2	3	4	5	6
1 IT1	-	– .16	– .14	– .04	.11	.11
2 Corsi f	– .26	-	**.62*** **	.21	.03	.16
3 Corsi b	**– .29***	**.66*****	-	.08	.10	.12
4 AVM	–.22	**.30***	.24	-	.16	.28
5 Digit f	– .02	.24	.22	.22	-	**.40****
6 Digits b	.00	.12	.18	.22	**.48*****	-
Dyslexia *n* = 40						
1 IT1	-	– .03	.02	– .05	– .15	–.29
2 Corsi f	– .05	-	.24	.28	– .01	.05
3 Corsi b	– .04	.22	-	**.45****	.35*	– .18
4 AVM	.00	.28	**.38***	-	– .08	– .13
5 Digits f	– .19	.12	– .08	.07	-	.36*
6 Digits b	– .07	.05	**.41***	.13	**.40***	-
DCD *n* = 33						
1 IT1	-	**– .53****	**– .41***	– .29	– .07	.14
2 Corsi f	**– .60*****	-	**.48***	**.44***	.17	– .01
3 Corsi b	**– .39***	**.47****	-	.35	**.38***	– .15
4 AVM	– .16	.28	.29	-	**.42***	.28
5 Digits f	.11	– .01	– .12	.33	-	**.40***
6 Digits b	– .05	.26	**0.38***	.28	**.39***	-
Dyslexia/DCD *n* = 18						
1 IT1	-	– .35	– .27	– .32	– .39	– .21
2 Corsi f	.02	-	**.67****	.37	**.57***	.36
3 Corsi b	– .15	**.72****	-	.40	**.61***	.12
4 AVM	– .32	.41	**.51***	-	**.64***	.27
5 Digitsf	.06	.45	.18	.24	-	**.57***
6 Digits b	– .44	**.51***	**.68****	**.71****	.42	-

Note. Significant correlations are in bold. Below the diagonal: Age + Visual Discomfort Scale controlled; above diagonal Visual Intelligence; AVM = abstract visual memory (Test of Memory & Learning-2; Reynolds & Voress, 2007,); b = backward; Corsi = Corsi block-tapping task *(*Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000; The Psychological Investigation Building Language, PEBL; Mueller, 2010); digit span (TOMAL-2); DCD = developmental coordination disorder; f = forward; IT1 = standard inspection time 1. * $p < .05$, ** $p < .01$, *** $p < .001$, two-tailed.

6.4. Discussion: Memory

The relationships between standard inspection time (IT1) and tests of memory were investigated in participants with and without SpLDs. In an SpLD group, a larger than typical correlation between inspection time and a test of memory is likely to be generated, directly or indirectly, from features characteristic of the SpLD. It could provide evidence for what inspection time evaluates. If inspection time depends on memory processes, in general, one would expect auditory as well as visual memory to correlate with inspection time. If visual memory is important to inspection time, one would expect abstract visual memory and Corsi block-tapping tasks to have significant links to inspection time.

Results showed that in the group of participants with typical development, the magnitude of correlations between inspection time and abstract visual memory was less than results from Nettelbeck and Burns (2010) who found that a picture recognition task in adults correlated (r (239) = – .49, p < .001). Also in that study, inspection time correlated significantly with digit span (r (239) = – .42, p < .001) as opposed to the negligible correlation found and reported above. Reasons for discrepancies between current and previous results are unclear. Smaller sample size could be partly responsible, but is unlikely to be the whole reason for not finding a medium sized correlation, for in Studies 1 and 2 with children (Appendix E), correlations with memory were of that order.

In the group of participants with DCD, after correlates that included VDS were controlled, inspection time's correlation with results of tests for Corsi block-tapping task forward and backward was medium or large and significant. These tests index visuospatial sequential and working memory, respectively. The results suggest that visuospatial memory has an important relationship to inspection time in the group of participants with DCD. Ranges of results of the Corsi block-tapping tasks in the DCD group, presented in the descriptive statistics, are more limited than is typical. So large, significant correlations between visuospatial memory and inspection time are not, as anticipated, probably accentuated by a significantly greater spread of values for visuospatial memory or for inspection time. In participants with DCD, visual spatial memory is deficient (Tables O1 & O2) compared to that in typically developing participants. One explanation of the results is that the inspection time task requires visuospatial memory. However, Corsi block-tapping task forward is also deficient in dyslexia but this group shows no large correlation between Corsi Block Task and inspection time, which suggests that the two parameters of inspection time and visuospatial memory have another variable in common. A likely candidate for a common variable is spatial awareness, known to be deficient in DCD, but not in dyslexia. A deficiency in spatial awareness could influence performance for the Corsi block-tapping tasks and may relate to evaluation of the pi-figure in inspection time. Robitaille, Muniz, Piccinin, Johansson and Hofer (2012) showed that visuospatial ability and the results of a digit symbol substitution task related to each other in older, typical participants. Their results cast doubt on the validity of the substitution task as a reliable test of speed of processes for participants with impaired spatial awareness because of this spatial confound. This conclusion could apply to tests of inspection time in participants with weak spatial awareness as indicated here, namely those with DCD, as well as in older adults (e.g., W. Johnson & Deary, 2011).

In participants with dyslexia/DCD, the absence of a significant relationship between inspection time and visuospatial memory is notable. This may be evidence that this group has a different aetiology to that of DCD. Regression analysis of group differences showed that participants in the DCD group, but not the dyslexia/DCD group, had significantly more difficulties with the Corsi block-tapping task backward than was typical. One explanation for this pattern could be that participants with dyslexia/DCD have characteristics linked to dyslexia, which could have a compensatory influence.

Limitations of this study are that accuracy of the Corsi block-tapping task may rely on motor skills, which could affect the responses of participants with DCD who have difficulty with motor coordination. A task that combined a request to remember and simultaneously direct movement may have distracted participants with DCD. In a review, it was noted that “Deficits are especially apparent for: dual tasks; tasks that demand more precision (both spatial and temporal), more advanced planning, or that stress the system in a way that requires some adaptation/adjustment at a perceptual-motor level to maintain stability“ (Wilson et al., 2017, p. 25). A touchscreen operated system rather than the click of mouse would reduce any concerns, but not eliminate them. It would also provide more direct feedback for participants with DCD, than would be obtained from directing the cursor on a screen. That said, the on-screen blocks which had to be identified by a mouse click were large and it is unlikely that adult participants would find it difficult to locate the correct block with the cursor. There was no indication that this was a problem from observations of participants with DCD during the test.

There were significant differences between the group with typical development and DCD for visuospatial memory tests (Tables O1 & O2). The difference between groups was reduced when the hierarchical regression analyses were repeated with the results of the VDS controlled. One interpretation would be that visual discomfort affected performance on this test of memory, in this group; however, an alternative explanation would be that both visual discomfort and memory relate to another variable. To support the second interpretation, analyses with digit span forward, a purely auditory test, also showed a reduction in the prediction after visual discomfort was controlled, this time in the dyslexia/DCD group. This suggests that VDS relates also to another, non-visual parameter.

In summary, results presented here did not support Hypothesis 2.2 that inspection time would relate significantly to both tests of auditory and visual memory in all groups. That hypothesis would have reflected a fundamental affinity between memory and inspection time. That the relationship would be greater in the groups that exhibited memory deficiencies, that is, the SpLD groups, was unsupported, except for DCD. The hypothesis was supported for the relationship between inspection time and visuospatial memory in the group of participants with DCD. It is speculated that this relationship may involve impaired spatial awareness in DCD rather than memory per se.

6.5. Results: Symbol Digits Modalities and Chronometric Tests

Question 2.3 asked about inspection time's relationship to measures of information processing speed and motor time. Processing speed tests were Symbol Digit Modalities Test (SDMT), simple decision time (SDT), choice decision time (CDT) and simple motor time (SMT). Correlation analyses established if age, gender and WRIT matrices for visual intelligence were covariates of these tests of speed. Correlations and partial correlations with covariates were between standard inspection time (IT1) and tests of speed. Processing speed as measured by inspection time is referred to as central processing speed, as it does not include motor processes.

Supplementary details are in Appendix P. They include hierarchical regression analyses to show differences for speed tests between groups when results of the VDS were and were not accounted for (Tables P1–4). They also include a principal component analysis (PCA) to investigate IT1's position among tests of memory and speed.

6.5.1. Descriptive statistics. Table 23 shows descriptive statistics for the results of processing speed tests.

6.5.2. Inferential statistics.

Correlation and partial correlation analyses: speed tests. Age, gender, results from WRIT matrices and VDS all correlated with some tests in some groups (Appendix P). Covariates were not included in the analysis in one matrix and in another, they were. Participant numbers were insufficient to analyse men and women separately. Table 24 below the diagonal shows correlational analyses between IT1, SDMT and chronometric tests in the separate groups, with covariates not controlled. In participants with DCD and dyslexia/DCD, there were significant negative correlations between IT1 and SDMT *($r_s(32) = -.38$, $p = .031$; $r_s(17) = -.54$, $p = .022$,* respectively). The correlation between IT1 and CDT in DCD was *($r_s(32) = -.37$, $p =$ .035).* All other correlations with IT1 were non-significant. When the typically developing participants and participants with dyslexia were added to form a larger group, a correlation analysis between IT1 and SDMT was negative, significant but still small ($r_s(89) = -.23$, $p = .028$).

Table 23

Study 3: Descriptive Statistics for Tests of Speed in Four Groups

N = 141	Skewness	SE skewness	Kurtosis	SE kurtosis	Shapiro-Wilk Test statistic	Median (ms)	Interquartile Range (ms)	Mean (ms)	Standard Deviation (ms)
Typical n = 50									
SDMT	0.63		0.74		.23	57	13	57	8
SDT	1.08		1.20		.92**	260	40	270	40
CDT	1.51	.34	3.51	.66	.90***	345	54	355	49
SMT	0.63		0.25		.96	94	31	99	27
Dyslexia *n* = 40									
SDMT	− 0.36		1.39		.33	50	10	49	9.5
SDT	3.50	.37	16.01	.73	.66***	281	57	298	76
CDT	3.77		18.32		.63***	379	65	408	112
SMT	4.02		20.68		.62	99	48	117	73
Developmental coordination disorder *n* = 33									
SDMT	0.10		0.35		.97	48	13	49	11
SDT	3.28	.41	14.39	.80	.69***	307	76	330	90
CDT	2.03		3.63		.72***	390	95	454	156
SMT	0.95		0.35		.92*	113	64	121	47
Developmental coordination disorder with dyslexia *n* = 18									
SDMT	− 0.35		− 1.11		.93	48	19	47	11
SDT	1.53	.54	2.58	1.04	.87*	321	105	340	91
CDT	1.40		1.48		.85**	396	185	440	148
SMT	0.70		− 0.42		.93	120	102	142	71

Note. SDT and CDT = simple and choice decision time; SMT = simple motor time; Symbol Digit Modalities Test (SDMT; Smith, 1982) measured in number of items coded. * $p < .05$; ** $p < .01$; *** $p < .001$.

Partial correlation analysis: inspection time, Symbol Digit Modalities Test and chronometric tests. Further partial correlation analyses were between IT1 and SDMT with control for Corsi block-tapping task backward (Table 23, in brackets). For DCD, control for Corsi block-tapping task backward reduced the relationship between IT1 and SDMT.

Table 24

Study 3: Spearman Correlation and Partial Correlation Matrices for Standard Inspection Time, Symbol Digit Modalities and Chronometric Tests in Four Groups

Typical *n* = 50					
	1	2	3	4	5
1 IT1	-	– .27 (– .23)	.05	.19	.05
2 SDMT	– .26	-	– .13	– .16	.03
3 SDT	.06	– .16	-	**.38****	**.50*****
4 CDT	.18	– .22	**.40****	-	.123
5 SMT	.12	– .05	**.50*****	.16	-
Dyslexia *n* = 40					
1 IT1	-	– .24 (– .24)	.23	.02	.04
2 SDMT	– .21	-	**– .56*****	**– .35***	.00
3 SDT	.28	**–.52****	-	**.49****	.31
4 CDT	.00	**– .38***	**.46****	-	.28
5 SMT	.13	–.08	**.47****	.32*	-
DCD *n* = 33					
1 IT1	-	**– .34*** (– .18)	.07	.26	.12
2 SDMT	**– .38***	-	– .34	**– .59*****	– .36
3 SDT	.18	– .24	-	**.58*****	.33
4 CDT	**.37***	**– .57****	**.60*****	-	.29
5 SMT	.16	**– .38***	**.35***	**.39***	-
Dyslexia/DCD *n* = 18					
1 IT1	-	**– .56* (– .56***)	.35	.39	.28
2 SDMT	**– .54***	-	**– .62****	**– .65****	– .45
3 SDT	.46	**– .76*****	-	**.84*****	**.69****
4 CDT	.33	**– .66****	**.77*****	-	**.56***
5 SMT	.22	**–.60****	**.70*****	**.63****	-

Note. Below diagonal: no control; above diagonal: control for age, WRIT matrices (Glutting, Adams & Sheslow, 2000) and Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999). In brackets with controls for Corsi block-tapping task backward (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000; The Psychological Investigation Building Language, PEBL; Mueller, 2010). DCD = developmental coordination disorder; dyslexia = developmental dyslexia; IT1 = standard inspection time; Symbol Digit Modalities Test (SDMT; Smith, 1982); SDT and CDT = simple and choice decision time; SMT = simple motor time. Significant correlations in bold. * $p < .05$, ** $p < .01$, *** $p < .001$, two-tailed.

Group predictions by paper-and-pencil tests of speed and other chronometric tests. Hierarchical regression analyses were made with SDMT, SDT, CDT and SMT as the dependent variable and SpLD groups as predictors compared to the group of participants who were typically developing (Tables P1–4, Appendix P).

Coding. Groups of participants with dyslexia, DCD and dyslexia/DCD all predicted SDMT ($ß$ = – .33, – .33 and – .28, p < .001, respectively).

Simple decision time. SDT was significantly predicted by the participants with DCD ($ß$ = .34, p < .001) and the participants with dyslexia/DCD (p = .001).

Choice decision time. Dyslexia, DCD and dyslexia/DCD significantly predicted CDT ($ß$ = *.20,* p =.036, $ß$ = *.35,* p <.001, $ß$ = *.23,* p = .013, respectively).

Motor time. Dyslexia/DCD significantly predicted SMT ($ß$ = *.23,* p = .014).

6.6. Discussion: Symbol Digit Modalities and Chronometric Tests

Correlational relationships. Relationships between inspection time, a coding test, and other chronometric tests were investigated in participants with and without SpLDs.

Typical development and dyslexia. In the groups of participants with typical development and dyslexia, all correlations between inspection time and the results of other tests: SDMT, SDT, CDT and SMT were small and non-significant. For the typically developing group, the strength of the correlation between inspection time and SDMT, the coding test, but not the significance, was consistent with results obtained by O'Connor and Burns (2003). On amalgamation of these two groups to form one group of a similar size to the group tested by O'Connor and Burns, the correlation between inspection time and SDMT became significant, but was still small. This correlation was smaller than that found between inspection time and a coding task in a larger study of 238 adult participants by Nettelbeck and Burns (2010; r = – .40, p = .001).

In Nettelbeck and Burns' (2010) study, there was a small significant correlation between inspection time and SDT in adults with typical development, so the negligible and non-significant correlation between inspection time and SDT for the group of participants with typical development was unexpected. There were several methodological differences between the current SDT test and Nettelbeck and Burns' (2010) study but also participants were aged up to 87 years old. These differences as well as fewer participants may be the reason the results from this study were different to those obtained previously.

A small and non-significant result for the correlation between inspection time and CDT is consistent with previous results for young adults (e.g., O'Connor & Burns, 2003) although the CDT in the current experiment was of a unique design and therefore not directly comparable with CDT measured from lights on a Jensen box, for example.

The small, non-significant correlation between inspection time and MT was expected (e.g., O'Connor & Burns, 2003).

In neither children nor adult participants with dyslexia, have there been previous reports of the relationships of inspection time with SDMT, SDT, CDT or MT, as far as is known.

Developmental coordination disorder*.* In a group of participants with DCD, the correlation between inspection time and SDMT was medium and significant. Furthermore, with results of Corsi block-tapping task backward controlled in the relationship, there was a reduction to non-significant correlation between inspection time and SDMT. This suggests that the additional shared variance related to tests of visual sequential working memory.

A significant correlation between inspection time and CDT lost its significance after it was controlled for age, visual intelligence and results of the VDS.

In children with DCD, inspection time and DT were measured in the same participants (Piek et al., 2007) but the measures were combined (Section 3.6). In that investigation, it was not clear whether DT included MT or not, so those results are not comparable to the results presented here.

Dyslexia/developmental coordination disorder. In a group of participants with dyslexia/DCD, the relationship between inspection time and SDMT was large and significant before and after age, visual intelligence, results of the VDS and memory were controlled. No results of previous research are available for participants with dyslexia/DCD. Unlike the results for DCD the results for the combined dyslexia/DCD group suggest that there is a shared component between inspection time and SDMT unrelated to memory and hence visuospatial skills. It is speculated that this could be speed.

