Effects of dyslexia on problem solving: Strategies and interventions for syllogistic reasoning

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Declaration

This thesis has not been submitted in support of an application for another degree at this or any other university. It is the result of my own work and includes nothing that is the outcome of work done in collaboration except where specifically indicated. Many of the ideas in this thesis were the product of discussion with my supervisor Professor Padraic Monaghan.

ABSTRACT

When solving syllogisms, people can adopt either a spatial strategy, where spatial representations are used to illustrate relations between terms, or a verbal strategy where the problem is represented in terms of letters and relational rules (Ford, 1995). People with dyslexia tend to adopt a spatial strategy when solving syllogisms while people without dyslexia tend to adopt a verbal strategy (Bacon, Handley & McDonald, 2007). But how fixed are these strategic approaches? This thesis examines whether training that focuses on verbal or spatial representations of the problems affected performance for people with and without dyslexia, and whether the effectiveness of this training varied according to whether the syllogisms were categorised as those easiest to solve for verbal reasoners, easiest for spatial reasoners, and equally difficult for both types of reasoners, based on Ford's (1995) results. Five studies were conducted to compare the performance of people with dyslexia to people without dyslexia to examine 1) individual differences in spontaneous reasoning strategies, 2) effects of figure and belief bias, 3) performance after being taught a verbal strategy, 4) performance after being taught a spatial strategy, and 5) the pattern of eye movements to observe where attention is focused while solving the syllogisms.

The results supported previous research that people do tend to reason spontaneously with a verbal or spatial strategy but failed to find evidence of a difference between participants with dyslexia and participants without dyslexia. The studies further showed that participants with dyslexia are affected by the figure of the syllogism (the placement of the middle term in relation to the end terms). Training was effective in encouraging all participants to switch solution strategies, but this appears independent of dyslexic status. Teaching a spatial strategy impacted learning

but did not promote problem solving and was not particularly helpful for the participants with dyslexia. It appears to make problems that are easier with a verbal strategy harder to solve.

Examination of eye movements revealed that the focus of attention during problem solving was more on the terms in the premises than the quantifiers. The pattern of eye fixations was the same regardless of the figure or problem type. There was an interaction between problem type x AOI, indicating a longer processing time for premise 2 for problems that are difficult to solve with a verbal or spatial strategy.

Overall, the studies suggest that there is a burden on participants with dyslexia in problem solving that is not alleviated by training in either spatial or verbal strategies, but that particular problems might be easier or harder to solve according to whether a spatial or verbal strategy is spontaneously used by the participant, and that these differences in problem type are marked by eye fixation patterns during problem solving.

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CHAPTER 1: INTRODUCTION

1.1. Definition of reasoning

Reasoning is a cognitive process that involves the ability to make judgements and draw conclusions about things from a variety of sources. According to Bruner (1973), the core of reasoning is going beyond the information given at the time. Most of the research on reasoning has tended to focus on the nature of the task rather than the nature of the reasoner, or more specifically, individual differences in reasoning. In a pioneering study, Ford (1995) suggested that people solve problems in very different ways. She identified two groups of reasoners – verbal and spatial. She found verbal reasoners tended to treat syllogisms like mathematical problems, re-writing them as equations, substituting words with letters and using arrows to indicate relationships between the terms of the premises. Spatial reasoners, on the other hand, tended to use shapes in different spatial relationships to represent different classes and their relationships.

Further, Bacon, Handley and MacDonald (2007) demonstrated that people with dyslexia tend to adopt a spatial strategy, while people without dyslexia tend to adopt a verbal strategy. My thesis further explores these differences in strategy, comparing the performance of people with dyslexia and people without dyslexia. In particular, in a series of studies I examine the way people with dyslexia and people without dyslexia reason when solving syllogisms and the effects of training to solve them with a different strategy. The aim of my research is to contribute to the understanding of reasoning, strategy selection and problem solving, and the development of intervention strategies for problem solving for people with dyslexia.

1.2. Background

A long-standing and commonly-used paradigm used in the study of reasoning is the task of solving syllogisms. A syllogism consists of a pair of premises presented to a participant who then has to either deduce a conclusion based on those premises (production task) or decide if the conclusion given is valid or invalid (evaluation task). The validity of a logical argument is not affected by whether its premises and conclusions are, in fact, true or false. Take the following example:

All cats are fish

All fish have gills

Therefore, all cats have gills

Even though one of its premises (All cats are fish) is obviously false, the other premise (All fish have gills) is obviously true, and the conclusion (Therefore, all cats have gills) is obviously false, the argument is still logically valid. Different theories have been proposed to describe the process of human reasoning. Three main theories and their proponents are Mental Models (Johnson-Laird & Byrne, 1991), Mental Logic (Braine & O'Brien, 1998) and Dual Processing (Evans, 1989).

1.3. Mental Models

According to Mental Models theory, an abstract representation is first created of members of a set in a spatial array and this is used to determine a conclusion (Johnson-Laird & Byrne, 1991). The process is proposed to follow a pattern:

1) A simple model is constructed based on the premises identified, and then a tentative conclusion is drawn relating the terms that are not repeated.

2) A further model is constructed in order to falsify the conclusion. If no falsifying evidence is found, the conclusion is accepted.
3) If the conclusion is falsified, there is an attempt to identify a new conclusion that is compatible with the initial models. If none is found, then a decision of no valid conclusion is accepted.
4) Steps 2 and 3 are repeated as necessary until a reasonable conclusion is found.

Johnson-Laird and Byrne (1991) found that, when asked to solve syllogisms, people tended to accept conclusions that matched the form of one of the premises, regardless of whether or not the conclusion was valid. In such instances, valid conclusions are accepted as necessary without the investigation of possible alternative solutions, whereas invalid conclusions require construction of an alternative falsifying model to be refuted (Hardman & Payne, 1995; Stupple & Ball, 2007).

The process of searching for counter examples (Johnson-Laird & Bara, 1984) or fleshing out of initially implicit mental models (Johnson-Laird & Byrne 2002) is effortful, error prone, and constrained by working memory capacity. Mental Models theory argues that sources of difficulty in syllogistic reasoning are due to the number of possible models that can be considered at the validation stage, as well as the figure of the syllogism at the description stage (Johnson-Laird, 1983). Stupple and Waterhouse (2009) suggest that these factors burden working memory, and the amount of difficulty is dependent on the number of rules required to complete an analysis. The greater the number of rules the greater the demand on working memory and the more likely an error will occur.

Working memory refers to the processes involved in control, regulation and active maintenance of cognitive functions (Miyake & Shah, 1999). It is described as a system consisting of the central executive that coordinates activities of two subsidiaries or ‘slave’ systems, the visuospatial sketchpad and the phonological loop (Baddeley & Hitch, 1974; Baddeley & Logie, 1999). The phonological loop processes spoken and written information. The visuospatial sketchpad processes visual or spatial information. The central executive does not have the ability to store information but it directs attention to either the phonological loop or the visuospatial sketchpad. There is also an episodic buffer (Baddeley, 2000a) that is described as a back-up store that communicates with long-term memory and the components of working memory.

The role of working memory in reasoning with syllogisms has been investigated mainly using dual task paradigms where participants perform a secondary task, such as simple pattern tapping or random number generation, designed to engage the various components of working memory. The idea being that disruption of the primary task can highlight which component of working memory the reasoner is using to solve the problem at hand. Vandierendonck and De Vooght (1997) found that tapping in a spatial pattern, shadowing a random pattern, or a memory load task such as repeating a string of digits, impaired performance of the visuo-spatial subsystem of working memory when reasoning on linear syllogisms. On the other hand, Toms, Morris and Ward (1993) found that repeating a string of digits affected performance on conditional syllogism whereas tapping tasks had no effect. Gilhooly, Logie, Wetherick and Wynn (1993) found a similar effect for categorical syllogisms.

1.4. Mental Logic

Mental Logic argues that human beings reason through an innate system of formal rules of logic which are abstract and general purpose in nature (Braine & O’Brien, 1998). The problem enters working memory where various rules are applied to the premises in order to draw out any relevant information. Any new information is added to the existing information in memory and then reassessed. This process is repeated until a conclusion is formed or the rules are exhausted. Braine and O'Brien (1998) distinguish between direct rules of inference, which are applied effortlessly and accurately, and indirect rules, which require conscious effort and are much more error prone. Some conclusions are easier to deduce than others because they are direct rather than indirect (Braine, Reiser & Rumain, 1984), or made forwards (production tasks in which answers are generated from the premises) rather than backwards (evaluation tasks which involve proving the conclusion can be made from the premises given) (Rips, 1983). In terms of syllogistic problem solving, a production task is one where the reasoner is given both premises and asked to come up with a conclusion (whether valid or invalid) based on the relationship between the terms of the premises or determine that there is no valid conclusion. An evaluation task is one where a reasoner is given the conclusions from both premises and asked to determine if the conclusion is valid or not valid.

A drawback with mental logic is that it cannot explain many of the findings in the experimental literature, such as belief bias (this will be discussed later), so theorists have proposed the operation of pragmatic reasoning schemas as well (Rips, 1994). Markovits and Nantel (1989) suggest a two-stage process in which reasoners first generate possible conclusions from the premises and then evaluate them. The first stage employs innate logical rules, while the second stage employs the use of knowledge already held about the terms in the premises. Using both production and evaluation tasks, Markovits and Nantel (1989) presented participants with two sets of syllogisms: neutral syllogisms designed to produce conclusions about which they had no a priori beliefs (eg. If a glock is a XAR, you can say that it is certain that the glock is a YOF, not a YOF, or not certain that it is a YOF or not), and positive syllogisms designed to produce conclusions which were unbelievable but logically valid (e.g., All mammals walk, Whales are mammals, therefore whales walk). The same forms were used in both production and evaluation conditions. Belief scores consisted of one point for each believable conclusion judged as valid or each unbelievable conclusion judged as invalid for evaluation tasks, and one point for each logically invalid but believable conclusion or logically valid but unbelievable conclusion for production tasks.

The results showed that belief scores were higher for positive forms than for neutral forms in both production and evaluation tasks. Analysis of the written responses indicated that subjects generated conclusions through inferential reasoning from the premises, and subsequent evaluation of those conclusions resulted in the introduction of real-world knowledge. This study provides evidence that subjects may resort to their beliefs when faced with uncertainty about a conclusion. However, the possibility exists that people either misinterpret or incompletely interpret the material and they reason logically, or they do not use complete or logical operations (Evans, 1989). Dual Processing theory provides an explanation for this.

1.5. Dual Processing

The current view of the dual process theory is there are two types of processes, Type 1 and Type 2 (Evans, 2018, 2019). Type 1 processing is defined as fast and autonomous and does not rely on working memory. It functions unconsciously to generate what are considered intuitive solutions to a problem (Bago & DeNys, 2017; Evans, 2018). It has been suggested that Type 1 processes may be influenced by stereotypical thoughts and beliefs (Bago et al., 2017). Type 2 processing is slow and controlled. It functions consciously and comes into play when analytic thinking and reasoning is required. It requires working memory and is focused on cognitive decoupling and mental simulation, which are important aspects of analytic thinking. Cognitive decoupling is the act of separating concepts into distinctive parts and thinking of them abstractly. The fast and intuitive nature of Type 1 processing can lead to incorrect solutions. Type 2 processing takes over when there is uncertainty and conflict which results in the need to seek alternative solutions. Evans (2019) suggests that Type 1 is the default process and Type 2 processing serves two purposes, the default process to support the Type 1 response and to provide further reasoning should the Type 1 response fail or does not sufficiently answer the question at hand. Rather than simply taking over the reasoning process if the initial solution is inadequate, Type 2 process first tries to justify that response before attempting to seek an alternative solution.

Type 1 and Type 2 processes are often described using the same terms as previous versions of the dual process theory, ‘intuitive’ or ‘heuristic’ vs. ‘deliberate’ or ‘analytical’ (Stanovich & Toplak, 2012). Earlier versions of the dual process theory of reasoning (Evans, 1989) distinguished between heuristic and analytic processes. Heuristic processes are automatic, associative, unconscious, and undemanding of executive working memory capacity; while analytic processes are consciously controlled, deliberate and effortful (Gillard, Van Dooren, Schaeken & Verschaffel, 2009). It was suggested that the heuristic system focused on the surface features of a problem, those features that appear at first glance to be relevant, while the analytic system is time-consuming and sequential, and operates on ‘decontextualised’ representations (Gillard et al., 2009). This means that when a person is trying to solve a problem, they select certain features of it as potentially relevant to the solution and then try to match their solution to the original premises. If they are unable to generate a reasonable conclusion, they resort to analytic processes to work on those selected features of the problem. Heuristic processes seem to initially take precedence over analytic processes which are recruited only if further analysis of the problem is required. Since analytic processes can only be applied to selected features, biases will occur when either logically relevant information is excluded or when logically irrelevant information is included by heuristic processing (Evans, 1989). In other words, while heuristics often provide correct solutions, they can bias reasoning in situations where more complex, analytic processing is needed (Evans, 2006).

The heuristic system was thought to rely on prior knowledge about the factors involved with or related to a problem in order to generate a solution (Sloman, 1996). Similar to the Mental Models theory, the heuristic system creates a representation or image of the problem to be solved. The heuristic system processes the problem based on whatever related information already resides in the problem solver's mind. Thus, problem solving and reasoning may initially be limited by a person's prior beliefs. However, sometimes the heuristic and analytic systems will conflict and cue different responses (Gillard et al., 2009), and a correct response can be found only when the analytic system overrides the heuristic system and the reasoner purposely tries to generate alternative solutions. Tversky and Kahneman (1983) suggest people often use shortcut heuristics rather than logical reasoning when they think about the probabilities of everyday events. In other words, solutions are based on the heuristic system working on the surface features of problems, rather than attempting to reason logically with the analytic system. This reduces the cognitive demands but increases the likelihood of errors (Chater & Oaksford, 1999).

Research has shown that under severe time pressure (Evans & Curtis-Holmes 2005) and concurrent working memory load (De Neys, 2006) reasoners shift from logical reasoning to belief-biased reasoning. When time and cognitive resources are limited, only heuristic processes are used, leading to a greater likelihood of errors. Rather than search for a valid link between the premises and a conclusion, a conclusion is accepted based on its believability (Evans, Handley & Bacon, 2009). This can also lead to more matching as this would be less cognitively demanding for the reasoner. Stupple and Ball (2008) have further suggested there may be a parallel dual process model for belief-biased syllogisms in which heuristic and analytic processes work alongside each other.

Another factor thought to affect reasoning is the amount of information presented at one time to the problem solver. Gilhooly (2005) has argued that when cognitive loads increase, participants tend to use less cognitively demanding strategies such as matching, therefore an increase in the frequency of matching responses can be expected when more demanding negated premises are presented. Matching occurs when participants select conclusions that have the same quantifier as one of the premises. The most conservative quantifier, the one with the easiest fit, is selected, and matching is more likely to take place when the same quantifier is featured in both premises (Wetherick, 1989; Wetherick & Gilhooly, 1995).

Franssens and De Neys (2009) demonstrated that a load task affected performance on problems that required analytic reasoning, but it did not affect performance on problems for which heuristic reasoning was adequate. A load task is an additional task designed to take working memory resources away from the experimental task at hand. In their study, participants solved three types of base-rate neglect problems: incongruent (a hypothetical person portrayed as a stereotypical member of the smallest group within a sample), congruent (base-rate and description pointed to the same answer), and neutral (non-stereotypical description). Base-rate neglect refers to the phenomenon where people ignore a much more likely probability of a fact or event in favour of a much less likely, but more attractive option (Kahneman & Tversky, 1973). Half of the participants were required to solve the problems under a secondary load which was a recall task, the aim being to limit cognitive resources that could be directed towards the problem solving task. Results showed that load manipulation only affected performance on the problems that required analytic reasoning: incongruent (47% no load, 35% load) and neutral (94% no load, 80% load). It did not affect the congruent problems (98% no load, 97% load) where heuristic reasoning was sufficient. This provides further support for the dual process theories that analytic reasoning is resource demanding, whereas heuristic reasoning is not. Thompson (2006) suggests that heuristic responses to reasoning problems are accompanied by a certain feeling of rightness or intuition and the strength of these feelings determines whether or not analytic responses are used. It has been suggested that both systems may simply be operating on a continuum (Cleeremans & Jimenez, 2002), where the quality of representation lies on a continuum and as the quality of the representation increases, there is a corresponding progression in the type of learning from implicit to explicit to automatic. Cleeremans and Jimenez (2002) refer to it as the dynamic graded continuum (DGC), where the role of consciousness changes for each type of learning (Cleeremans, Detrecqz & Boyer, 1998). Rather than separate systems, DGC is viewed as different levels of the same system. Representations allow the cognitive system to monitor the intermediate results of processing (Anderson, 1995), and for representations to enter awareness they need to be active enough to gain strength, become stable in time, and be sufficiently distinctive (O'Brien & Opie, 1999; O'Reilly & Munkata, 2000).

Osman (2004) compared dual process theories with the DGC system. She claims that the dual processing theory (Evans & Over, 1996), the dual-system theory (Sloman, 1996) and the two-systems theory (Stanovich & West, 2000) share some similarities in the way they are described: System 1 which is associative, automatic and fast, and System 2 which is rule-based, deliberate, flexible and slow. Osman argues that dual processing theories do not adequately explain the range of processes identified in studies of reasoning, and the terms implicit/explicit and automatic are used interchangeably, whereas DGC distinguishes between the two. Implicit reasoning involves making inferences without being consciously aware of them, explicit reasoning is having an awareness of inferences that are made, and automatic reasoning results from interacting with information until it becomes familiar. Osman (2004) further suggests that certain types of reasoning have been misclassified by dual process theorists as implicit and should instead be classed as automatic reasoning.

Various theories imply that the reasoning process is governed by one universal system (Johnson-Laird & Byrne, 1991) or the application of logical mental rules (Rips, 1994). There is a growing body of research that suggests that reasoning strategies are influenced by individual differences.

1.6. Meta-reasoning

A reasoner's level of confidence also plays a part in the reasoning process. The basis for the level of confidence is metacognition, the reasoner's awareness and understanding of their thought processes and a feeling of rightness (Ackerman & Thompson, 2017; Thompson, Prowse-Turner & Pennycook, 2011). This can affect whether a conclusion is accepted as valid or invalid, regardless of whether the conclusion is correct or incorrect. Borne out of the concept of dual processing, it has been suggested that metacognition and the feeling of rightness are both elements of fast and autonomous Type 1 processing (Thompson, 2009; Thompson et al., 2011). A poor feeling of rightness signals to the reasoner that further processing is required then Type 2 processing is engaged, thereby increasing the likelihood that the original answer will be changed. De Neys (2010; 2014) has demonstrated that people can identify when they have made a mistake in reasoning. Factors that might trigger a poor feeling of rightness include conflicting answers (Thompson & Johnson, 2014) and unfamiliar terms in the problems (Markovits, Thompson, & Brisson, 2015). A feeling of rightness signals to the reasoner that no further processing is required, and the conclusion is accepted (Thompson et al., 2011; Thompson, Evans, & Campbell, 2013; Thompson & Johnson, 2014). A strong feeling of rightness and greater confidence is engendered when an answer comes to mind quickly, even if the answer is not quite right (Thompson et al., 2013; Ackerman & Zalmanov, 2012; Thompson & Morsanyi, 2012).

Meta-reasoning is responsible for the regulation of thought processes, as well as the allocation of attention and time towards problem solving (Ackerman &Thompson, 2017 & 2018; Thompson et al., 2011). The mechanisms involved in the process operate at two levels. The objective level identifies the separate parts of the problem and the expected outcome, generates an initial autonomous response, initiates analytic processing if necessary, and then generates an answer. The monitoring level assesses current knowledge and potential reasoning strategies, produces an initial judgment of solvability, a feeling of rightness, an intermediate level of confidence,

and then provides a judgement of solvability (Ackerman & Beller, 2017; Payne & Duggan, 2011), a decision to seek help or not, or conclude there is no solution.
Prior knowledge, past experiences and beliefs influence how people reason and solve problems. Beliefs can distort interpretation of information and influence the deductive process (Garnham & Oakhill, 1994) and pre-existing beliefs may indeed influence the perception of new or additional data (Kormblith, 1993). The reliability of the monitoring process is dependent on how accurately these factors treat the nature of the problem at hand (Koriat, 1997). The monitoring process assesses the reasoner's level of certainty about their progress in solving the problem and determines the likelihood of success.

Markovits, Thompson and Brisson (2015) suggest that confidence is based on cues from experiences associated with problem solving, such as fluency. Fluency creates a sense of positivity (Winkielman & Cacioppo, 2001) for the reasoner and is a strong predictor of feeling of rightness (Thompson et al., 2011). It increases the probability that the reasoner will reconsider a conclusion and change it. As far as confidence is concerned, fluency does not discriminate between correct and incorrect answers (Ackerman & Zalanov, 2012). Markovits et al. (2015) examined how people evaluate their level of confidence in deductive reasoning. They hypothesised that a) representations of logical validity are the same across various contexts and confidence should be higher for logically correct than incorrect responses for both familiar and abstract problems, b) the evaluation of a conclusion is based on how congruent it is to their prior knowledge or beliefs, and c) the evaluation changes as a function of the characteristics of the problem at hand. The characteristics of a problem are incorporated into the reasoning process when they are available (Markovits, Lortie Forgues & Brunet, 2010).

Participants were presented with three inferential problems in four logical forms: one problem with conditional relations in the major premise, one abstract problem with nonsense terms, and two problems with causal conditional premises. They were first given a brief description of what is involved in making logical inferences but with no information about the content of the problems. They were then asked to evaluate their confidence in providing logical responses. They were asked to rate their confidence in their responses immediately after the experimental trials. The results revealed that confidence was higher for familiar premises than for abstract premises regardless of the logical correctness of the answers, suggesting that the ability to make decisions on the basis of prior knowledge promotes confidence (Shynkaruk & Thompson, 2006) and the meta-reasoning monitoring process is inferential and based on cues from the problem itself (Costermans, Lories, & Ansay, 1992; Koriat & Levy-Sadot, 2001). In addition, when the material is familiar to the reasoner, a judgment of confidence is influenced by the characteristics of the problem at hand, so was higher when the characteristics were more congruent with their prior knowledge and lower when they were not congruent.

1.7. Verbal versus Spatial Reasoning

Ford (1995) suggests that it is wrong to treat everyone as if they reason in the same way. She identified two groups of reasoners – verbal and spatial. In her study, twenty participants were presented with 27 syllogisms with valid conclusions and asked to solve them, speaking their thoughts out loud and also showing their workings in a workbook. The syllogisms contained distinct terms such as *vegetarians* and *gymnasts*, and common terms such as *lawyers*. The results showed that verbal reasoners tended to treat the syllogisms like mathematical problems, re-writing them as equations, substituting words with letters and using arrows to indicate relationships between the terms of the premises. They appeared to be using rules that are similar to modus ponens and modus tollens (see Ford 1995, pg 21 for an explanation of the rules). Spatial reasoners, on the other hand, tended to use shapes in different spatial relationships to represent different classes and their relationships. They used representations where the class itself was represented rather than the members of the class. Many of the spatial reasoners drew shapes that were similar to Euler circles to denote classes while at the same time, Ford notes, keeping the verbal tag of the syllogism in their mind. Some participants even appeared to use a combination of both strategies.

Verbal and spatial participants seemed to be affected differently by the forms of syllogisms. For example, in the case of constrained syllogisms such as All/None, where the first premise begins with 'All', the second begins with 'None', spatial reasoners appeared to examine the relationship between the terms in one premise and then add the third term from the other premise, ensuring it had the correct relationship with the term that was in common with the other premise. Their performance was worse on less constrained syllogisms such as All/Some, where the first premise begins with 'All', the second begins with 'Some', though not significantly so. In contrast, verbal reasoners demonstrated near perfect performance on less constrained syllogisms. In different form syllogisms, None/Some and None/All, spatial reasoners performed worse (20-46.7% correct) than verbal reasoners (6.3-73.3% correct). In the case of syllogisms containing premises Some X are not Y there was a tendency for participants to take it to mean that some X are Y. These were difficult for both verbal and spatial reasoners.

For symmetric syllogisms where the correct conclusion had the same form as one of the premises but where either order of the terms in the conclusion was correct, for example “All politicians are potters, Some of the politicians are chess players, Therefore some of the potters are chess players (or some of the chess players are potters)”, results were similar to that observed by Johnson-Laird and Bara (1984): Verbal participants tended to produce a conclusion in the same form as one of the premises, and to keep the A or C term of that premise in the same position in the conclusion (93.3% of correct responses belonged to the same form, same position category; 6.7% same form, different position). Spatial participants did not show a similar effect (43.5% same form, same position; 52.2% same form, different category; 4.3% different form). In contrast, spatial participants showed an effect of position for the non-symmetric figures (89% same form, same position; 5.5% same form, different position; 5.5% different form). Verbal participants were affected to a lesser extent (71.9% same form, same position; 7% same form, different position; 21.1% different form). Ford proposes this effect may depend on which rule the verbal participants were trying to apply. The verbal participants in Ford’s (1995) study seemed to not be reasoning with mental models, and the spatial participants appeared to be using a type of representation but not what Johnson-Laird described (1983).

1.8. Visual Imagery

In order to reason spatially, participants need to be able to construct visual reconstructions of the problem, likely requiring visual imagery. Shaver, Pierson, and Lang (1975) reported that the performance on three-term series problems (see DeSoto, London & Handel, 1965) depends on the type of materials and instructions presented, as well as the participant’s ability to form images. Clement and Falmagne (1986) found that materials rated as easy to imagine led to fewer errors in verbal reasoning (at least if the material is related to knowledge). In contrast, several studies found no effect of imageability on reasoning (Sternberg, 1980; Richardson, 1987; Johnson-Laird, Byrne, & Tabossi, 1989). An important consideration is what type of image a person holds in their mind and how this affects their decision making. Based on the Mental Models theory, a person first creates an image in their mind. The image will most likely be based on their impression of the premises concerned. So, if the premises presented use concrete objects, the resulting image will be of those objects. Therefore, if the objects have an explicit meaning for that person, the mental representations or images will relate to the meaning of those objects.

According to Knauff and Johnson-Laird's visual imagery impedance hypothesis (2002), irrelevant visual detail evoked by the relationship between terms can impede the reasoning process. For example, take the phrase "the hat is dirtier than the cup". It is easy to visualize a dirty cup in varying degrees of dirtiness. However, the resulting image contains a large amount of information that is irrelevant to the transitive inference (understanding of the relationship between two objects by knowing the relationship of each to a third object). For example, irrelevant information may be the style of the hat or design of the cup, or even the nature of the dirt on the cup or the hat. The large number of possible images puts unnecessary load on working memory. The reasoner has to determine what information is relevant but might be distracted by irrelevant visual details or images. There are four main types of relations that may impede transitive inference (Knauff & Johnson-Laird, 2002):

1) Visuospatial relations, such as above and below, which are easy to envisage visually and spatially.
2) Visual relations, such as cleaner and dirtier, which are easy to envisage visually but hard to envisage spatially.
3) Spatial relations, such as ancestor of and descendant of, which are hard to envisage visually but easy to envisage spatially.
4) Control relations, such as better and worse, which are hard to envisage either visually or spatially.

When confronted with any one of these types of relations, the inferential system has to sift out the irrelevant from the relevant factors from information presented. In a series of three experiments (Knauff & Johnson-Laird, 2002), visual relations were shown to slow down the process of reasoning in comparison with control relations, whereas visuospatial and spatial relations affected the reasoning process similarly to that of control relations. Knauff and Johnson-Laird (2002) argue that if a relation yields a model that is relevant to an inference, it should speed up reasoning; in comparison to those that elicit neither images nor spatial relations.