Principal components analysis. A principal components analysis (PCA; Appendix P) resulted in a two-factor solution, labelled Visual Memory and Speed, for components of results for tests of speed, visual memory, visual intelligence and age. Inspection time loaded entirely on the Speed factor but not so much as did SDT and CDT. SDMT loaded on both Speed and Visual Memory. In a further PCA analysis with just DCD and dyslexia/DCD groups, inspection time loaded on Visual Memory as well as Speed. This suggests that a limiting factor for inspection time is visual memory and from the discussion in Section 7.6, this may depend on spatial awareness.

Group differences. Differences in performance of the tests of SDMT, CDT, SDT and SMT in this experiment between participants with typical development and each of the SpLD groups, were investigated by hierarchical regression analyses in which age, gender and WRIT matrices were controlled (Appendix P).

For the SDMT, analyses showed that the results were slower than was typical in all SpLD groups. After visual discomfort, assessed with the VDS, was also controlled, the groups with dyslexia and dyslexia/DCD did not differ significantly from the group of typically developing participants, but the group with DCD did.

For CDT, all groups of participants with SpLDs reacted more slowly compared to the group of participants who were typically developing but again after visual discomfort evaluated by a questionnaire was controlled statistically, CDT was only significantly longer in the group with DCD.

For SDT, regression analysis showed that, only in the group of participants with DCD and dyslexia/DCD, was SDT slower than in the group of participants with typical development. Weaknesses remained after visual discomfort was included in the model.

For SMT, analysis showed that, in the group of participants with dyslexia/DCD, SMT was slower than was typical but again, after visual discomfort was controlled, SMT was not significantly different to participants without SpLDs.

Conclusions. For the SDMT, believed to be a test of processing speed, correlation analyses described above implicate memory in DCD but not in dyslexia/DCD. This may be because speed in the dyslexia/DCD group may be more influential for both tests than visuospatial memory, which may connect to performance in a task of visuospatial memory in DCD. Again, for the relationship between inspection time and choice decision time, there may have been contamination of the performance by visuospatial memory in the group with DCD. The results also suggest that visual discomfort relates to the performance of these tests that purport to record speed of various cognitive processes in participants with dyslexia, DCD or both dyslexia/DCD. This confirms and extends the work by Conlon et al. (1999). The tests affected were SDMT, CDT and SMT.

It is of note that visual discomfort relates to processes indexed by SMT that do not require accurate vision. Like the effects of the VDS on auditory memory, as described in Tables O4 and O5 (Appendix O), this suggests visual discomfort may not simply cause the differences. Thus, although it is tempting to assume that visual discomfort causes slower test results in some cases this may not necessarily be so and there could be a mediating variable responsible for visual discomfort and SpLDs of dyslexia and DCD. Importantly, the results of statistical analyses are not confirmation that visual discomfort affects or relates in some way to the other tests.

Hypothesis 2.3., that inspection time would relate significantly to a coding task in all groups was supported for DCD and dyslexia/DCD, bearing in mind the smaller numbers of participants in these groups. This relationship may be due to other variables, namely visual discomfort or visuospatial memory. That there would be significant but small correlations between inspection time and DTs, was supported only for CDT in participants with DCD and again visuospatial decisions may be implicated in the relationship. As expected, all correlations between inspection time and MT were non-significant. These results confirm that there are questions to be asked about whether central processing speed is all that the tests of speed explored above are measuring. If they do not index simply speed of processes, there are important implications for the use of inspection time, SDMT, similar coding tests and chronometric tests in the assessment of people with dyslexia, DCD and both.

Relationships between weak working memory, visual discomfort and inspection time are exposed in hierarchical regression analyses in different participant groups in stand-alone Chapter 7. In these upcoming analyses, both sets of stimuli are explored, that is, pi-figure and non-standard stimuli.

6.7. Results: Literacy Attainment: Rapid Automatic Naming

Question 2.4 asked about the relationships between inspection time and literacy attainment, which was assessed by: (a) rapid automatic naming (RAN), (b) reading and (c) handwriting speeds in participants with typical development, dyslexia, DCD or both. Unless otherwise stated, inspection time (IT1) was from the standard method in IT Test 1, with pi-figure stimuli and un-speeded responses, descriptive statistics and covariates for which are in Tables 4 and 5. First, results presented in Section 7.7 addressed the relationships between IT1 and RAN. Correlation analyses established covariates of RAN tests; and they explored relationships between IT1 and RAN tests, controlled by identified covariates. Supplementary analyses are in Appendix Q and include details of covariates for RAN tests and regression analyses to show relative performances for RAN between groups with and without SpLDs (Table Q1).

6.7.1. Descriptive statistics. Descriptive statistics were for four RAN tasks: digits, letters, colours and objects. Descriptive statistics (Table 25) show that most RAN test results were not normally distributed.

6.7.2. Inferential statistics.

Covariates: rapid automatic naming. WRIT matrices correlated significantly with RAN tests only in the group of participants with typical development. Visual Discomfort Scale (VDS) correlated significantly with RAN colours and objects only in participants with DCD.

Table 25

Study 3: Descriptive Statistics for Tests of Rapid Automatic Naming in Four Groups

Group	CTOPP-2 RAN Test	Skewness	SE skewness	Kurtosis	*SE* kurtosis	Shapiro-Wilk Test statistic	Median (ms)	Interquartile Range (ms)	Mean (ms)	Standard deviation (ms)
Typical (*n* = 50)	digits	0.32	0.34	− 0.84	0.66	.93**	11	3	11	2
	letters	− 0.04		− 0.46		.96	12	3	12	2
	colours	0.54		3.56		.97**	18	7	18	4
	objects	0.71		0.32		.95**	21	5	22	4
Dyslexia (*n* = 40)	digits	1.77	0.38	4.64	0.74	.85***	14	5	15	4
	letters	1.26		2.90		.92*	16	5	16	4
	colours	1.21		3.56		.92***	23	6	22.50	5
	objects	2.28		6.90		.78***	25	4	27	7
DCD (*n* = 33)	digits	1.29	0.41	1.30	0.81	.87**	13.5	5	15	5
	letters	1.97		4.57		.81***	15	7	16	6
	colours	1.32		1.77		.88**	22	6	23	6
	objects	0.56		− 0.89		.91*	24	10	26	6
Dyslexia and DCD (*n* =	digits	1.03	0.54	0.42	1.04	.87*	13	10	16	6
	letters	1.52		2.70		.84**	15	7	16	5
	colours	0.65		0.32		.93	24	9	24	5.50
	objects	1.12		0.96		.90	25	7	27	6

Note. DCD = developmental coordination disorder; dyslexia = developmental dyslexia; CTOPP-2 = Comprehensive Test of Phonological Processing -2 (Wagner, Torgeson, Rashotte & Pearson, 2013); RAN = rapid automatic naming.* *p* <.05; ** *p* <.01; *** *p* < 001.

Correlations: inspection time and rapid automatic naming. Table 26 displays correlation analyses between IT1 and RAN test results.

Table 26

Study 3: Spearman Correlation and Partial Correlations for Standard Inspection Time and Rapid Automatic Naming Tests in Four Groups

Variables controlled	CTOPP-2 RAN Tests			
Typical (*n* = 50)	digits	letters	colours	objects
None	.12	.21	.24	**.31***
WRIT matrices	– .03	.08	.11	.21
WRIT matrices and VDS	– .04	.06	.12	.24
Dyslexia (*n* = 40)				
None	.15	.30	.06	– .10
WRIT matrices	.12	.29	.05	– .09
WRIT matrices and VDS	– .01	.23	– .07	– .25
Developmental coordination disorder (DCD; *n* = 33)				
None	.33	.13	**.38***	**.52****
WRIT matrices	.30	.06	**.40***	**.54****
WRIT matrices and VDS	.13	– .17	.27	**.48***
Dyslexia/DCD (*n* = 18)				
None	.33	.30	.06	.04
WRIT matrices	.28	.34	.00	.04
WRIT matrices and VDS	.32	.41	.06	.07

Note. Statistically significant results in bold. CTOPP-2 = Comprehensive Test of Phonological Processing -2 (Wagner, Torgeson, Rashotte & Pearson, 2013); Visual Discomfort Scale (VDS; Conlon, Lovegrove, Chekaluk & Pattison, 1999); Wide Range Intelligence Test (WRIT) matrices (Glutting, Adams & Sheslow, 2000). * $p < .05$, ** $p < .01$, *** $p < .001$, two-tailed.

In groups of participants with typical development and those with dyslexia, the relationships between IT1 and RAN tests were largely non-significant. A medium correlation between IT1 and RAN objects in the group with typical development lost significance after controls were made. In the group of participants with DCD, there were significant, medium correlations between IT1 and RAN colours and objects (r_s (32) = .38, p = .032; r_s (32) = .52, p = .002, respectively). Relationships were similar with WRIT matrices controlled. With results of both WRIT matrices and VDS controlled, IT1's relationship with RAN colours diminished but the relationship with RAN objects remained significant (r_s (32) = .48, p = .009). For comparisons of the correlations between IT1 and RAN objects between groups of participants with dyslexia (r_s (39) = – .10, p = .565) and DCD (r_s (32) = .52, p = .002), the difference between the correlations was significant and the null hypothesis was rejected (Fisher's z = – 2.75, p = .003, one-tailed; Diedenhofen & Musch, 2015). For comparisons of the correlations between IT1 and RAN objects between groups of participants with DCD (r_s (32) = .52, p = .002) and dyslexia/DCD (r_s (17) = .04, p = .876), the difference between the correlations was significant and the null hypothesis was rejected (Fisher's z = – 1.70, p = .045, one-tailed; Diedenhofen & Musch, 2015). In the group of participants with dyslexia/DCD, there were no significant correlations between IT1 and RAN tests.

6.8. Discussion: Rapid Automatic Naming

In participants with typical development, the relationships between standard inspection time and RAN tests were small and non-significant, except for RAN objects. These results do not support the notion that RAN relies principally on rapid visual processes for single items, exemplified by the inspection time task. They do not suggest that inspection time preferentially relates to alphanumeric RAN, so the orthographic nature of inspection time appears unimportant. They do not suggest that central processing speed is shared by both tests.

As expected in participants with dyslexia, RAN tasks did not relate significantly to inspection time. This non-significant result was anticipated in dyslexia because of strong influences of language skills on RAN. Mclean et al. (2011) compared inspection time to RAN colours and objects in typically developing children and children with dyslexia. These authors also found little association between inspection time and RAN colours and objects. In adults with typical development and dyslexia, the relationships shown here between standard inspection time and RAN colours and objects is much the same as McLean et al.'s (2011) results for children. In dyslexia, the relationship of inspection time with RAN digits and letters has previously not been explored in any participant group, as far as is known.

In participants with DCD, as predicted, the relationship between standard inspection time and RAN objects was robust after control for WRIT matrices and results of the VDS. The firm relationship, which was significantly different to the correlation found in the group of participants with dyslexia, supports the hypothesis that spatial deficiencies in DCD limit standard inspection time. Similarly, within the DCD group the significant difference between letters' and objects' relationships to inspection time supports a notion that spatial deficiencies in DCD limit standard inspection time. The relationship between standard inspection time and RAN colours lost significance and became smaller after WRIT matrices and VDS were controlled. There have been no previous reports of RAN 's relationship to inspection time in DCD, as far as is known.

In participants with dyslexia/DCD, the results for correlations between RAN objects and standard inspection time were significantly different to those found in the DCD group. A speculation is that phonological deficiencies experienced by participants with dyslexia/DCD may override any spatial relationships that exist between standard inspection time and RAN in this group.

At the end of Chapter 3 was a hypothesis that in participants with typical development, inspection time would correlate significantly with RAN tasks. The hypothesis was unsupported, except for RAN objects, which correlated significantly with inspection time. The correlation between RAN objects alone and inspection time suggests common spatial influences. Results support another hypothesis that in participants with dyslexia, inspection time would not correlate significantly with RAN tasks. The last hypothesis for RAN was that, in participants with DCD, the correlation between inspection time and alphanumeric and colours RAN would be similar to that of participants with typical development but that there would be a firm relationship between inspection time and RAN objects. Results supported this hypothesis, although whether this was due to shared limits on visuospatial processing requires further investigation.

6.9. Results: Reading and Writing Attainment

Question 2.4 also asked about the relationship between inspection time and tests of (b) reading and (c) writing: TOWRE-2 sight word and phonemic decoding efficiency and four tests of handwriting from DASH: copy best, copy fast, alphabet writing and graphomotor speed. Correlation analyses established covariates of these tests of literacy and relationships with standard inspection time (IT1), controlled by identified covariates. Appendix R displays supplementary details of correlation analyses between reading and writing test results with age, gender, WRIT matrices and VDS. Hierarchical regression analyses established differences between groups for test results when account either was or was not taken of visual discomfort, assessed by the VDS (Tables R1–4).

6.9.1. Descriptive statistics. The smallest correlation between copy best and fast was in the DCD group ($r_s = .49$, $p = .004$), so for simplicity, and because it was completed under pressure of time, only copy fast was used for subsequent analyses. Table 27 displays descriptive statistics for the results of tests of literacy attainment. Some results were not normally distributed as shown by the Shapiro-Wilk Test.

6.9.2. Inferential statistics.

Covariates. In the group of participants with typical development, WRIT matrices correlated significantly to a medium level with both sight word reading and phonemic decoding efficiencies. In the group of participants with dyslexia, age, gender and VDS were all significant correlates of reading. In DCD, VDS was a significant correlate of reading.

Correlation analysis: inspection time with reading. Table 28 displays results of correlation and partial correlation analyses in the four groups between IT1 and tests of literacy.

Table 27

Study 3: Descriptive Statistics for Tests of Single Word Reading and Handwriting

N = 141	TOWRE-2 & DASH Tests	Skewness	*SE* skewness	Kurtosis	*SE* kurtosis	Shapiro-Wilk Test statistic	Median	Interquartile Range	Mean	Standard Deviation
Typical *n* = 50	Sight words	− 0.68		− 0.45		.90***	98	12	98	9
	Phonemic	− 1.20		2.28		.92**	58	10	56	8
	Copy best	0.15	.34	− 0.01	.66	.98	29	7	29	5
	Copy fast	0.55		0.63		.97	38	7	38	6
	Alphabet	0.71		1.79		.96	97	29	97	22
	Graphic speed	0.18		– 0.29		.99	40	19	40	12
Developmental dyslexia *n* = 40	Sight words	− 0.74		1.18		.95	83	20	82	14
	Phonemic	− 0.20		− 0.84		.96	42	17	43	10
	Copy best	− 0.32	.37	− 0.08	.73	.98	26	12	25	7
	Copy fast	0.26		− 0.64		.97	35	12	34	8
	Alphabet	0.21		− 0.59		.95	84	27	79	21
	Graphic speed	0.47		0.46		.98	39	17	39	11
Developmental coordination disorder (DCD) *n* = 33	Sight words	− 0.46		0.64		.96	88	16	88	13
	Phonemic	− 0.35		− 0.99		.95	53	15	53	8
	Copy best	− 0.03	.41	0.72	.80	.97	24	8	24	7
	Copy fast	0.01		− 0.60		.97	34	10.5	33	7
	Alphabet	− 1.01		0.58		.92*	86	29	81	22
	Graphic speed	0.20		– 0.80		.97	34	21	33	13
Dyslexia/DCD *n* = 18	Sight words	− 0.72	.54	0.51	1.04	.96	82	26	77	17
	Phonemic	− 1.37		2.13		.88*	43	20	40	14
	Copy best	0.57		0.27		.95	23	7	23	5
	Copy fast	0.18		− 0.74		.96	32	7.5	33	4.5
	Alphabet	0.29		− 1.25		.93	69	40	73	23
	Graphic speed	0.12		0.36		.99	26	15	27	11

Note. Scores are raw. DASH = Detailed Assessment of Handwriting 17+ (Barnett, Henderson, Scheib & Schulz, 2007); graphic = graphomotor; median and means in words (TOWRE) or words or letter/min (DASH); phonemic = phonemic decoding; sight words & phonemic decoding, Test of Word Reading Efficiency (Torgeson, Wagner & Rashotte, 2012); WRE = word reading efficiency. * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 28

Study 3: Spearman Correlation and Partial Correlations for Standard Inspection Time, Sight Word Reading Efficiency and Phonemic Decoding Efficiency in Four Groups

Typically developing (*n* = 50)	1	2	3
1 IT1	-	– .06 (–.06)	.07 (.09)
2 sight words	– .20	-	**.61*** (.61)**
3 phonemic decoding	– .07	**.68*****	-
Dyslexia (*n* = 40)			
1 IT1	-	.00 (.00)	.06 (.14)
2 sight words	– .02	-	.15
3 phonemic decoding	.04	**.37***	-
DCD (*n* = 33)			
1 IT1	-	**– .40*** (– .237)	– .11 (.08)
2 sight words	**– .42***	-	**.73*** (.71)**
3 phonemic decoding	– .12	**.74*****	-
Dyslexia/DCD (*n* = 18)			
1 IT1	-	– .02 (– .07)	.01 (– .01)
3 phonemic decoding	– .07	-	**.68** (.68)**
2 sight words	.072	**.65****	-

Note. Below the diagonal, no controls; above diagonal, age and WRIT matrices (Glutting, Adams & Sheslow, 2000) and in brackets with Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999). DCD = developmental coordination disorder; dyslexia = developmental dyslexia; IT1 = Inspection Time 1; sight words and phonemic decoding from Test of Word Reading Efficiency (Torgeson, Wagner & Rashotte, 2012). Significant correlations are in boldface. * $p < .05$, ** $p < .01$, *** $p < .001$, two-tailed.

In Table 28 it can be seen that in the group of participants with DCD there was a medium, negative correlation between IT1 and sight word reading efficiency ($r_s = –.42$, $p = .015$). Only after results of the VDS were controlled in a partial correlation analysis did this relationship lose significance.

Correlation analysis: non-standard inspection time Tests 3 + 4 with reading. Because there was a difference in performance of (IT3 + IT4) between groups of participants with SpLDs and those with typical development, further correlation analyses were run between tests of word reading efficiency and (IT3 + IT4) in the separate participant groups (Table R3, Appendix R). There were no significant correlations between (IT3 + IT4) and word reading efficiency in any group.

Correlation analysis: inspection time with writing. Both before and after age, WRIT matrices and results of the VDS were controlled, IT1 did not correlate significantly with alphabet writing, copying or graphomotor speed in any group.

6.10. Discussion: Reading and Writing

Reading. Single word reading and phonemic decoding efficiency from TOWRE-2 is just one of many ways to assess reading. TOWRE-2 does not test comprehension or horizontal tracking across text. Previous research in children with typical development has shown that reading fluency and untimed tests of basic reading skills were unrelated to inspection time (Kranzler et al., 1998; Mockler, 2003). Results from the current study are consistent with this previous research; standard inspection time (IT1) correlated significantly to a medium degree with efficiency of sight word reading in the DCD group only. Thus, in the group of participants with DCD, inspection time appears to have a, hitherto undiscovered, relationship with basic reading skills. This is possibly associated with visual discomfort, as assessed by the VDS because the relationship diminished when visual discomfort assessed by the VDS was controlled. As shown in Section 7.1, in DCD, standard inspection time correlated with visual discomfort assessed by the VDS. Moreover, sight word reading efficiency showed a medium negative correlation with VDS in DCD. It is likely that visual discomfort relates to both standard inspection time and reading. This raises a question about why this pattern of relationships is not apparent in participants with co-occurring dyslexia/ DCD. One would expect that effects from DCD would feature in the relationships between inspection time and sight word reading in dyslexia/DCD unless these have a different aetiology. Phonemic decoding efficiency did not correlate significantly with inspection time in participants with typical development or SpLDs. One possible reason is that phonemic decoding is not an automatic process and therefore dominated the relationship between reading, inspection time and VDS. This explanation may also account for an absence of any relationship in dyslexia/DCD as phonological issues may have obscured it.

Appendix R showed that tests of word reading efficiency were weaker in all SpLD groups compared to participants with typical development. For phonemic decoding, the differences between the group of participants with typical development and DCD were no longer significant after VDS had been controlled. For the DCD group, visual discomfort appeared to contribute more importantly than in the other groups to the difference from the group of participants with typical development for sight word reading efficiency. As expected, phonemic decoding was weaker than typical in groups of participants with dyslexia and dyslexia/DCD but not DCD.

In analyses for the DCD group, it cannot be concluded that visual discomfort as measured by the VDS causes the effects, either of diminished performance or correlation, that are seen to lessen when it is controlled statistically. A causal explanation is just one possibility. It would be important to explore, if it were possible, the removal of visual discomfort in practice, to establish its effects, if any, on literacy skills, rather than rely on mathematical manipulation, as in this investigation. It could be that the VDS taps other related differences. However, it seems likely and so is hypothesised here that there is, in DCD, a common cause for correlations between inspection time and weak reading and that these are due to visual anomalies.

At the end of Chapter 3, a hypothesis was that, in all participants, inspection time would correlate with sight word reading efficiency. The hypothesis is supported only for DCD and this association was not robust after control for visual discomfort.

Writing. Although there were group differences in handwriting speed, standard inspection time did not correlate significantly with any test of handwriting in any participant group. The hypothesis set out at the end of Chapter 3, therefore, was confirmed.

As shown in Appendix R, copy fast speed was impaired in all SpLD groups. Grapho-motor speed was impaired only in the group of participants with DCD and dyslexia/DCD. The differences between groups with typical development, dyslexia and dyslexia/DCD for copy fast and graphomotor speed, and graphomotor speed in DCD, were no longer significant after results of the VDS had been controlled. It is difficult to understand why visual discomfort should affect handwriting tasks, except for graphomotor speed, in which keen observation is required unless VDS reflects a wider set of neurological differences.

6.11. Results: Long Inspection Time Group Profiles

Question 2.5 asked about the cognitive and attainment profiles of participants with long inspection times, irrespective of original participant group. The hypothesis was that, based on inspection times in children with DCD, participants in a group with the longest inspection times would be comprised of participants with signs and symptoms of DCD. After controlling for WRIT matrices, correlation analyses between IT1 and a range of variables for the whole participant sample show significant correlations across a wide range of tests. These are in Table 29. Writing tests, phonemic decoding and results of the pattern glare test did not correlate significantly with inspection time across the whole participant sample. Although the DCD checklist for childhood symptoms showed a small significant correlation with IT1, indicating that more childhood symptoms were associated with longer inspection times, longer inspection times were also associated with a range of other test results. For the four groups in this study, 10% of typical participants had a z-score for inspection time (IT1) for the whole group below 1; 12.5% of dyslexic participants; 15% of the DCD group and 22% of dyslexia/DCD group. In Appendix S, are reported further analyses in which the participant sample was divided into long and short inspection time groups with the medium group as the reference. The new groupings were predictors in hierarchical regression analyses for a range of dependent variables, with age, gender and WRIT matrices controlled in step1. These analyses show that there are medium significant predictions by simple decision time, rapid automatic naming of digits and objects, lower significant *ß's* for a range of speeded tests but not working memory.

Table 29

Significant Spearman Partial Correlations Between Cognitive and Attainment Variables and Pi-Figure Inspection Time (IT1; Control: WRIT Matrices), N = 141

Dependent Variable	Spearman's whole sample partial correlations	
	r_s	p
SDT	.25	.003
SMT	.18	.035
CDT	.20	.017
SDMT	– .31	.001
Corsi block-tapping task forward	– .22	.010
Corsi block-tapping task backward	– .19	.026
Digits forward (TOMAL-2)	– .10	> .05
Digit backward	– .18	.037
RAN digits	.23	.007
RAN letters	.27	.002
RAN colours	.21	.012
RAN objects	.27	.002
Sight words	– .24	.005
Phonemic decoding	– .14	> .05
DASH Writing composite	– .11	> .05
Visual Discomfort Scale (n = 136)	.20	.019
DCD Checklist Section 1 childhood	.27	.001

Note. CDT = choice decision time; RAN = rapid automatic naming from Comprehensive Test of Phonological Processing-2 (Wagner, Torgeson, Rashotte & Pearson, 2013); Corsi = Corsi block-tapping task *(*Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000; The Psychological Investigation Building Language, PEBL; Mueller, 2010); DASH = Detailed Assessment of Handwriting 17+ (Barnett, Henderson, Scheib & Schulz, 2007); DCD Checklist = Adult Developmental Coordination Disorder/Dyspraxia Checklist (ADC) for Further and Higher Education (Kirby & Rosenblum, 2008);SDT = simple decision time; Symbol Digit Modalities Test (Smith, 1982); SMT = simple motor time; TOMAL-2, Test of Memory & Learning-2 (Reynolds & Voress, 2007); Test of Word Reading Efficiency-2 (Torgeson, Wagner & Rashotte, 2012); Symbol Digit Modalities Test (SDMT; Smith, 1982); Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). Statistically significant values are in boldface. p = two-tailed.

6.12. Discussion: Long Inspection Time Group Profiles

After controlling for intelligence across all participants in the study, the pattern of correlations between standard pi-figure inspection time and other cognitive and attainment variables was largely unremarkable, apart from a medium significant relationship with the coding test. The hypothesis that participants with long inspection times would have DCD was unconfirmed. More importantly, a high proportion of participants with long inspection times belonged to the dyslexia/DCD group. This pattern accords with previous results that show that the only group to have significantly longer than typical standard inspection times was the group with dyslexia/DCD. Otherwise, participants with long inspection times were distributed across all groups so the inspection time test cannot be considered a diagnostic test. The evidence from a long inspection time group that showed that long inspection times significantly predicted a range of speeded tests but not visuospatial memory does not support the hypothesis that long inspection times would be associated with signs and symptoms of DCD, because weak visuospatial memory is a key feature of DCD.

6.13. Summary for Chapter 6

Visual discomfort. Only in the group of participants with DCD, was there a significant relationship between standard inspection time and visual discomfort as assessed by the VDS. Other groups of participants did not show this relationship. Inspection time did not correlate with results of the PGT in any group. The PGT correlated with results of the VDS in all groups except the DCD group. These results suggest that, in DCD, pattern glare does not relate to visual discomfort as assessed by the VDS but that a different sort of visual discomfort in DCD relates to inspection time. The results suggest that measures of inspection time are confounded in participants with DCD by visual discomfort of an unknown origin. Possible candidates include fixation instability and accommodation insufficiency.

Memory. In the group of participants with DCD, there was a significant relationship between inspection time and results of tests for visuospatial working memory as opposed to non-significant relationships between inspection time and tests of memory in the other groups of participants. It is hypothesised that there is another variable in the relationship, which could be spatial awareness, known to be deficient in DCD.

Speed. In participants with typical development and dyslexia, the small, significant correlation between the coding task and inspection time reflected results of previous investigations. A different pattern of results to typical between inspection time, SDMT and chronometric tests was evident for groups of participants with DCD and dyslexia/DCD. There was no evidence that visual discomfort mediates the relationship from controlling for visual discomfort from the VDS as it did not impact on the correlation. In the group of participants with dyslexia/DCD, the large relationship between inspection time and SDMT was not reduced by controlling for visuospatial memory, so speed may be an important shared variable. This is further evidence that these participant groups are distinct. A PCA analysis showed that, normally, inspection time loads on a factor that includes SDMT and chronometric variables. However, upon amalgamation of DCD and dyslexia/DCD groups, memory appeared to be an equally limiting factor and it is postulated that this, in turn, may be because the test was dependent on spatial awareness. However, the PCA analysis could be criticised because, to provide sufficient numbers, two SpLD groups with separate characteristics were amalgamated.

Literacy attainment. At the end of Chapter 3 was a hypothesis that in participants with typical development, inspection time would correlate significantly with RAN tasks. The hypothesis was unsupported, except for RAN objects, which correlated significantly with inspection time, and it is postulated that this is from common spatial influences. Also at the end of Chapter 3, it was hypothesised that in all participants inspection time would correlate with sight word reading efficiency. The hypothesis is supported only for DCD. Although there were group differences in handwriting speed, standard inspection time did not correlate significantly with any test of handwriting in any participant group. The hypothesis set out at the end of Chapter 3, therefore, was confirmed.

Inspection time group profiles. Participants with slow inspection time are also slower for many other tests but do not necessarily have weak visuospatial memory. There were participants with long inspection times in dyslexia, DCD and dyslexia/DCD groups. Participants with DCD were no more likely to have long standard inspection times than were typical participants so a hypothesis that long inspection times would characterise adults with DCD was not supported.

CHAPTER 7

Inspection Time in Adults With Specific Learning Differences: Omnibus Analyses

This study compared *visual inspection time* (Vickers, Nettelbeck & Willson, 1972) between neuro-typically developing adults and three groups of adults with neurodevelopmental differences, namely, developmental dyslexia (dyslexia; e.g., Rose, 2009), developmental coordination disorder (DCD; American Psychiatric Association, 2013), and both dyslexia and DCD (dyslexia/DCD; Biotteau, Albaret, Lelong & Chaix, 2015). The main purpose was to explore the potential of inspection time, a psychophysical elementary cognitive task, over a traditionally used paper-and-pencil test of symbol-digit coding, for improved evaluation of processing speed in the assessment of these neurodevelopmental differences. Also, by evaluating how inspection time is affected by different task parameters (i.e., stimulus directionality, speed of response) and the relations between inspection time and participants' cognitive and perceptual characteristics (i.e., working memory and susceptibility to visual discomfort), the study sought to shed light on the information processing requirements of inspection time tasks.

Specialist teachers and assessors for people with learning differences frequently encounter both children and adults with difficulties that arise from their dyslexia, DCD or dyslexia/DCD. Although reported frequencies vary, an estimated over half of children with dyslexia have co-occurring DCD and a similar proportion of children with DCD have dyslexia (e.g., Biotteau et al., 2015; Chaix et al., 2007). Briefly, dyslexia affects the acquisition of literacy skills (Peterson & Pennington, 2012; Vidyasagar, 2019) and DCD is characterised by persistent problems with visuospatial analysis and motor coordination, handwriting in particular (Blank et al., 2019). Both dyslexia and DCD cause life-long s*pecific learning differences* that affect literacy and they are idiopathic. The term *specific* implies that the differences are not necessarily due to below average intelligence for if they were, the learning differences would be *global*. An effective assessment of specific learning differences in children and adults with dyslexia, DCD, or co-occurring dyslexia/DCD includes tests for identification of a weakness in attainment in reading, writing or both, and a complementary cognitive deficit. The complementary deficit is often a weakness in language processing in dyslexia (e.g., Bradley & Bryant, 1983; Ramus & Ahissar, 2012) or motor coordination and visuospatial processing in DCD (e.g., Purcell, Scott-Roberts & Kirby, 2015; Wilson & McKenzie, 1998). The type and severity of cognitive impairment is specific to each individual with specific learning differences, hence necessitating individual assessment.

Another cognitive attribute argued to be impaired in some people with a specific learning difference is so-called *information processing speed,* that is*,* the speed of cognitive processes (e.g., Posthuma & de Geus, 2008). Kail (2000) described *information processing speed,* a term frequently abbreviated to *processing speed,* as a "key element in people's ability to think, to reason and remember" (Kail, 2000, p. 52). There are reports of slow processing speed in dyslexia, DCD, and dyslexia/DCD (Beidas, Khateb & Breznitz, 2013; Biotteau et al., 2015; Wilson & McKenzie, 1998). A revised Cattell-Horn Carroll (CHC) model of human cognitive abilities classifies processing speed within the general ability of *Speed and Efficiency* or more recently *General Speediness (*Schneider & McGrew, 2012; 2018). Three of the four broad abilities that comprise *General Speediness* are relevant here. These are specifically, Gps, Gt, and Gs. Gps is psychomotor speed, the speed and fluidity of physical body movements such as movement time and handwriting speed. Gt is decision/reaction time in response to stimuli presented one at a time and is often an electronically based psychophysical task. For example, a decision time task could measure the time needed to release the home key on a response box after the appearance of a target stimulus on a computer screen (Jensen, 2006). Finally, Gs is the capacity for quick fluent performance for simple repetitive cognitive tasks that require sustained concentration and fluency. In such tasks, a series of items appear simultaneously so that the person proceeds from one to the other in their own way. Gs is a broad measure of efficiency because it reflects the total amount of time needed to perceive information, arrive at decisions and enact appropriate responses from items in a series. Schneider and McGrew (2018) proposed that reading fluency be classed as Gs. Development of automaticity, which contributes to speed during such tasks, may be slower in people with dyslexia (Nicolson & Fawcett, 2017).

Typically, an assessment report for specific learning differences includes a judgement about processing speed made from the outcome of a variety of tasks (e.g., Jones & Kindersley, 2017; SpLD Assessment Standards Committee, 2016, p.40). These tasks include paper-and-pencil tasks that index Gs or Gps. One task, commonly used by assessors to inform about a person's processing speed, is symbol-digit coding. This task is an example of Gs and entails repeatedly identifying symbols arranged in a grid of many symbols and writing below them the correct digit from a symbol-digit key. Clearly symbol-digit coding is a blunt instrument because performance will depend on a variety of skills, which include the ability to manipulate a pencil, visually track from the key with symbols to numbers in a grid to record them, identify and remember the shapes of the symbols, and automate a response to multiple sequential processes. Slow processing speed as measured by this test may therefore have different aetiologies in different people. Such diverse aetiologies make this test inadequate for the purpose of individual psychological diagnostic assessment, which seeks to pinpoint specific deficiencies, the reason for which is to make recommendations for targeted intervention and effective management.

Potentially, the psychophysical cognitive task, visual inspection time (Vickers et al., 1972), that accompanies decision time in Gt in the Cattell-Horn Carroll model (Schneider & McGrew, 2012), could offer a more focussed index of processing speed in assessment of specific learning differences than other tests in Gps, Gs and Gt. The reported strengths of significant relationships between inspection time and decision time in Gt vary between studies (e.g., Deary & Ritchie, 2016; Johnson & Deary, 2011; Nettelbeck & Burns, 2010) but inspection time has an affinity with more complex tests of clerical speed that are in Gs, such as coding (e.g., O'Connor & Burns, 2003; Nettelbeck & Burns, 2010). Importantly, inspection time has an advantage over other tests in Gps, Gs, and Gt because it is motor-free. Even the psychophysical test of decision time includes the time required to generate motor processes to enact the response. However, to date inspection time tasks are confined to experimental evaluations of processing speed or efficiency (e.g., Anderson, 2008; Deary & Ritchie, 2016) and have not generally been applied to clinical practice.