1.9. Ethics

Ethics approval for the studies in this thesis was granted by the Lancaster University Research Support Office. There were three ethics applications as follows:

- Chapter 3: Syllogism solving (Study 1) and Sentence-Picture verification (Study 2).
- Chapter 4 (Verbal strategy training) and Chapter 5 (Spatial strategy training).
- Chapter 6 (eye tracking)

In all studies, participants were asked to read an information sheet explaining the tasks they would be undertaking, that they had the right to withdraw at any time without having adverse consequences and no explanation needed to be given. They were then asked to sign a consent form indicating that involvement in this study was of their own free will and if they were unsure about anything mentioned in the form then they could ask the researcher present for help. After the experimental trials they were given a debriefing sheet explaining the outline of the study and that their personal data (name and age) would be immediately separated from the experimental data and it would not be possible to link this data back to them. See Appendix 1 for copies of the information sheets, consent form, and debriefing sheets.

1.10. Outline of the thesis

As this thesis focuses on strategies in reasoning for people with dyslexia, Chapter 2 describes the theoretical background to dyslexia. It reviews learning styles and metacognition of people with dyslexia, and how structure and presentation of teaching materials and classes impacts upon their educational experiences.

Chapter 3 examines individual differences among reasoners. There are different strategies used by individuals in problem solving. Key strategies involve spatial or verbal strategies. People with dyslexia tend to use spatial strategies but can be affected by visual noise in their problem solving. However, certain problems are solved more effectively by spatial than verbal strategies, according to Ford (1995), and this has not yet been taken into account in terms of people's strategic preferences. Furthermore, we do not yet know if we can influence people's strategy use. If a spatial strategy is more appropriate for certain people, is it effective to train them in that strategy? If a spatial strategy is better for certain problems, is training in spatial strategy particularly useful for those types of problems? This thesis investigates these issues in a series of experimental studies with people with and without dyslexia.

The syllogisms used in chapters 3, 4 and 5 were selected from those identified by Ford (1995) as easiest for spatial reasoners, easiest for verbal reasoners and equally difficult for both types of reasoners. The rationale for this is to determine which types of syllogisms might be made easier or more difficult to solve using different strategies. For example, a syllogism that is deemed easy for verbal reasoners should be made even easier with a verbal strategy. If a reasoner is using inappropriate strategies can they be taught to reason in a different way to their natural inclination. Would it be easy or difficult for a reasoner to switch to a different way of working? In particular, how does the performance of participants with dyslexia compare to the performance of participants without dyslexia? Will forcing a verbal strategy flummox the participants with dyslexia because of their phonological deficit (Snowling, 2000) or will they outshine their counterparts without dyslexia if learning a spatial strategy did indeed enhance their style (Bacon et al., 2007) or play to their visuospatial skills (Von Karolyi et al., 2003; Galaburda, 1993)?

Chapter 3 examines individual differences in reasoning strategies, individual differences in strategy in combining spatial and verbal information, and observing figural effects as well as belief bias, focusing on the difference between participants with dyslexia and participants without dyslexia. This chapter features two studies. The first study investigates strategy selection and figural effects with all 27 syllogisms with a valid conclusion, but separated into three categories as per chapters two, three and four. The second study examines belief bias with a sentence-picture verification task and a syllogism solving task and how these tasks are affected by dyslexia.

Chapter 4 compares the performance of participants with dyslexia and people without dyslexia after being taught a rule-based strategy for solving syllogisms. The strategy was based on the algorithm from Stenning and Yule (1998). It was expected that reasoners who would naturally process syllogisms primarily in a spatial or visual manner would likely experience difficulty when expected to work through a specified series of verbal or rule-based steps to reason out a conclusion.

Chapter 5 compares the performance of people with dyslexia and people without dyslexia after learning to solve syllogisms using a spatial strategy, more specifically a method based on Euler Circles. The hypothesis of this study was that if people with dyslexia are predominantly spatial reasoners (Bacon & Handley, 2010) they would perform better on problems that are easiest for spatial reasoners than on problems that are easiest for verbal reasoners.

Chapter 6 observes the use of eye tracking to ascertain the focus of attention of reasoners while solving syllogisms, and to identify if the pattern of eye movements was influenced more by the level of difficulty or the figure of the syllogism. It examines the different patterns of attentional focus/information processing according to problems that are solved with a spatial versus a verbal strategy. Each syllogism was separated into eight areas of interest, one for each of the quantifiers and terms in each premise. Treating each quantifier and term as a separate area of interest made it possible to track which part of the premise attention was allocated to at any point during the experimental trials.

Chapter 7 provides a summary and conclusion of my thesis, shows how my work has added to the existing body of knowledge about reasoning strategies and how they are impacted by dyslexia. I also suggest ways to progress future studies on the topic.

CHAPTER 2: DYSLEXIA

2.1. What is dyslexia?

The International Dyslexia Association defines dyslexia as "one of several distinct learning disabilities. It is a specific language-based disorder of constitutional origin characterised by difficulties in single word coding, usually reflecting insufficient phonological processing abilities. It is manifested by a variable difficulty with different forms of language, including, in addition to a problem with reading, a conspicuous problem with acquiring proficiency in writing and spelling" (Snowling, 2000).

Dyslexia affects around 5-10% of the population. It is generally associated with reading and spelling difficulties, poor short-term memory, poor concentration, poor performance in recalling the visual image of a word, the sequence of letters in spelling, or numbers and signs in maths, poor motor integration, directional confusion, and problems with sequencing and organisation. People with dyslexia have difficulty with tasks that require short-term memory processing such as mental arithmetic, writing and learning new information (Ramus & Szenkovits, 2008; Snowling, 2000). It has become widely accepted that dyslexia is the consequence of a phonological deficit, the way the brain codes or 'represents' the spoken attributes of words (Snowling, 2000). One of the main characteristics of phonological deficit is phonological awareness which is the ability to consciously access and manipulate phonological representations of words (Ramus, Rosen, Dakin, Day, Castellote, White & Frith, 2003; Wagner and Torgesen, 1987). Ramus and Szenkovits (2008) suggest that the phonological deficit surfaces only as a function of certain task requirements, in particular short-term memory, conscious awareness, and time constraints.

This chapter describes the theoretical background to dyslexia. It reviews learning styles and metacognition of people with dyslexia, and how structure and presentation of teaching materials and classes impacts upon their educational experiences.

2.2. Theories of Dyslexia

2.2.1. Phonological Deficit Hypothesis

A phonological deficit is an impairment in the ability to access phonological representations of words. The phonological deficit hypothesis posits that developmental dyslexia is language-specific and is a manifestation of a disorder in the speech processing system (Frith, 1985; Snowling, 2000; Stanovich, 1988). Research suggests that phonological representations in people with dyslexia are degraded and not distinct enough (Mody, Studdert-Kennedy & Brady, 1997; Snowling, 2000), coarsely coded, under-specified or noisy (Elbro, 1996; Hulme & Snowling, 1992). Wagner and Torgesen (1987) cite three main characteristics of phonological deficit:

a) Poor phonological awareness which involves conscious access, attention to and manipulation of phonological representations and their sub-units. This can be detected through phoneme deletion tasks.
b) Poor verbal short term memory, which involves the storage of words for a short period of time in phonological buffers or cycling them through the phonological loop during processing. This can be detected through digit span or non-word repetition tasks.

c) Slow lexical retrieval, which involves the retrieval of lexical phonological representations from long term memory. This can be detected through rapid automatic naming tasks.

To gain a better understanding of the phonological deficit in dyslexia, Szenkovits and Ramus (2005) used words and nonwords to examine lexical and sublexical representations in university students with and without dyslexia. Their study consisted of six experiments with two experimental tasks, repetition and auditory comparison, as well as a control auditory comparison task. The stimuli were either words that required lexical and sublexical representations or nonwords that required only sublexical representations. The control auditory suppression task was articulatory suppression which was used to prevent participants from explicitly rehearsing the words or nonwords while performing the experimental tasks.

In experiments 1 and 2, participants were required to repeat each sequence of words or nonwords that ranged in length from 3 to 8 words as accurately as possible in the correct order. The words were presented in four sequences per block for a total of 8 blocks. In experiments 3 and 4, participants were required to listen to two sequences of nonwords presented by a male and a female speaker. Each sequence was separated by one second of unintelligible babble designed to prevent participants from relying on echoic memory and to encode the stimuli at the phonological representational level. The sequences that ranged in length from 3 to 8 words were presented in 12 blocks per trial, half were the same (included two identical sequences) and half were different (included sequences that differed by one minimal pair of words or nonwords). Participants had to decide whether the sequences were the same or different. Experiments 5 and 6 were exactly the same as experiments 3 and 4, but with the added articulatory suppression task of having to say a sequence of nonsense syllables, bababa, while deciding whether the sequences were the same or different. Articulatory suppression ensured that there was no involvement by the phonological loop.

The results revealed significant differences between dyslexic and control groups in all conditions, suggesting the phonological deficit appears regardless of the level (lexical or sublexical) or type (input or output) of representation and whether, or not, articulatory suppression was used. Participants with dyslexia were relatively more impaired in discrimination than in repetition tasks. Articulatory suppression slightly decreased overall performance in both groups. Ramus and Szenkovits (2008) suggest the reason people with dyslexia perform poorly under memory load is because phonological representations are degraded, and some phonetic features are missing when they need to be repeated or discriminated; or the representations are intact but there is not enough capacity in their short term memory to carry out the tasks.

Ramus and Szenkovits (2008) conducted further tests to check for a phonological similarity effect, an effect where the more similar the words the more difficult they will be to recall (Baddeley, 1984). Their hypothesis was that if the phonological representations of people with dyslexia are degraded then they should show a greater similarity effect than for people without dyslexia. There were two conditions, minimal and maximal, with sequences made up of two to seven nonwords. The minimal condition consisted of sequences that were either identical or differed by one phonetic feature such as taz – ta ʒ. The maximal condition consisted of sequences that differed by three phonemes, such as taz – gum, and a few phonetic features. To ensure the sequences were encoded phonetically rather than acoustically they were spoken by two different voices which alternated constantly within the sequences and in opposite orders between sequences.

The results showed a phonological similarity effect where performance was poorer in the minimal condition than in the maximal condition, and that participants with dyslexia performed more poorly than those without dyslexia. When phonological similarity was reduced the performance of the participants with dyslexia increased by the same amount as the performance of participants without dyslexia. These results did not support the hypothesis that a phonological deficit was the result of degraded representations, but rather that a phonological deficit may be associated with the short term memory processes operating on phonological representations, such as the input and/or phonological buffers or the phonological loop between input and output sublexical representations (Ramus & Szenkovits, 2008). Some researchers make the claim that deficits in processing depend on the type of task rather than a specific stimulus (Amitay, Ben-Yehudah, Banai & Ahissar, 2002; Banai & Ahissar, 2006; Ben-Yehudah, Sackett, Malchi-Ginzberg & Ahissar, 2001) or may be an inability to form a ‘perceptual anchor’ (Ahissar, Lubin, Putter-Katz & Banai, 2006).

Banai and Ahissar (2006) examined the notion that deficits in processing depend on the type of task rather than a specific stimulus with a frequency discrimination and speech perception study with children with an average age of 14 years. The frequency discrimination study required the participants to discriminate between tones across three conditions. The frequency of the test tone was always higher than the others and was always changed in a 2 down/1 up staircase procedure (step size was 40 Hz for the first 5 reversals and 5 Hz thereafter) converging at a performance level of 70.7% (Levitt 1971). The frequency of the reference tone was fixed at 1000Hz. The participants were required to tell the researchers their answers to reduce the possibility of sensory-motor confusion. The conditions were:

- High-low discrimination: Two 50-ms tones with 1000-ms interstimulus interval (ISI) were presented in each trial. The participants were required to indicate which tone was higher.
- Same-different discrimination with two tones: Two 50-ms tones (with 1000-ms ISI) were presented in each trial. The participants were required to indicate whether the tones were the same or different. Same and different trials had an equal probability of appearance.
- Same-different discrimination with three tones: A fixed reference tone was followed by a 1500-ms silent interval and then by two other tones (with 950-ms interval between them), one of which was a repetition of the reference and the other was different. Participants had to indicate which tone was the same as the reference tone.

The speech perception study required participants to discriminate minimal phonemic pairs. They were presented with 24 pairs of 2-syllable pseudowords that differed by one consonant. The consonant pairs used were d-t, b-d, b-p, v-f, m-n, and s-z and they appeared either at the beginning or at the end of the word. Only the vowels a, e, i and u were used. All stimuli were spoken by a native female Hebrew speaker. There were two conditions:

- Same-different with two words: Participants heard 24 different pairs and 24 same pairs and they were required to state if the pairs were the same or different.
- Same-different with three words: Participants first heard a pair of pseudowords. After a 2-s interval, one of the pseudowords was repeated, and the task was to indicate which word from the first pair had been repeated. Each pair was repeated twice, each time with a different repeated word.

The results of both studies revealed that participants with dyslexia were able to discern mild frequency changes in simple pure tones and minimal phonemic changes in complex speech sounds when task required only simple same or different discriminations. However, performance was significantly reduced when they were required to determine the direction of frequency change or the ordinal position of a repeated tonal or speech stimulus. The results suggest that the deficits occur whether processing speech or nonspeech sounds and the level of difficulty is a function the structure of the task rather than by stimulus composition or complexity (Banai & Ahissar, 2006).

Perceptual anchoring is the process of forming a connection between the characteristics of one stimulus relative to another one (Ahissar, 2007; Banai & Ahissar, 2006). Perceptual anchor theorists (Ahissar, 2007; Ahissar, Lubin, Putter-Katz & Banai, 2006; Banai & Ahissar, 2006) suggest that people with dyslexia are less efficient at forming perceptual anchors due to limited working memory capacity. Ahissar, Lubin, Putter-Katz and Banai (2006) examined this concept in a two-part study using simple tones and speech sounds. The first part of the study was frequency discrimination and speech perception consisting of two tasks in which participants were asked which of two sequentially presented tones had the higher pitch. There were two conditions: a standard one where participants were presented with a standard tone (1,000 Hz) in each trial as well as another tone that was always higher. They had to judge which tone was higher. The standard condition facilitated the gradual formation of a perceptual anchor based on the repeated standard tone; and a no-standard one where participants were presented with pairs of tones, none of which were standard. This required them to actively listen and compare the tones to determine which was the higher one. The no-standard condition was dependent on manipulation of the representations involving high-level 'executive' working memory operations.

Ahissar et al. (2006) hypothesised that performance of participants with dyslexia would be impaired in both conditions but the no-standard condition would be more difficult if they were impaired in their ability to manipulate the representations. The results revealed that the performance of participants with dyslexia on the standard task was very poor. However, their performance in the no-standard task did not differ from that of the participants without dyslexia. This finding suggests that the difficulty may lie in the process of switching from observing the different tones to recalling them from memory for comparison.

The same participants were tested in the second part of the study on speech perception in quiet and in noise. The experimental trials consisted of a small stimulus set (a subset of ten pseudo-words chosen from a larger set). Participants were asked to repeat the pseudoword that they barely heard, then the experimenter pressed the 'right' or 'wrong' key so that the intensity of the next pseudoword adapted to the participant's performance. Participants with dyslexia showed difficulties both in tone and in speech perception only when a limited set of stimuli was used repetitively. The degree of this failure to form perceptual anchors correlated with the degree of their difficulties in phonological and working memory tasks, suggesting that attentional (Hari & Renvall, 2001) and working memory (Swanson, 1993) impairments in people with dyslexia may manifest from the same core deficit.

Di Filippo, Zoccolotti, and Ziegler (2008) contend that the perceptual anchor theory does not account fully for a phonological deficit in dyslexia. They compared the rapid naming of objects and numbers in a small set of five repeated items with a large set of 50 non-repeated items. One of the post popular measures of naming speed is the Rapid Automatized Naming (RAN) test in which a series of high frequency letters, numbers, colours or objects are presented to participants in random order. The perceptual anchor theory claims there should not be a deficit with the large non-repeated set of items (Ahissar, 2007), while the phonological deficit theory claims there should be comparable deficits in both conditions (Di Filippo et al., 2008). The results revealed significant deficits in RAN for non-repeated sets of numbers and objects, with the deficit being bigger for the large-set condition than for the small-set condition.

2.2.2. Double Deficit Hypothesis

The Double Deficit Hypothesis posits that phonological awareness and naming speed are both important for reading skills and a lack of both these elements can have a detrimental effect on the reader (Wolf & Bowers, 1999; Wolf, Bowers & Biddle, 2000). Phonological awareness is the ability to understand words from the sounds that make up those words. Naming speed is the ability to retrieve and label an array of items presented sequentially, for example letters, numbers, colours and objects. Research has shown that children with deficits in phonological awareness as well as naming speed score lower on reading tasks than those that are deficient in only one of them (Lovett, Steinbach & Fritters, 2000; Wolf &Bowers, 1999; Wolf, Bowers & Biddle, 2000). It has been further suggested that the processes involved in phonological analysis, rapid naming and working memory work together but on different functions under the umbrella of phonological ability (Torgensen, Wagner, Rashotte, Burgess & Hecht, 1997; Wagner, Torgensen & Rashotte, 1994).

RAN incorporates attentional, visual, lexical, temporal and recognition subprocesses which are all necessary for reading (Wolf et al., 2000). Performance is measured by the time taken to provide a label for the items. Participants taking longer than average (generally one standard deviation below the mean) are judged to have a naming speed deficiency (Wolf and Bowers, 1999; Kail, Hall, & Caskey, 1999), suggesting that poor performance on the RAN is linked to poor reading skills.

Cirino, Israelian, Morris, and Morris (2005) evaluated the Double Deficit Hypothesis (DDH) in college students who had been referred for learning difficulties. In particular, they measured the impact of phonological awareness (PA) and visual naming speed (VNS) on reading performance. When PA and VNS were examined individually, the results showed that, while both PA and VNS influence reading skills, VNS did not predict performance in untimed reading comprehension. Cirino et al. (2005) suggest the possibility that when time pressures are not involved there is less demand for holding syntax and context in memory, particularly for college students who have encountered significantly more reading expectations in the course of their educational experiences.

When examined together, the results showed the impact of PA and VNS differed depending on the nature of the stimulus and the task. PA was a stronger predictor than VNS for untimed decoding for both real words and nonwords.

Interestingly, studies of children show PA and VNS to be equivalent for untimed reading of real words (Wolf, Goldberg O'Rourke, Gidney, Lovett, Cirino & Morris, 2002). Cirino et al. (2005) also found that in timed decoding PA and VNS were similar for nonwords, but VNS had a greater impact on real words.

With regards to reading comprehension and consistent with the study of children (Cornwall, 1992), PA had a greater impact than VNS in the untimed condition. In contrast, other studies found VNS to have a significant impact on reading skills (Compton, De Fries & Olson, 2001; Wolf et al., 2002). Cirino et al. (2005) suggest that VNS may not be overly difficult for college students when they are not limited by time, as they would have developed vocabulary and general educational skills for this academic level. College students with dyslexia are likely to have developed coping strategies throughout their educational career to better aid them in the demands of their studies so may not be affected in the same way as their younger counterparts.

PA and VNS demonstrated similar capability for predicting performance in timed reading comprehension. However, the impact of VNS increases when there are greater demands on reading time. This is particularly relevant for college students who are required to do a lot of reading in limited time to meet the demands of their courses.

Comparing the performances of the double-deficit subgroup with the single-deficit and no-deficit subgroups of PA and VNS, the double-deficit group demonstrated the lowest overall performance in all reading conditions. Looking at the pattern of cognitive processing against traditional methods of diagnosing reading difficulties, there were a greater number of double-deficit people relative to the single-deficit and no-deficit groups, suggesting that adults with an impairment are highly likely to have co-existing deficits in PA and VNS in untimed decoding and reading comprehension. The categorisation of double-deficit hypothesis was not significant in predicting whether reading difficulty criteria would be met for timed decoding and reading comprehension. These results suggest there is more at play when time constraints are involved.

2.2.3. Automatisation

Automatisation is the process of learning to do something and then practicing it until it becomes automatic. Anderson (1982) states there are two stages in the process of acquiring a new skill. First is the process of gathering the necessary information required to perform the skill. This is followed by practice of the skill until it sets in memory and becomes automatic. For example, a person learning to drive a manual car may start off paying close attention to when they need to change gears, looking at the gear stick to ensure the correct gear has been selected and consciously thinking about pressing and releasing the clutch pedal in tandem with the accelerator. After some practice, the task eventually becomes second nature and they change up and down with near perfect efficiency throughout their motor journeys.

According to Shiffrin and Schneider (1977), "automatic processing is well learnt in long term memory, is demanding of attention only when a target is presented, is parallel in nature, is difficult to alter, to ignore or suppress once learned, and is virtually unaffected by load". The Dyslexia Automatisation Deficit Hypothesis (DAD) posits that children with dyslexia have difficulty in automatising skills (Nicolson & Fawcett, 1990) and many are able to 'hide' this deficit with conscious compensation. Conscious compensation is the process of expending greater effort towards concentration and the performance of actions that are usually automatic. The outcome appears normal but is the result of harder work than is necessary. It has been further suggested that DAD can account for difficulties experienced by people with dyslexia under dual task conditions (Nicolson & Fawcett, 1990; Yap & Van der Leik, 1994) because if the first task is not performed automatically then there are not enough cognitive resources available to perform the second task. Hazell, Carr, Lewin, Dewis, Heathcote, and Brucki (1999) state that some processes, such as encoding of temporal or spatial relationships, frequency monitoring, and the activation of word meaning, may be pre-programmed or innate, while others such as riding a bicycle, become automatic with practice, and suggest that a deficiency in the pre-programmes or innate automatic processing may have some responsibility for DAD.

Nicholson and Fawcett (1990) used a dual-task paradigm to compare motor balance of children with dyslexia and children without dyslexia. The primary task required the children to balance on a beam in one of five different conditions with their arms outstretched: balance on a beam on both feet for one minute, balance on their left foot only for 30 seconds, balance on their right foot only for 30 seconds, walk up and down the beam five times whilst allowed to look at their feet, and walk up and down the beam five times but with the requirement to look straight ahead. The secondary tasks were a) counting backwards and b) auditory choice reaction to computer generated tones. A computer generated a high or low tone once every two seconds and the participants had to press the left button when they heard a high tone and the right button when they heard a low tone. The auditory choice reaction task did not require any phonological processing. The children were required to perform the primary task twice, once as a single task and once while performing the secondary task as well.

Results of the first study using the primary task and the secondary task of counting backwards revealed no significant difference in performance of the primary task only condition between children with dyslexia and children without dyslexia. However, under the dual task condition, the children with dyslexia were significantly impaired in performance of the primary task. 16 out of the 23 children with dyslexia were unable to maintain balance while counting backwards. In addition, the children with dyslexia showed a decrease in accuracy in counting backwards. The results suggest that poor performance in the dual task condition by the children with dyslexia may indeed be due to the fact that they expended more effort in concentrating on the secondary task, in effect engaging in conscious compensation for the balancing which they cannot do when performing the secondary task of counting backwards.

Results of the second study using the primary task and the secondary task of auditory choice reaction revealed no significant difference in performance of the primary task only between children with dyslexia and children without dyslexia. For the dual task condition, significant impairment on the secondary task was found only for the children with dyslexia in the beam walking trials, again suggesting that they may be engaging in conscious compensation.

Nicholson and Fawcett (1990) note that the impairment in the auditory choice reaction was less marked than for the counting backwards task. However, while calibration was done to ensure the tones were of a similar level of difficulty for all participants, there is no mention in the study that the children could all easily identify the difference between their left and right. A participant could have performed poorly because they simply did not know the difference between left and right rather than not being able to tell the difference between the tones they heard.

Automatisation is a very important skill in reading and writing (Fawcett & Nicolson, 1999) and the better the reader is at automatisation of each of the sub-skills involved in fluent reading, the lower the cognitive load and therefore the higher the processing speed. A deficit in one of the sub-skills required for reading can lead to poorer overall reading ability (Hunt, 1978). Research suggests that spatial attention (Facoetti, Paganoni & Lorusso, 2000) and central attention (Moores, Nicolson & Fawcett, 2003) may be problematic for people with dyslexia because reading requires the constant switching of attention between words on the page (Moores, Nicolson and Fawcett, 2003). Central attention helps to determine cognitive processes, representations, and behaviours for tasks at hand (Tamber-Rosenau & Marois, 2016). Brannan and Williams (1987) found differences between adults and children with good or poor reading skills on Posner's spatial cueing task, but only when attention needs to be shifted rapidly. It is possible that people with dyslexia process information at a normal pace once attention has been allocated to the task in question, but that the allocation takes longer than usual (Moores et al., 2003).

Moores, Nicolson and Fawcett (2003) examined the role of attention deficits in automatisation in teenagers with and without dyslexia across two studies. The first study examined whether teenagers had deficits in one of the three main elements of selective attention: a) selective or focus attention on a specific stimulus, b) shifting attention rapidly from one stimulus to another, and c) sustaining attention over a period of time. There were assigned three conditions:

1. Focus (target - white ovals)
2. Shift (target - white ovals and blue squares alternately)
3. Focus 2 (target – dark blue squares).

The stimuli were presented in the same order for all conditions but with four different interstimulus intervals. Shapes were presented one at a time at a mean rate of just over one per second. Target shapes were presented less frequently than distractor shapes. Participants were required to ignore non-targets and respond to a specific target by clicking a button. In focus conditions the target stayed the same. In the shift condition, the target alternated between the white ovals and dark blue squares. If the target was missed it stayed the same. Responses were recorded as hits if they came within 1000ms of the target and were acknowledged as such by a short tone.

The results revealed no significant difference between participants with dyslexia and participants without dyslexia in speed or accuracy in the focus attention task. Participants with dyslexia performed significantly worse than participants without dyslexia in speed and accuracy in the shifting attention task. The shifting attention task required more cognitive resources to complete because the target had to be kept in memory while the participant continued to perform the focus task. Therefore, it is necessary for parts of the focus task to be automatised leaving enough available resources to follow through on the shifting attention task.

To this end, Moores et al. (2003) conducted a second study to examine automaticity of shape recognition in dyslexia, again using teenage participants. There were four conditions:

1. Focus normal (target – triangles)
2. Shift normal (target – alternating triangles and circles)
3. Focus degraded (target – squares)
4. Shift degraded (target - alternating squares and diamonds)

All the stimuli were the same colour to avoid recognition by colour alone. In all conditions, focus was always performed first to control for practice and fatigue effects. As with study one, the shift stimuli were presented more frequently than the focus stimuli and participants were required to ignore non-targets and respond to a specific target by clicking a button.

The hypotheses at play were: a) task performance will suffer a qualitative change from automatic to controlled or when the resources ceiling is reached, otherwise it will decrease linearly with task difficulty, b) degraded stimuli are processed in a less automatic way by both dyslexic and non-dyslexic participants, and c) DAD predicts a marked decrement for controls but not dyslexics as dyslexics are already processing stimuli non-automatically. GRD (general resource deficit) predicts greater deficit for dyslexics since they are already close to their ceiling.

Results showed that the participants without dyslexia were disproportionately affected by the visual degradation of the stimuli while the participants with dyslexia were relatively unaffected. This suggests they were performing the shape recognition task non-automatically even with intact stimuli. Degraded stimuli require more attentional capacity to process so use more resources and prevent shape recognition occurring automatically. These findings are consistent with hypothesised existence of an automatisation deficit in children with dyslexia.

The shift condition requires the target to be kept in memory and it has to be changed after each correct hit. Changing the target was not problematic as the dyslexic group performed similarly to the non-dyslexic group. The problem is in having to maintain the target in memory while performing the focus task.

The Dyslexia Automatisation Deficit Hypothesis (DAD) asserts that people with dyslexia have difficulty in automatising skills (Nicolson & Fawcett, 1990) and this can account for difficulties experienced by people with dyslexia under dual task conditions (Nicolson & Fawcett, 1990; Yap & Van der Leik, 1994) because if the first task is not performed automatically then there are not enough cognitive resources available to perform the second task.

It has been suggested that a dysfunctional cerebellum is associated with dyslexia (Ramus, Rosen, Dakin, Day, Callote, White & Frith, 2003; Nicolson & Fawcett, 1990, 2007). The cerebellar deficit hypothesis states that the cerebellum is active during early stages of skill learning, but less active when the skill becomes automatized (Nicolson & Fawcett, 1990) and this cerebellar dysfunction is the neural implementation of the DAD.