Traditionally, the inspection time task requires rapid perception and accurate discrimination between two mirror images of a stationary pi-figure composed of vertical lines of different length, placed randomly left or right, centrally located on a screen. These pi-figures, presented one at a time, appear for varying short intervals before they are backward masked. After the mask has obscured the image, the participant makes an unhurried response to indicate which image had appeared, that is, with the shorter line to left or right (i.e., a two-alternative forced choice; Macmillan & Creelman, 2004). Inspection time from many trials represents, in milliseconds, the time taken for decision processes that contribute to the accurate assessment of the brief stimulus image before it is masked, not motor responses to it. Accordingly, the inspection time task specifically evaluates speed/efficiency of perception. Inspection time has also been referred to as "central processing speed" (e.g., Scotland, Whittle & Deary, 2012, p. 360) as it obviates the need for coordinated fine motor skills and some eye movements required for reading and writing. The term *central* in the rest of this chapter implies sensory and cognitive processes without a motor response. The inspection time task is a more streamlined index of processing speed compared to either tasks that need fast motor responses such as decision time, or the symbol-digit coding test that also requires the development of fluency.

Given that inspection time is an obvious candidate for more focussed evaluation of speed/efficiency of visual perception in specific learning differences, there have been remarkably few studies of inspection time in participants with dyslexia and DCD. Moreover, these studies tested children rather than adults and did not include participants with dyslexia/DCD even though assessors frequently encounter both children and adults with dyslexia, DCD and dyslexia/DCD. Notably, McLean, Stuart, Coltheart and Castles (2011) did not find a significant difference in group mean inspection times between children with dyslexia and neuro-typically developing children, although two previous smaller studies were inconclusive (Kranzler, 1994; Whyte, Currie & Hale, 1985). McLean et al.'s findings suggest that not all aspects of processing speed in children with dyslexia are impaired, with their poor performance on traditional tests such as symbol-digit coding, instead, reflecting deficiencies other than central processing speed. In contrast, significant differences in inspection time *were* found between children with DCD and children with typical development (Piek, Dyck, Francis & Conwell, 2007), confirmed by a later study (Dyck & Piek, 2010). The extent and manner in which deficient inspection time might reflect inefficient sensory-motor networks that support internal modelling of movement, believed deficient in people with DCD, remains unclear (Piek et al., 2007; Wilson et al., 2017).

It is worth noting, that studies that measured inspection time in children with dyslexia or DCD may have had methodological shortcomings. First, mindful of maintaining children's interest during the task, the researchers in some investigations (viz., McLean et al., 2011; Piek et al., 2007, Dyck & Piek, 2010) used complex alien stimulus images. Therefore, the procedure was not as simple as Vickers et al. (1972) originally intended. Second, in the investigations of DCD (Piek et al., 2007; Dyck &

Piek, 2010), the unusual simultaneous collection of reaction time (RT) during the inspection time task may have affected results adversely, especially for the DCD group. Although inspection time and motor time are argued to be unrelated in typical participants (O'Connor & Burns, 2003), it is possible that, among children with DCD, awareness of their limited movement skills meant that they opted for speed over accuracy (e.g., Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010) during the inspection time task. Moreover, in a review, Wilson et al. (2017) noted that dual tasks or tasks that require perceptual-motor adjustments and precision particularly challenge children with DCD.

As pointed out earlier, the inspection time task has a clear advantage over traditional coding tasks in eliminating the need for speeded responses. Nevertheless, inspection time may be subject to other confounds, particularly for people with specific learning differences. The standard inspection time task requires discrimination between left and right, which maps directly onto the response needed from the participant (i.e., left button press for a left-positioned target and right button press for right-positioned target). It is well documented that left/right confusions occur in dyslexia, believed to be linked to reading experience (Fernandes & Leite, 2017, for a review). Thus, problems with left-right discrimination, left-right response, or both, may confuse participants with weak visuospatial skills sometimes reported for dyslexia and characteristic of DCD (e.g., dyslexia: Gilger, Allen & Castillo, 2016; Tafti, Boyle & Crawford, 2014; DCD: Wilson & McKenzie, 1998; Wilson et al., 2017).

Other possible challenges to the validity of the inspection time task as an index of processing speed are highlighted by previous research with neuro-typically developing participants. First, such research has shown that inspection time and tests of memory have medium, significant negative correlations in children and young adults (Johnson & Deary, 2011; Nettelbeck & Burns, 2010; Nettelbeck & Rabbit, 1992). It has been pointed out that participants must hold the percept of the inspection time stimulus in working memory long enough to make the response. Weak visuospatial working memory occurs often in people with DCD and dyslexia (e.g., Alloway & Archibald, 2008; Beidas, Khateb & Breznitz, 2013) so long inspection times in these people may reflect their weak visuospatial memory. Second, it is well documented that many people with specific learning differences report visual discomfort or stress, which may be from pattern glare, ocular anomalies or both (Allen, Hussain, Usherwood & Wilkins, 2014; Evans & Allen, 2016; Kriss & Evans, 2005; Rafique & Northway, 2015; Sumner, Hutton, Kuhn & Hill, 2016). It is possible that the visual inspection time task could provoke visual discomfort from pattern glare due to high contrast images and pulsed stimuli from CRT monitors. Thus, people with specific learning differences could once again be disadvantaged on inspection time tasks relative to neuro-typically developing people for reasons that are not directly or at all attributable to processing speed.

7.1. The Present Study: Aims and Hypotheses

The primary aim of the current study was, for the first time in the literature, to evaluate visual inspection time in adults with formal diagnoses of dyslexia, DCD or dyslexia/DCD relative to neuro-typically developing adults. Evaluation was by a standard pi-figure inspection time task and, in addition, participants undertook a paper-and-pencil based symbol-digit coding test, computer-based tests of simple and choice decision time, and tests of verbal and nonverbal intelligence, working memory, visual discomfort and reading attainment.

Based on the studies of inspection time in children with dyslexia and DCD, it was predicted that inspection time in adult participants with dyslexia would be no different to inspection time from typically developing adults, whereas inspection time would be longer than typical in DCD and dyslexia/DCD. In contrast, expectations were that the typical group would outperform all three specific learning differences groups on tests of coding and decision time. It was also hypothesised that, across the sample, there would be significant correlations between inspection time, symbol-digit coding and decision time, with correlations remaining robust after controlling for intelligence, working memory, and visual discomfort.

Additionally, the study sought to shed light on the information processing demands of the inspection time task in two ways. *First, task parameters pertaining to stimulus and response were manipulated to ascertain their effects on inspection time.* For the stimulus, inspection time was evaluated for a non-standard figure that could be rotated through 180 ° without causing asymmetry. In one orientation, participants were required to judge whether the shorter limb was located to the left or right of the non-standard stimulus figure (i.e., left/right discrimination) and they made their response in the usual way by pressing either left or right button on the response box. In the other orientation, the shorter limb was at the top or the bottom of the figure (i.e., an up/down discrimination) so the left/right choice was eliminated. Here, the response box was in a sideways position so, once again, there was consistent mapping between the location of the critical information in the image and the location of the correct button response. Manipulation of the stimulus was motivated by the earlier described evidence of weak visuospatial skills, particularly relating to left-right discrimination, in participants with dyslexia and DCD. Given these possible sources of confusion, it was hypothesised that participants with dyslexia, DCD and dyslexia/DCD would show faster inspection times to the non-standard stimulus in the up/down position than the left/right position. In contrast, it was anticipated that the inspection times of the typical group would be unaffected by the orientation of the non-standard stimulus.

In relation to the response, results for a typical un-speeded measurement of inspection time to the standard pi-figure were compared to those for the same inspection time task combined with the instruction to respond as fast as possible. Manipulation of the response was motivated by the concern, mentioned earlier, in relation to studies of inspection time in children, that participants with motor difficulties might show a speed/accuracy trade-off when they are instructed to respond quickly. It was predicted that that the requirement for speeded responses would generate slower inspection times in all groups, but particularly in participants with DCD because of their fragile confidence for planned movements.

Second, this study examined the relations between inspection time and two dimensions of individual differences relevant to specific learning differences, namely, visuospatial working memory and susceptibility to visual discomfort. Evidence of a contribution of visuospatial working memory to inspection time (e.g., Johnson & Deary, 2011) led to the prediction that, across the whole sample, weaker working memory would be associated with longer inspection times. Because many people with dyslexia and DCD have impairments of visuospatial working memory (e.g., Alloway & Archibald, 2008; Beidas, Khateb & Breznitz, 2013), analyses were conducted to see whether group differences in inspection time remained reliable after controlling for working memory. Because no previous studies have investigated the impact of visual discomfort on performance in inspection time tasks, exploratory analyses were conducted to determine first, the strength of associations between inspection time and measures of visual discomfort across the participant sample, and second, whether group differences in inspection time remain reliable after controlling for visual discomfort.

7.2. Method

7.2.1. Participants. There were 141 participants (48 men) between 18–56 years, recruited over 12 months either from the student and staff population of Anglia Ruskin University and from the wider community, all with 12 or more years of formal education (see Table 30 for demographic variables and group sample sizes). A Kruskal-Wallis H-Test with post hoc paired comparisons from Dunn's procedure showed that median age was not significantly different between any specific learning differences group and the typical group ($\chi 2$ (3, 137) = 0.17, $p > .05$). There were nearly twice as many women participants as men in the typical, dyslexia and DCD groups, but in the dyslexia/DCD group women outnumbered men, more than four to one.

Table 30

Ages and Gender of Participants in Four Groups, N = 141

	Typical	Dyslexia	DCD	Dyslexia/DCD
n (men)	50 (17)	40 (14)	33 (13)	18 (4)
Age in years (IQR)	29 (11)	31 (12)	30 (11)	31 (12)
Age range	18–55	18–56	20–54	19–53

Note. IQR = inter-quartile range

All participants reported normal or corrected-to-normal vision and were able to read font size N 10 of the Sussex Near Vision Reading Test (Sussex Vision International, 2015) held at 60 cm. Volunteers with English as a second language, autism and conditions such as schizophrenia and multiple sclerosis were excluded. Participants without a history of specific learning differences formed a typical development group. Participants in dyslexia, DCD or dyslexia/DCD groups had had their specific learning differences identified by an educational psychologist or specialist teacher with a Practicing Certificate validated by the Specialist Assessment Standards Committee (SASC; www.sasc.org.uk). Results of questionnaires and the several tests of cognition and attainment described in the next section supported official identification of learning differences for participants with specific learning differences.

7.2.2. Procedure. The Research Ethics Panel of the Department of Psychology of Anglia Ruskin University approved the study. For every participant, testing was conducted individually in a laboratory at Anglia Ruskin University in one sitting that lasted approximately 90 minutes. During this session, participants completed four inspection time tasks, plus tests of decision time, symbol-digit coding, working memory, visual discomfort, verbal and non-verbal intelligence, and reading attainment.

To avoid monotony, tests of cognitive, perceptual and attainment skills were administered in the same order but so that the nature of the task varied. A Latin square (Williams, 1949) counterbalanced the order of administration of four inspection time tests, namely, standard pi-figure un-speeded (IT Test 1), standard pi-figure speeded (IT Test 2), non-standard left-right stimulus un-speeded (IT Test 3) and non-standard up-down stimulus un-speeded (IT Test 4), as well as simple decision time (SDT) and choice decision time (CDT).

7.2.3. Materials.

Inspection time. Stimuli were delivered from a CRT monitor using a customised program developed in MATLAB R14a (The Mathworks Inc. Natick MA, USA) with Psychophysics Toolbox extensions, Version 3.0.11 (PTB-3; Brainard, 1997; Kleiner et al., 2007). Correct or incorrect responses were recorded by one finger on a response box (The Black Box ToolKit Ltd, Sheffield, UK) with horizontally aligned, 2 cm keys with 3 cm between the their centres. Instructions and sequences were adapted from a different program, kindly supplied by Preiss and Burns (2012).

Inspection time Tests 1 and 2 used pi-figure stimuli (Figure 1) with lightning flash masks to give variables IT1 and IT2 in milliseconds. The viewing angle for difference between long and short limbs was 1.38° at a distance of 60 cm. Non-standard stimulus images for Tests 3 and 4 used the same linear elements as in the pi-figure (Figure 2). Left/right inspection time Test 3 was to establish inspection time (IT3) while retaining the left/right decision and response to left or right key on the response box. Rotation of left/right inspection time Test 3 stimulus generated the stimulus for up/down inspection time Test 4 (IT4), and required an up/down decision and response—on the response box rotated through 90°.

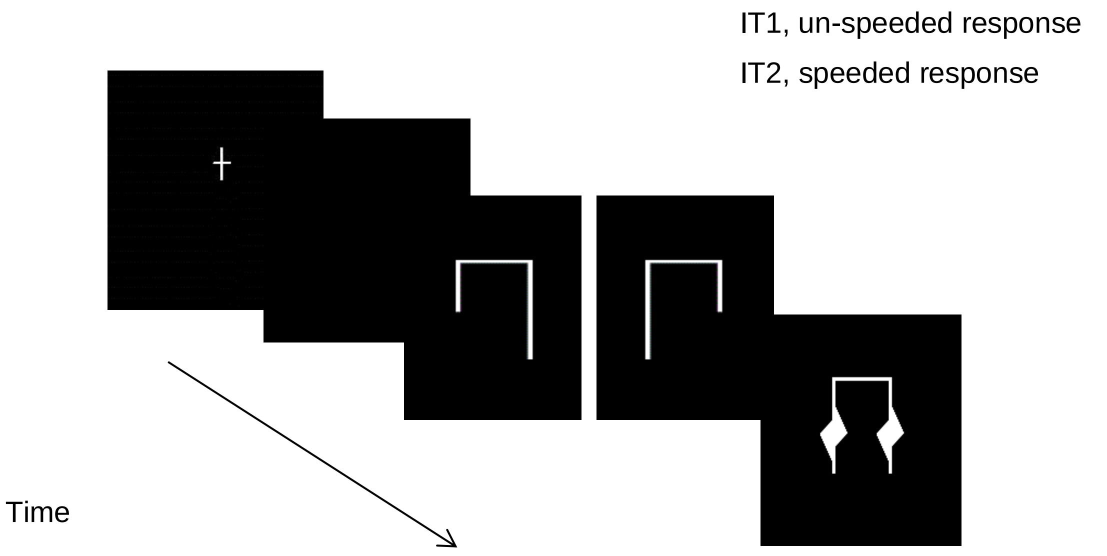


Figure 5. Inspection time task: locating cross, blank black background, standard left/right mirrored pi-figure stimuli and a flash mask. *Note*. One pi-figure appears for each trial.

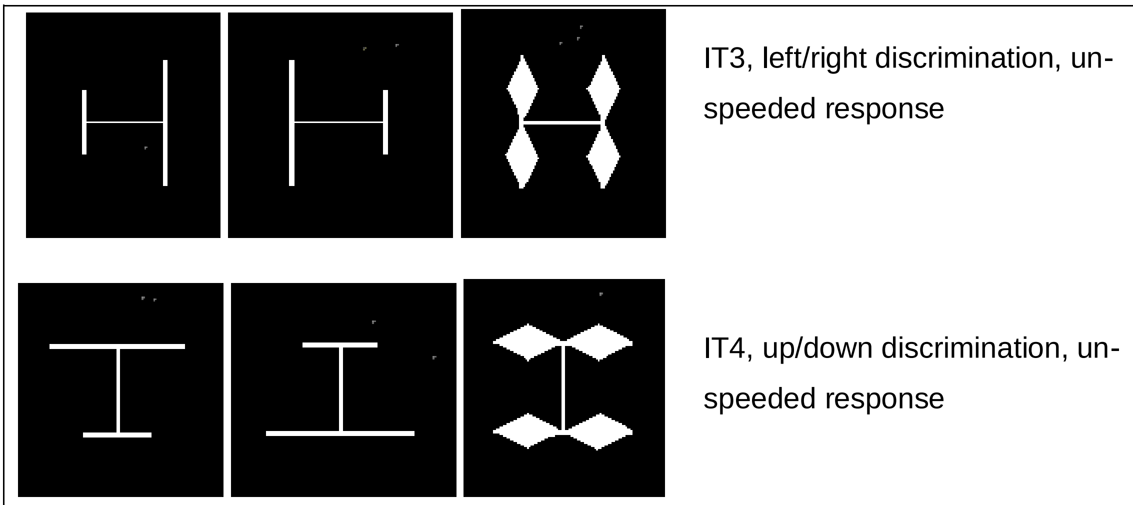


Figure 6. White left and right; and up and down non-standard stimuli, mask and response conditions for left/right and up/down (IT3) and (IT4) on black background.

Participants initiated each trial routine when they were ready by pressing the middle, home key. They were directed to respond “as fast as possible” for IT2. Responses for IT1, IT3 and IT4 were un-speeded. Up to 20 introductory trials, until there were five consecutive correct responses, were comprised of a cross for 353 ms (30 X IFI), a blank black background, followed 1058 ms (90 x IFI) ms later by a left or right-hand stimulus image for 165 ms (14 × IFI), replaced immediately by the mask for 353 ms. Main trials were the same except they resolved each participant’s inspection time, using trials with a predetermined duration from a *two-down, one-up* adaptive staircase, method of limits, procedure, starting at stimulus duration 165 ms. Two correct responses, two-down, were required before the stimulus duration was reduced and after one incorrect response the stimulus duration increased, one-up. A direction change in the adaptive staircase was a *reversal.* Initial step sizes down were two inter-frame-intervals (IFIs) until below 80 ms or a reversal, and one thereafter. Trials ended after 10 reversals.