Research has shown that people with dyslexia have some motor learning difficulties, such as balancing (Fawcett & Nicolson, 1999), rapid pointing and peg moving (Stoodley, Fawcett, Nicolson and Stein, 2006). Behavioural and neuroimaging tests indicate dyslexia is associated with cerebellar impairment in about 80% of cases (Nicolson, Fawcett & Dean, 2001). Some researchers feel that difficulties in automatisation are linked to the cerebellum (Ito, 1984; Stein & Glickstein, 1992), particularly as a high percentage of children diagnosed with dyslexia show behavioural evidence of abnormal cerebellar function in areas such as skill automatisation, time estimation, balance and dystonia (Nicolson et al., 2001).

The cerebellum is involved in the learning and automatisation of motor skills (Ito, 1984; Jenkins, Brooks, Nixon, Frackowiak and Passingham, 1994; Krupa, Thompson and Thompson, 1993) and overlearned tasks such as driving and reading (Nicolson et al., 2001). Research has also shown that the cerebellum plays an important role in language (Ackermann & Hertrich, 2000; Fabbro, Moretti & Bava, 2000; Silveri & Misciagna, 2000) and reading (Fulbright, Jenner, Mencl, Pugh, Shaywitz, Shaywitz, Frost Skudlarski, Constable, Lacadie, Marchine & Gore (1999).

Nicolson and Fawcett (1999) measured brain activity in adults with dyslexia while performing a finger exercise. Participants were required to carry out a sequence of finger movements with their right hand while their eyes were closed. There were two conditions, one that was highly overlearned and one that was newly learned. Participants with dyslexia showed greater activation in the frontal and pre-frontal areas of the brain during the task of learning the new sequence. Participants without dyslexia showed greater activation during both tasks.

Ramus, Pidgeon and Frith (2003), on the other hand, found that only a small proportion of people with dyslexia have motor problems, thereby suggesting that cerebellar problems may be associated with factors arising from other developmental disorders such as ADHD. Similarly, Irannejad and Savage (2012) found that cerebellar tests did not successfully differentiate between participants with and without dyslexia. In addition to ADHD, balance deficits can be accounted for by other factors such developmental coordination disorder (Rochelle and Talcott, 2006).

Kasselimis, Margarity and Vlachos (2008) examined the performance of children in cerebellar and cognitive tasks associated with dyslexia. Children with ADHD were included to examine the claim by Ramus et al. (2003). The participants in their study were made up of three types of children: 10 with dyslexia, 10 without dyslexia and 10 with ADHD. They underwent a series of test in three categories: cerebellar tests, cognitive tests and an articulation speed test.

The cerebellar tests were:

- Balance time: Participants were blindfolded and asked to stand up straight, with their feet together and their arms stretched forward. The score was the time required for them to make their first sway off balance.

- Weight time: Participants were blindfolded and asked to stand up straight, with their feet together and their arms stretched forward, while holding the neck of two bottles containing 1 litre of water each. They were asked to hold their arms outstretched for as long as possible. The score was the time until their arms fell by at least 20 degrees.
- Hand declination: Participants were asked to sit down with their elbows on the desk, so their wrists were at the same level with their shoulders and allow their hands to flop as if they were paralyzed. The angle between the forearm and the top of the hand was measured with a protractor. The score was the difference between the measures of the two hands.
- Kicking speed: Participants were asked to stand up straight with their feet together towards a firm vertical surface. Then they were asked to kick the surface as fast as possible, letting the sole of their feet touch the floor after each kick. The sound and speed of the kicks were recorded. The score was the time interval between the second and the twelfth kick.
- Past pointing: A bullseye target was stuck on the wall at eye level. Participants were shown how to point repeatedly to the bull's eye using a marker. They were then blindfolded and were required to perform 10 trials. A score was fixed for each annulus of the target, ranging from 0 for the trials that fell out of it to 10 for the bullseye.

The cognitive tests were:

- Word naming processing time speed: Participants were required to read aloud 12 single words, presented individually, as fast as possible. The score was the mean time required to read all the words.

- Picture naming processing time speed: Participants were required to name 12 single pictures, presented individually, as fast as possible. The pictures corresponded to the words used in the word naming processing time speed task. The score was the mean time required to name all the pictures.
- Verbal short-term memory test: Participants were required to repeat a sequence of words uttered by the experimenter with an approximate rate of 1 word/2 sec. The test was divided into six levels of difficulty according to the number of words to recall. Each level had three conditions of complexity in terms of morphology. The test was discontinued after failure in all three conditions of a level. The score was the number of conditions (word strings) that were correctly recalled.
- Nonword repetition: Participants were required to repeat 20 single nonwords spoken by the experimenter. The nonwords were divided into 4 subgroups: two-, three-, four-, and five-syllable nonwords, generated from real words by changing one or two consonants. The score was calculated by summing the number of correctly repeated nonwords.
- Nonword rhyme judgment: Participants were presented with 20 pairs of nonwords typed on a piece of paper. The nonwords were created in the same manner as the nonword repetition task. Participant were given 90 seconds to underline the paired nonwords that rhymed (a total of 10 pairs). The score was the number of correctly underlined pairs.

The articulation speed test:

Participants were required to say out loud the days of the week, then the 12 months, and, then the Greek national anthem twice (The study was conducted in

Greece). The word-strings were chosen because they are overlearned sequences that require minimum effort for recall. Four scores were generated: the time to say the seven days of the week, the 12 months of the year, the Greek national anthem twice, and the total time required for all three of the word-strings.

The results revealed that, for the cognitive tasks, participants with dyslexia performed significantly worse than those without dyslexia and those with ADHD on the word naming, time speed and non-word tasks. There were no significant differences for the rest of the cognitive tasks. With regard to the cerebellar tasks, contrary to other studies that found an impairment in several cerebellar tasks (Fawcett & Nicolson, 1999; Fawcett, Nicolson & Dean, 1996), the participants with dyslexia showed significant impairment only in the balance time task in comparison to those without dyslexia. The participants with ADHD performed similarly to those without dyslexia on the cerebellar tests, suggesting that cerebellar deficits may not share comorbidity with ADHD (Ramus et al., 2003). The results also showed that participants with dyslexia demonstrated slower articulation speed than those without dyslexia and those with ADHD. Further analysis of the data revealed articulation speed to be positively correlated with verbal short-term memory and nonword repetition. The results of the study partially support the notion of cerebellar deficit hypothesis, as well as suggesting that slower articulation speed can be used as an indicator of dyslexia.

Van Oers, Goldberg, Fiorin, Van den Heuvel, Kapelle, and Wijnen (2018) investigated cerebellar involvement in dyslexia in young adults to determine if they showed impaired performance on tasks that rely on cerebellar involvement and if this was associated with reduced reading performance. Participants were Dutch university students, 26 with dyslexia and 25 without dyslexia. Cerebellar tests involved bead threading and time discrimination. The bead threading task required participants to thread 15 beads as fast as possible with their left hand while holding the string in their right hand (left-handed participants were not used). The time discrimination task was used to test non-motor cerebral function. Participants were presented with pairs of tones and asked to judge if the second was shorter or longer than the first one. The first tone in each pair was 1200 ms long with a frequency of 392 Hz. The comparison tones were of longer (1220, 1240, 1260, 1300, 1350, 1400, 1450, 1500, 1600, 1700, or 2000 ms) or shorter duration (1180, 1160, 1140, 1100, 1050, 1000, 950, 900, 850, 800, 700, or 400 ms) but identical in frequency.

Results showed the participants with dyslexia had impaired performance on the bead threading and time discrimination tasks. Those with worse cerebellar performance did not show larger literacy impairment. There is no clear support for a causal relationship between cerebellar function and reading skills.

In summary, automatisation is the process of learning to do something and then practicing it until it becomes automatic. It is very important for reading and writing (Fawcett & Nicolson, 1999) and the better the reader is at automatisation of each of the sub-skills involved in fluent reading, the lower the cognitive load and therefore the higher the processing speed. Spatial attention (Facoetti, Paganoni & Lorusso, 2000) and central attention (Moores, Nicolson & Fawcett, 2003) may also be problematic for people with dyslexia because reading requires the constant switching of attention between words on the page (Moores, Nicolson and Fawcett, 2003). It is possible that people with dyslexia process information at a normal pace once attention has been allocated to the task in question, but that the allocation takes longer than usual (Brannan & Williams, 1987; Moores et al., 2003). The Dyslexia Automatisation Deficit Hypothesis (DAD) posits that people with dyslexia have difficulty in automatising skills (Nicolson & Fawcett, 1990) and this can account for difficulties experienced under dual task conditions (Nicolson & Fawcett, 1990; Yap & Van der Leik, 1994) because if the first task is not performed automatically then there are not enough cognitive resources available to perform the second task.

To further summarise, it has been suggested that a dysfunctional cerebellum is associated with dyslexia (Ramus et al., 2003; Nicolson & Fawcett, 1990, 2007). The cerebellum plays an important role in language (Ackermann & Hertrich, 2000; Fabbro, Moretti & Bava, 2000; Silveri & Misciagna, 2000) and reading (Fulbright et al., (1999) and is involved in the learning and automatisation of motor skills (Ito, 1984; Jenkins et al., 1994; Krupa et al., 1993) and tasks such as driving and reading (Nicolson et al., 2001). The cerebellar deficit hypothesis states that the cerebellum is active during early stages of skill learning, but less active when the skill becomes automatized (Nicolson & Fawcett, 1990) and it is this cerebellar dysfunction that is responsible for reduced skill automatization in people with dyslexia. Cognitive load impacts on working memory, thereby creating the potential for affecting automatisation by the impairment of memory rehearsal processes. different proportions.

2.2.4. Magnocellular Deficit Hypothesis

The magnocellular deficit hypothesis says that people with dyslexia have a deficit in the magnocellular pathway while at the same time have a normal functioning parvocellular pathway (Stein & Talcott, 1999). Research suggests that a magnocellular deficit may influence reading ability through abnormal saccadic suppression processes (Breitmeyer & Ganz, 1976), impairments in binocular fixation and rapid eye movements (Stein & Talcott, 1999) or as a result of inferior processing of rapid auditory information (Tallal, 1980; Witton, Talcott, Hansen, Richardson, Griffiths, Rees & Green, 1998).

There are two major pathways in the visual system, magnocellular and parvocellular. The magnocellular system responds to low contrast and low spatial frequencies (Kaplan, Lee, & Shapely, 1990; Lee, Pokorny, Smith, Martin, & Valberg, 1990; Stein, 2001) and is sensitive to rapid changes in visual input (Nowak & Bullier, 1997; Schiller, Logothetis & Charles, 1990). The parvocellular system is sensitive to high spatial frequencies and changes in colour (Kaplan, Lee & Shapley, 1990; Kaplan & Shapley, 1986).

Magnocells are responsible for locating stimuli and tracking their movements (Stein, 2012). Research has shown that poor readers and people with dyslexia have deficits in the magnocellular system (Lovegrove, Martin & Slaghuis, 1986; McLean, Stuart, Coltheart & Castles, 2011; Stein, 2001). Readers briefly fixate each word between saccades at which time the fine details of the letters in a word can be processed (Stein, 2012). The magnocellular system helps to control eye movements and stabilize the eyes during each fixation. If the image unintentionally moves off the fovea, signals from the magnocellular system are used to bring the eyes back to the target. This sensitivity to visual motion may impact the development of orthographic skills.

Several studies have not supported the magnocellular deficit hypothesis (Amitay, Ben-Yehudah, Banai & Ahissar, 2002; McLean et al., 2011; Sayeur, Béland, Ellemberg, Perchet, McKerral, Lassonde & Lavoie, 2013; Skottun, 2000). Ramus, Rosen, Dakin, Day, Callote, White and Frith (2003) conducted a multiple case study to assess the three leading theories of dyslexia: phonological deficit theory, magnocellular theory and cerebellar theory and found evidence for phonological deficit in all participants with dyslexia, with a significant proportion also suffering from motor, visual and auditory disorders.

2.2.5. Memory and Dyslexia

Research suggests that there are deficits in short term working memory of people with dyslexia (Ackerman & Dykman, 1993; Brunswick, McCrory, Price, Frith & Frith, 1999; McDougall & Donohoe, 2002; Mcloughlin, Fitzgibbon & Young, 1994; Plaza, Cohen & Chevrie-Muller, 2002). Working memory is a system of several components that work together in the storage of information for manipulation in higher level processing (Baddeley & Hitch, 1974; Baddeley, 1996, 2000b). The central executive controls two slave systems in working memory, the phonological loop and the visuospatial sketchpad (Baddeley, 1986). The phonological loop is responsible for language-based material and the visuospatial sketchpad is responsible for visual and spatial information.

Research has shown that increased cognitive load can lead to deficits on both verbal and visuospatial working memory in people with reading disabilities (Swanson, Ashbaker & Lee, 1996), and suggests that visuospatial memory deficits in people with dyslexia come to the forefront only when the task at hand requires phonological processing (Gould & Glencross, 1990; Thomson, 1982). It has also been suggested that people with dyslexia are less efficient at forming perceptual anchors, a connection between the characteristics of one stimulus relative to another one, due to limited working memory capacity (Ahissar, 2007; Ahissar, Lubin, Putter-Katz & Banai, 2006; Banai & Ahissar, 2006). Smith-Spark, Fisk, Fawcett and Nicolson (2003) report evidence of verbal working memory impairments in people with dyslexia, while spatial memory appears to be largely unimpaired. Von Karolyi, Winner, Gray and Sherman (2003) found children with dyslexia were significantly faster to recognise impossible figures as being impossible than were children without dyslexia.

Smith-Spark et al. (2003) examined the role of the central executive in people with dyslexia, focusing on the phonological loop and visuospatial working memory. They conducted two experiments using university students with and without dyslexia. Experiment 1 examined the phonological loop, employing digit and word span short term memory tasks as well as a letter updating task. Participants were presented with auditory lists, previously used by Fisk and Warr (1996), for the digit and word span tasks. The lists started with two stimuli. The number of stimuli per list was increased to three if the participant was able to recall two or more of the two-stimuli lists successfully. The list size increased until the participant could no longer recall at least two of the three stimulus sets. The letter updating task consisted of lists of 6, 8, 10 and 12 consonants. Participants were required to recall the six most recent items. This task involved retaining the first six items in memory. If there were more than six items on the list, they had to drop that most recent item and replace it with the next item. This was to be repeated for each additional item for lists of more than six items. The last six items had to be recalled in the order of presentation. The items were presented one per second and there was no time limit for each list. The consonants were presented randomly, and no letter appeared more than once in the same list.

The results showed that participants with dyslexia performed more poorly than those without dyslexia on the digital span test, the word span test and the letter updating task. Overall performance on the letter updating task decreased as the number of letters increased for both groups of participants. With regards to serial position of the letters, there was better recall for the letters presented later in the sequence than for those presented earlier. Smith-Spark et al. (2003) suggest that poor performance at the early serial positions may be due to a failure of the articulatory control process. The articulatory control process circulates information in the phonological loop, refreshing the memory through subvocal rehearsal (Baddeley & Hitch, 1994). Therefore, the central executive may not be able to function adequately if the phonological loop is impaired at the outset (Smith-Spark et al., 2003).

Experiment 2 in Smith-Spark et al. (2003) examined the effects on performance of participants with dyslexia when the static-dynamic distinction in short term memory is made explicit. Static memory tasks require the short-term storage of information that is presented simultaneously within the visuospatial working memory. Dynamic memory tasks involve the recall of both location and order of stimuli presented sequentially. In the static condition, participants were presented with a 5x5 matrix and were required to recall the location of seven cells marked simultaneously with an ‘X’. In the dynamic condition, participants were presented with four cells highlighted sequentially in a 5x5 matrix and they were required to recall the location of each highlighted cell in the correct order. The updating condition was the same as the dynamic condition, except the highlighted cells varied between 4, 6, 8 and 10. Participants were required to update their memory when an additional cell was highlighted and recall the last 4 in each trial.

The results revealed no significant difference between participants with dyslexia and participants without dyslexia in their performance on the static, dynamic or updating tasks using spatial information. The complexity and serial position of pattern elements had a greater effect on performance for both types of participants, with recall of later items being better than for earlier items. There was a significant difference in recall between the dynamic and updating conditions with both types of participants being affected by the uncertainty associated with that condition in that there was no indication about the number of cells that would be highlighted in each trial.

Smith-Spark et al. (2003) posit that this lack of a difference is consistent with the phonological deficit hypothesis as the task is non-verbal. However, further analysis indicated that a significant difference becomes apparent as the task increases in difficulty. This effect which is brought on by an increased cognitive load can be explained by automatisation deficits in the central executive (Smith-Spark et al., 2003). Disruption and impairment in processing can occur when information has to be moved around the systems in the central executive. The ability to manipulate information may be hindered by an impaired phonological loop (Smith-Spark et al., 2003).

In summary, an increased cognitive load can lead to deficits on both verbal and visuospatial working memory in people with reading disabilities (Swanson, Ashbaker & Lee, 1996), and the visuospatial memory deficits in people with dyslexia come to the forefront only when the task at hand requires phonological processing (Gould & Glencross, 1990; Thomson, 1982) or when the level of difficulty increases (Smith-Spark et al., 2003) or when there is a need to form a perceptual anchor (Ahissar, 2007; Ahissar et al., 2006; Banai & Ahissar, 2006). The etiology of dyslexia is a complex combination of many factors, each seeming to affect individuals in different proportions.

2.3. Learning Styles and Metacognition

It cannot be assumed that all students with dyslexia experience reading and learning difficulties in the same way as students without dyslexia or even in the same way as each other. There is a huge range of preferred learning styles among all students (Drago & Wagner, 2004). Riding and Raynor (1998) suggested that there are two basic types of contrasting learning styles, verbal versus visual and holistic versus analytic. Verbal learners prefer to learn in by reading or listening, while visual learners prefer to learn with graphs, diagrams, or pictures (Kirby, Moore & Schofield, 1988). Holistic learners process information based on the whole picture while analytic learners build the whole picture from its smaller parts (Wittrock & Alesandrini, 1990). It has been suggested that different brain hemispheric processing patterns in people with dyslexia may indicate a preference for visuospatial strategies (Bakker, 1990; Everatt, Steffert & Smythe, 1999; Galaburda, 1993; West, 1997). Visuospatial processing is effective for a concrete word such as 'cat' but poses some difficulty for an abstract word such as 'is' (Mills, 2018). In an effort to form a representation of an abstract word, a visuospatial student may end up with a distortion or misrepresentation of the word (Kraus, 2012), resulting in the possibility of the student skipping the word and trying to understand the text by using any contextual cues that connect to a specific visual memory (Flink, 2014; Ramus, 2014; Kang, Lee, Park & Leem, 2016). Bacon and Handley (2010) demonstrated that people with dyslexia are more likely to use a spatial strategy when reasoning with syllogisms.

University students with dyslexia often experience difficulties such as taking lecture notes, writing essays, synthesising course materials for examination, or comprehending large quantities of text (Gilroy & Miles, 1996; Olofsson, Ahl & Taube, 2012; Mortimore & Crozier, 2007; Riddick, Farmer & Sterling, 1997; Simmons & Singleton, 2000). In comparison to students without dyslexia, students with dyslexia report significantly greater use of study aids and time management studies (Kirby, Silvestri, Allingham, Parrila, & La Fave, 2008) as well as reading summaries of recommended readings, looking for alternative and shorter texts and collaborating with classmates (Olofsson et al., 2012). This may be due to the fact that those who have reached post-secondary education are more likely to have developed or been taught strategies for coping with their difficulties, thereby resulting in a greater reliance on the use of study aids.

Students with dyslexia are more likely to report a deep approach to learning in comparison to university students without dyslexia (Kirby et al., 2008). A deep approach is described by Biggs, Kember and Leung (2001) as being motivated intrinsically to learn and attempting to comprehend underlying meanings of a learning task. Conversely, students with a surface approach to learning appear to be motivated by a fear of failure and thereby resort to the strategy of rote-learning (Biggs et al., 2001). Kirby et al. (2008) suggest that students with dyslexia would either have difficulty with using a deep approach because of their text processing difficulties or would adopt the deep approach to compensate for their lower level text processing difficulties. Evidently, different strategies are developed over time to cope with learning difficulties.

MacCullagh, Bosanquet and Badcock (2016) examined the learning experiences of university students with dyslexia and how they cope with them. The main issues that came to light were:

- Lectures: The students liked face to face lectures because of the ability to access visual, auditory and non-verbal cues simultaneously but found it difficult when they were longer than two hours. Recorded lectures were appreciated and often used in addition to face-to-face lectures. Some students found lecture slides difficult to follow and described strategies such as reading the lecture slides before class or just listening in class and ignoring the slides, and some felt it was helpful when the lecturer drew diagrams while verbally explaining the slides. Some students said they were unable to listen to the lecturer and write notes at the same time so just listened during the physical lecture and write notes later from the recorded lecture.

- Readings: Some students found it difficult to read long or complex journal articles and recommended readings. There was also difficulty in reading materials online. Approximately half of the students said they preferred to read printed than online copies, the main difficulties lying in glare and eye strain when reading online.
- Auditory and visual distractions: Some students said they needed a quiet space free of distractions for other study tasks such as watching recorded lectures and reading while others needed soft music, ambient noise or small group discussion in order to study effectively. Students reported choosing their seats very carefully in lecture theatres so as to reduce the level of distractions.
- Assessments/exams: Many students felt that assessments should be divided into more frequent, shorter, lower weighted tasks, as well as offering wider choice of assessment types such as individual conversations with a tutor, practical skills demonstrations and video assignments.

Everatt, Seffert and Smythe (1999) found that, while primary and secondary school children with dyslexia performed on a level with their peers without dyslexia on a test which involved making drawings from a number of different shapes (figural creativity), adults with dyslexia presented consistent evidence of greater creativity in tasks requiring novelty or insight and more innovative styles of thinking. This evidence suggests that children with dyslexia learn to use various coping strategies as they grow older. Miles (1993) presents observations of compensatory strategies used by people with dyslexia which seem very creative, such as the use of mnemonics. He cites an example of a boy called Jason who used his own name as a mnemonic to remember the middle months of the year – July, August, September, October, November (Miles, 1993).

Research has shown that people with dyslexia tend to conceptualise information in a visuospatial rather than a verbal way (Von Karolyi, 2001; Von Karolyi, Winner, Gray and Sherman, 2003) and may compensate for their difficulties with language with visuospatial talents (Galaburda, 1993; Miles, 1993). Enhanced visuospatial processing may be an important component of creative talents (Garrett, 1976; Katz, 1978). For instance, Von Karolyi et al. (2003) observed that individuals with dyslexia were able to recognise impossible figures more rapidly but no less accurately than those without dyslexia. Impossible figures are those that cannot exist in three-dimensional space, like an ambiguous illusion. Research has implied that people with dyslexia tend toward higher visuospatial processing (Von Karolyi & Winner, 2004). In detailed interviews with adults with dyslexia, Gerber, Ginsberg and Reiff (1992) found that discovering different and varying approaches to solving problems and creatively overcoming obstacles was one of the characteristics used earlier in life and more often by those who were deemed successful in their chosen careers (there is a high number of people with dyslexia in careers that use more creative skills). These types of learned strategies may prove useful in helping a person with dyslexia to overcome some of the problems associated with the learning difficulty.

Exley (2003) determined the preferred learning styles of seven 12 to 14- year old participants and taught them spelling and numeracy, targeting their strengths. The participants were taught in two single-sex groups for one or two lessons a week. All the participants improved their performance, with most of them demonstrating a preference for a visuospatial/kinaesthetic learning style, lending support to the theories of Stein (1995) and West (1997). This research shows that students with dyslexia can achieve academically as long as they receive adequate support for their learning.

Metacognition, which is an individual's awareness and understanding of their thought processes and a feeling of rightness (Ackerman & Thompson, 2017; Thompson, Prowse-Turner & Pennycook, 2011), can influence the level of confidence when performing a task and can affect the learning outcomes for students with dyslexia. A strong feeling of rightness creates a greater feeling of confidence (Thompson et al., 2013; Ackerman & Zalmanov, 2012; Thompson & Morsanyi, 2012). Research on metacognition has demonstrated that people can identify when they have made a mistake (De Neys, 2010, 2013). A poor feeling of rightness can be triggered by conflicting answers (Thompson & Johnson, 2014) and unfamiliar terms in the problems (Markovits, Thompson & Brisson, 2015). Furnes and Norman (2015) examined three forms of metacognition (knowledge, skills and experience) in students with dyslexia in a reading exercise for which the dependent variable was memory of the passages of text. Participants self-reported their metacognitive knowledge and skills, while their metacognitive experiences were assessed by predictions of performance and judgments of learning. The results showed that participants with dyslexia rated themselves lower in knowledge about reading strategies than participants without dyslexia, but no different to participants without dyslexia in their use of deep and surface learning strategies. The results suggest that people with dyslexia have metacognitive insight into their own difficulties with reading and that they are capable of adjusting their expectations in line with their skills.

2.4. Conclusion

A vast amount of research has been conducted around the causes and manifestations of dyslexia. The varying results suggest there is no single cause and every person with dyslexia is not affected in the same way. Giess, Rivers, Kennedy, & Lombardino (2012) note that evidence-based approaches that use multi-sensory techniques help to increase the learning opportunities for both verbal-linguistic and visual-spatial reasoners across all age groups and content areas.

Research has shown that increased cognitive load can lead to deficits in both verbal and visuospatial working memory in people with reading disabilities (Swanson, Ashbaker & Lee, 1996), and suggests that visuospatial memory deficits in people with dyslexia come to the forefront only when the task at hand requires phonological processing (Gould & Glencross, 1990; Thomson, 1982). Smith-Spark et al. (2003) demonstrated that an increased cognitive load can affect processing in the central executive. If disruption and impairment in processing can occur when information has to be moved around the systems in the central executive Smith-Spark et al., 2003), students with dyslexia are likely to spend more time and energy phonologically processing problematic words or trying to recognise a word within the context of familiar words than typical readers (Ramus, 2014; Shaywitz, 2005). The delay in phonological processing causes a decrease in retention in working memory of previously decoded words and if the words are remembered, the student is likely to process the meaning out of order, leading to improper comprehension (Mills, 2018).

While the key deficit in dyslexia is phonological, different combinations of causes will lead to individuals reasoning in different ways. The way study materials are presented, such as the type and size of the font, distance between letters, colours of words and background on lecture slides, can affect processing and comprehension in students with dyslexia. The Public Sector Bodies (Websites and Mobile Applications) (No. 2) Accessibility Regulations 2018 in the UK goes a long way to ensuring that online documents are user-friendly for people with disabilities, and work software that aids students with reading and visual disabilities. Work needs to be done to ensure that written documentation meets the needs of students with all types of reading and visual disabilities. The studies in this thesis seek to address the way people with dyslexia reason in comparison to people without dyslexia and how any differences can be considered in the development of teaching materials and intervention strategies.

CHAPTER 3: INDIVIDUAL DIFFERENCES IN REASONING STRATEGIES

3.1. Introduction

There is a large variety of procedures or strategies that people bring to every task they encounter. In many instances, the choice of strategy will be governed by the nature of the task at hand (Siegler, 1999; Dierckx & Vandierendonck, 2005). This begs the question of which strategy is likely to come to the forefront in any given situation and what determines which of all the possible ones will take precedence. This chapter discusses individual differences in reasoning strategies and then reports two experiments that compared the performance of people with dyslexia to people without dyslexia when solving categorical syllogisms, considering factors that may affect their performance.

Experiment 1 reports one study investigating individual differences in reasoning strategy, focusing on the differences between participants with dyslexia and participants without dyslexia. The participants were required to solve all 27 syllogisms with a valid conclusion (Johnson-Laird & Byrne, 1991). The syllogisms were separated into three categories based on level of difficulty for verbal and spatial reasoners (Ford, 1995): easiest for verbal reasoners (EV), easiest for spatial reasoners (ES), and equally difficult for both types of reasoners (HSV). The study also examined if the reasoning process was affected by the figure of the syllogism. The figure is the structure of the syllogism denoted by the placement of the middle term ‘B’ in relation to the major term ‘A’ in the first premise and the minor term ‘C’ in the second premise. The set of 27 syllogisms was also separated by figure: AB/BC, AB/CB, BA/BC and BA/CB. The aim of the study was to ascertain which strategies would be most prominent for the respective groups of participants and how this would be affected by the problem type or indeed the figure of the syllogism.