Decision time. For simple and choice decision time (SDT & CDT), there was no staircase or mask. To maintain participants’ attention, target cross and decision stimulus interval varied randomly, between 0.5–2 seconds. The image remained on the screen until participants pressed the appropriate response key, with verbal and on-screen instructions to do so “as fast as possible”. For simple decision time the stimulus image was a left-hand pi-figure. For choice decision time, the choice was between left or right pi-figures with the choice recorded as correct or incorrect. Results were an average from 20 trials.

Coding. The Symbol Digit Modalities Test (SDMT; Smith, 1982) assessed coding speed. Participant converted with a key, in 90 seconds, as fast as possible, meaningless geometric symbols into digits, 1–9. The symbols use visual processes and numbers include verbal processes. The Symbol Digit Modalities Test was preferred to similar coding tests because it requires participants to write familiar numbers rather than unfamiliar symbols, a task that makes additional demands on cognitive processes. Moreover, specialist teachers routinely use the Symbol Digit Modalities Test to assess so-called processing speed.

Intelligence. Two of the four subtests of the Wide Range Intelligence Test (WRIT; Glutting, Adams & Sheslow, 2000) assessed intelligence because of its expected shared variance with inspection time (Sheppard & Vernon, 2008) and its likely shared variance with other measures of cognition and attainment. WRIT matrices individually assess nonverbal analytical, visual fluid ability. Participants had 30 or 45 seconds to choose one of 3–6 pictures that best complete each matrix. Untimed WRIT verbal analogies tests oral language understanding and knowledge. It requires an appropriate verbal response and assesses crystallised, verbal ability. Factor loadings for matrices and analogies subtests of the WRIT for visual and verbal intelligence were visual, (.64), and verbal, (.81), respectively.

Working memory. Tests of working memory were Corsi block-tapping task forward and backward from The Psychological Investigation Building Language (PEBL; Corsi, 1972; Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000; Mueller, 2010). Nine large squares of colour were on the screen during each trial. The squares lit up briefly, initially two and for each successive trial the number increased by one square up to seven squares. After the sequence had appeared on the screen, participants clicked with a mouse-controlled cursor on the squares in the same (forward) and then reversed (backward) order of presentation. Total correct score forward and total correct score backward indexed visuospatial short-term memory and working memory, respectively.

Visual discomfort. The Pattern Glare Test (PGT; Evans & Wilkins, 2001) and Visual Discomfort Scale (VDS; Conlon, Lovegrove, Chekaluk & Pattison, 1999) evaluated visual discomfort. Ocular rather than psychophysiological conditions can cause symptoms similar to Meares-Irlen Syndrome, so reported symptoms from the Visual Discomfort Scale, the Pattern Glare Test or both do not equate to a diagnosis of Meares-Irlen Syndrome. Pattern glare is diagnostic of Meares-Irlen Syndrome when there are no optical anomalies. Although participants claimed normal or corrected to normal vision, in the absence of professionally conducted eye examinations, optical anomalies must be considered.

The Pattern Glare Test. This test consists of questions about visual distortion and discomfort that participants had experienced, after they had looked at low, medium, and high frequency (0.5, 3 & 12 cycles per degree), square wave monochrome gratings for five seconds. Pattern glare has occurred if there are more than three positive answers to the questions for the medium grating (B. Evans, personal communication, October 8, 2017). Nominal data were susceptibility to pattern glare (1), or not (0).

The Visual Discomfort Scale. This scale has 23 questions. Responses, graded on a 0–3 Rasch scale, sum to values between 0–69. Conlon et al. (1999, p. 649) defined *low visual discomfort* as a score of less than 24 positive answers on the Visual Discomfort Scale.

Reading speed. Tests of reading were two subtests from Test of Word Reading Efficiency (TOWRE-2; Torgeson, Wagner & Rashotte, 2012): sight words reading and phonemic decoding efficiency (speed + accuracy). Participants had 45 seconds to read the vertically arranged words for each subtest.

7.2.4. Statistical Procedures. Analyses were carried out with the software package IBM SPSS Statistics for Windows, Version 24 (IBM Corp., Armonk, NY, USA). Statistical analyses used .05 as the decisive significance value of alpha. Verbal descriptions of effect sizes conformed to Cohen's standard (Cohen, 1988): value 0.10 to 0.29, a small association; 0.30 to 0.49, medium; 0.50 or over, large. Initially when looking for trends, it is expedient to tolerate possible Type I errors to avoid overlooking significant results (e.g., Streiner & Norman, 2011) so adjustments for multiple correlations were omitted. Measures not normally distributed, as determined by the Shapiro Wilk test, indicated the application of nonparametric analyses in some instances.

Data were analysed by parametric and nonparametric analyses of variance for group differences and nonparametric correlational analyses for relationships between measures. Nonparametric signed-rank tests or sign tests explored differences between inspection time tests within groups. To examine group differences in inspection times while controlling for memory and/or visual discomfort, hierarchical multiple regression (Cohen, Cohen, West & Aiken, 2013) were used with inspection time as the dependent variable and nonverbal intelligence, groups and either memory or visual discomfort as independent variables. In the regression analyses, specific learning differences groups were dummy coded. The reference was the typical group, always coded as 0, while the named specific learning difference group was coded as 1 and the two remaining groups as 0. In all regression analyses, variables were "entered" (SPSS, regression) in each step, multi-collinearity was absent, linearity and homoscedasticity were acceptable and values for leverage were not above .2, that would indicate unwanted influences from outliers. Straight lines in quantile-quantile (q-q) plots confirmed that the distribution of residuals were approximately normal. When residuals were approximately normal, analyses on dependent variables that were not normally distributed were appropriate. In the regression analyses, a significant β indicated that the variable significantly predicted inspection time.

7.3. Results

The results are in six sections. Section 1 examines group differences on all measures. Section 2 presents correlations between all measures across the sample. Section 3 examines the effects of speeded versus un-speeded responses by comparing performance on IT1 and IT2. Section 4 examines the effects of stimulus directionality (left/right versus up/down) by comparing performance on IT3 and IT4. Section 5 investigates whether group differences in inspection time remain reliable after controlling for working memory. Finally, Section 6 investigates whether group differences in inspection time remain reliable after controlling for visual discomfort.

7.3.1. Between-group differences for all measures. Table 31 shows descriptive statistics for all measures in participants with typical development, dyslexia, DCD or dyslexia/DCD. Table 31 also indicates significant group differences in measures of central tendency, which were analysed using one-way ANOVA and Kruskal-Wallis H test. Post hoc comparisons were between the group with typical development and each group with a specific learning difference. Post hoc tests included Tukey-Kramer tests for normally distributed data (namely, WRIT matrices and analogies and Symbol Digit Modalities Test), Dunn's procedure for when distributions were not normal (namely, simple and choice decision time and the Visual Discomfort Scale), and when there was heterogeneity of variance, ranks (namely, Corsi block-tapping forwards and backwards, TOWRE sight words and phonemic decoding). Results show that the typical group differed significantly from all groups with specific learning differences on the Symbol Digit Modalities Test, choice decision time, Visual Discomfort Scale, Pattern Glare Test and sight word reading. Additionally, the typical group differed significantly from (1) the group with dyslexia for phonemic decoding efficiency; (2) the group with DCD for simple and choice decision time and Corsi block-tapping backward; and (3) the group with dyslexia/DCD for WRIT matrices, IT1, IT2 and IT4, simple and choice decision time, Corsi block-tapping backward and phonemic decoding efficiency. As WRIT matrices were significantly different to typical only in the group with dyslexia/DCD, and there were no significant differences from typical for WRIT analogies in any group, in subsequent analyses, control for nonverbal intelligence was by WRIT matrices.

It had been hypothesised that inspection time in adult participants with dyslexia would be no different to inspection time from typically developing adults, whereas inspection time would be longer than typical in DCD and dyslexia/DCD. The results shown in Table 31 supported this hypothesis for dyslexia and dyslexia/DCD, except for

IT3, which in dyslexia/DCD was no different to typical. It was not supported for the group of participants with DCD, which showed no difference to the typical group.

Table 31

Measures of Central Tendency From Four Groups, Analyses of Variance and Post Hoc Tests, N = 141

	Medians (IQR) or *Means* # *(SD)*				ANOVA (3,137)		Post Hoc Paired Comparisons with Typical Group (*p*)		
n	Typical 50	Dyslexia 40	DCD 33	Dyslexia/ DCD 18	*F* # or *χ2*	*p*	Dyslexia	DCD	Dyslexia/ DCD
Intelligence (WRIT standard scores)									
Analogies #	100 (14)	97 (15)	100 (11)	90 (13)	2.50#	< .05			
Matrices #	105 (12)	101 (15)	102 (14)	95 (16)	2.84#	.040	NS	NS	.023
Processing Speed (ms)									
IT1	50 (14)	54 (23)	59 (21)	66 (19)	3.86	.010	NS	NS	.006
IT2	51 (16)	51 (20)	60 (34)	56 (45)	4.70	.004	NS	NS	.003
IT3	46 (24)	56 (35)	60 (37)	66 (34)	2.75	.045	NS	NS	NS
IT4	49 (69)	57 (36)	62 (26)	68 (59)	4.26	.007	NS	NS	.005
Simple Decision Time	260 (40)	281 (57)	307 (80)	321 (100)	25.67	< .001	NS	< .001	.001
Choice Decision Time	345 (54)	379 (65)	390 (95)	396 (185)	22.12	.001	.001	< .001	.008
SDMT # (items in 90s)	57 (8)	49 (9)	49 (11)	48 (11)	9.32#	< .001	< .001	< .001	.001
Working Memory (blocks)									
Corsi Task Forward	62 (42)	50 (24)	49 (25)	46 (26)	6.90	NS	NS	NS	NS
Corsi Task Backward	62 (34)	53 (20)	43 (25)	46 (30)	15.13	.002	NS	< .001	.012
Visual Discomfort (positive answers; *N* = 136)									
Visual Discomfort Scale (*n* = 136)	8 (8)	30 (23)	30 (30)	36 (24)	61.18	< .001	< .001	< .001	< .001
Pattern Glare Test # (*n* = 136)	16	22	20	15	6.28##	.001	.009	.004	.009
Reading Attainment (TOWRE-2;words in 45s)									
Sight Words	98 (12)	82 (20)	87.5 (16)	77 (26)	43.29	< .001	< .001	.001	< .001
Phonemic Decoding	56 (10)	43 (17)	53 (15)	40 (20)	45.04	< .001	.001	NS	.001

Note. # Normal distributions as determined by Shapiro Wilk test analysed by one-way ANOVA. Post hoc Tukey-Kramer test; Distributions not normal, used Kruskal-Wallis H test; ## Welch/Games-Howell or † Dunn procedure for median differences; if no homogeneity of variance, rank differences; Corsi = Corsi block-tapping task (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000). DCD = developmental coordination disorder; dyslexia = developmental dyslexia; IT1 and IT2 = pi-figure inspection time, IT2 = speeded response; IT3 = non-standard left/ right figure; IT4 = non-standard up/down figure; NS = not significant > .05; Pattern Glare Test (mean (sum) positive responses; Wilkins & Evans, 2001); SDMT = Symbol Digit Modalities Test (Smith, 1982); TOWRE-2 = Test of Word Reading Efficiency (Torgeson, Wagner & Rashotte, 2012); Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000).

7.3. 2. Correlations between measures across the sample. Table 32 shows results of Spearman's nonparametric correlation analyses, conducted using the whole sample, across all measures. Notably, these results show that there were significant correlations between the four inspection time tests and other measures of processing speed; between the four inspection time tests and working memory; between inspection time Tests 1–3 and the Visual Discomfort Scale; and between inspection time Tests 1–3 and sight word reading. Outcomes for simple and choice decision time and the symbol-digit coding task similarly showed significant correlations with working memory and visual discomfort, as well as with both sight word reading and phonemic decoding.

To see whether inspection time shared unique variance with other measures of processing speed, partial correlations were calculated between IT1–4, simple and choice decision time and symbol-digit coding, after controlling for non-verbal intelligence, working memory and visual discomfort. Results showed that there were significant Spearman's correlations between inspection times from all inspection time tasks (p values < .001 between IT1 & IT2; between IT1 & IT3; between IT2 & IT3; between IT2 & IT4; between IT3 & IT4, and p value < .01 between IT1 & IT4). Except for IT4, there were significant correlations between inspection times and simple decision time (IT1, p value < .01; IT2, p value < .001; IT3, p value < .05). There were significant correlations between inspection times and choice decision time (IT1, IT3 & IT4, p value < .05; IT2, p value < .01). There were significant correlations between inspection times and symbol-digit coding, except IT3 (IT1, IT2, p values < .01; IT4, p value < .05) and between symbol-digit coding and inspection times except IT3 (p values < .01 for IT1 & IT2; p value < .05 for IT4). These results strongly suggest that, in line with hypotheses, these tests have a common element of processing speed.

Given a significant, positive correlation between scores for Corsi block-tapping task forward and backward, z scores for these tests were averaged to create a composite score for working memory. Likewise, given a significant, positive correlation between scores for the Pattern Glare Test and Visual Discomfort Scale, z scores for these tests were averaged to create a composite score for visual discomfort. All subsequent analyses used the composite measures.

Table 32

Spearman and Kendall Tau-b Correlation Analyses of Inspection Times, Intelligence, Cognitive and Attainment Measures, N* = 141

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 IT1	1.00														
2 IT2	**.527****	1.00													
3 IT3	**.375****	**.468****	1.00												
4 IT4	**.231****	**.390****	**.373****	1.00											
5 WRIT M	– .164	– .133	– .117	**– .233****	1.00										
6 WRIT A	– .054	– .048	.021	– .045	**.286****	1.00									
7 SDT	**.258****	**.274****	**.265****	**.213***	– .101	–.109	1.00								
8 CDT	.212	**.285****	**.208***	**.206***	– .098	– .008	.603**	1.00							
9 SDMT	**– .334****	**– .321****	**– .302****	**– .356****	**.304****	– .045	**– .458****	**– .514****	1.00						
10 Corsi f	**– .240****	**– .215***	**– .267****	**– .233****	**.193***	076	– .204	**– .260****	**.321****	1.00					
11 Corsib	**– .220****	– .153	– .140	**– .221****	**.241****	**.022**	**- .326****	**– .324****	**.416****	**.533****	1.00				
12 VDS	**251**** $^{(n = 136)}$	**.211***	**.323****	.123	– .134	– .095	**.335****	**.372****	**– .358****	**- .228****	**– .275****	1.00			
13 * PGT	.142 $^{(n = 136)}$	.076	.079	.103	– .127	– .054	**.185****	**.155***	**– .223****	**- .198****	**– .153***	**.439****	1.00		
14 SWR	**– .258****	**– .236****	**– .246****	– .136	**.211***	**.303****	**– .445****	**– .376****	**.466****	**.171***	**.247****	**– .502****	**– .294****	1.00	
15 PDE	– .125	– .098	– .136	– .075	**.190***	**.257****	**– .232****	**– .243****	**.339****	.078	.057	**– .359****	– .149	**.711****	1.00

Note. CDT & SDT = choice & simple decision time; Corsi task f & b = forward & backward Corsi Block-Tapping Task (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000); DCD = developmental coordination disorder; dyslexia = developmental dyslexia; IT1 and IT2 = pi-figure inspection time, IT2 = speeded response; PGT = Pattern Glare Test (Wilkins & Evans, 2001); SDMT = Symbol Digit Modalities Test (Smith, 1982); VDS = Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999); WRIT = Wide Range Intelligence Test (Glutting, Adams & Sheslow, 2000). Kendall *Tau-b,* PGT; Statistically significant bold. Correlations (r_s > .05) highlighted. * p < .05; ** p < .01 two-tailed.

7.3.3. Inspection time and response speed. To test the hypotheses regarding the effects of response speed on inspection time, Wilcoxon signed-rank tests or, when the distributions were asymmetrical, sign tests, were used to compare un-speeded inspection time (IT1) and speeded inspection time (IT2) within each group. Results showed no significant differences for any group for the difference between medians of speeded (IT2) and un-speeded (IT1) inspection times. For the difference between IT1 and IT2, results were: typical ($z = -.50$, $p > .05$); dyslexia ($z = -.38$, $p > .05$); DCD ($z = -.53$, $p > .05$); dyslexia/DCD ($z = 0$, $p > .05$). Thus, the hypothesis that speeded responses would affect inspection times in some groups was unsupported.

Given all groups performed similarly for IT1 and IT2, and that there were significant correlations of medium strength between IT1 and IT2, scores for these two measures were averaged to form a composite measure for the pi-figure stimulus (IT1/IT2) and this was used in all subsequent analyses.

7.3.4. Inspection time and directionality. To test the hypotheses regarding the effects of stimulus directionality on inspection time, Wilcoxon signed-rank tests or, when the distributions were asymmetrical, sign tests, were used to compare left/right inspection time (IT3) and up/down inspection time (IT4) within each group. Results showed no significant differences for any group of participants in the study for the difference between medians of left/right (IT3) and up/down (IT4) inspection times. For differences between IT3 and IT4, results were: typical ($z = .14$, $p > .05$); dyslexia ($z = -.24$, $p > .05$); DCD ($z = 0$, $p > .05$); and dyslexia/DCD ($z = .68$, $p > .05$). Thus, the hypothesis that left/right decisions would affect inspection times in some groups was unsupported.

As all groups performed similarly for IT3 and IT4, and there were significant correlations of medium strength between IT3 and IT4, scores were averaged to create a composite measure of inspection time that used the non-standard stimulus figure (IT3/IT4) and this was used in all subsequent analyses.

7.3.5. Inspection time and working memory. To evaluate whether group differences in inspection time were underpinned by visuospatial working memory, nested hierarchical regression analyses were conducted. There were two dependent variables, first the IT1/IT2 composite (see Table 33), and second, the IT3/IT4 composite (see Table 34). The predictor variables were (1) non-verbal intelligence entered on the first step, (2) groups (dummy coded) entered on the second step, and (3) visuospatial working memory entered on the final step.

Table 33

Hierarchical Regression Analyses Predicting Inspection Time (IT1/IT2) as a Function of Nonverbal Intelligence, Group and Visuospatial Working Memory N = 141

Predictor	*B (SE B)*	*β*	ΔR^2	ΔF
Step 1				
Nonverbal Intelligence	**– 8.7 (3.18)**	**– .23****	**.05**	**7.42****
Step 2				
Nonverbal Intelligence	– 6.19 (3.17)	– .16		
Dyslexia vs. Typical	2.47 (7.77)	.04		
DCD vs. Typical	8.63 (8.21)	.10		
Dyslexia/DCD vs. Typical	**34.75 (10.31)**	**.30****	**.08**	**4.06****
Step 3				
Nonverbal Intelligence	– 3.92 (3.17)	– .10		
Dyslexia vs. Typical	– 1.83 (7.69)	– .02		
DCD vs. Typical	1.46 (8.32)	.02		
Dyslexia/DCD vs. Typical	**28.63 (10.22)**	**.25****		
Visuospatial Working Memory	**– 5.58 (1.85)**	**– .26****		
Total adjusted R^2 *(F)* **.15 (6.11***)**			**.06**	**9.22****

Note. DCD = developmental coordination disorder; dyslexia = developmental dyslexia; IT1/IT2 composites from IT1, pi-figure inspection time, IT2 pi-figure with speeded response. Nonverbal intelligence (matrices, Wide Range Intelligence Test, Glutting, Adams & Sheslow, 2000; Memory: Corsi block task forward + backward (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000). Statistically significant values, i.e., < .05, are in boldface. * p < .05; ** p < .01; *** p < .001, two-tailed.

Table 34

Hierarchical Regression Analyses Predicting Inspection Time (IT3/IT4) as a Function of Nonverbal Intelligence, Group and Visuospatial Working Memory N = 141

Predictor		*B (SE B)*	*β*	*ΔR^2*	*ΔF*
Nonverbal Intelligence		**– 7.78 (3.67)**	**– .18**	**.03**	**4.52***
Step 2					
Nonverbal Intelligence		– 5.01 (3.68)	– .11		
Dyslexia vs. Typical		**20.98 (9.01)**	**.22***		
DCD vs. Typical		**20.49 (9.51)**	**.20***		
Dyslexia/DCD vs. Typical		**34.94 (11.94)**	**.27****	**.07**	**3.71***
Step 3					
Nonverbal Intelligence		– 2.98 (3.73)	– .07		
Dyslexia vs. Typical		17.13 (9.03)	.18		
DCD vs. Typical		14.06 (9.77)	.14		
Dyslexia/DCD vs. Typical		**24.46 (12.00)**	**.23***		
Visuospatial Working Memory		**– 5.01 (2.18)**	**– .20***		
Total adjusted R^2 *(F)*	**.11 (4.34**)**			**.06**	**5.31***

Note. DCD = developmental coordination disorder; dyslexia = developmental dyslexia; IT3/IT4 composites from IT3, non-standard left/ right figure, IT4, non-standard up/down figure. Nonverbal intelligence (matrices, Wide Range Intelligence Test,Glutting, Adams & Sheslow, 2000; Memory: Corsi block task forward + backward (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000). Statistically significant values, i.e., < .05, are in boldface. * $p < .05$; ** $p < .01$, two-tailed.

For IT1/IT2, results for step 2 indicated that the difference in inspection time between the typical group and the dyslexia/DCD group remained significant after controlling for nonverbal intelligence. Results for step 3 indicated that the difference in inspection time between the typical group and the dyslexia/DCD group was still significant after further controlling for working memory, indicating that visuospatial working memory is not the only reason for this group difference from typical. Moreover, in the final model, working memory was also a significant predictor of IT1/IT2 inspection time.

For IT3/IT4, results for step 2 indicated that all the differences between the typical group and the remaining groups remained significant after controlling for nonverbal intelligence. However, results for step 3 showed that only the difference between the typical group and the dyslexia/DCD group remained significant after further controlling for working memory. The finding that dyslexia and DCD no longer predicted IT3/IT4 indicates that visuospatial working memory is one reason for the difference from typical in these groups. In the final model, working memory was also a significant predictor of IT3/IT4 inspection time.

It had been predicted that weaker working memory would be associated with longer inspection times and the results reported here support that prediction. It was also of interest to discover if group differences remained reliable after controlling for working memory. Here it is shown that the difference from typical only remained robust for dyslexia/DCD.

7.3. 6. Inspection time and visual discomfort. To establish whether visual discomfort contributed to group differences in inspection times, the hierarchical regression analyses from the previous section were repeated but this time entering visual discomfort rather than working memory on the final step. The dependent variables were, first, the IT1/IT2 composite (see Table 35), and second, the IT3/IT4 composite (see Table 36). These tables contain only the results of step 3 because those for step 1 and 2 can be obtained Tables 4 and 5.

For IT1/IT2, results for step 3 showed that dyslexia/DCD still predicted IT1/IT2, after controlling for visual discomfort, which indicates that visual discomfort is not the only reason for this group difference from typical. Moreover, in the final model, visual discomfort was not a significant predictor of IT1/IT2 inspection time.

Table 35

Hierarchical Regression Analyses Predicting Inspection Time (IT1/IT2) as a Function of Nonverbal Intelligence, Group and Visual Discomfort, N = 136

Predictor		*B (SE B)*	*β*	*ΔR^2*	*ΔF*
Step 3					
Nonverbal Intelligence		– 6.24 (3.22)	– .16		
Dyslexia vs. Typical		– 4.86 (9.03)	– .05		
DCD vs. Typical		5.02 (9.32)	.06		
Dyslexia/DCD vs. Typical		**28.55 (11.59)**	**.25***		
Visual Discomfort Composite		2.50 (2.23)	.11		
Total adjusted R^2 *(F)*	**.12 (4.51**)**			.01	1.42

Note. DCD = developmental coordination disorder; dyslexia = developmental dyslexia. Nonverbal ability (matrices subtest, Wide Range Intelligence Test, Glutting, Adams & Sheslow, 2000; Visual Discomfort Composite = Pattern Glare Test (Wilkins & Evans, 2001) + Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999); IT1/IT2 composite from IT1 = pi-figure inspection time+ IT2 = pi-figure with speeded response. Statistically significant values, i.e., < .05, are in boldface. * p < .05; ** p < .01, two-tailed.

Table 36

Hierarchical Regression Analyses Predicting Inspection Time (IT3/IT4) as a Function of Nonverbal Intelligence, Group and Visual Discomfort N = 136

Predictor		*B (SE B)*	*β*	*ΔR^2*	*ΔF*
Step 3					
Nonverbal Intelligence		– 5.16 (3.69)	– .12		
Dyslexia vs. Typical		12.90 (10.35)	.13		
DCD vs. Typical		18.47 (10.68)	.18		
Dyslexia/DCD vs. Typical		**30.97 (13.29)**	**.24***		
Visual Discomfort Composite		1.57 (2.56)	.06		
Total adjusted R^2 *(F)*	.08 (3.22**)			0	0.38

Note. DCD = developmental coordination disorder; dyslexia = developmental dyslexia. Nonverbal ability (matrices subtest, Wide Range Intelligence Test, Glutting, Adams & Sheslow, 2000; Visual Discomfort = Pattern Glare Test (Wilkins & Evans, 2001) + Visual Discomfort Scale (Conlon, Lovegrove, Chekaluk & Pattison, 1999); IT3/IT4 from IT3 = non-standard left/ right figure + IT4 = non-standard up/down figure. Statistically significant values, i.e., < .05 in boldface. * p < .05; ** p < .01, two-tailed.

For IT3/IT4, results for step 3 showed that only the difference between the typical group and the dyslexia/DCD remained significant after controlling for visual discomfort. The finding that dyslexia and DCD no longer predicted IT3/IT4 indicates that visual discomfort is one reason for the difference from typical in these groups. In the final model, visual discomfort was not a significant predictor of IT3/IT4 inspection time.

7.4. Discussion

This study, for the first time, explored inspection time in adults for its potential in the assessment of processing speed in neurodevelopmental differences. *Primarily,* it compared inspection time from a group of neuro-typically developing adults to inspection times from groups of adults with dyslexia, DCD and co-occurring dyslexia/DCD. Other group comparisons were made for tests that are believed to index processing speed, namely, symbol-digit coding and decision time. The main finding was that standard inspection times from pi-figure stimuli in the group of adults with dyslexia/DCD were significantly longer than was typical whereas those from adults with dyslexia or DCD were not. In contrast to inspection time, performances for symbol-digit coding and choice decision time were less specific; results for these tests differed significantly from typical in all three groups with specific learning differences.

One explanation for these results could be that the inspection time task is designed to eliminate a motor response and thus to index central cognitive processing speed. The task achieves this special status because the dependent variable is duration of the stimulus image not duration of the response to it. In contrast, after a decision about the visual stimulus, coding and decision times also include time for motor processes for the response. Despite these differences, there were small significant correlations between inspection times and coding speeds or decision times across the sample, a result consistent with those obtained in previous studies for typically developing participants (e.g., O'Connor & Burns, 2003; Nettelbeck & Burns, 2010). Correlations between coding, decision time and inspection time remained significant even after the elimination of two possible influences on them, namely working memory and level of visual discomfort. All this is evidence that inspection time and coding or decision time have something in common, which it seems fair to conclude, is central processing speed.

The findings that show standard inspection time to be normal in dyslexia are consistent with results from McLean et al. (2011) in children. For DCD, the current results contrast with previously reported unequivocal group differences from typical (Piek et al., 2007, Dyck & Piek, 2010), but which were collected under speeded conditions from a relatively more complex space alien stimulus than the pi-figure. The difference in results between children and adult studies raises a further research question of whether children in previous studies of DCD found the space alien stimulus or some other aspect of the experimental procedure relatively more difficult than they would have a pi-figure stimulus. It is possible that inspection time was not a pure measure and long inspection times noted in children with DCD resulted from the methods used. For instance, the difference in stimuli was not compatible with the response, that is, the choice was between two lines of the same and different lengths. Children responded by pressing either a red or blue button and this would involve working memory to remember which button belonged to which type of stimulus figure, even more difficult when the response had to be speedy. Furthermore, the complex space alien stimulus images were relatively small, difficult to distinguish and the screen lit up after a correct response, which could have provoked visual discomfort in children prone to it.

An alternative interpretation of the difference between results obtained previously for children with DCD and those obtained here for adults is that there is a developmental delay, which in adults had been resolved for the requirements that underpin inspection time. This could be by the recruitment of alternative strategies for the skills necessary to complete the task. There has been much discussion about possible strategy use in inspection time in typical participants (e.g., Nettelbeck, 2011). In adults, any resolution of the manifestations of DCD in children cannot necessarily apply across all features of DCD as more than half of adults with DCD continue to have motor difficulties (Blank et al., 2019). Future research with children must use inspection time tasks that are not so complicated to decide between these two explanations.

Thus, the inspection time task was more specific than coding as anticipated, but it was deficient only in the group of adults with dyslexia/DCD. This indicates a deficiency of speed of processes in adults with dyslexia/DCD. Longer inspection times for the group of adults with dyslexia/DCD support a proposal (Willcutt, 2018) that stronger, perhaps developmental, influences provoke co-occurrence of more than one specific learning difference in affected individuals, and consequently effects are greater. Alternatively, for inspection time, there may be synergy between different aspects of cognition, deficient in dyslexia and DCD, so that they are more influential when combined. Again, a different explanation, compensatory cognitive mechanisms for participants with either dyslexia or DCD may not be available for participants with both dyslexia and DCD. Moreover, there is evidence from studies of DCD for the importance of myelin (e.g., Debrabant et al., 2016); myelin integrity has been linked to inspection time (Chevalier et al., 2015; Kuznetsova et al., 2016; Wiseman et al., 2018), and is thus a strong candidate for a cause of slow processing speed. Further likely causes of long inspection times are weak accommodation (Rafique & Northway, 2015, for a review) and fixation instability (Sumner, Hutton, Kuhn & Hill, 2016) shown in DCD. Clinically, that the group of adults with dyslexia/DCD has significantly longer inspection time could be important for individual assessment in which one hopes to establish which specific learning difference a person has and what the consequences are of having it. This, bearing in mind that individual diagnostic assessment relies partly upon the relationships between the results of several different tests and focusses more on differences between these tests than diagnosis from any one test.

The second main aim of the study was, by means of two approaches, to see if inspection time tasks also measure skills other than processing speed and thus to shed light on other contributions to inspection time task performance. The first approach was to manipulate task parameters, namely speed of response (un-speeded versus speeded) and stimulus directionality (left/right discrimination versus up/down discrimination). It was hypothesised that compared to participants who were typically developing, participants with specific learning differences would have shorter inspection times to the non-standard stimulus in the up/down position than in the left/right position. This was thought to be likely because participants with specific learning differences are known to experience left/right mirror image confusions. Another prediction was that the requirement for a speeded response would generate longer inspection times in all groups, particularly DCD. This was likely because of a possible speed-accuracy trade off. The second approach was to administer tests of working memory and susceptibility to visual discomfort, to establish, first if performance on these tests was predictive of inspection time, and second, whether group differences in inspection time disappeared after controlling for these variables, for, if they did, this would indicate that the processes contributed to long inspection times in these groups.

Results of the manipulations of response speed and stimulus directionality were unequivocal. None of the four groups showed a significant difference in inspection time between speeded and un-speeded tasks and none of the four groups showed a significant difference in inspection time depending on whether they were required to discriminate between left or right stimuli and up or down stimuli. The first finding indicates that the inspection time task circumvents motor difficulties even if participants are encouraged to respond quickly. Concerns that long inspection times in DCD resulted from the speeded task in Piek et al.'s (2007) children remains possible, but now seem less likely. Similarly, the second finding shows that visuospatial difficulties that affect many people with specific learning differences are not an impediment to their performance on inspection time tasks. Thus, it seems that fears of left/right confusion in the inspection time task were unjustified. While this is clear for adults, it is still unproven for children. It is still possible that the participants' level of education and, in particular, their reading experience, may have moved them on beyond the point at which left/right confusion had an appreciable impact. Thus, these studies need confirmation in children with DCD before the possibility of left/right confusion can be dismissed entirely.

As mentioned above, results of the inspection time task showed significant correlations with working memory and susceptibility to visual discomfort. The results for memory confirmed previous research with neurotypically developing adults (Johnson & Deary, 2011; Nettelbeck & Burns, 2010; Nettelbeck & Rabbitt, 1992). Nevertheless, evidence of atypically long inspection times in adults with dyslexia/DCD remained after controlling for working memory and visual discomfort. Specifically, regression analyses showed that the group difference remained significant even though both working memory and visual discomfort made an additional, independent contribution to the variance in inspection time. Therefore, the findings support the earlier conclusion that inspection time tasks with pi-figure stimuli have the potential to provide a reliable measure of central processing speed, that this is significantly deficient in the group of adults with dyslexia/DCD and that therefore it could be useful in professional assessment of specific learning differences.

There is one important caveat to the previous discussion. Unexpectedly, results from the non-standard inspection time task (IT3/IT4) revealed significantly slower inspection times in all three specific learning differences groups, relative to the typical group. Unlike the standard pi-figure, the non-standard image was more complex which, although composed of exactly the same linear elements as the pi-figure, had two points of focus rather than one. The decision whether it was a left or right figure depended on evaluation of a short line placed centrally in relation to a longer line. As such, the decision about the stimulus difference was slightly more complex. After controlling for visuospatial working memory, there was no longer a difference between typical and dyslexia or typical and DCD groups for the non-standard stimulus and this implies that working memory was tapped during the non-standard task in these groups. Similarly, for visual discomfort, there was no longer a difference between typical and dyslexia or DCD groups after statistical removal of the influence of visual discomfort. One possibility to explain these results in dyslexia is that a more complex stimulus may be less easy to evaluate for some groups because of divided visual attention. Research by Bosse, Tainturier and Valdois (2007) supports a visual attention span deficit in dyslexia. The visual attention span is the number of elements in a multi-element array processed at one time. The non-standard stimulus, which could act as a two-element array, may thus challenge participants with dyslexia over and above a stimulus with a single element. Explanations for why IT3/IT4 inspection time, with its slightly more complex image, is weaker than typical in DCD may relate to weaker visuospatial memory characteristic of DCD, or could be more difficult to focus on, given the likelihood of optometric insufficiencies in DCD.