Experiment 2 reports two studies that observed the effect of belief bias in people with dyslexia compared to people without dyslexia. The first study is a sentence-picture verification task (Macleod, Hunt & Matthews, 1978) that assessed how participants with and without dyslexia represent and process linguistic structures. It is particularly important to understand how linguistic and spatial information is processed if we are to determine how people with dyslexia reason with syllogisms. More so, as some form of verbal coding into memory is required for the premises as well as the acceptance of dyslexia as phonological deficit (Snowling, 2000). The results suggested that participants with dyslexia tended more towards a visuospatial or pictorial strategy. If people with dyslexia tend to adopt a spatial strategy (Bacon et al., 2007) and conceptualise information in a visuospatial rather than verbal way (Von Karolyi et al., 2003), it was expected that they would demonstrate a slower processing speed for sentence comprehension than the cost for converting the sentences into pictorial representations. Some of the causes of poor reading skills have been attributed to shorter working memory span (Bowers & Wolf, 1993; Catts, Gillispie, Leonard, Kail, & Miller, 2002) and a slower processing speed (Breznitz, 2003, 2006), and these two factors affect the way visual information is translated into its phonological form by the phonological loop in working memory (Hulme & Snowling, 1992b; Palmer, 2000).

The second study is a syllogism solving task designed to examine the belief bias effect. Participants solved 24 syllogisms in three conditions: abstract (single letter terms), neutral (terms describing unrelated people or objects) and belief bias (terms describing people or objects that could be related in some way). If people with dyslexia tend to use a more spatial approach to problem solving and are hindered by visually rich stimuli (Bacon & Handley, 2010), then it was expected that they might be more affected by visually rich belief bias syllogisms and therefore perform worse on those than participants without dyslexia.

3.2. What is a reasoning strategy?

According to Siegler and Jenkins (1989), a strategy is ‘any procedure that is non-obligatory and goal directed’. Evans (2000) describes a strategy as a series of slow, goal-directed, systematic and conscious processes. In contrast, Johnson-Laird, Savary and Bucciarelli (2000) describes it as a series of steps in problem solving, and each step within that process is an unconscious tactic. Strategy selection can be influenced by factors such as age or expertise in the subject area (Lemaire & Fabre, 2005). Several strategies for solving syllogisms have been identified by research, such as a diagrammatic system of drawing circles around the end terms or a mathematical system of treating them like algebraic equations (Ford, 1995; Bacon et al., 2003). Some participants have been found to use more than one strategy. Roberts (2000) suggests that deductive performance can be accounted for by three strategies: spatial, verbal and task specific rather than a single theory such as mental models or rules-based concepts. Strategies may be influenced by prior knowledge of the terms or a related situation, and this has been judged to be one of the causes of failures to apply the correct rules when solving a problem (Braine & O’Brien, 1998). Wetherick and Gilhooly (1990) claim that when the logic of a problem is not obvious or easily discernible reasoners tend to generate a response by choosing a conclusion where the quantifier matches one of those in the premises. Where there is a choice, they tend to choose the most conservative one. For example, in the syllogism “All B are A, Some C are B”, they are likely to choose the conclusion “Some C are A”.

Newton and Roberts (2000) suggest that the ability to discover new strategies for solving problems depends on the quality of the initial representation. According to Crowley, Shrager and Siegler (1997), strategy development is born out of “a competitive negotiation between metacognitive and associative mechanisms”. An unfamiliar or new task increases the workload of metacognitive processes. Practice consolidates and automates some of the process, leaving the metacognitive resources available to pick up discrepancies and search for alternative solutions. Newton and Roberts (2000) demonstrated with a series of experiments that new strategies are discovered through experience with a task rather than prior knowledge of one strategy or another. They used two categories of direction tasks: the first was instructions to use cancellation to solve the problems and the second was a free choice of strategy.

Experiment 1 examined whether people with a highly spatial strategy would choose a cancellation strategy after being introduced to one. Participants were allocated to one of four groups:

- Baseline: Participants were given two sets of directions tasks.
- Instructed: Participants were given two sets of directions tasks, one with cancellation instructions and one with free choice of strategy. They should revert to their initial strategy if there is was a stylistic preference. The results revealed that cancellation was the preferred strategy when free choice was an option.
- Dax/Med: Participants were given one set of Dax/Med Word puzzles and one set of directions tasks. Dax/Med puzzles consisted of strings of the words dax (equivalent to east); med (west); slok (north); and rits (south). In any string,

dax cancelled med, and slok cancelled rits, so that (slok dax rits rits dax) reduced to (dax rits dax) - equivalent to east southeast (Newton & Roberts, 2000). The directions tasks were similar to those on the Dax/Med puzzles and did not use the words cancellation or opposite. The results revealed no transfer of cancellation strategy to the directions tasks.

- Paper and Pencil: Participants were given two sets of directions tasks. They were allowed to use paper and pencil for one set of tasks but not the other. The results showed no increase in a cancellation strategy, suggesting that the use of paper and pencil may not free enough metacognitive resources for the discovery of new strategies.

Newton and Roberts (2000) concluded that if a strategy can be performed reasonably well there is a greater likelihood of a successful search for an alternative one, and that being cognizant of one's failures may play an important part in the process of evaluation and selection of a new strategy. They further state that reducing cognitive load, for example the provision of paper and pencil for workings, does not raise the probability of discovery of cancellation as a strategy.

Experiment 2 investigated the notion that the use of pencil and paper may be suppressing the discovery of an alternative strategy. Participants in this experiment were allocated to one of two groups:

- Baseline: Participants were given two sets of directions tasks with paper and pencil for workings.
- Instructed: Participants were given two sets of directional tasks, one with cancellation instructions and the other with the freedom to choose to use paper

and pencil. The results showed that they continued to use cancellation for the second directions tasks, suggesting that the use of pencil and paper does not suppress the strategy of choice.

Experiment 3 examined the notion that some people may need to evaluate a new strategy before using it. They compare the old strategy with the new one and if the result is the same, they acknowledge the new strategy is a valid one. Assessing the validity of a new easiest for those who can reason well with the original strategy (Newton et al., 2000). There were three groups in this experiment, all received two sets of directions tasks:

- Group 1: Participants were not given any feedback for their answers.
- Group 2: Participants were given feedback for correct answers only.
- Group 3: Participants were given feedback for correct answers and correct answers were provided for wrong solutions.

The results revealed that the level of feedback affected the development of a cancellation strategy. The likelihood of strategy development was greater when feedback about the required answers was provided, highlighting the importance of showing where the reasoner went wrong as well, not just which answers were correct.

Morris and Schunn (2005) posit a logical strategy model where an individual will draw from a range of strategies depending on the nature of the problem and the available information. They assert that no individual will use only one strategy across an entire problem set, that the strategy the individual uses is a function of the problem type and task demands. They identify several strategies:

Token based (mental models): A propositional analysis of the premises creates a representation of the surface structure which is just enough to encode it in working memory where models are generated then searched and evaluated for a solution (Johnson-Laird, 1983; Johnson-Laird, Schaeken & Byrne, 1992). This strategy is useful for problems with spatial relations such as linear syllogisms, for example "John is to the left of Paul, Paul is to the left of Mike, Is Mike to the left of John?". The reasoner has to create a mental picture of John, Paul and Mike in the spaces described in the premises in order to deduce Mike's location.

Verbal (mental logic): This strategy is based on content-free and logical transformation rules that are applied to linguistically derived mental structures (Rips, 1994; Braine & O'Brien, 1998). Information is represented in a sentential format and processed using a series of logical rules to evaluate it for a solution. This strategy is useful for solving abstract problems that focus on relationships between elements, such as the syllogism "If A is B, then B is C". The reasoner has to convert each premise sentence into a mental representation then determine the relationship between the A and C terms.

Knowledge-based heuristics: This strategy relies on prior knowledge of similar content for which there are existing rules. Once the content is activated the rules become accessible to the reasoner who can then apply them to the present situation or problem. This strategy does not need to generate a valid conclusion but may result in a logic-like performance (Cheng & Holyoak, 1985; Cosmides, 1989).

Superficial heuristics: This strategy focuses on the surface structure rather than the content. The reasoner identifies the main surface elements and then applies rules to them. For example, in the Wason card selection task, reasoners are reported to pick the cards named in the rules rather than the cards that are not named (Evans, 1972).

This strategy leads to matching biases (Evans, 1989) and atmosphere effects (Woodsworth & Sells, 1935). The atmosphere effect is the tendency for form of the premises to set a favourable tone for acceptance of a conclusion in a similar form. For example, if a syllogism contains two universal affirmative premises such as All A are B; All B are C, the tendency will be to accept the universal affirmative conclusion of All A are C. Matching bias occurs when a conclusions is selected because it has the same quantifier as one of the premises and is more likely to take place when the same quantifier is featured in both premises (Wetherick, 1989; Wetherick & Gilhooly, 1995).

Analogy: This strategy uses existing knowledge to derive solutions to novel problems (Holyoak & Thagard, 1989). The reasoner accesses a source from memory that is similar to the present problem and uses that similarity to derive a solution (Gentner, 1983; Holyoak & Thagard, 1995).

Task specific procedures: The reasoner may develop short cuts (Roberts, 2000) that resemble simple rules. This strategy is context dependent and involves the reasoner encoding only the relevant features of the problem and then activating an appropriate process to derive a solution. Prior knowledge and belief can come into play and can lead to errors due to incomplete encoding of the problem features.

In order to explore the range of strategies used by participants, Morris and Schunn (2005) asked participants to evaluate the conclusions of 24 syllogisms and conditionals. There were three sets of stimuli: abstract versus concrete (eg, letters versus related items), familiar versus unfamiliar (eg, dogs versus fictitious terms), and simple versus difficult (taken from Braine & O’Brien, 1998). Examples of the stimuli are as follows:

Syllogism (abstract)

No A are B

Some C are B

Conclusion: Some C are not A

Conditional (familiar)

If Bill is here, then Sam is here

If Sara is here, then Jessica is here

Bill is here or Sara is here

Conclusion: Sam or Jessica is here

The task was to evaluate the syllogisms for valid or invalid conclusion, and to test the conditionals with a given rule in Wason tasks (Wason, 1961). The researchers predicted that the participants would use a variety of strategies and the strategy would be related to the problem type. The results showed that the participants used a variety of strategies and varied in their preferred one. No subject used just one strategy, two used a single strategy for more than 75% of the problems, and two-thirds of them used all five strategies at least occasionally. Strategy use was also related to problem type. Their participants reported using knowledge-based strategies when there was familiar content, superficial heuristics for more difficult and less familiar problems, and token-based strategies for Wason-type tasks.

Ford (1995) also investigated the range of strategies that participants bring to bear on syllogism performance. She suggested that it is mistaken to treat everyone as if they reason in the same way. She identified two groups of reasoners according to their strategy – verbal and spatial. In her study, twenty participants were presented with 27 syllogisms with valid conclusions and asked to solve them, speaking their thoughts out loud as well as showing their workings in a workbook. The syllogisms contained distinct terms such as *vegetarians* and *gymnasts*, and common terms such as *lawyers*. The results showed that verbal reasoners tended to treat the syllogisms like mathematical problems, re-writing them as equations, substituting words with letters and using arrows to indicate relationships between the terms of the premises. They appeared to be using rules similar to modus ponens and modus tollens. Modus ponens and modus tollens are rules used to make arguments and form conclusions. Modus ponens operates by affirming an argument, eg. If A is true, then B is true. A is true. Therefore, B is true. Modus tollens operates by denying an argument, eg. If A is true, then B is true. B is not true. Therefore, A is not true.

Ford's results (1995) also showed that spatial reasoners, on the other hand, tended to use shapes in different spatial relationships to represent different classes and their relationships. They used representations where the class itself was represented rather than the members of the class. Many of the spatial reasoners drew shapes to denote classes while at the same time, Ford notes, keeping the verbal tag of the syllogism in their mind. Some participants even appeared to use a combination of both strategies.

3.3. Figural effects of syllogisms

Another factor influencing strategy choice is the figure of the syllogism (Johnson-Laird & Bara, 1984; Bara, Bucciarelli & Johnson-Laird, 1995; Bara, Bucciarelli & Lombardo, 2001), thereby creating a figural effect. The figure is the structure of the syllogism denoted by the placement of the middle term 'B' in relation to the major term 'A' in the first premise and the minor term 'C' in the second premise. Table 3.1 shows the four figures and the response biases. Storring (1908) has been cited as the first researcher to document this phenomenon. Research has shown that a figural effect occurs when drawing conclusions from syllogisms (Polk & Newell, 1995; Wetherick & Gilhooly, 1990; Dickstein, 1978; Chater & Oaksford, 1999) and this is most prominent for Figure 1 (AB/BC) and Figure 2 (BA/CB). The figural effect is the tendency to create solutions in the same form as the premise containing the subject, also known as a response bias. It has been suggested that the figural effect is a result of how information is processed in working memory and this is based on the notion of first in, first out (Johnson-Laird & Steedman, 1978; Johnson-Laird & Bara, 1984). The reasoner states the conclusion in the order the premises were presented and in which the terms were used to construct the mental representation of those premises. For example, in Figure 1, the A in the first premise enters working memory first, the reasoner focuses on B in that premise and then compares it with B in the second premise, and since A was the first term into working memory it will naturally be the first term out. Broadbent (1958) demonstrated that it is easier to recall a series of digits in the same order as their presentation.

Johnson-Laird and Bara (1984) further suggest that the effect is caused by the difficulty in constructing the representation in working memory. Figure 1 is easier because the middle term is adjacent in each premise. In Figure 1 the middle term appears together so only one model needs to be constructed. Figure 2 is harder because the reasoner must first switch the terms then integrate them together to form a conclusion. A bias for A-C answers for Figure 3 and Figure 4 indicates a preference for constructing an initial model using the first premise; this process requires fewer operations. As the level of difficulty increases and more models are required there is an increase in the amount of errors. In addition, Figure 2 syllogisms are generally processed faster than Figure 1 syllogisms (Espino, Santamaria & Garcia-Madruga, 2000).

Table 3.1: Syllogism figures and response biases.

	Structure	Conclusion
Figure 1	AB/BC	AC
Figure 2	BA/CB	CA
Figure 3	AB/CB	No response bias
Figure 4	BA/BC	No response bias

Wetherick and Gilhooly (1990) argue that the effect is the tendency to place the first term in the conclusion as the term that appeared as the subject of one of the premises. A is the subject of the first premise in Figure 1 leading to the A-C solution, and C is the subject of the second premise in Figure 2 leading to the C-A solution.

Rips (1994) felt the figural effects occurred only in deductive reasoning tasks where the subject is required to generate their own conclusion from the premises. Johnson-Laird and Steedman (1978) found that when participants generated their own conclusions there was a preference for A-C conclusions for Figure 1 and C-A conclusions for Figure 2. In addition, syllogisms where the conclusion coincided with the figure were easier to solve than when there was no coincidence. Jia, Lu, Zhong and Yao (2009) distinguished between evaluation and generation of conclusions and found that the effect appears to be the reverse when participants are asked to evaluate a conclusion rather than generate one of their own.

Chater and Oaksford (1999) argue that the phenomenon occurs because of the attachment-heuristic. The conclusion is determined by which premise contains the end term as its subject. If the min-premise has the end term as the subject, that term becomes the subject of the conclusion. If not, then the end term of the max-premise becomes the subject of the conclusion. The max-premise is the first premise and is the basis for consideration in comparison with the second (min-premise) to determine the conclusion of the syllogism. The max-premise is the most informative one, while the min-premise is the least informative one. For example, in the syllogism:

> All B are A (max-premise is most informative as it defines the relationship between A and B)
> Some C are B (min-premise is least informative as it contains additional information to be considered)
> Some C are A (by attachment the subject of the min premise appears in the conclusion)

Yule and Stenning (1997) use the Source-Founding Hypothesis to explain the effect. They state that "the terms from the source premise will tend to precede the other end term in conclusions and will tend to retain the order in which they appear in the source premise"(Stenning & Yule, 1997, p. 128), suggesting that the figural effect occurs when the individual description is constructed from the source premise. The source premise contains the end term that forms the basis of comparison. For example, in the syllogism "All A are B, All B are C", A is the end term of the source premise.

3.4. Belief bias

Belief bias is also thought to influence the reasoning process. It is described as the tendency for people to produce or endorse a conclusion that they believe to be true, even though that conclusion may be logically incorrect (Evans, Barston & Pollard, 1983; Evans & Curtis-Holmes, 2005; Newstead, Pollard, Evans & Allen, 1992; Roberts & Sykes, 2003). That is, conclusions are accepted not because they are necessary, but because they are believable. Therefore, an invalid conclusion may be chosen simply because it feels right (Thompson, 2009). Beliefs can distort interpretation of information and influence the deductive process (Garnham & Oakhill, 1994). Pre-existing beliefs may indeed influence the perception of new or additional data (Kormblith, 1993).

Belief bias responses are also thought to increase under time pressure (Evans & Curtis-Holmes, 2005; Shynkaruk & Thompson, 2006; Thompson, Prowse-Turner & Pennycook, 2011) or working memory load (De Neys, 2012). Whether or not beliefs affect judgement depends on the demands of the task as well as the nature of the reasoner (Wiswede, Koranyi, Mueller, Langner & Rothermund, 2013). Research suggests that some reasoning processes happen independently of each other (Bago & De Neys, 2017; Morsanyi & Handley, 2012; Trippas, Handley, Verde & Morsanyi, 2016) and some suggest they happen simultaneously (De Neys, 2012, 2014; Handley & Trippas, 2015; Pennycook, Fugelsang & Koehler, 2015; Sloman, 2014).

Default-interventionists claim that belief bias reasoning occurs first because it is fast and autonomous Type 1 reasoning, and it is more likely to occur when there is conflict between belief and logic and processing time is limited (Evans & Stanovich, 2013a). Type 1 reasoning is fast and autonomous while Type 2 reasoning requires the use of working memory (Evans & Stanovich, 2013a, 2013b). In contrast, proponents of Parallel-processing claim that belief-biased and logically based processing commence at the same time (Trippas, Thompson & Handley, 2017). Mental Models theorists suggest that the type of response is determined by the complexity of the problem and the number of representations that are required to solve it (Johnson-Laird, 2001). Trippas et al. (2017) hypothesised that the degree to which logical validity affects belief judgments, and vice versa, depends on the complexity of the reasoning process required to solve the problem at hand. They suggest that as the complexity of the problem increases, so too does the likelihood of logic being affected by belief. They examined this hypothesis over a series of experiments.

Experiment 1 examined the notion that conflict between logic and belief should have a greater impact on belief judgements than logic judgments. Participants were presented with logical problems (eg. If a child is happy, then it cries; Suppose a child is happy; Does it follow that the child cries?) and asked to judge if the conclusion was valid or believable. Half of the problems were in modus ponens form (i.e., if p, then q; p, therefore q): valid/believable, invalid/unbelievable, and half were in modus tollens form (If p, then q; not q, therefore not p): valid/unbelievable and invalid/believable. The results showed that when there is a conflict between belief and logic, logical validity interfered with belief-judgments more than beliefs interfered with logic-judgments for modus ponens problems but this was not the case for more complex modus tollens problems. In the case of modus tollens problems, the effect occurred both ways. That is, logical validity affected belief judgments to the same degree that beliefs affected logic judgments. The results suggest that the effect of a conflict between belief and logic is a function of the complexity of the problem at hand (Handley & Trippas, 2015).

Experiment 2 examined the notion that the opposite effect should happen if the logical complexity of the problem was increased. The experimental procedure was the same as that used in Experiment 1. The results showed that belief judgments interfered with logic judgments more when the problems were more complex. The results support the notion of parallel-processing, that both Type 1 and Type 2 processes are initiated at the same time (Handley & Trippas, 2015; Newman, Gibbs & Thompson, 2017; Pennycook et al., 2015; Sloman, 2014) and the process that generates the solution is influenced by the complexity of the problem.

It has been suggested that individuals with a greater working memory capacity are better able to avoid belief bias (De Neys, Schaeken, & D'Ydewalle, 2005) by overriding Type 1 processing and engaging with Type 2 processing to generate additional representations necessary for working through problems (Copeland & Radvansky, 2004; De Neys et al., 2005; Johnson-Laird, 2010; Markovits et al., 2002). Robison and Unsworth (2017) investigated the hypothesis that individuals with a higher working memory capacity were better able to reason independently of their beliefs and therefore be less susceptible to a belief bias effect. Participants were presented with three tasks measuring working memory capacity (operation span, symmetry span, and reading span), two tasks measuring fluid intelligence (letter sets and number series), and a syllogistic reasoning task. There were four categories of syllogisms: valid/believable conclusion; valid/unbelievable conclusion; invalid/believable conclusion; and invalid/unbelievable conclusion. The results showed no decrease in belief bias effect for participants with a higher working memory capacity. The experiment was repeated using syllogisms with nonsense words to rule out the possibility that resistance to belief bias was due merely to a lack of verbal reasoning abilities. The results turned out to be similar to those of the first experiment, providing further support for the notion that working memory capacity may not be an indicator of susceptibility to belief bias.

Individual differences in reasoning style might affect how beliefs influence a person's approach to problem solving. Past experience may engender a particular approach which may or may not lead to the correct solution but may feel right for that individual. It is possible that some people may be naturally more prone to Type 1 processing than Type 2 processing and will go with that approach regardless of the complexity of the problem.

3.5. Dyslexia and reasoning

Strategies involve either spatial or verbal representations. It is known that people with dyslexia have particular difficulty in manipulating written, verbal representations, and so they are an interesting group to investigate in terms of whether strategy choice is driven by difficulty of representation. The only study found that looks specifically at dyslexia in relation to reasoning is one conducted by Bacon, Handley and McDonald (2007), which examined how people with dyslexia handled reasoning with abstract and concrete or visually rich syllogisms in comparison with people without dyslexia, and the effects of visual imagery on dyslexia and reasoning. They posit that a visual image may create 'noise' (Sperling, Lu, Manis and Seidenberg, 2005) for people with dyslexia and this may influence how they reason or solve problems. In an earlier study, Bacon, Handley and Newstead (2004) concluded that verbal reasoners are able to work with abstract propositional form, drawing almost entirely on verbal working memory, while spatial reasoners require explicit visual images and use both verbal and spatial memory.

In a study observing how different strategies may affect reasoning, Bacon, Handley and McDonald (2007) found that verbal reasoners appeared to manipulate information in its abstract form. Like the participants in Ford (1995), verbal reasoners in the Bacon et al. study (2007) seemed to work the syllogisms like mathematical equations, switching and substituting the terms between the premises. They appeared to be using rules that related the conclusions with the quantifier and, as a result, experienced difficulties with problems where the logical conclusion had a different quantifier to the premises. Their verbal reports described actions such as replacing, substituting and cancelling syllogistic terms. In contrast, spatial reasoners manipulated the information in a more concrete way. Their workings showed terms within shapes which signified spatial relationships between the premises, while their verbal reports described terms as groups or subsets. In addition, spatial reasoners consistently reported using vivid images of the material when reasoning, whereas verbal reasoners did not. Bacon, Handley and Newstead (2004) suggest that while verbal reasoners use mainly verbal working memory and seem happy to reason with information in a fairly abstract form, spatial reasoners use both verbal and spatial resources and seem to require a more explicit visual representation.

Bacon et al. (2007) manipulated stimulus content in order to compare reasoning strategies across concrete and abstract materials. It was expected that if individuals with dyslexia conceptualised information in a visuospatial rather than verbal way, then a higher proportion of people with dyslexia should be spatial reasoners.

Two sets of problems were created from eight of the 27 valid syllogism forms identified by Johnson-Laird and Byrne (1991). The first set contained sporting terms in English, for example, “Some golfers are tennis players, All tennis players are surfers”. This set was used as the concrete condition because the terms were supposedly easier to visualise (Bacon et al., 2007). The second set contained the same English sporting terms translated into Welsh, for example, “Some ymholiadou are perythnas, All perythnas are diweddaru”. This represented the abstract condition. Participants were required to write down all their workings in a workbook and say out loud their reasoning which was recorded on a dictaphone.

Strategies were identified based on the procedure from a previous study (Bacon et al., 2003). In this study participants were presented with the same 27 syllogisms used by Ford (1995) in two conditions, the first employing both verbal and written protocols, and the second employing written protocol only. The results revealed participants to be using verbal and spatial strategies. Verbal reasoners substituted the common term from one premise into another, drew arrows to signify relationships between terms, and their verbal reports described activities such as cancelling terms. Spatial reasoners treated terms in the premises as groups or sub-groups, drew spatial arrays to describe relationships, and their verbal reports described group membership and spatial arrangements.

Of the participants with dyslexia (N = 20) in the Bacon et al. (2007) study, 55% demonstrated a spatial approach, 20% a verbal approach, 20% were mixed, and 5% were indeterminate. Of the participants without dyslexia (N = 19), 32% demonstrated a spatial approach, while 58% demonstrated a verbal approach, 10% were indeterminate, and none were mixed. Therefore, 75% of all the participants with dyslexia (mixed approach participants were included) demonstrated a spatial approach, compared to just 35.3% of the participants without dyslexia. Both groups of participants tended to substitute letters for words in the abstract (Welsh) condition and performed similarly. With regards to the concrete condition, participants with dyslexia produced 10% more correct conclusions to syllogisms with Welsh terms, compared to those with English terms. Participants without dyslexia performed slightly better in the concrete condition. These results suggest that the reasoning strategy used by participants with dyslexia may be impaired with visually concrete materials. The imagery clutters the working memory and thereby creates a greater likelihood for errors (Knauff & Johnson-Laird, 2002).

If people with dyslexia are operating under working memory constraints (Ackerman & Dykman, 1993; Brunswick, McCrory, Price, Frith & Frith, 1999; McDougall & Donohoe, 2002; Mcloughlin, Fitzgibbon & Young, 1994; Plaza, Cohen & Chevrie-Muller, 2002), it may be the case that more complex reasoning or conflicts between belief and logic are less likely to be carried forward to Type 2 processing (De Neys et al., 2005; Trippas et al., 2017). Research has shown that load task affected performance on problems that required analytic (Type 2) reasoning but not on problems that required heuristic (Type 1) reasoning (Franssens & De Neys, 2009) and that visuospatial memory deficits come to the forefront only when the task at hand requires the person to engage with it verbally (Gould & Glencross, 1990; Thomson, 1982). In addition, a phonological deficit (Frith, 1985; Snowling, 2000; Stanovich, 1988) may render the representations degraded and not distinct enough (Mody, Studdert-Kennedy & Brady, 1997; Snowling, 2000) for further processing.

One point to consider with the Bacon et al. (2007) study is that participants were not tested for non-verbal ability, to ensure there were no significant differences between the participants with dyslexia and those without dyslexia. While it can be assumed that a certain level of cognitive ability must be present to pursue university level education, differences may be masked by the use of various coping strategies.

Another point to note is that the English terms are all sporting terms, thus making the assumption that all participants are familiar with them. There may be participants with no interest in sports and are thus less capable of visualising many of the terms. A difficulty in forming representations of the sporting terms could have caused some participants to treat them as abstract rather than concrete terms.

To ensure comparability between groups of participants, the studies in my thesis tests for non-verbal ability using the Ravens Progressive Matrices test, and the terms in the syllogisms come from a variety of areas of people and objects.

3.6. Purpose of the studies in this chapter

The aim of the experiments in this chapter is twofold. The first aim is to examine the reasoning strategies of participants with dyslexia compared to participants without dyslexia and observe if they were affected differently by figural effects. The figural effect is the tendency to create solutions in the same form as the premise containing the subject, also known as a response bias. Participants were required to solve all 27 syllogisms with a valid conclusion. The syllogisms were separated into three categories based on level of difficulty for verbal and spatial reasoners (Ford, 1995): easiest for verbal reasoners (EV), easiest for spatial reasoners (ES), and equally difficult for both types of reasoners (HSV). If people with dyslexia tend to employ a spatial strategy, the participants with dyslexia were expected to perform better on syllogisms that are easiest for spatial reasoners and less well on syllogisms that are easiest for verbal reasoners. Participants without dyslexia were expected to perform better on syllogisms that are easiest for verbal reasoners and less well on syllogisms that are easiest for spatial reasoners.

The second aim was to observe the effect of belief bias in participants with dyslexia compared to participants without dyslexia. Belief bias is the tendency for people to produce or endorse conclusions that they believe to be true, regardless of their logical validity. In other words, a conclusion might be accepted not because it is logical or necessary, but because it is believable. Dyslexia has been widely accepted as a consequence of a phonological deficit, the way the brain codes or ‘represents’ the spoken attributes of words (Snowling, 2000). Bacon et al. (2007) demonstrated that people with dyslexia tend to adopt a spatial strategy, while people without dyslexia tend to adopt a verbal strategy. They further suggest that when reasoning involves visually rich information (concrete terms that evoke strong visual images) the use of a spatial strategy may lead to less effective reasoning in people with dyslexia.

To determine how people with dyslexia handle reasoning with syllogisms it is necessary to understand how linguistic information is processed. A sentence-picture verification task (Macleod, Hunt & Mathews, 1978) is one way of assessing how well people represent and process linguistic structures involved in deductive reasoning problems. However, Roberts, Wood and Gilmore (1994) suggest it is difficult to classify people from this type of research into types of strategies. For example, participants may not fully understand the nature of the task they are required to perform (Marquer & Pereira, 1990), or one strategy may be masked by another if the method for measuring them is not robust enough (Siegler, 1987). Roberts et al. (1994) report that while there are issues with the various methods for classifying strategy choices, the principle that makes the best use of their individual cognitive resources is sound.

In sentence-picture verification tasks participants compare the representation of a negative or affirmative sentence with a picture then decide whether the sentence matches that picture or not. The conditions are usually true affirmative (TA), false affirmative (FA), true negative (TN), and false negative (FN) in combinations of the sentences using the words star and plus, such as STAR IS ABOVE PLUS, STAR IS NOT ABOVE PLUS, and PLUS IS BELOW STAR. The sentences are followed by a picture of a star and a cross in a form that either matches or doesn't match the sentence. Macleod, Hunt and Mathews (1978) have shown that sentence comprehension time was significantly longer for negative sentences than for affirmative sentences, and picture verification time was longer for false responses than for true responses, and negative responses were longer than affirmative responses. They found participants tended to use one of two strategies: a pictorial-spatial strategy in which the subject reads the sentence, forms a representation of the sentence, converts the sentence representation to a picture representation, observes the picture, forms a representation of the picture, then compares the picture representation with the sentence representation; and a linguistic strategy in which the subject reads the sentence, forms a representation of the sentence, observes the picture, converts the picture to a sentence representation, then compares the representations. The difference between the two strategies is the extra step employed by the pictorial model of converting the sentence representation to a picture representation before moving on to observing the picture. This extra step increases response time. Hence, participants who adopt a spatial style will tend to take longer on the task than those who adopt a verbal strategy.

3.7. Study 1

This study investigated individual differences in reasoning strategy selection when solving syllogisms, as well as observing any figural effects, focusing on the differences between participants with dyslexia and participants without dyslexia. The participants were required to solve all 27 syllogisms with a valid conclusion (Johnson-Laird & Byrne, 1991). The syllogisms were separated into three categories based on level of difficulty for verbal and spatial reasoners (Ford, 1995): easiest for verbal reasoners (EV), easiest for spatial reasoners (ES), and equally difficult for both types of reasoners (HSV). The hypothesis is that if people with dyslexia tend to employ a spatial strategy, then the participants with dyslexia are expected to perform better on syllogisms that are easiest for spatial reasoners and less well on syllogisms that are easiest for verbal reasoners, and participants without dyslexia are expected to perform better on syllogisms that are easiest for verbal reasoners and less well on syllogisms that are easiest for spatial reasoners.

3.7.1. Method

Participants

Participants were 43 Lancaster University undergraduate students: with dyslexia (13 female, 6 male) and without dyslexia (19 female, 5 male) with mean age 19.8 years (SD = 2.12). The mean age of participants with dyslexia was 19.9 years (SD = 2.25) and the mean age of participants without dyslexia was also 19.7 years (SD = 2.05). Participants without dyslexia were recruited via Sona, the department's online participant recruitment system. Self-reported participants with dyslexia were also recruited via Sona. On behalf of the researcher, the Student Support office kindly contacted students who were recorded by the university as having been officially assessed as having dyslexia. Participants with dyslexia and participants without dyslexia who were not psychology majors were paid £7.50. Psychology majors were given course credit. Twenty-nine of the participants were Psychology majors. Reasoning with syllogisms was not a topic on the Psychology syllabus during the testing period. The non-Psychology majors were students in Engineering, Natural Sciences, Social Work, Accounting & Finance, and Philosophy.

Materials

A shortened version on the Ravens Standard Progressive Matrices (Bilker, Hansen, Brensinger, Richard, Gur, & Gur, 2012) was used to test general cognitive ability of all participants.

All 27 syllogisms with a logical conclusion (Johnson-Laird & Byrne, 1991) were separated into three categories based on level of difficulty for verbal and spatial reasoners (Ford, 1995). The categories were: easiest for verbal reasoners (EV), easiest for spatial reasoners (ES), and equally difficult for both types of reasoners (HSV). The terms of the premises were all taken from Ford's (1995) study. The figure of the syllogisms was not evenly distributed across the three conditions. Table 3.2 shows the distribution.

Table 3.2: Distribution of the figure of the syllogisms x problem type.

	Problem Type		
Figure	HSV	ES	EV
AB/BC	0	4	2
AB/CB	1	4	1
BA/BC	5	3	1
BA/CB	1	1	4

Each syllogism was presented separately in random order on a Mac computer. Below each syllogism was a box for participants to type their solutions. Clicking the OK button advanced to the next syllogism.

Design

A 2 x 3 mixed design was used. The between-subjects factor was dyslexic status (dyslexia, non-dyslexia) and the within-subjects factor was problem type (ES, EV, HSV). The dependent measures were the number of syllogisms solved correctly and the time taken to solve each one.

Procedure

Participants were tested in a single session lasting approximately one hour. The shortened version of the Ravens Standard Progressive Matrices was presented first in a booklet. Participants were given the choice of either circling their selection or writing their selection number in the space for the missing piece. They took approximately 15 minutes to complete the task.

The participants were then presented with all 27 syllogisms, one at a time in random order on a Mac computer. They were asked to type their conclusion in the box provided and were told they had two minutes (120 seconds) to do so. If no response was made after the two-minute time limit, a message would pop up to prompt them to write their answer. No participant required prompting. The longest response time was 118.90 seconds.

3.7.2. Results

The study data were analysed by problem type: easiest for verbal reasoners (EV), easiest for spatial reasoners (ES), and equally difficult for both types of reasoners (HSV); and by the figure of the syllogism, which is determined by the location of the middle term, B, in the standard form, where A is the major term, and C is the minor term (Johnson-Laird, 1983). The dependent variables were accuracy and response times. The data were not analysed by problem type x figure x dyslexic status due to the uneven distribution of figure in each problem type.

Accuracy

Problem type

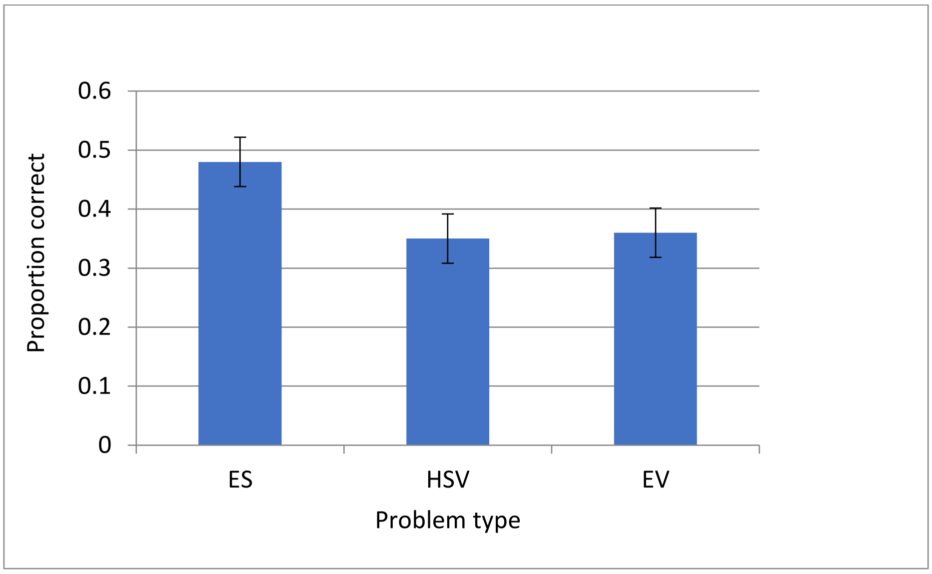
A mixed design ANOVA was performed on the number of correctly solved syllogisms with the problem type (ES, EV and HSV) as the within-subjects factor and dyslexic status (dyslexia v non-dyslexia) as the between-subjects factor, and number of correctly solved problems as the dependent variable. The proportion of correctly solved syllogisms for each subject was calculated as the total of each type correctly solved divided by the number of each type (ES = 9 problems, HSV = 11 problems, EV = 7 problems). See Table 3.3.

Table 3.3: Proportion of correctly solved problems by level of difficulty for verbal and spatial reasoners.

	ES		HSV		EV	
	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic
Mean	0.51	0.45	0.37	0.34	0.42	0.32
SD	0.29	0.28	0.24	0.27	0.28	0.21

The main effect of dyslexic status was not significant, F (1, 41) = .66, p = .42, η^2 = .02. There was a significant main effect of problem type, F(1, 41) = 10.49, p < .001, η^2 = .20. The number of correctly solved syllogisms was higher for ES (M = 0.48, SD = 0.28) than for EV (M = 0.36, SD = 0.24) and for HSV (M = 0.35, SD = 0.25), whereas the number of correctly solved syllogisms was almost identical for EV and HSV. See Figure 3.1. A pairwise comparison using Bonferroni correction showed a significant difference between ES and HSV, and between ES and EV, but no significant difference between HSV and EV. There was no significant interaction between problem type x dyslexic status, $F(1, 41) = .795$, $p = .46$, $\eta^2 = .02$.

Figure 3.1: Overall number of correctly solved syllogisms x problem type.



An independent samples t-test using the raw scores from the shortened version of the Ravens Standard Progressive Matrices showed a significant difference between participants with dyslexia (M = 6.47, SD = 2.22) and participants without dyslexia (M = 5.25, SD = 1.23), $t(39) = 2.29$, $p = .027$.

The ANOVA was repeated again with the scores from the Ravens Standard Progressive Matrices test as a covariate. The main effect of problem type was not significant, $F(2, 80) =.49$, $p = .62$, $\eta^2 = .01$. The interaction between problem type x Ravens status was also not significant, $F(2, 80) = .05$, $p = .95$, $\eta^2 = .001$, as well as that of problem type x dyslexia, $F(2, 80) = .74$, $p = .48$, $\eta^2 = .02$. The between-subjects effect of dyslexia group was also non-significant, $F(1, 40) = .04$, $p = .83$, $\eta^2 = .001$.

Figure

In order to test the effect of different syllogistic Figures on performance, the data was collated by the figure of the syllogisms and analysed with a repeated measures 2 x 4 ANOVA with Figure (Figure 1, Figure 2, Figure 3, Figure 4) as within-subjects factor and dyslexic status (dyslexia, non-dyslexia) as between-subjects factor. Table 3.4 shows the proportion of correctly solved syllogisms by Figure.

Table 3.4: Proportion of correctly solved problems by Figure.

	Figure 1 (AB/BC)		Figure 2 (BA/CB)		Figure 3 (AB/CB)		Figure 4 (BA/BC)	
	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic
Mean	0.33	0.38	0.44	0.38	0.51	0.35	0.43	0.38
SD	0.24	0.24	0.27	0.27	0.30	0.25	0.28	0.25

There was a significant main effect of Figure, $F(3, 41) = 2.66$, $p = .05$, $\eta^2 = .06$. The overall number of correctly solved syllogisms was similar for Figure 1 (M = 0.36, SD = 0.24) and Figure 4 (M = 0.39, SD = 0.26). Likewise, the overall number of correctly solved syllogisms and was similar for Figure 2 (M = 0.42, SD = 0.27) and Figure 3 (M = 0.42, SD = 0.28). More Figure 2 and Figure 3 syllogisms were solved correctly than Figure 1 and Figure 4 syllogisms. The main effect of dyslexic status was not significant, $F(1, 42) = .66$, $p = .42$, $\eta^2 = .02$.

There was a significant interaction between Figure x dyslexic status, $F(3, 41) = 4.52$, $p = .005$, $\eta^2 = .10$. Figure 2 shows participants with dyslexia solved more problems correctly than participants without dyslexia for the Figure 2, Figure 3 and Figure 4, and participants without dyslexia solved more problems correctly for the Figure 1. Participants without dyslexia performed consistently across all four figures.

Post hoc comparisons indicated a significant difference between groups only for Figure 3, $F(3, 41) = 3.83$, $p = .057$, $\eta^2 = .09$. Participants with dyslexia solved significantly more problems correctly than participants without dyslexia for Figure 3. There were no significant differences for Figure 1 (F (3, 41) = .44, $p = .51$, $\eta^2 = .01$), Figure 2 (F (3, 41) = .53, $p = .47$, $\eta^2 = .01$), or Figure 4 (F (3, 41) = .57, $p = .46$, $\eta^2 = .01$).

The ANOVA was repeated with the Ravens Standard Progressive Matrices scores as a covariate to account for the difference in scores between groups. The main effect of Figure was not significant, F(3, 41) = .24, p = .89, $\eta^2 = .005$. There was also no significant interaction between Figure x Ravens, F (3, 41) = .22, $p = .88$, $\eta^2 = .006$. Likewise, the effect of dyslexic status was not significant either, F (3, 41) = .09, $p = .77$, $\eta^2 = .002$. The Figure x dyslexic status was still significant, although the effect was reduced, F (3, 41) = 3.42, $p = .02$, $\eta^2 = .08$.

Response Time

Problem Type

A mixed design ANOVA was performed on the time (in seconds) taken to solve the syllogisms with the problem type (ES, HSV, EV) as the within-subjects factors and dyslexic status (dyslexia, non-dyslexia) as the between-subjects factors, and response time (in seconds) as the dependent variable. The response time score was the average time taken for each type of problem for each participant. Table 3.5 shows the mean response times for each problem type: easiest for verbal reasoners (EV), easiest for spatial reasoners (ES), and equally difficult for both types of reasoners (HSV).

Table 3.5: Response times (in seconds) for problem type.

	ES		HSV		EV	
	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic
Mean	46.33	43.25	46.51	43.57	49.61	41.69
SD	11.97	11.4	13.85	11.92	14.26	12.18

The main effect of problem type was not significant, $F(1, 41) = .16$, $p = .85$, $\eta^2 = .004$. The interaction between problem type x dyslexic status was also not significant, $F(1, 41) = 1.69$, $p = .19$, $\eta^2 = .04$. Overall, participants with dyslexia took longer to solve the problems than their counterparts without dyslexia, but not significantly so. The between-subjects main effect of dyslexic status was not significant, F(1, 41) = 1.85, $p = .18$, $\eta^2 = .04$.

Figure

The data was collated by Figure of the syllogisms and analysed with a repeated measures 2 x 4 ANOVA with Figure (Figure 1, Figure 2, Figure 3, Figure 4) as within-subjects factors and dyslexic state (dyslexia, non-dyslexia) as between-subjects factors. Table 3.6 shows the average response times for solving the problems when analysed by Figure of the syllogism.

Table 3.6: Time taken (in seconds) to solve problems by Figure.

	Figure 1		Figure 2		Figure 3		Figure 4	
	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic
Mean	45.18	41.51	48.64	45.86	48.06	44.06	45.28	40.38
SD	13.00	11.85	11.94	14.35	13.68	13.63	15.28	9.83

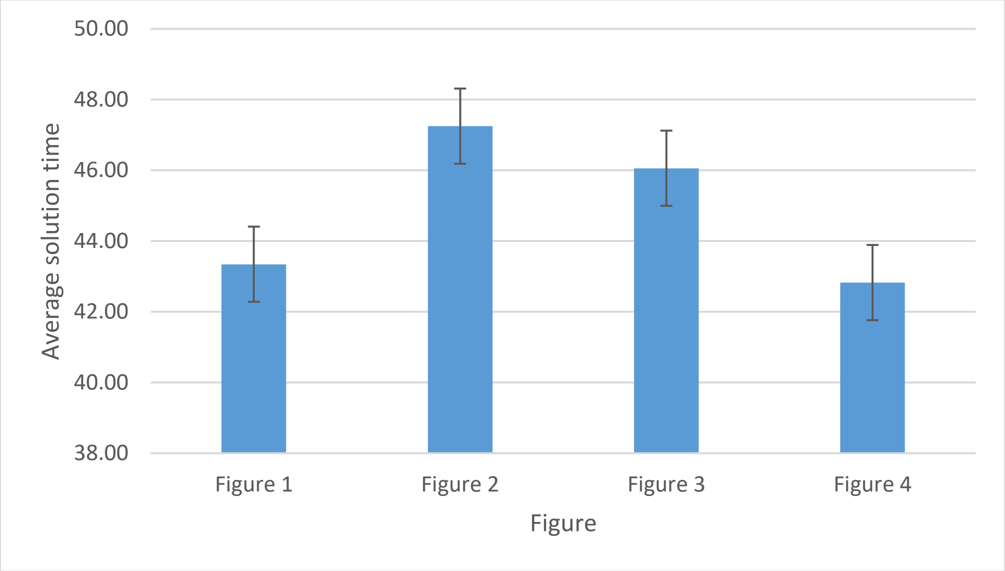
A Shapiro-Wilk's test (p>.05) (Shapiro & Wilk, 1965; Razali & Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots showed that the response times for each syllogism figure type were approximately normally distributed for both people with dyslexia and people without dyslexia, with skewness and kurtosis as shown in Table 3.7.

Table 3.7: Skewness and kurtosis of dyslexic status x syllogism figure type.

		Skewness		Kurtosis	
		Statistic	Std. Error	Statistic	Std. Error
Figure 1	Dyslexic	-0.05	0.52	-0.82	1.01
	Non-dyslexic	-0.37	0.47	-0.92	0.92
Figure 2	Dyslexic	-0.28	0.52	-0.49	1.01
	Non-dyslexic	0.78	0.47	1.50	0.92
Figure 3	Dyslexic	-0.11	0.52	-1.07	1.01
	Non-dyslexic	0.57	0.47	-0.65	0.92
Figure 4	Dyslexic	0.54	0.52	-0.27	1.01
	Non-dyslexic	0.82	0.47	0.55	0.92

The ANOVA results showed a significant main effect of Figure, $F(3, 41) = 2.78$, $p = .04$, $\eta^2 = .06$. As shown in Figure 3.2, overall Figure 2 took the longest to solve (M = 47.25, SD = 13.15), followed by Figure 3 (M = 46.06, SD = 13.67), then Figure 1 (M = 43.34, SD = 12.43), and then Figure 4 (M = 42.83, SD = 12.56). A pairwise comparison showed significant differences between Figure 1 and Figure 2 ($p = .03$), and Figure 2 and Figure 4 ($p = .01$).

Figure 3.2: Average solution time (in seconds) for syllogism figures.



While participants with dyslexia took an average of 4 seconds longer (M = 46.79, SD = 13.48) than participants without dyslexia (M = 42.95, SD = 12.41) in all of the Figures, there was no significant between-subjects main effect of dyslexic status, $F(3, 41) = 1.34$, $p = .26$, $\eta^2 = .03$. The interaction between Figure x dyslexic status was also not significant, $F(3, 41) = .03$, $p = .86$, $\eta^2 = .001$.

Analysing the data with the Ravens Standard Progressive Matrices scores as a covariate reduced the significance of Figure, $F(3, 41) = 2.24$, $p = .09$, $\eta^2 = .05$. There was no significant between-subjects main effect of dyslexic status, $F(1,40) = 2.39$, $p = .13$, $\eta^2 = .06$. There was no significant interaction of response Figure x Ravens, $F(3, 41) = 1.40$, $p = .25$, $\eta^2 = .03$, or Figure x dyslexic status, $F(3, 41) = .03$, $p = 1.0$, $\eta^2 = .00$.

3.7.3. Discussion

This study aimed to determine strategy selection when solving syllogisms, focusing on the differences between participants with dyslexia and participants without dyslexia. Participants were required to solve all 27 syllogisms with a logical conclusion (Johnson-Laird & Byrne, 1991). The syllogisms were separated into three categories based on level of difficulty for verbal and spatial reasoners (Ford, 1995): easiest for verbal reasoners (EV), easiest for spatial reasoners (ES), and equally difficult for both types of reasoners (HSV). The results showed no overall difference between participants with dyslexia and participants without dyslexia. There was a significant main effect when the data were analysed by problem type. Overall, the number of correctly solved syllogisms was higher for ES than for EV and for HSV. In fact, performance was almost identical for EV and HSV.

The results support the notion that people tend to reason in a verbal or spatial manner (Ford, 1995), but failed to support the hypothesis that there is a difference in strategy selection between participants with dyslexia and participants without dyslexia. It should be noted that participants with dyslexia solved more syllogisms correctly on average than participants without dyslexia in all categories, but not significantly so.

Some studies have shown that the figure of the syllogism can affect reasoning (Johnson-Laird & Bara, 1984; Stupple & Ball, 2007). Morely, Evans and Handley (2004) found evidence that figural bias occurred in the absence of belief bias in a production task. Research has suggested that syllogistic reasoning is affected by the position of the terms (Wetherick & Gilhooly, 1990; Ford, 1995; Polk & Newell, 1995; Chater & Oaksford, 1999; Yule & Stenning, 1992). Jia, Lu, Zhong and Yao (2009) demonstrated that Figure 1 (A-B, B-C) is more cognitively demanding than Figure 2

(B-A, C-B). Johnson-Laird and Bara (1984) suggest that figural effects occur when participants integrate premises. Results of the present study suggest that the position of the end terms in each premise could indeed be an important factor in reasoning strategy for participants with dyslexia. Participants without dyslexia performed similarly across all Figures. Participants with dyslexia performed better than those without dyslexia on Figure 2, Figure 3 and Figure 4. Their performance was best on Figure 3, implying that solution is easier for participants with dyslexia if the end term is the subject of both premises.

This suggests the possibility that syllogisms are easier for people with dyslexia to solve if the end term is the predicate in the first premise and the subject of the second premise. Therefore, for Figure 1 and Figure 3, the reasoner would have to reverse the position of the end term so that it appears last. When it comes to integrating the second premise, they would have to reverse the end terms for Figure 1 and Figure 4. This will result in one change each for Figure 1 and Figure 4, and two changes for Figure 1 because the end terms have to be reversed for each of the premises. If we assume that the first premise forms the basis of judgment, at least for people with dyslexia, it can possibly explain the similarity in performance in Figure 2 and Figure 4. The first premise is in the correct order, so they only need to adjust the end terms in the second premise – meaning that only one additional operation had to be performed. Similarly, for Figure 3, the reasoner only needs to reverse the end terms in the first premise. Figure 1 is different from the others in that the end term is the subject of the first premise and the predicate of the second premise. This would require two operations to prepare it for calculation. The first premise must be adjusted so the end term becomes the predicate and the second premise must be adjusted so the end term becomes the subject. As Jia et al (2009) suggest, an increased demand on working memory can affect the calculation process, as disruption and impairment in processing can occur when information has to be moved between the modality-specific memory systems by the central executive.

The interaction between figure x dyslexic status provides some support for the notion that people with dyslexia tend towards a spatial strategy when reasoning (Bacon et al., 2007). Four out of the six Figure 3 (AB/CB) syllogisms were in the category that was easiest for spatial reasoners (Ford, 1995). Research by Smith-Spark, Fisk, Fawcett and Nicolson (2003) show evidence of verbal working memory impairments in people with dyslexia, while spatial memory appears to be largely unimpaired. Having to perform fewer operations with syllogisms in their favour may have afforded them a measure of advantage over their non-dyslexic peers.

Another explanation for the relatively poorer performance on Figure 1 syllogisms by participants with dyslexia is the notion of backward processing. Dickstein (1978) found that more errors occurred when the direction of information promotes backward processing of information. He highlights the fact that no significant difference occurs when both forward and backward processing leads to the same conclusion. The issue of phonological processing problems may hinder participants with dyslexia more so than participants without dyslexia.

People with dyslexia tend to perform less well in tasks that are particularly demanding in terms of phonological processing (Szenkovits & Ramus, 2005). A deficit in phonological processing may be due to impairment in forming high-fidelity phonological representations or it may be impairment in memory for phonological representations. It has been suggested that phonological representations are unimpaired, and it is only phonological memory load that makes a difference (Swan & Goswami, 1997), and that the phonological deficit surfaces only as a function of certain task requirements, particularly those that involve short-term memory (Amitay, Ben-Yehudah, Banai & Ahissar, 2002; Banai & Ahissar, 2006; Ben-Yehudah, Sackett, Malchi-Ginzberg & Ahissar, 2001; Ramus & Szenkovits, 2008). Ramus and Szenkovits (2008) suggest the reason people with dyslexia perform poorly under memory load is because phonological representations are degraded, and some phonetic features are missing when they need to be repeated or discriminated; or the representations are intact but there is not enough capacity in their short term memory to carry out the tasks.

Wagner and Torgesen (1987) say the main characteristics of phonological deficit are poor phonological awareness involving conscious awareness and manipulation of phonological representations; poor verbal short term memory involving the storage of words for a short period of time in phonological buffers or cycling them through the phonological loop during processing; and slow retrieval of lexical phonological representations from long term memory. Research suggests that phonological representations in people with dyslexia are degraded and not distinct enough (Mody, Studdert-Kennedy & Brady, 1997; Snowling, 2000), coarsely coded, under-specified or noisy (Elbro, 1996; Hulme & Snowling, 1992a).
A phonological deficit creates an impairment in the ability to access phonological representations of words (Frith, 1985; Snowling, 2000; Stanovich, 1988).

Participants with dyslexia in the present study were faced with having to hold their original representations in working memory while trying to switch around the terms to solve the problems, meaning that those representations may have gradually become degraded over time. Figure 1 (AB/BC) requires backward processing (Dickstein, 1978) and will have likely put greater pressure on their working memory.

In addition, impairments to phonological working memory would affect conversion of representations from verbal to non-verbal.

A limitation of this study is that background reading and spelling measures were not taken for self-reporting participants and for those without dyslexia. The participants with dyslexia had already been assessed by the university disabilities office.

3.8. Study 2

The aim of this study was to observe the effect of belief bias in participants with dyslexia compared to participants without dyslexia. The study was conducted in two parts. Part 1 was a sentence-picture verification task to assess how participants with and without dyslexia represent and process linguistic structures. If people with dyslexia tend to adopt a spatial strategy (Bacon et al., 2007) and conceptualise information in a visuospatial rather than verbal way (Von Karolyi et al., 2003), it is expected that they will take longer on sentence comprehension as they will be more likely to take the extra step of converting the sentences into pictorial representations. Carpenter and Just (1975) describe a constituent comparison model which makes three assumptions: sentences are represented internally by logical propositions that are a function of the surface structure, pictures are represented internally by the logical propositions that are equivalent to the affirmative statement which describes them, and after both representations are formed they are compared until the constituent components are agreed or resolved.

Part 2 was a syllogism solving task. If people with dyslexia tend to use a more spatial approach to problem solving and are hindered by visually rich stimuli (Bacon & Handley, 2010), then it is expected that they might be more affected by visually rich belief bias syllogisms and therefore perform worse on those than participants without dyslexia.

Each of these stages is presented in turn, in terms of method and results.