These results show that the complexity of the image used in inspection time tasks is an important consideration; such tasks can provide a relatively pure measure of processing speed only if the image is very simple. Otherwise, confounding influences, for example of working memory and visual discomfort, influence the results. It should be noted however, that only working memory made an additional, independent contribution to the variance in inspection time, and visual discomfort did not. On the assumption that masking of the stimulus was adequate, the chance that visible persistence was influential can be ruled out. Thus, it seems that inspection time reflects to some extent the efficiency of consigning the image to working memory although this, in turn, could depend on speed. The group of participants with dyslexia/DCD still predicted inspection time even after controlling for visuospatial working memory and visual discomfort but the groups of participants with dyslexia and DCD did not. In their paper, Vickers et al. (1972) originally emphasised the importance of a simple decision between two lines of different length to reduce confounds from processes other than speed of perception and seemingly, their cautious approach was justified.

In summary, *first* there are important implications for clinical practice. To include an inspection time test alongside paper-and-pencil tests would allow assessors to tease apart and evaluate the influence on speed of cognitive processes that do not include motor responses, during an assessment for suspected dyslexia, DCD and dyslexia/DCD. Absence of a deficiency in standard inspection time in the presence of weak coding, suggests a deficit other than processing efficiency of very simple visual stimuli. *Second*, there are important implications for those wishing to research into inspection time in specific learning differences. The inspection time task in adults appears not to be susceptible to contamination from left/right decisions or different methodologies that use speeded responses. However, unlike for pi-figure stimuli, evaluations of processing speed by more complex stimuli do not provide results relatively uncontaminated by visuospatial working memory or visual discomfort. While this contamination would be important to avoid in some situations, it also opens up the possibility of exploring different stimulus designs that provoke different outcomes in participants with dyslexia or DCD, which could ultimately have a clinical application. For example, from the results presented here, a participant who has a slow inspection time from a complex stimulus, but not to a simple pi-figure stimulus, is more likely to have dyslexia or DCD rather than co-occurring dyslexia/DCD. *Third,* the results have shown that participants with dyslexia/DCD have longer than typical inspection times and this reflects slow processing speed. It will be of interest to establish whether longer inspection times are a feature of co-occurrence in general or whether long inspection times in co-occurring dyslexia/DCD is specific to this group. Are the exceptionally long inspection times shown here in participants with dyslexia/DCD a feature of other co-occurrences such as ADHD/DCD and ADHD/dyslexia? The implications for intervention for this strong characteristic of dyslexia/DCD are unknown. These ideas and others indicate the need for further research and development into inspection time in specific learning differences. Research could include an investigation into inspection time standard deviation by means of the method of constant stimuli to explore how neural oscillation theory (Jensen, 2006; Vidyasagar, 2019) relates to inspection time in participants with dyslexia, DCD or both. Inspection time with different stimuli might extend the attention span deficit theory of Bosse et al. (2007) in dyslexia. Clearly, inspection should be measured in children with DCD by means of a simple pi-figure stimulus. These and other ideas for future work are revisited at the end of Chapter 8.

CHAPTER 8

General Discussion

This thesis explored a proposal that inspection time could offer a focussed index of so-called *information processing speed*, for use in individual assessment of specific learning differences (Chapter 1). This was because in an inspection time test the dependent variable, duration of correctly identified stimulus, obviates the need to record the time for a motor response. This feature of the inspection time task could bestow an advantage over other tests of speed for the assessment of specific learning differences. Inspection time only indexes speed or efficiency of processes that occur after stimulus onset and before a motor response, referred to here as *central* processing speed.

The usual method used to assess processing speed in a diagnostic assessment is by paper-and-pencil tests, often coding. Weaknesses in motor coordination, that could affect the speed at which a paper-and-pencil test of coding is performed, is a feature of developmental co-ordination disorder (DCD), a specific learning difference that is commonly encountered by assessors of people with specific learning differences and which sometimes contributes to a cognitive and attainment profile. In individual diagnostic assessment, access to the results of a motor-free inspection time test would be particularly helpful for the job of teasing apart from other influences the extent to which motor deficiencies contribute to a person's literacy difficulties or learning differences.

However, a review of the literature (Chapter 2) revealed an incomplete understanding of inspection time. Certainly, it shares significant variance with results of processing speed tests classed as Gs and Gt in the Cattel-Horn-Carroll (CHC) model (see Chapter 1) but there are also reports of significant relationships between inspection time and indices of memory, although of inconsistent strength (Section 2.3.2). Other influences also may be important to inspection time evaluation, such as inspection time's relationship to visuospatial awareness (Section 2.3.3). There had been separate reports of inspection time in dyslexia and DCD (reviewed in Section 3.4). These showed unusually long inspection times in children with DCD (e.g., Piek et al., 2007), but not in most children with dyslexia, although ten percent of the dyslexic children in the most recent study had exceptionally long inspection times (McLean et al., 2011). There had been no evaluations of inspection time in adults with dyslexia or DCD or studies of inspection time in children or adults with dyslexia/DCD. There had been no investigations of relationships between inspection time and visual discomfort, which sometimes co-occurs with specific learning differences. Thus, in view of the potential importance to individual diagnostic assessment, inspection time in the specific learning differences mentioned above warranted further investigation.

8.1. Pilot Studies: Typically Developing Children

Development of the inspection time task began with Studies 1 and 2 in children (Appendices F & G, respectively). There were 26 children aged 11–12 years who, except for three participants, were typically developing.

In Study 1, there was a variety of stimuli, which tested for 2-D spatial influences on inspection time, namely for left/right and length discrimination. These studies encountered methodological problems of mask design. The mask of random dots was ineffective for solid elements of letter-like stimulus figures. The inadequate mask prevented fair tests and may have enhanced the contributions of memory to inspection time performance, as there were strong correlations between results of tests of memory and inspection time.

In Study 2, the random dot mask was effective for new stimulus figures drawn from circles. One interesting result from Study 2 showed that there was an exceptionally large, significant correlation between inspection time from the most difficult circles stimulus and a test for nonverbal ability (MidYIS, see Appendix G). A common characteristic of inspection time and this MidYIS test is detailed 2-D spatial discriminations of size, position and orientation between figure designs, which signals a need for further investigation into the importance of spatial awareness in inspection times. In an fMRI investigation, Deary et al. (2004) also noted the relationship between inspection time and processes involved with spatial awareness. Unfortunately, although it was successfully masked, the circles experiment was limited because these stimuli may have tapped gestalt processes, so were incompatible with previous work with typically developing participants that largely have used letter-like stimuli. Other drawbacks of Study 2 were the range and type of stimuli that over-complicated the analyses and the limited range of tests.

8.2. Main Study: Adults With Specific Learning Differences

Study 3 used letter-like stimuli with lightning flash backward masks and included additional tests and questionnaires. Participants in Study 3 were adults, assigned to three specific learning differences groups, namely dyslexia, DCD and dyslexia/DCD by a prior professional diagnosis or no diagnosis in the case of the group with typical development. Results of a range of cognitive and attainment tests confirmed the specific profiles of the three different groups with learning differences. However, it is worth noting that results from a self-report scale about visual discomfort and a test for pattern glare had important findings across all three groups of participants with specific learning differences. Although they did not have formal diagnoses of Meares-Irlen

Syndrome (MIS) and they self-reported normal or corrected to normal eyesight, significantly more participants than was typical reported that they experienced more than low visual discomfort, evaluated by the visual discomfort scale and there were more instances of pattern glare.

There were two main aims of Study 3, the results are in Chapters 5 and 6, revisited in Chapter 7 and summarised below.

8.2.1. Study 3: Aim 1. The first aim of Study 3 was to establish standard, pi-figure inspection times in the three groups of adult participants with specific learning differences compared to those with typical development, after controlling for intelligence. Additionally, the task was manipulated in order to shed light on whether speeded or left/right responses, as used in studies with children, could account for long inspection times previously shown in studies of children with DCD.

Inspection time from pi-figure stimuli in adults with specific learning differences compared to typically developing adults. *For participants with dyslexia,* results of an inspection time task that used standard stimuli were consistent with Kranzler (1994) and McLean et al.'s (2011) mean results for group analyses of inspection time in children that included groups with dyslexia. That is, there was no difference between inspection times from pi-figure stimuli between adults with typical development and adults with dyslexia (Table 6). *For participants with DCD,* results from Study 3 were in contrast to previous results from children with DCD (e.g., Piek et al., 2007). That is, there was also no difference between inspection times from pi-figure stimuli between adults with typical development and adults with DCD. As inspection time in the adults with DCD had not been measured when they were children, it is unknown if they had long inspection times when young but had improved as they grew older. Improvement upon maturation is contrary to the view that DCD is the result of disordered neural arrangements rather than a developmental immaturity (e.g., Wilson et al., 2017). Furthermore, the interpretation that there is a developmental immaturity, for the different findings in adults in the current study, does not correspond to the fact that other signs and symptoms of DCD persist in adults. Thus, it remains feasible that tests in the investigation by Piek et al. (2007) challenged children with DCD more than typically developing children because of the methods that were used to collect inspection time. *For participants with dyslexia/DCD,* as far as is known, this was the first study of inspection time in adults or children. Results showed that unlike participants with either dyslexia or DCD, participants with dyslexia/DCD had significantly longer standard pi-figure inspection times than adults with typical development. Because the results are not purely additive, this supports a theory (Willcutt, 2018) that co-occurring specific learning differences are the result of a more severe initial influence during development.

Inspection time task manipulations. The *first* task manipulation tested the possibility that the speeded nature of the task that had been used with children may have influenced the results, particularly for children with DCD who have unconfident movements. The *second* manipulation investigated whether the left/right decisions necessary to the task that used a pi-figure design could affect participants who have issues of left/right directionality. While, in fact, previous research into inspection time in children with DCD (Piek et al., 2007) did not use a left/right decision, in previous investigations into dyslexia this had been the method and as mentioned above ten percent of children with dyslexia in the most recent study (e.g., McLean et al., 2011) had unexplained exceptionally long inspection times. Thus, tests collected inspection time with and without a speeded response and a further two tests used non-standard stimuli to explore whether left/right decisions produced longer inspection times than up/down.

Results of these task manipulations found no differences in any group or across the whole participant sample for the difference between speeded and un-speeded or left/right versus up/down choices (Table 8, Table J1; Chapter 7). The possibility remains open that, in previous studies, another aspect of the task challenged children who had long inspection times or, indeed, they had truly slower central processing speed.

8.2.2. Study 3: Aim 2. The second aim of Study 3 was to explore what inspection time tasks are really measuring, after doubts raised in Chapter 2 that inspection time may be a contaminated index of processing speed, especially for some participants with specific learning differences.

Processing speed. The skill of symbol-digit coding belongs in Gs, Speed and Efficiency or Speediness, of the Cattel-Horn-Carroll model and assessors use it as a test of processing speed. There were significant, medium, negative correlations between inspection times from standard and non-standard tasks and symbol-digit coding across the whole participant sample both before and after controlling for intelligence (Tables 32 & 29, respectively). These results accord with previous research with typically developing participants (Deary & Ritchie, 2016; Johnson & Deary, 2011; O'Connor & Burns, 2003; Nettelbeck & Burns, 2010). The hypothesis advanced in Section 3.6, that inspection time would significantly correlate with a paper-and-pencil test of coding in all groups, was not fully supported because standard inspection time did not correlate significantly with symbol-digit coding in the typically developing and dyslexia groups although it did in DCD and dyslexia/DCD.

Thus, although standard inspection time does not measure motor processes, it has some affinity with coding. Moreover, examination of group differences in a coding task confirmed a hypothesis that while all specific learning difference groups would show deficiencies of paper-and-pencil coding compared to the typical group this would not follow for inspection time. Only dyslexia/DCD was significantly different for standard inspection time. These results reflect that evaluation of speed of processes is more restricted when measured by inspection time and the reasons may be absence of motor processes and the trial after trial nature of the task.

Decision time and motor time belong to Gt in the Cattel-Horn-Carroll model. Across the participant sample, both before and after controlling for intelligence (Table

32 & Table 29), there were no significant medium or large correlations between standard inspection time and simple and choice decision times or motor times. For the separate groups, there was a medium significant correlation between standard inspection time and choice decision time in DCD, in which group the significant correlation was medium strength (Table 24). These results were expected from results in previous studies (e.g., Nettelbeck & Burns, 2010). Results of group differences from typical also showed that choice decision time was deficient in all specific learning differences groups whereas, simple decision time was only deficient in DCD and dyslexia/DCD, not dyslexia. These differences may be of clinical use.

Working memory. Based on previous research, a hypothesis was that inspection time would relate significantly to both tests of auditory and visual memory in all groups. Analyses in Chapter 6 (Table 20) showed that standard inspection time did not relate significantly to digit span forward or backward in any separate group. Across the whole participant sample, before and after control for intelligence, no test of inspection time had more than small significant correlations with any memory test result (Table 29). These results held for visuospatial working memory and standard inspection time in separate groups (Table 20), except for DCD, in which group correlations between visuospatial working memory were medium and large. They lend support to the hypothesis that the relationships between inspection time and visuospatial working memory would be significantly larger in groups that exhibit visuospatial working memory deficiencies and that inspection time would relate more strongly to visuospatial memory than auditory memory, particularly in DCD.

Furthermore, regression analyses in Chapter 7 (Tables 33 & 34) showed that across the whole participant sample, after controlling for participants with specific learning differences who experience a range of cognitive deficiencies, predictions for pi-figure and non-standard inspection time stimuli by visuospatial memory remained reliable. This result strongly suggests that inspection time indexes visuospatial working memory. This relationship may not be straightforward because working memory may depend on processing speed or vice versa or another variable may be involved. Importantly, for inspection time from the non-standard stimulus (Table 34), there were group differences from typical in participants with dyslexia and DCD as well as dyslexia/DCD but they no longer predicted inspection time after control for working memory. These results are confirmation that inspection time is a contaminated measure of processing speed as it also involves visuospatial working memory, but that this is particularly evident in inspection time that is measured by more complex stimuli such as the non-standard stimulus in these groups.

Visual discomfort. As explained above, levels of visual discomfort were higher in participants with specific learning differences than without. Chapters 6 and 7 contain and discuss results in depth. Furthermore, results from the scale and pattern glare test correlated significantly across the participant sample. To summarise, there was no evidence that either standard or non-standard stimuli provoked pattern glare and there were only small positive correlations between inspection time from both stimulus figures and visual discomfort measured by the scale (Table 32). However, on analysis of the separate groups, there were differences between the DCD and other groups. In DCD alone, pattern glare and visual discomfort from the scale did not correlate significantly and the significant correlation between visual discomfort scale and inspection time was large (Table 18). An interpretation of these results advanced in Section 6.2 is that symptoms of visual discomfort in DCD have a different aetiology to symptoms in other groups. To support this speculation, there are, indeed, reports of anomalies of accommodation and fixation stability (Section 3.2) in children with DCD, which could extrapolate to explain this relationship with inspection time for DCD in adults. Rafique and Northway (2015) showed a link between reading disabilities, accommodation and motor skills in children with DCD. Furthermore, in children with DCD, Sumner, Hutton, Kuhn and Hill (2016) noted fixation instability. Hitherto, there has been an assumption that inspection time measurement avoids visual difficulties because it occurs during one fixation. Deficiencies of accommodation and fixation stability could affect performance within one saccade; hence, they could affect inspection time.

Analyses in Chapter 7 showed that, although dyslexia and DCD groups predicted inspection time from the non-standard stimulus figure, after control for visual discomfort the predictions by these groups did not reach significance. Thus, in groups with dyslexia and DCD, visual discomfort from the non-standard stimulus figure may interfere with a straightforward interpretation of inspection time as a reliable, uncontaminated measure of central cognitive processing speed. The observation that inspection time was deficient in children with DCD (Piek et al., 2007) could relate to visual disturbances or, indeed, working memory as explained above, as well as a deficit in cognitive processing speed/ efficiency.

Literacy. Among the tests administered were those for rapid automatic naming, sight word reading, phonemic decoding and handwriting speed. Several hypotheses were advanced for the relationship between inspection time and rapid automatic naming (Section 3.6, H 2.4). Of these, there was support for the hypothesis that inspection time would have significant, medium relationships with rapid automatic naming of objects in DCD, which held up after control for visual discomfort, as it hints at a common process hypothesised to be spatial awareness. As regards sight word reading speed, only in DCD was the hypothesised significant relationship with inspection time supported. It was of interest that this relationship was reduced once visual discomfort had been controlled. For DCD, again, visual (optical) anomaly is an obvious candidate for a mediating influence on both sp eed of sight word reading and inspection time. Finally, it was not expected that inspection time would correlate with measures of handwriting and neither did it, across the sample or in any particular group.