3.8.1. Part 1 – Sentence-Picture verification

The aim of Part 1 was to compare the performance on a sentence-picture verification task of people with dyslexia to people without dyslexia. Participants were presented with true affirmative, true negative, false affirmative and false negative concrete and less concrete sentences in random order. From this point on, the less concrete sentences will be referred to as abstract. The participants could choose when to view a picture which either matched or did not match the sentence. Abstract sentences were paired with abstract pictures and concrete sentences were paired with concrete pictures. The experimental trials were manipulated so that half of the stimuli were abstract, while the other half were concrete. The abstract sentence stimuli were the words star and plus. The concrete picture stimuli were boat and plane. Boat and plane were selected as they were expected to be more likely to evoke strong visual imagery.

3.8.2. Method

Participants

A total of 39 participants took part in the experiment, 20 females (mean age 20.73, SD = 0.99) and 19 males (mean age 20.26, SD = 1.82). The participants were all Lancaster University students whose first language was English. Of the total amount of participants, there were 19 with dyslexia (8 female, 11 male) and 20 without dyslexia (11 female, 9 male). One participant's data was not used as he was not able to complete task 2.

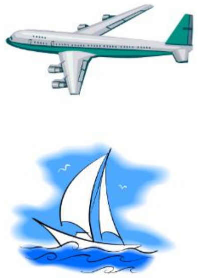
The participants with dyslexia were recruited through an advertisement in the Job Shop section of the Lancaster University Student Union website, a poster on the notice board in the department, and the Sona system (the Psychology Department's online participant recruitment system). Participants without dyslexia were recruited only through the Sona system. Participants were tested individually in sessions lasting one hour and were paid £6. No participant in Experiment 1 participated in Experiment 2.

Materials

The stimuli for the sentence-picture verification task were modelled from those used by MacLeod et al. (1978). The stimuli consisted of two sets of sentences and pictures, one abstract and the other concrete. The abstract set consisted of the sentences STAR OVER PLUS, PLUS OVER STAR, STAR NOT OVER PLUS, and PLUS NOT OVER STAR followed by a picture of either a star above a plus or a plus above a star. The concrete version consisted of the sentences PLANE OVER BOAT, BOAT OVER PLANE, PLANE NOT OVER BOAT and BOAT NOT OVER PLANE followed by a picture of either a plane above a boat or a boat above a plane. The pictures were all sourced from Microsoft Clipart. The stimuli were presented on a Mac computer in a research lab in the Psychology Department. The response keys were labelled TRUE and FALSE. The same computer was used for all participants. Figure 3.3 shows an example of the abstract and concrete stimuli.

Figure 3.3: Example of abstract and concrete stimuli.

Concrete: Plane over boat



Abstract: Star over cross

*

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Design and Analysis

A 2x2x2x2 mixed design was used. The within-subjects factors were sentence and picture type (abstract, concrete), positivity of sentence (is, is not), match between sentence and picture (match, no match). The between-subjects factor was dyslexic status. The dependent measures were the sentence comprehension time (RT1) and the picture verification time to identify whether the picture matched the sentence presented before (RT2) or not. Two sets of data were recorded for each trial: a) response time from presentation of the sentence to when the subject pressed a key for presentation of the picture and b) response time for when the subject selected true or false.

To ensure reliability of the data, only reaction times for correct responses that fell within three standard deviations above and below the overall mean within each condition for each participant were used in the analysis. All data fell within three standard deviations above and below the mean, so no data was omitted. Elimination of the incorrect responses resulted in a loss of 7% of the data collected.

Procedure

Participants in this study were not tested for cognitive ability. The multiple parts of this study precluded testing for cognitive ability due to time constraints. After reading a brief description of the experiment and signing a consent form, participants were given the following instructions:

> You are going to be asked to make judgments about whether a simple picture is true in relation to a sentence. Here's how the task will work. First, you will see the sentence for as long as you need. For example, STAR IS ABOVE PLUS may appear. When you are ready for the picture, click the 'OK' button. A half-second later, a picture will appear. Your task is to indicate whether this picture is true with relation to the sentence you just read. If it is, click the 'TRUE' button; if not click the 'FALSE' button. Then the next sentence will appear, and so on. What we are interested in is how long you spend in reading the sentence and on making your True-False judgment for the picture. You should try to go as quickly as you can, without making errors.

Participants were then given two practice trials and the opportunity to ask questions. The experimental stimuli were presented on a Mac computer in two blocks of 32 trials, with a short break in between. The order of sentences and pictures were fully randomised by the computer. Participants were instructed to indicate whether or not the picture matched the sentence by pressing keys on the computer keyboard labelled TRUE or FALSE. Pressing any key revealed the next sentence and then, pressing any key revealed the picture after a half second delay. Most participants ended up using the true and false keys to move the stimuli along.

3.8.3. Results

Mean response times were collated for each participant within each test condition (dyslexic abstract match, dyslexic concrete match, non-dyslexic abstract match, non-dyslexic concrete no match, and so on). The mean response times for sentence comprehension and picture verification across all conditions are presented in Table 3.8.

Table 3.8: Mean response time (in seconds) for sentence-picture verification task.

	Sentence (RT1)				Picture (RT2)			
	Is		Is not		Is		Is not	
	Match	No-match	Match	No-match	Match	No-match	Match	No-match
Dyslexic abstract	2.61	2.60	3.54	3.52	1.40	1.78	2.14	2.65
Dyslexic concrete	2.69	2.72	3.40	3.74	1.60	1.56	2.11	2.22
Non-dyslexic abstract	1.74	1.75	2.60	2.79	1.05	1.38	1.73	1.84
Non-dyslexic concrete	1.78	1.86	2.72	2.64	1.19	1.50	1.77	1.81

Sentence comprehension (RT1)

A 2 x 2 x 2 x 2 repeated measures ANOVA with sentence comprehension (RT1) as the dependent variable showed a significant main effect for verification response (is/is not), F(1, 35) = 94.19, $p < .001$. Viewing times were longer for negative sentences (M = 3.12, SD = 1.02) than for affirmative sentences (M = 2.22, SD = .70). The main effect of dyslexic status was significant, F(1, 35) = 9.43, $p < .05$. Overall, participants with dyslexia took longer to view the sentences (M = 3.10, SD = 1.20) than participants without dyslexia (M = 2.24, SD = 1.16). Table 3.9 shows the mean response times for participants with dyslexia and participants without dyslexia for affirmative and negative sentences. The main effect of sentence type (abstract/concrete) was not significant, F(1, 35) = .72, p = .40. The main effect of match was also not significant, F(1, 35) = 1.46, p = .24.

Table 3.9: Mean response times (in seconds) for participants with dyslexia and participants without dyslexia for affirmative and negative sentences.

	Affirmative (is)	Negative (is not)
Dyslexia	2.65	3.55
Non-dysexia	1.78	2.69

There was no significant interaction between sentence type x dyslexic status, F(1, 35) = .11, p = .74. There was also no significant interaction between affirmative/negative x dyslexic status, F (1, 35) = .001, p = .98 and between match/dyslexic status, F(1, 35) = .11, p = .75. The interaction between sentence type x affirmative/negative was not significant, F(1, 35) = .42, p = .52. The interaction between sentence type x match/no match was not significant, F(1, 35) = .20, p = .66. The interaction between affirmative/negative x match/no match was also not significant, F(1, 35) = .51, p = .48.

The interaction between sentence type x affirmative/negative x dyslexic status was not significant, F(1, 35) = .02, p = .88. The interaction between sentence type x affirmative/negative x dyslexic status was not significant, F(1, 35) = 1.96, p = .17. The interaction between affirmative/negative x match/no match x dyslexic status was also not significant, F(1, 35) = .35, p = .56. The interaction between sentence type x affirmative/negative x match/no match was also not significant, F(1, 35) = .006, p =

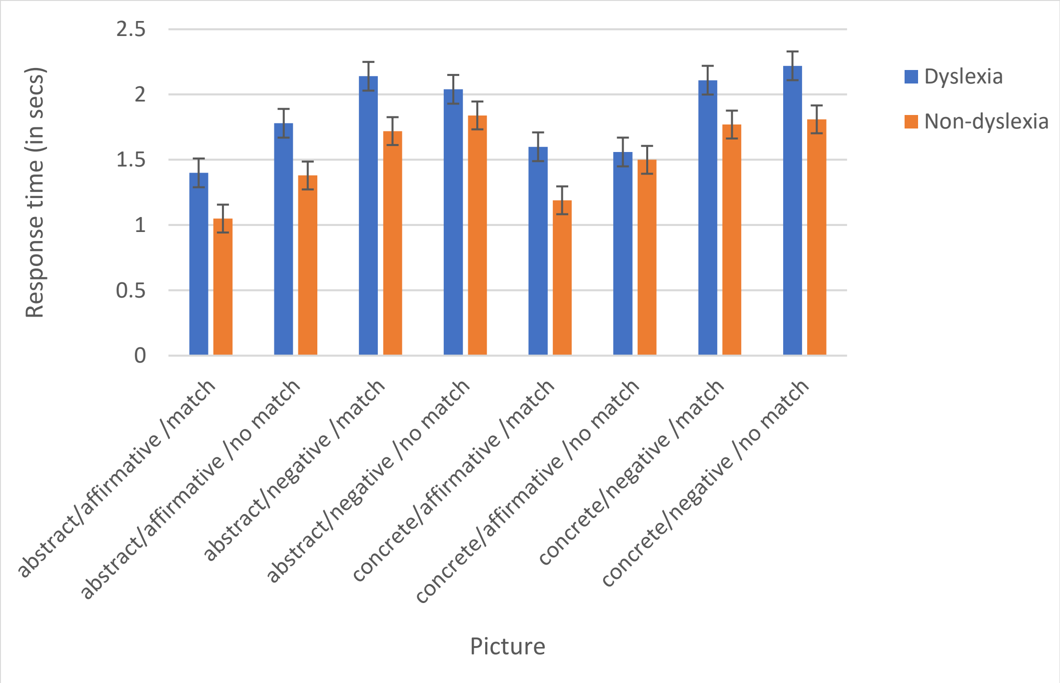
.94. The interaction between sentence type x affirmative/positive x match/no match x dyslexic status was not significant, F(1, 35) = 2.73, $p = .11$.

Picture verification (RT2)

A 2 x 2 x 2 x 2 repeated measures ANOVA showed a significant main effect for is/is not F(1,35) = 47.77, $p < .001$, indicating that response times were longer when a picture followed a negative sentence (M = 1.96, SD = .71) than when it followed an affirmative sentence (M = 1.43, SD = .41). There was also a significant main effect for match/no match F(1,35) = 8.302, $p < .05$, indicating that responses were longer when the sentence did not match the picture (M = 1.77, SD = .51) than when the sentence did match the picture (M = 1.63, SD = .59). The main effect of dyslexic status was not significant F(1,35) = 3.24, $p = .08$. The main effect of abstract/concrete was not significant, F(1, 35) = 1.10, $p = .30$.

There was a significant interaction between abstract/concrete x is/is not x match/no match x dyslexia/non-dyslexia F(1,35) = 5.41, $p < .05$. Participants with dyslexia took longer than participants without dyslexia to solve the problems across all conditions, with the longest time being when concrete pictures appeared with a negative sentence and did not match (Dyslexia: M = 2.22, SD = .75; Non-dyslexia: M = 1.81, SD = .65). See Figure 3.4. Comparing performance in each condition percentagewise, performance was most similar when concrete pictures appeared with a positive sentence and did not match (Dyslexia: M = 1.56, SD = .45; Non-dyslexia: M = 1.50, SD = .45), a difference of 4%, and the least similar was when concrete pictures appeared with a positive sentence and matched (Dyslexia: M = 1.60, SD = .57; Non-dyslexia: M = 1.19, SD = .32), a difference of 41%. Comparing performance in each condition timewise, performance remains most similar when concrete pictures appeared with a positive sentence and did not match, but is least similar when abstract pictures appeared with negative sentences and matched (Dyslexia: M = 2.14, SD = .90; Non-dyslexia: M = 1.73, SD = .85), a difference of 42 seconds.

Figure 3.4: Mean response times (in seconds) for abstract/concrete x is/is not x match/no match x dyslexic status.



The interaction between is/is not x match/no match was not significant, F(1,35) = 3.56, p = .067 (see Figure 3.5); as was the interaction between abstract/concrete x is/is not x match/no match F(1,35) = 3.74, p = .06 (see Figure 3.6).

The interaction between abstract/concrete x dyslexic status was not significant, F(1, 35) = .14, p = .71. The interaction between is/is not x dyslexic status was not significant, F(1, 35) = .05, p = .83. The interaction between match/no match x dyslexic status was not significant, F(1, 35) = 1.17, p = .29. The interaction between abstract/concrete x is/is not was not significant, F(1, 35) = .04, p = .85. The interaction between abstract/concrete x is/is not x dyslexic status was not significant, F(1, 35) =

.80, $p = .38$. The interaction between abstract/concrete x match/no match was not significant, $F(1, 35) = 1.20$, $p = .28$. The interaction between abstract/concrete x match/no match x dyslexic status was not significant, $F(1, 35) = .20$, $p = .66$. The interaction between is/is not x match/no match x dyslexic status was not significant, $F(1, 35) = .14$, $p = .72$.

Figure 3.5: Mean response times (in seconds) when pictures match or do not match affirmative and negative sentences.

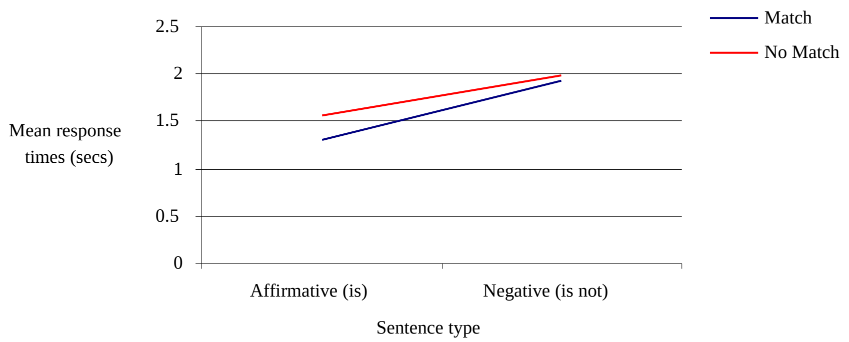
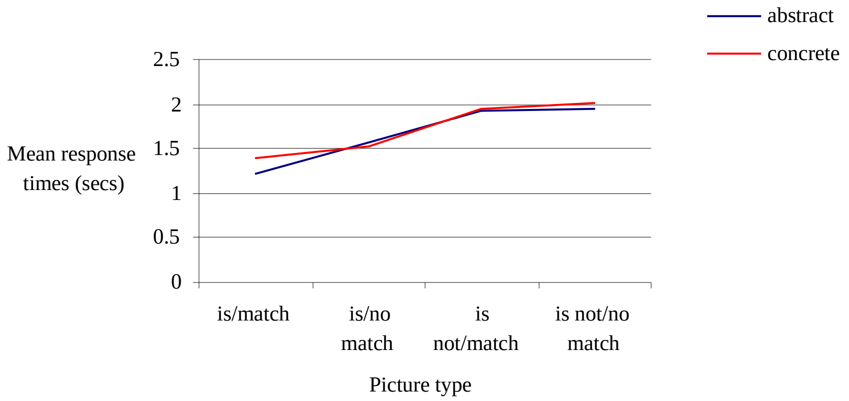


Figure 3.6: Mean response times (in seconds) for picture verification.



3.8.4 Discussion

Sentence comprehension

Overall, response times were longer for negative sentences than for affirmative sentences. Response times were also longer for participants with dyslexia than participants without dyslexia. The main effect for affirmative/negative sentences supports previous research that negatives slow down processing time (Gough, 1965; Slobin, 1966), which in turn suggests that individuals may be first converting negative terms into positive terms (Trabasso, 1970), thereby increasing sentence comprehension time.

The significant main effect of dyslexic status supports the notion of a phonological deficit in people with dyslexia (Snowling, 2000; Wagner & Torgensen, 1987). In the current study, participants in with dyslexia demonstrated longer response times than participants without dyslexia for both negative and positive sentences, so the suggestion that negatives slow down comprehension time cannot account solely for the differences. High processing demands increases the cognitive load and this can lead to deficits on both verbal and visuospatial working memory in people with reading disabilities (Smith-Spark, Fisk, Fawcett and Nicolson, 2003; Swanson, Ashbaker & Lee, 1996). Research suggests that visuospatial memory deficits come to the forefront only when the task at hand requires the person to engage with it verbally (Gould & Glencross, 1990; Thomson, 1982).

Picture verification

Overall participants took longer to judge whether a picture matched the sentence when it followed a negative sentence than when it followed an affirmative sentence. They also took longer when the sentence did not match the picture than when it did match the picture. The interaction between is/is not x match/no match which approached significance suggests that while responses were longer when sentences do not match pictures, the effect is greater when the no-match follows a negative sentence.

Perhaps after forming a representation of the affirmative sentence the subject already has an expectation of seeing a matching picture so when the picture turns out not to match the sentence, the subject then has to reformulate the picture representation and compare it again with the sentence. According to the constituent comparison model (Just & Carpenter, 1975), the initial representation of the sentence is based on the surface structure and the representation of the picture is based on the logical proposition, so the time to process the problem is influenced by whether or not there is a match between the sentence and the picture.

Another interesting interaction which also approached significance was abstract/concrete x is/is not x match/no match. The difference is greater when there is a match between an affirmative sentence and a picture. It appears that all things being equal i.e. affirmative sentence paired with a picture that matches expectations, working memory is ‘free’ to process information without constraints. These two interesting results, even though they are not significant, may be explained by the lack of a significant main effect of abstract/concrete. However, the power of this study will be low for a 4-way ANOVA.

One possible explanation for the lack of significant results for abstract/concrete conditions in picture verification could be that the cross and star pictures may have been seen as concrete images rather than abstract, so the only difference between the conditions was actually the affirmative or negative sentences and whether or not they matched the pictures. It is reasonable to say that everyone would have come across drawings of stars, for example in books or on Christmas cards, and crosses on a pharmacy sign or band aid box. In that respect, the star and cross would indeed be more concrete than abstract. More abstract stimuli can possibly be simple abstract drawings or non-alphabetic characters that are less likely to produce vivid imagery.

Finally, lack of significance for dyslexic status may be due to the reasoning process treating the abstract and concrete stimuli in the same way. Smith-Spark, Fisk, Fawcett and Nicolson (2003) have shown evidence of verbal working memory impairments in people with dyslexia, while spatial memory appears to be largely unimpaired. In the present study, the amount of effort required to process the linguistic structure would be relatively similar whether the picture stimuli is abstract or concrete.

Another possibility is the use of learned coping strategies. Kirby et al. (2008) reported that many students with dyslexia who have reached postsecondary studies have learnt various strategies, such as time management and the use of study aids, as well as deeper learning, for coping with their difficulties. Since the participants in the present study were all university students, they may be operating under whatever strategies or coping mechanisms they have learnt during their school years.

3.9. Part 2 – Syllogism solving

Part 2 examined the effect of belief bias in participants with dyslexia versus participants without dyslexia when solving syllogisms. participants solved 24 syllogisms in three conditions: abstract, neutral and belief bias. Abstract syllogisms contained single letter terms – A, B and C. Neutral syllogisms contained terms describing people or objects that were not related to each other. Belief bias syllogisms contained terms describing people or objects that could be related to each other. The hypothesis of this study is that participants with dyslexia might be more affected by visually rich belief bias syllogisms and therefore perform worse on those than participants without dyslexia when trying to solve them.

3.9.1. Method

Participants

The participants were those used in Part 1.

Materials

A paper workbook was used for the syllogism solving task. It contained three sets of syllogisms: eight abstract (eg All B are C, Some B are C), eight neutral (eg All politicians are potters, Some politicians are chess players), and eight belief bias (eg None of the snakes are poisonous, Some of the snakes are cobras). See Appendix 2 for a complete list of syllogisms used and their correct conclusions. The terms for the neutral and belief bias syllogisms, as well as some syllogisms in full, were taken from studies by Bacon et al. (2003, 2007), Cherubini, Garnham, Oakhill and Morley (1998), and Ford (1995). The problems types of the syllogisms were selected based on their level of difficulty for participants in Ford's (1995) study: one of the hardest for verbal reasoners only, one of the hardest for spatial reasoners only, the hardest for both types of reasoners, two of the easiest for both types of reasoners, and three of average difficulty for both types of reasoners. All problems were randomly sorted within each condition (abstract, neutral and belief bias), for a total of 24 syllogisms. Each condition contained the same problem types, i.e they contained the same problem types but with different terms. In each workbook, there was one syllogism per page, with a space for workings and several lines for participants to write their conclusion(s). The abstract syllogisms always appeared first, followed by the neutral, and then the belief bias ones. Three randomised versions of the workbook were produced. An Olympus digital voice recorder was used to capture verbal protocols. The time taken to solve each syllogism was timed with a stopwatch.

Design

A 2 x 3 mixed design was used. The within-subjects factor was type of syllogism (abstract, neutral, belief bias) and the between-subjects factor was dyslexia/non-dyslexia. The dependent measure was the number of syllogisms solved correctly.

A verbal strategy was judged to have been one where participants worked out the syllogisms as if they were mathematical equations, using notations such as equal signs, substituting letters for words, and using arrows to describe relationships between terms. A spatial strategy was one where participants attempted to solve the syllogisms by drawing diagrams similar to Euler circles to indicate relationships between the terms of the premises.

Procedure

Participants were first given an information sheet outlining the study. After signing a consent form, they were presented with one of the three randomised workbooks with the following instructions:

You are taking part in an investigation about how people use information in order to draw conclusions. You will be solving a series of syllogistic reasoning problems. A syllogistic problem consists of two premises (statements), for example:

Some B are A
All B are C

Your task is to write down the conclusion (if any) which follows logically from these. A logical conclusion is a conclusion which must be true, if the premises are true. In this example, notice that the B appears twice, once in each premise, and the A and C are non-repeated terms. You are to draw a conclusion about these non-repeated terms. The conclusion must be in one of the following forms, where the question mark stands for a non-repeated term in the problem.

All ? are ?
No ? are ?
Some ? are ?
Some ? are not ?
None ? are ?

For example, Some B are A
All B are C

Conclusion: Some of the Cs are As or Some of the As are Cs

As we are trying to find out how people solve these problems, it is vital that you ‘think aloud’ while you are working out your answers. Please speak out loud while solving each problem to explain to the experimenter how you reached your conclusion. There should not be any silent periods on the tape. We also need a written record of your work. Therefore, it is also vital that you use the pen and the space below the statements to show any working out that you use to help you solve the problems. Feel free to write or draw anything that helps you. When you have reached your conclusion, simply state that conclusion clearly in writing. You will be timed with a stopwatch. You will have 2 minutes for each problem. Do not refer to previous problems once you have completed them.

Participants were required to determine the conclusion for each pair of premises and indicate how they arrived at their conclusions. They were also required to speak out loudly as they solved the syllogisms to facilitate digital recording.

Upon completion of the testing session, participants were given a debriefing sheet that explained the purpose of the study. The information sheet, consent form and debriefing sheet are shown in Appendix 1.

3.9.2. Results

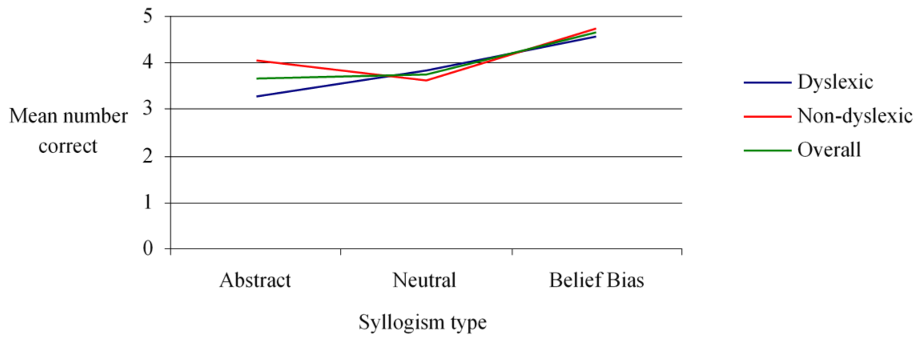
The mean score for all correctly solved syllogisms was combined within each condition, so each participant ended up with one average score for each of abstract, neutral and belief bias. The mean number of correct solutions is displayed in Table 3.10. A 2 (dyslexia, non-dyslexia) x 3 (abstract, neutral, belief bias) repeated measures ANOVA revealed a significant main effect of syllogism type, $F(2,70) = 6.774$, $p < .01$. More syllogisms were solved correctly in the belief bias condition ($M = 4.65$, $SD = 1.36$) than in the abstract condition ($M = 3.68$, $SD = 1.93$) and the neutral condition ($M = 3.73$, $SD = 1.56$). See figure 3.7. A pairwise comparison showed no significant difference between the abstract and neutral condition, but the difference between abstract and belief bias was $p < .01$, and between neutral and belief bias was $p < .05$.

There main effect of dyslexic status was not significant, $F(1, 35) = .37$, $p = .55$. The interaction between dyslexic status and syllogism type was also not significant, $F(2, 70) = 1.37$, $p = .26$.

Table 3.10: Mean number of syllogisms solved correctly.

	Abstract	*Neutral*	*Belief Bias*
Dyslexic	3.28	3.83	4.56
Non-dyslexic	4.05	3.63	4.74
Overall	3.68	3.73	4.65

Figure 3.7: Mean number of syllogisms solved correctly.



Despite instruction and, in some cases, a reminder, some participants still did not say out loud their workings, resulting in mostly silent recordings. There were five silent participants with dyslexia and one silent participant without dyslexia.

3.9.3. Discussion

Study 2 focused on the reasoning strategies of participants with dyslexia compared to participants without dyslexia when solving syllogisms. Participants solved 24 syllogisms in three conditions: abstract, neutral and belief bias. Abstract syllogisms contained single letter terms – A, B and C. Neutral syllogisms contained terms describing people or objects that were not related to each other. Belief bias syllogisms contained terms describing people or objects that were related to each other. Results showed only one significant main effect of syllogism type where more syllogisms were solved correctly in the belief bias condition than in the abstract and neutral conditions. A similar number of both abstract and neutral syllogisms were solved correctly. There was no main effect or interaction of dyslexic status. Despite instructions, a little more than half of the participants failed to write out their workings. Of those that did, the majority demonstrated a verbal strategy. The number of participants who demonstrated a spatial strategy was not enough to conduct a separate analysis of verbal versus spatial strategies. Participant 27 who did not speak her workings out loud said "If I say my thoughts as well, I lose what I think sometimes", while a few others barely spoke. Participants in the present study solved 25% more belief bias syllogisms correctly than both the abstract and neutral syllogisms. This could be due to the fact that belief bias terms were easier to imagine even if they did not make sense to the participant.

Despite being given instructions to show their workings in the space provided, only seventeen out of the thirty-nine participants did so. Of those that showed workings, six were male (3 with dyslexia, 3 without dyslexia) and eleven were female (4 with dyslexia, 7 without dyslexia). Examination of their written protocols revealed that the majority of those participants (6 with dyslexia, 9 without dyslexia) appeared to adopt a verbal strategy, while the remaining two participants (1 with dyslexia, 1 without dyslexia) appeared to adopt a spatial strategy. An examination of the verbal protocols did indeed reveal participants speaking of substituting letters for words and describing mathematical operations or referring to objects or people in their respective groups.

Each participant was asked about their experience during the experiment. Almost all participants found the abstract syllogisms the hardest, and those with neutral and belief bias terms easiest. No participant distinguished between specific neutral and belief bias syllogisms, as though all syllogisms in both of these categories were considered one and the same. They reported that the problems were easier when they had something specific, meaning an object or person description, to think about. Some participants appeared to think of the task as letters versus words. For example, participant 32 was “worried that if I thought of them as words, the logic would contradict what you know”, while participant 30 felt “you have to see past that and see it as an arbitrary object” and “objects are easier to visualise even if they don’t go together”. Participant 23 felt it was easier to “say it as a sentence, which made it easier to reason”, while participant 2 said “the words are easier when you have something to picture”, and participant 19 said “I was trying to think of them as numbers not letters”.

Interestingly, with the belief bias syllogisms, they reported having to “throw reality out of the window” (participant 8) in order to work logically, and the fact that you “can always put the other ones in context” (participant 6), and “when it started to be animals and stuff, I could visualise it more” (participant 9). Participant 30 said “It was very easy to get thrown by the ones that were things that were obviously you know would ordinarily expect them to go together, like the red roses, but no flowers are red. You’d have to see past that I guess and just see it as an arbitrary object”.

Again, despite instruction and, in some cases, a reminder, some participants still did not say out loud their workings, resulting in mostly silent recordings. Even though there were no significant results for dyslexic status, it is interesting to note that the ‘silent’ participants were predominantly dyslexic. It is possible that the dual task of narrating and solving the problems affected the performance of participants with dyslexia. The Dyslexia Automatisation Deficit Hypothesis can account for the difficulties experienced by these participants (Nicolson & Fawcett, 1990; Yap & Van der Leik, 1994), where if the first task is not performed automatically then there are not enough cognitive resources available for them to perform the second task. Solving syllogisms is not an everyday type of task and was new to all participants. Having to consciously focus on performing the task while thinking about and verbalising the process at the same time will have increased cognitive load competing for working memory space in the central executive (Smith-Spark et al., 2003).

In comparison with the Bacon et al. (2007) study, when results were combined across dyslexic and non-dyslexic status, participants performed similarly in the abstract condition. Based on the nature and terms used, Bacon et al.'s concrete (English) condition can be equated to the neutral condition in the present study, thereby making the performance in that condition also similar. That is, the terms used in the concrete (English) condition were of generic sporting occupations, while those in the present study were people and generic occupations or activities. The present study failed to find any differences between participants with dyslexia and participants without dyslexia. In fact, participants appeared not to be hindered by the 'concreteness' of the terms in the belief bias condition. Rather, the concreteness appeared to assist the reasoning process regardless of dyslexic status. Using terms in the premises that are related to each other may have made it easier for participants to reason about them. This is evidenced by the fact that many participants reported that the syllogisms containing words were easier and that the belief bias syllogisms were judged as easier than the neutral syllogisms.

Cherubini, Garnham, Oakhill and Morley (1998) have suggested that belief bias is suppressed when previous knowledge is incompatible with the premises, and therefore the premises are always considered. Testing English and Italian participants on syllogisms (the syllogism presented to Italian participants were translated from English to Italian) in which all the conclusions were valid, they found that true invalid conclusions were drawn when they were compatible with the premises and the valid conclusion was unbelievable. They hardly found instances of participants producing an invalid true conclusion to incompatible premises. Cherubini et al. (1998)

hypothesise that the background is modelled first. That is, previous knowledge relating the end terms is retrieved first, premises are checked to see if they are compatible with that knowledge, and then the previous knowledge is accepted as a true conclusion from the premises. If the previous knowledge is incompatible with the premises, the reasoning process starts anew and continues until a logical conclusion is found.

The use of letters in the abstract condition seemed to be confusing for all participants as almost all of them stated that the letters were the most difficult and it became easier when the problems suddenly switched to words, and even easier when they made sense. It can be argued that some of those that did show workings substituted letters for terms in the other conditions, so there should not have been much difference in performance. The performance by all participants was not much better for substituting letters for words in the neutral condition. It is possible that neutral terms that are unrelated to each other are treated in the mind as abstract as opposed to belief bias terms that bear some sort of relationship. Attesting to this is a classic study by Wilkins (1928) found that replacing the abstract letters A, B or C with actual words improved syllogistic reasoning, and demonstrated that when the content of the syllogism conflicted with the participant's beliefs their performance was worse, but it was not as bad as when abstract or nonsense words were used.

A problem with this study was participants not writing out their workings despite instructions to do so. One solution may be to provide examples in verbal, spatial and non-specific formats and, hopefully, participants would gravitate towards their preferred style.

3.10. Conclusion

Study 2 observed the effect of belief bias in people with dyslexia compared to people without dyslexia when solving syllogistic reasoning problems. It was conducted in two stages: a sentence-picture verification task to assess how participants with and without dyslexia represented and processed linguistic structures, and a syllogism solving task to determine how they were affected by visually rich stimuli in belief bias syllogisms. Participants with dyslexia took longer on sentence comprehension than participants without dyslexia, suggesting that participants with dyslexia tended more towards a visuospatial or pictorial strategy of converting the sentence representations into pictorial representations before processing the information. However, no difference between participants with dyslexia and participants without dyslexia, with regard to belief bias, was found. A phonological deficit can also account for the slower processing of the syllogisms by participants with dyslexia. Ramus and Szenkovits (2008) suggest the reason people with dyslexia perform poorly under memory load is because phonological representations are degraded, and some phonetic features are missing when they need to be repeated or discriminated; or the representations are intact but there is not enough capacity in their short term memory to carry out the tasks. Impairments to phonological working memory would affect conversion of representations from verbal to non-verbal. Research by Smith-Spark, Fisk, Fawcett and Nicolson (2003) shows evidence of verbal working memory impairments in people with dyslexia, while spatial memory appears to be largely unimpaired.

The results suggest that while participants with dyslexia demonstrated a more visuospatial strategy in sentence comprehension, as evidenced by their slower performance, both types of participants were affected by the visual imagery of the belief bias premises in the syllogism task. Clement and Flamagne (1986) suggested that materials that are easy to imagine leads to fewer errors in verbal processing. Since the heuristic system is assumed to use prior knowledge (Sloman, 1996), the data from the present study adds support to the notion that when there is conflict between the premises presented and prior knowledge or beliefs, the analytic system takes over and continues to reassess the premises until a logical solution is found. When forced to make judgements about real world attributes, those that make sense in the reasoner's frame of reference, people may reason more from a visuospatial sense than a verbal sense because the terms of the premises are people or objects that they can relate to. This in turn makes it easier to reason logically.

3.11. General discussion

The experiments in this chapter examine individual differences in reasoning strategies. An attempt was made to identify the predominant strategy for the different groups of participants based on categories of syllogisms identified by Ford (1995) with respect to whether they are easy or hard to solve by spatial or verbal reasoners. It was found that people with dyslexia are affected by figure.

The experiments attempted to show if these same participants are affected by belief bias and if this can be related in any way to a verbal or spatial strategy, and how strategy is influenced by the believability of the premises.

The results of Study 1 showed no overall difference between participants with dyslexia and participants without dyslexia, but a significant difference became apparent when the data was analysed by problem type. Performance was almost identical for EV and HSV but was higher for ES. The results support the hypothesis that people tend to reason in a verbal or spatial manner (Ford, 1995) but failed to support the hypothesis that there is a difference in strategy selection between participants with dyslexia and participants without dyslexia.

Some studies have shown that the figure of the syllogism can affect reasoning (Johnson-Laird & Bara, 1984; Stupple & Ball, 2007). Handley et al. (2004) found evidence that figural bias occurred in the absence of belief bias in a production task. Research has suggested that syllogistic reasoning is affected by the position of the terms (Wetherick & Gilhooly, 1990; Polk & Newell, 1995; Chater & Oaksford, 1999; Yule & Stenning, 1992). Jia, Lu, Zhong and Yao (2009) demonstrated that Figure 1 (A-B, B-C) is more cognitively demanding than Figure 2 (B-A, C-B). Johnson-Laird and Bara (1984) suggest that figural effects occur when participants integrate premises. Results of the present study suggest that the position of the end terms in each premise could indeed be an important factor in reasoning strategy for people with dyslexia. While participants without dyslexia performed similarly across all Figures, participants with dyslexia performed worst with Figure 1. Their performance was best on Figure 3, implying that solution is easier for people with dyslexia if the end term is the subject of both premises.

This suggests the possibility that syllogisms are easier for people with dyslexia to solve if the end term is the predicate in the first premise and the subject of the second premise. Therefore, for Figure 1 and Figure 3, the reasoner would have to reverse the position of the end term so that it appears last. When it comes to integrating the second premise, they would have to reverse the end terms for Figure 1 and Figure 4. This will result in one change each for Figure 1 and Figure 4, and two changes for Figure 1 because the end terms have to be reversed for each of the premises. If we assume that the first premise forms the basis of judgment, at least for people with dyslexia, it can possibly explain the similarity in performance for Figure 2 and Figure 4. The first premise is in the correct order, so they only need to adjust the end terms in the second premise – meaning that only one additional operation had to be performed. Similarly, for Figure 3, the reasoner only needs to reverse the end terms in the first premise. Figure 1 is different from the others in that the end term is the subject of the first premise and the predicate of the second premise. This would require two operations to prepare it for calculation. The first premise must be adjusted so the end term becomes the predicate and the second premise must be adjusted so the end term becomes the subject. As Jia et al. (2009) suggest, an increased demand on the working memory can affect the calculation process. While high processing demands can lead to deficits on both verbal and visuospatial working memory in people with reading disabilities (Swanson, Ashbaker & Lee, 1996), visuospatial memory deficits come to the forefront only when the reasoner has to engage verbally with the task (Gould & Glencross, 1990; Thomson, 1982). Earlier representations may become degraded (Ramus & Szenkovits, 2008) and thereby not available for use later in the reasoning process.

The results of Study 2 showed overall response times were longer for negative sentences than for affirmative sentences. Response times were also longer for participants with dyslexia than participants without dyslexia. The main effect for affirmative/negative sentences supports previous research that negatives slow down processing time (Gough, 1965; Slobin, 1966), which in turn suggests that individuals may be first converting negative terms into positive terms (Trabasso, 1970), thereby increasing sentence comprehension time.

The significant main effect of dyslexic status supports the notion of a phonological deficit in people with dyslexia (Snowling, 2000; Wagner & Torgensen, 1987). Participants with dyslexia had longer response times than participants without dyslexia for both negative and positive sentences, so the suggestion that negatives slow down comprehension time cannot account solely for the differences. Macleod et al. (1978) have suggested that there are individual differences in reasoning, where participants tend to adopt either a linguistic or a pictorial-spatial strategy. The possibility exists that participants with dyslexia tended more towards employing a visuospatial or pictorial strategy of converting the sentence representations into pictorial representations before processing the information. While the results fit the pattern, participants in this study were not tested for their verbal or spatial ability, so it cannot be assumed that this was generally the case.

CHAPTER 4: VERBAL STRATEGIES

4.1. Similarities and differences between visual or spatial processes and verbal or rule-based processes in problem solving

Deductive and analytic reasoning has been at the core of psychological theory, with William James examining the role of analysis and abstraction in processes of deductive reasoning as one of the key properties of human thought (Mayer, 1977). A problem must be broken down into parts and each part must be examined in the light of its function within the problem at hand. The reasoner must perform a series of analytic operations, often in the abstract, by substituting some parts in other places to solve the problem or at least come to a viable conclusion (Mayer, 1977). There has been much research about the processes employed by individuals when solving problems. A major area of research has been on whether problem solving is based on visual or spatial processes (Johnson-Laird, 1983; Stenning & Oberlander, 1995), or verbal or rule-based processes (Rips, 1994). One way to conceive of this distinction is whether the premises are assumed to be mapped onto representations of a set of characteristics of a term, as in Mental Models theory, or mapped onto sets of relationships or rules as in the mental rules theory (Galotti, Baron & Sabini, 1986). Mental Models theory is discussed in Chapter 1, Section 1.3. It has been further suggested that the computational steps in the deductive process in Mental Models and the rule-based strategies are very similar (Stenning & Yule, 1998).

The introduction to this chapter focuses on the similarities and differences between visual or spatial processes and verbal or rule-based processes in problem solving. First, I will describe a mental models approach to problem solving, then review the rules based approach, before highlighting the potential overlap and distinctions between these approaches in terms of the type of representation used in problem solving and the operations over those representations. I will then highlight studies that have measured individual differences in use of spatial and verbal strategies for problem solving.

Mental Models (Johnson-Laird, 1983) is one version of a system using a visual or spatial representation for reasoning. It suggests that a spatial representation is used to represent sets of individuals with properties described by the problem. Rules-based approaches to the process of reasoning (Rips, 1994) suggest that the representation is verbal, and the operations are the manipulations of those verbal representations.

The main proponent of the Mental Models theory, Johnson-Laird (1983), proposes that the reasoner goes through three stages when reasoning through a problem. First, the reasoner generates an initial mental representation of the premises. The representation is generally based on existing knowledge about the sets of individuals referred to in the premises and will usually contain just enough information for the reasoner to gain a basic understanding of the problem. The knowledge is both explicit (what is stated in the premises) and implicit (what they may already know about the individuals). The second stage is to combine information from both premises to form a conclusion. If no conclusion is found, then the reasoner progresses to the third stage which involves searching for alternative models. The process is repeated until a valid conclusion is found or the reasoner decides there is no valid conclusion. Errors arise when the reasoner accepts a conclusion that appears to be valid. The more representations that need to be generated the greater the likelihood of errors occurring.

Rules-based processes suggest that people possess an inherent mental logic (Rips, 1994; Braine & O'Brien, 1998; Bacon, Handley & Newstead, 2003) and that the processes operate solely in manipulations of the premises (Braine & O'Brien, 1991; Galotti, Baron & Sabini, 1986; Rips, 1983). That is, the reasoner does not generate intermediate representations between the stages of reasoning but rather works through a sequence of logical operations on each premise. An initial representation of the premises is generated but this only acts as a short-term store and does not feature in the analysis process (Rips, 1983). The representation manifests as a verbal or abstract description of the premises. The reasoner then uses their inherent mental logic (Roberts, 1993; Rips, 1989) to work through the problem and generate a conclusion. Logical operators such as 'and', 'not', and 'if…then' determine which rules are brought to bear on the problem at hand (Manktelow, 1999). Two or more rules can be used in conjunction with each other to work on the problem but subsequent representations are not generated as is the case with mental models. The system does not combine intermediate solutions to form a new representation to be worked on. Rather, it applies rules to the abstract logical form that has been extracted from the premises and if a conclusion has not been found it moves on to apply further rules. Common rules applied are modus ponens (if A then B, and A, then B) or modus tollens (if A then B, and not B, then not A) where the problems are re-encoded to match a set of rules. If there is no match it is re-encoded again until a solution has been found. Errors occur due to the number of logical operations that must be performed on the representation in order to draw a conclusion or to determine that there is no valid conclusion. The more operations that are performed, the more likely the reasoner is to be taken in the wrong direction, and therefore the greater likelihood of errors.

Research suggests that many people tend to adopt either a visuospatial or a verbal strategy for problem solving (Ford, 1995; Bacon, Handley & Newstead, 2003; Bacon, Handley, Dennis & Newstead, 2008). Verbal reasoners manipulate the verbal form of the syllogism, rearranging the terms of the premises and using rules to determine a conclusion. Spatial reasoners manipulate the model, using spatial arrays to determine the conclusion. The distinction between visuospatial and verbal strategies was also observed in sentence-picture verification studies (MacLeod, Hunt & Matthews, 1978) where preferences were associated with performance on independent tests of verbal and spatial ability. Roberts, Gilmore and Wood (1997) found some participants in their compass point direction study were able to switch their strategies according to the demands of the tasks. Chater and Oaksford (1999) suggest reasoners may be forced to change their strategy depending on the information presented at the time, as well as the demands of the task, and this leads to individual differences.

Ford (1995) found that out of 20 participants, eight participants in her study used verbal substitutions as reflected in their oral descriptions of problem solving strategies, substituting one premise term for another to arrive at a conclusion. She reports that the participants viewed one premise as having a term that needs substituting and the other premise providing that term. The premise that provides the value for substitution acts as a rule for relating B to A, while the premise containing the term which needs to be substituted acts as a case whose status with regards to A or C is known. She proposed four rules for substitution:

A. If a rule exists affirming of every member of the class C the property P then:

(i) whenever a specific object, O, that is a member of C is encountered it can be inferred that O has the property P and

(ii) whenever a specific object, O, that lacks property P is encountered it can be inferred that O is not a member of C

B. If a rule exists denying of every member of the class C the property P then:

(i) whenever a specific object, O, that is a member of C is encountered it can be inferred that O does not have the property P and

(ii) whenever a specific object, O, that possesses the property P is encountered it can be inferred that O is not a member of C

According to Ford (1995), verbal substitutions can predict which syllogisms are likely to yield errors. The participants in her study who used verbal substitution performed poorly. She reports that neither the spatial nor the verbal reasoners showed evidence of using mental models. The spatial reasoners appeared to manipulate a model where the class itself rather than the finite members of the class was represented. The verbal reasoners tended to use the inference rules of modus ponens and modus tollens.

Bacon, Handley and Newstead (2003) conducted a study to replicate and extend Ford's findings by testing her predictions on a larger sample. The aims of their study were to clearly identify verbal and spatial reasoning strategies, as well as gaining insight into strategy choices without the drawbacks of verbal protocols. participants were presented with all 27 syllogisms that were used in Ford's study and a questionnaire that was designed to identify the reasoning strategies they used. They were randomly assigned one of two conditions: a verbal and written protocols group or a written protocol only group. The verbal and written protocol condition was a direct replication of Ford's study where participants were asked to solve all 27 syllogisms and their verbal protocol was tape-recorded. The written protocol only condition required the participants to solve all 27 syllogisms and write down their reasoning strategies in whichever way suited them best. participants in both conditions were asked to complete the questionnaire about the strategies they used.

The study confirmed Ford's finding that reasoners tend to be spatial or verbal. participants in the verbal and written protocol group demonstrated evidence of individual differences. Verbal reasoners referred to activities such as replacing, substituting and cancelling terms. Spatial reasoners described the terms by their perceived relationships in groups or subsets. The verbal reports from the verbal and written protocol condition did not always provide sufficient evidence of the strategy the participants used. The written protocol only reports were more clear-cut, making it easier to distinguish between verbal and spatial strategies.

Verbal reasoners appeared to apply naive substitution (Ford, 1995) by simply taking the value of the B term from the first universal affirmative premise they encountered and substituting it into the other premise to get a conclusion with the same quantifier as that premise. Bacon et al. (2003) observed that while the verbal reasoners appeared to begin the reasoning process with the universal affirmative premise, the spatial reasoners appeared to begin with the first premise presented to them, regardless of the form or mood, and they simply added the information from the second premise. The questionnaires in both conditions supported the notion of spatial and verbal strategies. The study failed to find the within-strategy variations that Ford (1995) identified as a function of type of substitution rule (verbal) or constraint of premises (spatial). Rather, reasoners showed a consistent approach for all problems. Verbal reasoners tended to provide a conclusion that matched the form of one of the premises. They tended to process the universal affirmative 'All' first, regardless of whether that premise was presented first or second. This lends support to Wetherick and Gilhooly's (1995) claim that participants adopt this matching heuristic if they are unable or unwilling to reason with logic. Bacon et al. (2003) found evidence that some participants appeared to be using a combination of verbal and spatial strategies. This raises the question of whether it is possible to teach a particular strategy for solving syllogisms.

4.2. Training and Strategies

Training is the process of learning or developing new skills with the ultimate goal of improving performance in a particular area. Various studies have considered the effect of training participants to solve syllogisms using one or more methods, most commonly a spatial or rule-based method. Interventions demonstrate alternative ways of solving problems. Training has been shown to improve reasoning skills and abilities (Kruger & Dunning, 1999; Morris & Nesbitt, 1993; Leighton, 2006; Prowse, Turner, & Thompson, 2009). Nisbett et al. (1987) propose that people do make use of inferential rules and that they can be readily taught. They argue that when people reason with logic they tend to match their process to the solution. Leighton (2006) reports a decrease in reported rule-based strategies and a significant increase in model-based strategies with the improvement of categorical reasoning skills.

However, the effects of training might vary according to individual differences. Individual differences in abilities and style preferences influence how people respond to information presented to them (Monaghan & Stenning, 1998). Some people prefer to process information visually through graphics, diagrams and illustrations (Johnson-Laird & Bara, 1984; Kirby, Moore & Schofield, 1988) while others may prefer to process the information verbally or linguistically (Rips, 1994;

Braine & O'Brien, 1998). MacLeod, Hunt and Matthews (1978) demonstrated that preferences for visuo-spatial representations are linked to high spatial ability. MacLeod et al. (1978) demonstrated that the difference in reaction times on the Sentence Picture Verification task is a reliable indicator of style preferences. Psychometric tests of verbal and spatial ability of their participants correlated well with the RT scores of the Sentence Picture Verification task in terms of whether encoding the picture or the sentence took longer for participants. Prowse, Turner, and Thompson (2009) report evidence that reasoners may spontaneously use a visual strategy as they observed participants drawing diagrams when they were not instructed to do so. It has been suggested that constructing a verbal mental model influences deductive spatial reasoning (Krumnack, Bucher, & Nejasmic, 2010).

Monaghan and Stenning (1998) compared the performance of two groups of participants after being trained on either Euler Circles (EC) or natural deduction (ND) strategies. Participants were assigned to groups based on their scores on the GRE Analytic Reasoning Test (a test for analytic skills) and the PFT (a paper folding test for spatial skills (French, Ekstron & Price, 1963). In addition, their processing style was assessed as serialist or holist (Ford, 1985). The researchers hypothesised that participants with high GRE scores would perform better on EC and worse on ND.

The participants were presented with eight syllogisms (five with valid conclusions and three with no valid conclusion) and were asked to speak aloud their thought processes while they solved the problems. The sessions were recorded on video and the verbal protocol was also transcribed. Nine participants were taught to use EC and eight were taught to use ND. All participants were taught their respective methods for the same amount of time. However, not all of them managed to complete the experimental task. The dependent variables were the number of errors and the number of corrective or directive interventions made by the instructors. Instructors intervened if there were queries or the participants needed to be pointed in the right direction. The independent variables were the taught strategy, processing style (serial or holistic), and the score on the PFT and GRE.

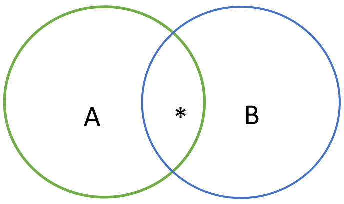
The results revealed that participants who scored high on the GRE test required more instructor interventions when translating premises into representation using the ND strategy and fewer interventions when translating into EC. When manipulating the representations, those high in GRE scores made fewer errors and required fewer interventions with EC but made more errors and required more interventions with ND. The serialists made more errors and required more interventions than the holistics with the EC. For the translating-out, the serialists made more errors and required more interventions than the holistics with EC.

The researchers suggest that serialists made more errors when forming conclusions using the EC strategy due to having to simultaneously consider all the information represented by each term in order to draw a conclusion. On the flip side, the holistics were better on EC because they are purportedly cognitively better at seeing the bigger picture than the serialists.

It has been further suggested that the computational steps in the deductive process in mental models and the rule-based strategies may be very similar (Stenning & Yule, 1998). Some reasoners appear to use a form of Euler Circles to solve categorical syllogisms (Stenning & Oberlander, 1994; Ford, 1995; Stenning & Yule, 1997). Euler Circles, attributed to the 18th Century Swiss mathematician Leonhard Euler, are diagrammatic representations of sets of items and their relationship to each other. Figure 4.1 is an example of Euler Circles representing the syllogism premise ‘Some A are B’. The circle on the left contains all the members of category A and the circle on the right contains all the members of category B. The area within the overlapping portion contains those members that are common to both categories and they are denoted by the asterisk. The reasoner would then create a similar diagram for the second premise followed by one that combines both premises to form a conclusion.

Figure 4.1: Example of Euler Circles representing ‘Some A are B’.

The asterisk denotes the relationship between A and B.



Stenning and Yule (1998) suggest that operations in Euler Circles can be matched to a simple natural deduction method in “a fragment of propositional calculus”. This notion suggests it is feasible to compare performances between the various strategies. For example, information may be presented graphically as in Euler Circles (see Figure 4.2) or in a sentential manner as in natural deduction (see Figure 4.3) and the reasoner must work through a logical process to determine a conclusion. Euler Circles combine the information about the terms from both premises into a diagram and then draws a conclusion from the relationship of both terms to the middle term. Natural deduction uses modus ponens or modus tollens to derive a conclusion. This is done in a serial fashion where each premise is considered separately and then a conclusion is drawn. The stages that are common to both methods are: translating the premises into the representation, manipulating the information, and translating the final representation to a conclusion (Monaghan & Stenning, 1998).

Figure 4.2: Completed example using Euler Circles.

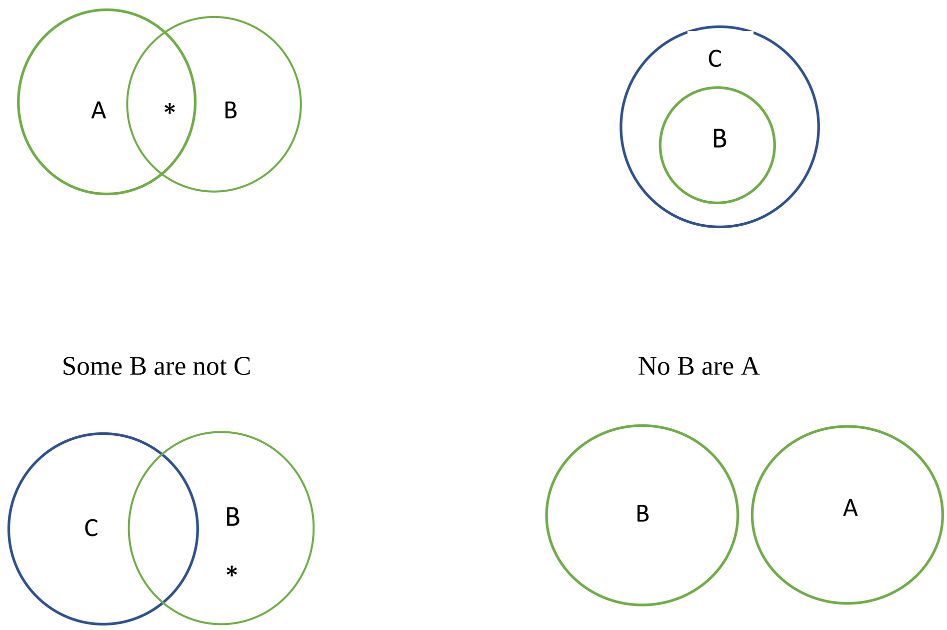


Figure 4.3: Examples of natural deduction representations.

Premise	**Representation**
Some A are B	A & B
All B are C	B → C
Some B are not C	B & ¬ C
No B are A	B →¬ A

Sternberg and Weil (1980) posit that reasoning strategies depend on verbal and spatial abilities. They describe several reasoning strategies. A spatial strategy where information from both premises is integrated and represented in a spatial array (De Soto et al, 1965; Huttenlocher & Higgins, 1972). A linguistic strategy (Clark, 1969) where information from the two premises is not integrated and is represented by deepstructural linguistic propositions. A mixed model where information is decoded into linguistic format and then recoded into a spatial format, the subject scans the spatial array for the correct answer then use the linguistic proposition to validate their conclusion. An algorithmic strategy (Quinton & Fellows, 1975) which is a surface-structural linguistic presentation and the subject uses a simple set of rules to solve the problem. A spatial-linguistic strategy (Johnson-Laird, 1972; Wood, Shotter & Godden, 1974) where the reasoner uses a spatial strategy first then switches to a linguistic one after some practice, and a linguistic-spatial strategy that operates in reverse (Shaver, Pierson & Lang, 1975) where the reasoner uses a linguistic strategy first then switches to a spatial one.

Sternberg and Weil (1980) used linear syllogisms to determine if it was possible to train participants to use particular reasoning strategies. A linear syllogism is one in which a comparison is made between terms that are based on more or less of a property or characteristic relative to each other. An example of a linear syllogism is, “John is taller than Bill, and Bill is taller than Pete. Who is tallest?”. Linear syllogisms can also involve negations, such as “Bill is not as tall as John.” Participants in the study were randomly assigned to one of three groups. The first group received no training in how to solve linear syllogisms. They were expected to work out their own method for solving the syllogisms. The second group received visualisation training in how to form spatial arrays. They were told to try and visualise the relationships presented in the syllogism statements in a pictorial format. They were also given examples of what an array might look like. The third group received algorithmic training using methods developed by Quinton and Fellows (1975). They were told to read the last question first, then the first statement, answer the question in terms of the first statement and then scan the second statement. The participants were required to read the statements and choose the answer they felt was correct from a panel.