8.3. Slow Processing Speed in Dyslexia/DCD

Importantly, analyses in Chapter 7 showed that inspection times in the dyslexia/DCD group were significantly slower than typical even after controlling for the influences of visuospatial memory and visual discomfort. This was true for inspection times derived from both the pi-figure and the non-standard figure (Tables 33–36). There must be a reason for long inspection times in dyslexia/DCD further to visual discomfort and visuospatial working memory. Bellocchi et al. (2018) in a study of children with DCD, dyslexia and both noted that among children with dyslexia/ DCD the only increase in severity of symptoms was in a test for oculomotor control measured by a test of vertical and horizontal pursuit. Although it is possible that a decrease in oculomotor control could lead to slower inspection times, inspection times remained robust after controlling for visual discomfort making this explanation less likely. Furthermore, in children with dyslexia/DCD, Biotteau et al. (2017) concluded that the there was only a small visuospatial deficit, so this is further evidence that suggests a visuospatial deficit was less likely to be responsible for the long inspection times seen here in this group. Slow inspection may be from a variety of bottlenecks between stimulus and sensation but precise mechanisms are unknown. By elimination, judged from whole sample correlation analyses and previous research with typical participants, results here reinforce strongly the supposition that in this group with dyslexia/DCD, pi-figure inspection time also indexes a factor that can be described as central processing speed or efficiency but that this is of unknown origin.

As explained in Section 5. 2., that the group with the slowest inspection times is one in which dyslexia and DCD co-occur supports the theory that both learning differences have the same aetiology; unusual brain development has led to a group of cognitive weaknesses shared across co-occurring disabilities (Willcutt, 2018). There is evidence for unusual brain development in dyslexia and DCD alone and the cerebellum, in particular, has been implicated for both (e.g. Brown-Lum & Zwicker, 2015; Stoodley & Stein, 2013). Unusual cerebellar development that leads to motor deficiencies could be linked to weak inspection time via inefficient eye movement control. However, as mentioned above, weak inspection time in dyslexia/DCD remained after control for visual discomfort, making this less likely a cause of slow inspection time in dyslexia/DCD. Another possible shared neurocognitive attribute is inefficient top-down control as explained in Section 2.2.3. Inefficiencies such as would accompany low-frequency wave patterns or neural oscillation, discussed in more depth by Vidyasagar (2019), have not so far been excluded for dyslexia/DCD. These could translate as slow central processing speed, reflected in slow inspection times and higher inspection time standard deviation, but would also impact other processes. It is not clear also, whether slow inspection time indicates slow processing across both auditory and visual domains. Other possibilities to explain long inspection times in the dyslexia/DCD group are that there is synergy between weak processes in both dyslexia and DCD; compensatory mechanisms may not be possible for participants with both dyslexia and DCD; dyslexia/DCD may be a separate, third SpLD; or a combination of these reasons.

8.4. Implications for Clinical Practice

One purpose for this study was to investigate whether inspection time could be useful for diagnostic assessment of specific learning differences. Although the group of participants with dyslexia/DCD had significantly different inspection times from various tasks to the group with typical development, there was overlap in the range of values between all groups. Thus, inspection time alone cannot be diagnostic of any specific learning difference but it could be useful in individual assessment for specific learning differences as part of a cognitive profile from several tests. As an illustration, such a test is the Comprehensive Test of Phonological Processing (CTOPP-2), used to identify the phonological differences that are characteristic of dyslexia. This battery of tests provides evidence that could account for specific weaknesses in reading proficiency, for example, by highlighting phonological weaknesses. When a test taps a cognitive weakness that heralds a weakness in attainment, it has *predictive validity* (Eignor, 2013). Similarly, deficient performance for the Movement Assessment Battery for Children (MABC-2; Henderson, Sugden & Barnett, 2007) provides supporting evidence for a diagnosis of DCD. One would expect a low score on MABC-2 to predict weak handwriting skills. Tests such as CTOPP-2 and MABC-2 contribute to profiles of cognitive and attainment differences, which support the effective assessment of dyslexia or DCD, respectively. These tests are not in themselves diagnostic. The results here suggest that differences in inspection times between the groups investigated could contribute in a similar way.

In the study with adults, a symbol-digit coding task, which is the usual method used by specialist teachers to evaluate processing speed in diagnostic assessment, did not discriminate between specific learning differences. That a coding task is a seemingly blunt instrument is an advantage for a screening tool but not as useful in diagnostic assessment. Inspection time in the current study was more specific in its ability to show a deficiency and therefore could be complementary to coding tasks for diagnostic assessment. In individual assessment, long or short inspection time could provide one strand of evidence for a learning difference from a battery of tests. This battery might include other elementary cognitive tasks (ECTs). Hitherto, inspection time or other elementary cognitive tasks have not been widely used for diagnosis but they could be, not least because trial outliers can be isolated to assess intra-individual variation between them, unlike paper-and-pencil tests. Inspection time has stability over time (Nettelbeck & Wilson, 2004); need not be dependent on knowledge of facts; and can be free of influences from culture, language and educational attainment. Previously elementary cognitive tasks may not have been used because they require relatively sophisticated equipment although, with advances in technology, their use could become more widespread; standardised equipment and software, an imperative, could be made portable and, eventually, inexpensive. For inspection time to be useful to clinicians and educators, normative values would be necessary. Any test that enables early identification of specific learning difference is welcome and S.E. Williams, Turley, Nettelbeck and Burns (2009) have already succeeded with measurements of inspection time in very young children.

An important aspect of diagnostic assessment is to use a person's cognitive profile to explain their levels of attainment. Inspection time's usefulness to enable identification of specific learning differences could partly depend on its predictive validity, yet unknown, which would inform intervention. The medium relationship between inspection time and reading speed in DCD (Table 28) may depend on another deficiency, possibly visual discomfort, as the relationship between inspection time and sight word reading speed across the whole participant sample while significant was small. As anticipated and in line with results for simple motor speed, above, inspection time from pi-figure stimuli did not correlate significantly with any test of handwriting speed in any participant group.

8.5. Methodological Limitations

This work has taken the information processing approach to investigation into specific learning differences that has been criticised for a lack of ecological validity (e.g., Wade & Kazeck, 2016). Although numbers of participants with specific learning differences in this study are comparable to or exceed numbers in previous studies, it would have been more informative to have more participants with dyslexia/DCD. Moreover, the main investigation was with adults from a restricted, tertiary educated background. Participants may have had other unidentified co-occurring learning differences and there may have been, unaccounted for, subtypes within the three main categories of specific learning differences. These last concerns apply to many research projects that involve specific learning differences.

For statistical analyses, unequal sample sizes limited their power. Correlations between variables have inherent limitations that make conclusions about causal relationships untenable and much of this study depended upon correlational analysis. Multiple correlations were uncorrected to avoid overlooking important associations but this approach risks Type 1 errors, hence a policy in this document to focus on medium strength correlations and above.

For measurements, the monitor dictated the frame rate, which imposed a limit on the shortest inspection time possible to measure and the size of increments above this duration. The method of limits, that requires fewer trials than the method of constant stimuli, impeded attempts to measure inspection time standard deviation, thus abandoned. Test-retest reliability was unestablished for all inspection time tests, in common with other work in the field. The range of other tests was narrow, particularly for tests of attainment and vision. Future work should address these limitations on measurements although the requisite additional trials and tests would add demands on participants.

8.6. Directions for Future Research

As inspection time has potential for clinical use, future work should aim for the construction of a standardised battery of inspection time tests that can contribute to the individual assessment and diagnosis of specific learning differences. This battery of tests might include inspection time from stimuli of different levels of complexity and intra-individual standard deviations for these tests. Indications are that after more research and development, the inspection time task could offer an opportunity to evaluate and compare nuanced aspects of visual processing efficiency, uncontaminated by motor processes and more accurate than a record taken from the time for many consecutive trials. This ultimately could inform individual assessment that relies on evidence of deficiencies from a variety of sources, even though, to date, the implications for intervention and remediation for people with slow inspection time are not always fully understood. The battery might include simple and choice decision times. These other elementary cognitive tests would add further information about the processes for which individuals were impaired. Results from this study show that simple decision time is no different from typical in the group with dyslexia but is significantly slower in both DCD and dyslexia/DCD groups, whereas, like symbol-digit coding, choice decision time is also significantly different in the group with dyslexia. An example of a useful but incompletely understood test is one that assesses rapid automatic naming, also key to diagnostic assessment of specific learning differences.

The nature of appropriate targeted support for long inspection times is yet unknown and long inspection times may be due to other factors than central processing speed. Although the predictive validity for attainment of inspection time is unknown, across the participant sample, after controlling for intelligence, standard inspection time related to a number of speeded tests (Table 29). A first step in discovering the implications for intervention and remediation would be a longitudinal study of children as they progress through Key Stage 1 to determine if inspection time predicts a range of achievements to include literacy and numeracy.

One of the most interesting and important lines of investigation with theoretical and clinical implications, suggested by the work presented here, comes from reason to believe that under some circumstances there is greater intra-individual variability of inspection time in people with specific learning differences. Inspection time standard deviation would be informative in view of neural oscillation theories of dyslexia (Vidyasagar, 2019). Inspection time standard deviation might also be useful in research to evaluate the severity of the effects of co-occurring specific learning differences, which exhibit deficient central processing speed. As Willcutt (2018) explained “Because the coarse measures of processing speed used in previous studies are not sensitive to these [general slow processing and intermittent lapses] different possibilities, future research is needed using more sensitive measures of trial level processing efficiency…” (Willcutt, 2018, p. 277). Inspection time and inspection time standard deviation could be an appropriately sensitive measure, especially if the non-

Gaussian part of the distribution was evaluated, as has been found beneficial in studies of reaction time in ADHD (e.g., Galloway-Long & Huang-Pollock, 2018; Tamm, Narad, Antonini, O'Brien, Hawk, & Epstein, 2012). Attempts to evaluate inspection time standard deviation in the current study were unreliable compared to those that would have been obtained had the method of constant stimuli been used, so this avenue was abandoned. However, a different measure of variability, *change scores,* defined as sign-less differences between test scores regardless of whether the differences were positive or negative, accounted for differences between paired resolved inspection time results. These were from either speeded/un-speeded inspection times or left/right and up/down discrimination inspection times (Chapter 5). Change scores were greater in participants with specific learning differences than in participants who were typically developing but also differed between specific learning differences. Test-retest reliabilities of inspection time for different stimuli or for the other task manipulation of speeded inspection time were not established, so it was difficult to interpret the larger than typical variability in change scores for specific learning difference groups. It was unknown whether larger change scores reflected greater overall variability in performance regardless of test type. Some questions: does response variability occur in other chronometric tasks in the groups examined here? Is greater intra-individual variability between inspection time tasks characteristic of other co-occurring learning differences, such as ADHD/DCD or ADHD/dyslexia? Is greater intra-individual variability between tasks specific to test type? If so, are they characteristic of different learning differences? As regards other groups of participants, results of recent investigations into ADHD show that inspection times and inspection time standard deviations are no different to typical in this group (Galloway-Long & Huang-Pollock, 2018). Inspection time has not been measured concurrently in conditions such as autism, schizophrenia or multiple sclerosis, which could have atypical inspection times and inspection time standard deviations.

Of theoretical interest, it emerged that, unlike the pi-figure, inspection times from the non-standard stimulus figures were longer than was typical in the groups with dyslexia and DCD. The inspection time task and inspection time standard deviation warrants further investigation in children and adults with dyslexia and DCD, because it could offer a straightforward means to evaluate and compare nuanced aspects of visual processing efficiency by the use of different designs of stimuli. This would help to improve theoretical understanding of visual processing efficiency in dyslexia. For dyslexia, this finding for non-standard stimuli supports the visual attention span hypothesis (Bosse et al., 2007) and is important because this theory and other visual processing investigations in dyslexia (e.g., Stenneken et al., 2011) have been criticised (e.g., Goswami, 2015) for their dependence on letters in the partial and full report methods used to show a deficit. Presented here is evidence of a deficit in appraisal/decision time of certain visual stimuli for participants with dyslexia and one that does not depend on an ability to distinguish or remember a sequence of letters or develop a repetitive task to automaticity, a difficulty often implicated in dyslexia. For example, future work could investigate different numbers of loci for the critical information on the stimulus, for which fair comparisons for stimulus designs would require some thought before it was a fair test. Could inspection time be a more effective way to investigate visual attention span or crowding (e.g., Joo et al., 2018) in participants with dyslexia? Because it is more specific than a series of letters, inspection time with different designs of stimuli might help to establish if deficiencies were general or found only in a sub-group.

To accurately define slow processing in DCD and to improve theoretical understanding of inspection time, measurement of inspection time in children with DCD should be done again but with the un-speeded method that uses pi-figure stimuli, and with responses that map directly to the critical information on the stimulus. Previous studies with children with DCD did not map directly. In these studies (e.g., Piek et al., 2007), the response button was defined by colour and the choice was between two lines of the same length and different lengths. To remember which button to press for each stimulus type, which was done under speeded conditions, would be likely to require more working memory than an unspeeded response to a simple pi-figure with direct mapping, so the inspection time could be contaminated by levels of working memory. Furthermore, a different design of stimulus figure is required to determine whether a discrimination of length or the complexity of the stimulus is influential. Future investigations should establish whether exceptionally long standard inspection times also occur in children with dyslexia/DCD.

Of clinical importance, in the groups of participants with typical development, dyslexia and dyslexia/DCD and across the whole participant sample, results from the visual discomfort scale correlated significantly with those of the pattern glare test. This indicates that they assessed some similar aspects of visual unease or a similar latent variable controlled both. This situation in most groups is consistent with the findings of Conlon et al. (1999) for participants with typical development. In contrast, in the group of participants with DCD, there was no significant correlation, which implies that an additional influence obscured any underlying relationship, perhaps from visual anomalies. Research needs to confirm or discount relationships between inspection time and fixation instability and accommodation deficiencies in children and adults with and without dyslexia, DCD and dyslexia/DCD. This would also help to theoretically define the group with dyslexia/DCD and contribute to the discussion about the origins of long inspection times and co-occurrence in the dyslexia/DCD group. Interrelationships between vision anomalies, inspection time and reading, especially in DCD are yet uncharted. Eye examinations in participants, both children and adults with DCD, alongside experiments with inspection time are required to illuminate further the extent of any visual effects on inspection time. It has been generally assumed that inspection time, within one saccade, is not affected by optical efficiency but this is now questionable because of the results presented in Section 6.1 and 6.2. Another avenue for future research would be to investigate the role of microsaccades (see Section

2.2.1), as it is possible that these could influence inspection time by altering the power of the signal to the retina and they may ultimately influence inspection time. These experiments would improve theoretical understanding of inspection time.

Other theoretical lines of enquiry concern the relationships between inspection time, visuospatial awareness and working memory in people with DCD. In participants with DCD, the relationship between inspection time and visuospatial working memory was large, negative and significant. Visuospatial working memory was deficient in the group of participants with dyslexia as well as DCD but it did not correlate significantly in dyslexia with inspection time. A possibility to explain these results and in need of investigation is that the visuospatial aspects of both inspection time and visuospatial memory tests are important, but are evident in DCD alone because of the visuospatial difficulties in this group. The studies presented here did not include a test of spatial awareness, such as 2-D rotation. With data from a test of spatial awareness and visuospatial working memory, it would be possible to test the hypothesis that spatial awareness is important to the relationship between inspection time and visuospatial working memory in DCD. If this were to be the case, there are important clinical implications not only for DCD but also for other groups of participants with any sort of visuospatial weakness. Visuospatial awareness skills underpin ways of tackling a number of everyday tasks such as text or map reading, neat handwriting and problem solving. Visuospatial processes decline in older participants (e.g., Iachini, Iavarone, Senese, Ruotolo, & Ruggiero, 2009). Thus, if the relationship between inspection time and visuospatial skills is important, decline of inspection time in older age (e.g., Deary, W. Johnson & Starr, 2010) may not simply be due to decline in speed of processes but may originate from decline in visuospatial skills.

8.7. Conclusions

Reservations about the use of so-called *information processing speed* for individual assessment of dyslexia, DCD and dyslexia/DCD, particularly by paper-and-pencil tests prompted this research. By their nature, paper-and-pencil tests of processing speed invariably include motor processes and are the sum of repeated items in the test. Doubts included those about value for diagnosis and for provision of information that would help with subsequent intervention from such tests. The research presented here indicates that the inspection time task, once standardised, could be a useful, more specific, addition to paper-and-pencil tests for processing speed in individual assessment of specific learning differences. Motor processes are not included in inspection time evaluation, made trial by trial, so that each trial is separate from its neighbours. Results show that unlike results of a paper-and-pencil test of coding, which are deficient in dyslexia, DCD and dyslexia/DCD, standard inspection time with pi-figure stimuli was significantly deficient only in the group of adults with dyslexia/DCD, in which it suggests deficient central processing speed. However, for individual assessment, inspection time's concurrent validity is not without question. Measures of working visuospatial memory and visual discomfort in some participants, particularly those with dyslexia or DCD, suggest that inspection times' position as an index for speed of central cognitive processes is not straightforward, especially when more complex stimuli are used. The question mark over its concurrent validity should be the subject of future research, but it does not preclude inspection time's potential to be useful in diagnostic assessment of specific learning differences. Inspection time deserves development both as a research tool to characterise specific learning differences and as a standardised test to explore strengths and weaknesses of individuals during an assessment for specific learning differences.