The results showed a significant difference in mean response times for untrained, visualisation and algorithm. Further analysis revealed that the difference was only between algorithm and both of untrained and visualisation groups. There was no significant difference between the untrained and the visualisation groups. They found that algorithm training reduced response times relative to the untrained and visualization group, while visualisation training had no effect on response times relative to no training. It appeared that the visualisation group were solving the syllogisms in the same manner as the untrained group. This finding supports Prowse, Turner and Thompson's (2009) report suggestion that reasoners may be spontaneously using a visual strategy.

Research suggests that people with dyslexia are more likely to use spatial representations for syllogistic reasoning (Bacon & Handley, 2010). Bacon and Handley (2010) investigated the role of visual processes of participants with dyslexia when solving linear syllogisms by examining written and verbal protocols. Participants were presented with 16 sets of problems, eight that contained relational adjectives identified by Knauff and Johnson-Laird (2002) as being easy to imagine and eight that contained neutral adjectives. They were required to write down their workings and speak out loud their reasoning process as they worked. The results revealed a significant interaction between strategy and dyslexic status. There was no effect for accuracy as most participants achieved over 90% correct. The participants with dyslexia tended to generate explicit representations of the properties for both relational and abstract problems, while the participants without dyslexia tended to just order the properties. The results might provide support for earlier research by Egan and Grimes-Farrow (1982) who found participants they termed as ‘abstract directional thinkers’, which compares to the participants without dyslexia, possessed the ability to decipher relationships between items just by placing them in order, and ‘concrete-properties thinkers’, which compares with the participants with dyslexia, determined relationships by making visual comparisons between the properties.

4.3. Study: Performance of participants with dyslexia and participants without dyslexia after being taught a verbal strategy for solving syllogisms

Current research focuses more on discovering the processes by which participants with dyslexia solve problems, and not on what would happen if they were introduced to a new way of thinking about a problem. The present study compared the performance of participants with dyslexia and participants without dyslexia after being taught a verbal strategy for solving syllogisms. Using the groups of syllogisms that Ford (1995) found were easiest for spatial reasoners, easiest for verbal reasoners and equally difficult for both types of reasoners, it was predicted that participants with dyslexia would perform worse than the participants without dyslexia after learning the verbal strategy. Reasoners who would naturally process syllogism problems primarily in a spatial or visual manner are likely to experience some difficulty when expected to work through a specified series of steps to reason out a conclusion.

Research suggests that people with dyslexia may experience some difficulty switching from a default strategy (Bacon, Parmentier & Barr, 2013), the default being the strategy they would naturally choose to use. Miyake, Friedman, Emerson, Witzki, Howerter, and Wager (2000) make the claim that switching a strategy may involve specific executive processes: updating, inhibition, and shifting. Incoming information is monitored to determine how relevant it is, content in working memory is revised and updated, and then the new information is encoded. Teaching someone a new strategy involves a similar revision and updating process until it becomes automatic. The extra processing load that verbal (as opposed to spatial) material provides places increased pressure on working memory and may hinder the performance of people with dyslexia (Smith-Spark & Fisk, 2007).

4.3.1. Method

Participants

Participants were 30 Lancaster University undergraduate students: with dyslexia (13 female, 2 male) and without dyslexia (8 female, 7 male) with a mean age of 21 years (SD = 4.0). Due to practical and time constraints we were limited to collecting data from 15 participants with dyslexia and 15 participants without dyslexia. The mean age of the participants with dyslexia was 20 years (SD = 4.5) and the participants without dyslexia was 20 years (SD = 3.0). Participants without dyslexia were recruited via Sona, the Psychology department's online participant recruitment system. Participants with dyslexia were recruited, on the basis of self-identification, through advertisements placed on Job Shop on the Lancaster University Students Union website, notices in the stairwell of the Psychology building and via Sona. All participants were paid £10.50.

Materials

Raven's Standard Progressive Matrices was used as a test of general cognitive ability. No significant difference in cognitive ability was found between participants with and without dyslexia.

The pre-training workbook consisted of 12 syllogisms using neutral premise terms that were not related to each other (e.g. Some of the weavers are historians, None of the historians are tennis club members). All 12 syllogisms were taken from Ford's (1995) study and were selected based on the level of difficulty for the participants in her study: four that were shown to be easiest for verbal reasoners (EV), four that were easiest for spatial reasoners (ES), and four that were equally difficult for both types of reasoners (HSV). See Appendix 3 for the list of pre-training syllogisms used in the study. The 12 syllogisms were randomly sorted into three different orders, resulting in three different pre-training workbooks. Each syllogism appeared on a separate page with a clear space for workings and lines at the bottom of the page for writing out the solution(s). There was a separate line for each possible answer form (e.g. All…………… are…………..; Some………… are not…………; etc) to ensure participants correctly formatted their solutions.

The training booklet was a step by step guide that demonstrated how to solve each of three syllogisms using a verbal strategy based on the algorithm from Stenning and Yule (1998). There was a written description of each premise and how to combine the terms to solve the problems. The correct solution was provided for each example. The examples were all formats that appeared in the pre-training and post-training workbooks. Figure 4.4 shows a worked example from the training booklet. See Appendix 5 for a copy of the pre-training booklet.

Figure 4.4: Example from the training booklet.

An easy way of solving syllogisms is by examining the relationship between the terms of the premises. For example, take the syllogism

Some A are B
All B are C

Some A are B is represented as A & B, which means there's at least something that's an A and a B. There might still be some A that are not B, and some B that are not A, but we are only concerned with facts that we know about the premises.

All B are C is represented as B → C. This means that if you're a B, you're also a C. But there might also be C that are not B, we just don't know.

So, now we've got:

A & B
B → C

The next step is to see if we can apply a rule to join the two representations together.
We can break down the A & B into an A, and a B: A, B

Then, the next stage is to see if we can put either the A or the B with the B → C ("if you're a B you're also a C") representation.

In this case, we can:

From B and B → C, we can get C

So, we now have A, B, C. So, we can now get rid of the B:

A, C.

We can only use information we're certain of, that we have an A that's also a C, we don't know that all A are C, or all C are A. So the conclusion is: Some A are C.

The post-training workbook consisted of 12 syllogisms in the same forms as those in the pre-training workbook. The terms used, however, were different so as to prevent any interference from the pre-training set of syllogisms. See Appendix 4 for a list of post-training syllogisms. It was felt that some participants may remember the terms from the pre-training set and this may influence their solution or strategy. The post-training terms were also taken from the syllogisms used in Ford's (1995) study. The order was kept the same as for the pre-training workbook to control for order effects in the pre-training and the post-training workbooks, so each post-training workbook had a matching pre-training workbook. Each syllogism in the post-training workbook appeared on a separate page with a blank space for workings and lines at the bottom of the page for writing out the solution(s). See Appendix 7 for a copy of the pre-training and Appendix 8 for a copy of the post-training answer workbooks.

Design

A 2 x 2 x 3 mixed design was used. The between-subjects factor was dyslexic status (dyslexia, non-dyslexia) and the within-subjects factors were training (pre-training v post-training) and problem type (HSV, ES, EV). The dependent measure was the number of syllogisms solved correctly.

Procedure

Participants were tested in one session lasting approximately ninety minutes. They were asked to read an information sheet explaining that the main aim of the study was to examine how people reason and the different types of learning strategies that people use, and that we were particularly interested in whether there are different learning approaches for people with and without dyslexia, as well as the tasks they would be required to do. They were then asked to sign a consent form. They were free to withdraw from the study at any time without giving a reason and with no adverse consequences.

A shortened form of Raven's Standard Progressive Matrices was administered first. The problem solving task was administered immediately afterwards. The participants were presented with the pre-training workbook containing 12 randomised syllogisms. They were allowed two minutes to solve each syllogism. Upon completion of the pre-training workbook, participants were presented with the training booklet. They were allowed as much time as they needed to study the material and to ask the researcher questions for clarification. Immediately after the training session, the participants were presented with the post-training workbook containing 12 randomised syllogisms in the same order as the pre-training workbook, but with different premise terms. Again, they were allowed two minutes to solve each syllogism.

Upon completion of the experimental trials, participants were given a debriefing sheet explaining the aim of the study in greater detail and an outline of the study design.

4.3.2. Results

Results of the Ravens Standard Progressive Matrices indicated that all participants were of similar cognitive ability. The overall mean raw score was 5.7, with *SD* = 1.6 (dyslexic: *M* = 5.7, *SD* = 2.0; non-dyslexic: *M* = 5.7, *SD* = 1.2), indicating an age equivalence of 18 years. An independent samples t-test of the Ravens Standard Progressive Matrices scores revealed no difference between the groups, t (28) = .00, p = 1.0, d = 0.

The mean score for all correctly solved syllogisms was combined within each condition so each participant ended up with one average score for each of HSV, ES and EV syllogisms. The mean number of correct solutions is displayed in Table 4.1.

The data were analysed in a repeated measures 2 x 2 x 3 ANOVA. The between-subjects factor was dyslexic status (dyslexia, non-dyslexia). The within-subjects factors were training (pre-training, post-training) and syllogism type (HSV, ES, EV). The dependent measure was the number of syllogisms solved correctly.

Table 4.1: Mean number of correctly solved syllogisms.

	Pre-training		Post-training	
Syllogism Type	Dyslexia	Non-dyslexia	Dyslexia	Non-dyslexia
HSV	.27 (.29)	.33 (.28)	.30 (.31)	.55 (.33)
ES	.48 (.31)	.55 (.27)	.43 (.34)	.67 (.18)
EV	.55 (.33)	.68 (.31)	.48 (.42)	.73 (.27)

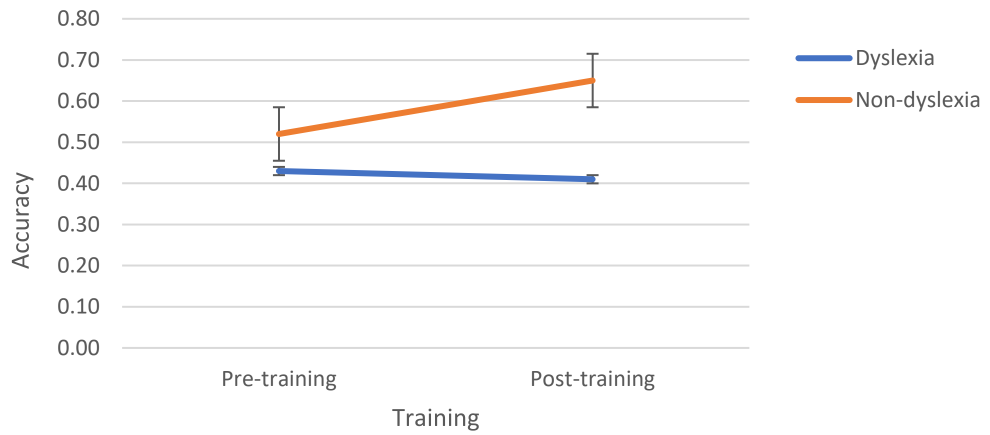
Note: N = 30 (15 participants with dyslexia and 15 participants without dyslexia). The number is parentheses is the standard deviation.

The results revealed a main effect of syllogism type $F(1, 28) = 17.64$, $p < .001$. Overall, performance was significantly better on EV (M = .61) than ES (M = .53) and HSV (M = .36). There was no main effect for training, $F(1, 28) = 2.17$, $p = .15$. The effect of dyslexia group approached significance, $F(1,28) = 3.72$, $p = .06$. The participants with dyslexia performed slightly worse (M = .42) than the participants without dyslexia (M = .59).

However, there was a significant interaction between training and dyslexic status, $F(1,28) = 5.26$, $p < .05$, but not between syllogism type and dyslexic status, $F(1,28) = .13$, $p = .87$ or between training and syllogism type, $F(1,28) = 1.93$, $p = .154$.

Figure 4.5 shows that overall performance improved for participants without dyslexia after training (pre-training M = .52, post-training M = .65) but not for participants with dyslexia (pre-training M = .43, post-training M = .41, SD = .36). Training on a verbal strategy did not have a positive effect on problem solving on the performance of participants with dyslexia.

Figure 4.5: Mean number of correctly solved syllogisms before and after training.



A post hoc 2 x 2 repeated measures ANOVA was conducted to compare the performance of participants with dyslexia to the performance of participants without dyslexia before and after training. The between-subject factor was dyslexic status (dyslexia, non-dyslexia), and the within-subjects factor was training (pre-training, post-training). There was no main effect of training, $F(1, 28) = 2.17$, $p = .15$ or dyslexic status, $F(1, 28) = 3.72$, $p = .06$. There was a significant interaction between training v dyslexic status, $F(1, 28) = 5.26$, $p < .05$.

A one-way between subjects ANOVA was conducted to compare the effects of pre-training and post-training for each group of participants. The results revealed no significant effect of training for participants with dyslexia, $F(1, 14) = .31$, $p = .59$. There was a significant effect of training for participants without dyslexia, $F(1, 14) = 7.45$, $p < .05$. Training on a verbal strategy benefitted the participants without dyslexia but not those with dyslexia.

To examine the nature of the interaction between training and dyslexic status, separate analyses were conducted between training and dyslexic status and each syllogism type, though it is noted that there were no significant interactions with syllogism type. Each 2 x 2 ANOVA was conducted with the between-subject factor as dyslexic status (dyslexia, non-dyslexia), and the within-subjects factors as training (pre-training, post-training). The results for each analysis are presented separately.

EV (Syllogisms that are easiest for verbal reasoners)

There was no significant main effect of training, $F(1,28) = .02$, $p = .90$ or dyslexic status, $F(1,28) = 3.31$, $p = .08$. There was no significant interaction between training and dyslexic status, $F(1,28) = .80$, $p = .38$.

ES (Syllogisms that are easiest for spatial reasoners)

There was no main effect of dyslexic status, $F(1,28) = 2.46$, $p = .13$. There was a significant interaction between training and dyslexic status, $F(1,28) = 4.64$, $p < .05$. The performance of participants with dyslexia decreased after training (Before training: $M = .48$, After training $M = .43$) while the performance of participants without dyslexia increased (Before training: $M = .55$, After training $M = .67$). Figure 4.6 shows that after training the percentage of correctly solved syllogisms decreased by approximately 10% for participants with dyslexia and increased by approximately

22% for participants without dyslexia. These results indicate that differences exist around the learning of strategies rather than their dyslexic status.

Figure 4.6: Mean number of correctly solved ES syllogisms in dyslexia v non-dyslexia before and after training.

HSV (Syllogisms that are equally hard for both verbal and spatial reasoners.

There was a significant main effect of training for HSV, F(1,28) = 6.28, $p < .05$. Figure 4.7 shows that overall performance improved after training. There was no significant effect of dyslexia, $p = .12$. There was no significant interaction between training and dyslexic status approached significance, F(1,28) = 3.38, $p = .08$, although participants without dyslexia showed some improvement (before; M = .33, after M = .55) after training compared to participants with dyslexia (before M = .27, after M = .30). See Figure 4.8.

Figure 4.7: Mean number of HSV syllogisms solved correctly before and after training.

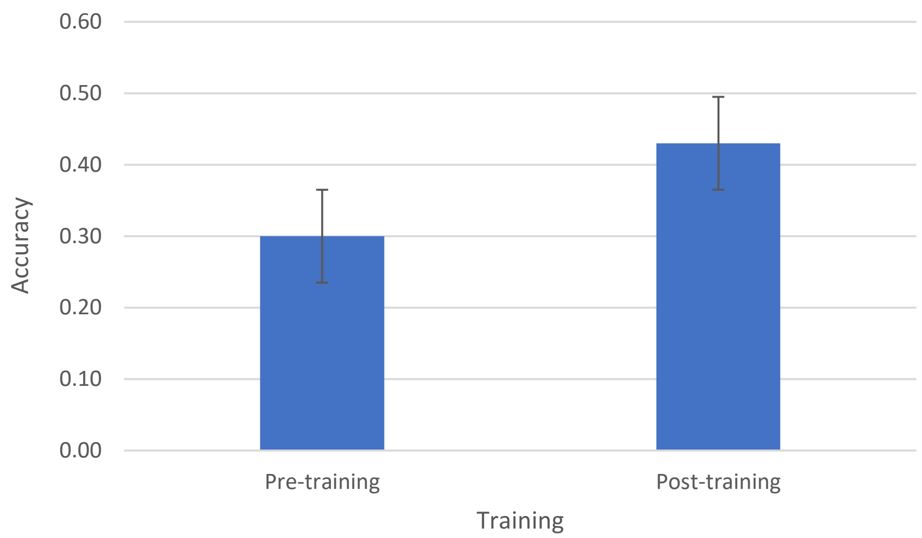
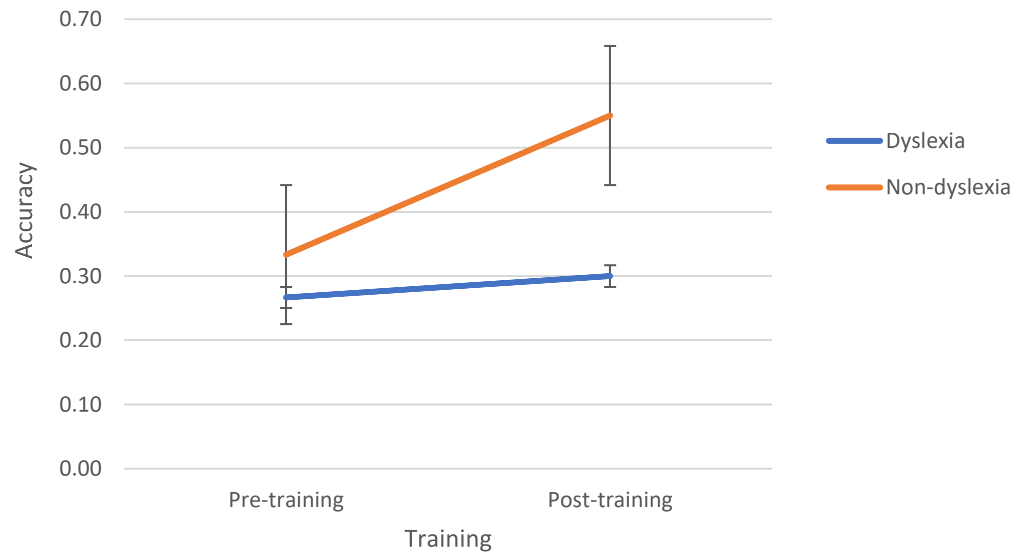


Figure 4.8: Mean number of correctly solved HSV syllogisms for participants with dyslexia v participants without dyslexia before and after training.



4.3.3. Additional analysis of reasoning strategy data

The pre-training workbooks were inspected for evidence of a clear reasoning strategy in order to determine whether participants' spontaneous strategy use in the pre-training items had an impact on the effectiveness of the training method. To count as clear evidence of a strategy the participant was required to present with at least four problems showing workings in a verbal or spatial strategy as described by Ford (1995). Four was chosen as the clear strategy criteria because the workbooks consisted of four of each type of syllogism - ES, EV and HSV, so a participant showing workings should show them in their predominant style corresponding to the relevant type of syllogism. Eight out of the 27 participants demonstrated a clear verbal strategy (2 with dyslexia, 6 without dyslexia), while four demonstrated a clear spatial strategy (2 with dyslexia, 2 without dyslexia). The 15 remaining participants either showed no workings at all or not enough workings to determine a clear strategy, so they were classified as undefined and their data was not included in the analysis.

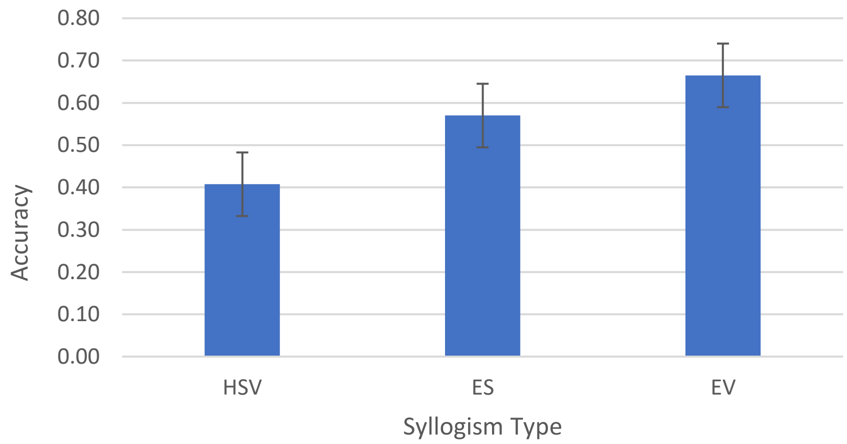
The data was not analysed by dyslexic status as there were fewer than four participants in three out of the four conditions. The data for the verbal and spatial participants was analysed in an explorative 2 x 2 x 3 ANOVA. The within-participants factors were training (pre-training, post-training) and syllogism type (HSV, ES, EV). The between-participants factor was reasoning strategy (clear verbal, clear spatial). The dependent variable was the number of correctly solved syllogisms. Table 4.2 shows the mean performance across all conditions.

Table 4.2: Mean accuracy across all conditions. Standard deviation is shown in parentheses.

Syllogism Type	Verbal Strategy		Spatial Strategy	
	Pre-training	Post-training	Pre-training	Post-training
HSV	0.34 (0.27)	0.47 (0.31)	0.38 (0.43)	0.44 (0.43)
ES	0.75 (0.19)	0.78 (0.16)	0.44 (0.38)	0.31 (0.24)
EV	0.81 (0.22)	0.84 (0.19)	0.63 (0.43)	0.38 (0.48)

The results yielded a main effect of syllogism type, F(2, 20) = 8.09, $p < .05$. Overall performance was poorer on syllogisms that are equally difficult for spatial reasoners as well as verbal reasoners (M = 1.48) than for syllogisms that are easiest for spatial reasoners (M = 2.19) and easiest for verbal reasoners (M = 2.55). See Figure 4.9.

Figure 4.9: Mean accuracy for syllogism type.

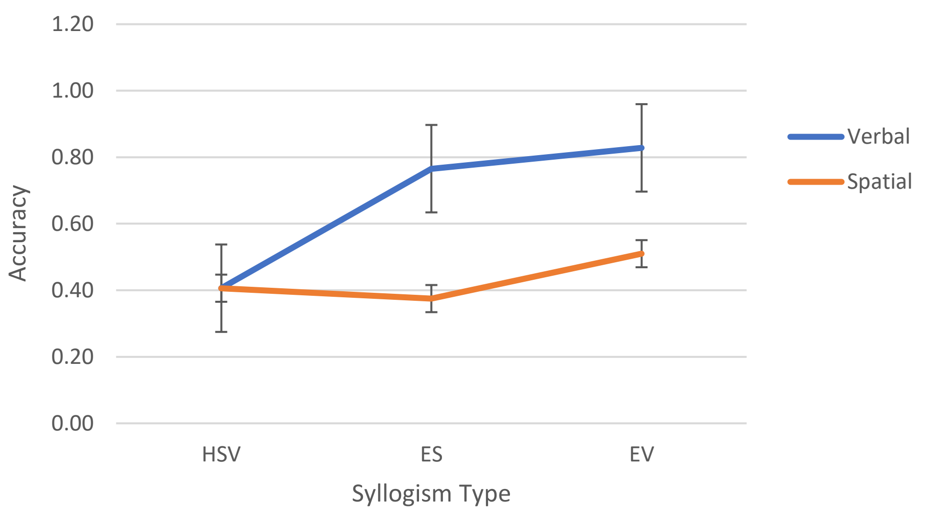


A post hoc separate independent-samples t-test was conducted for each problem type (HSV, ES, EV) to further examine the performance for clear verbal and clear spatial strategies. There was a significant difference for ES for verbal strategy (M = .77, SD = .16) and spatial strategy (M = .38, SD = .27), t(10) = 3.24, p = <.01.

There was no significant difference for EV for verbal strategy (M = .83, SD = .19) and spatial strategy (M = .50, SD = .42), t(10) = 1.92, p = .08. There was no significant difference for HSV for verbal strategy (M = .41, SD = .20) and spatial strategy (M = .41, SD = .41), t(10) = .00, p = 1.00. Overall, verbal reasoners correctly solved twice as many ES syllogisms using a verbal strategy than spatial reasoners.

There was a significant interaction between syllogism type and reasoning strategy, F(2, 20) = 5.23, $p < .05$. Verbal reasoners performed similarly to spatial reasoners in syllogisms that are equally difficult for both groups, and better than spatial reasoners in syllogisms that are easiest for spatial reasoners and in syllogisms that are easiest for verbal reasoners. See Figure 4.10.

Figure 4.10: Interaction between syllogism type and reasoning strategy.



There was no significant main effect of training, F(1,10) = .16, $p = .70$ or of strategy, F(1,10) = 3.05, $p = .11$. There was also no significant interaction between training and reasoning strategy, F(1,10) = 2.53, $p = .14$ or between training and syllogism type, F(2, 20) = 1.45, $p = .26$.

The data for the Ravens Standard Progressive Matrices for verbal and spatial reasoners were analysed. The results indicated that all participants were of similar cognitive ability. The overall mean raw score was 5.4 with SD = 1.5 (verbal: M = 6.3, SD = 1.8; spatial: M = 4.5, SD = 1.3). An independent samples t-test revealed $t(10) = 1.8$, $p = .11$.

4.3.4. Discussion

The study examined the effects of training participants to solve syllogisms using a rule-based strategy, comparing the performance of participants with dyslexia with that of participants without dyslexia. It was expected that reasoners who would naturally process syllogism problems primarily in a spatial or visual manner are likely to experience some difficulty when expected to work through a specified series of verbal or rule-based steps to reason out a conclusion. Furthermore, if people with dyslexia are more prone to using spatial representations for syllogistic reasoning (Bacon, Handley & McDonald, 2007; Bacon & Handley, 2010) then they were expected to be negatively affected by a rule-based strategy in comparison to their counterparts without dyslexia.

While the initial results showed that training on a verbal strategy improved performance of participants without dyslexia, and had a detrimental effect on participants with dyslexia, a separate analysis of the data for each problem type revealed the effect to be only for problems that are easiest for spatial reasoners. However, a closer inspection of the data for only those participants that showed a clear verbal or spatial reasoning strategy suggests that the difference in performance in each syllogism type is perhaps more a function of strategy choice rather than dyslexic status. If individuals with dyslexia are predominantly spatial reasoners (Bacon, Handley & McDonald, 2007), it would be difficult to distinguish them from spatial reasoners without dyslexia under these conditions, and this may account for the lack of a significant interaction with dyslexic status in the additional analysis of the data for clear strategies.

The interaction between dyslexic status and training is an important result. Participants with dyslexia were impaired with the training strategy. This has implications for how people with dyslexia are supported in their study materials. Forcing them to use a verbal strategy will make performance worse compared to their peers without dyslexia. While training has been shown to improve reasoning skills and abilities (Kruger & Dunning, 1999; Morris & Nesbitt, 1993; Leighton, 2006; Prowse, Turner, & Thompson, 2009), the training must consider the learning styles of individuals to be truly effective. Ramus and Szenkovits (2008) suggest that phonological deficit in dyslexia surfaces only as a function of certain task requirements, notably short-term memory, conscious awareness, and time constraints. A phonological deficit may also be associated with the short term memory processes operating on phonological representations (Smith-Spark, Fisk, Fawcett & Nicolson, 2003; Smith-Spark & Fisk, 2007) as well as the type of task rather than a specific stimulus (Amitay, Ben-Yehudah, Banai & Ahissar, 2002; Banai & Ahissar, 2006; Ben-Yehudah, Sackett, Malchi-Ginzberg & Ahissar, 2001). The Dyslexia Automatisation Deficit Hypothesis (DAD) can offer another possible explanation for difficulties experienced by people with dyslexia under dual task conditions (Nicolson & Fawcett, 1990; Yap & Van der Leik, 1994), in this case having to solve the problems with a newly learned strategy as well as producing workings on paper, because if the first task is not performed automatically then there are not enough cognitive resources available to perform the second task. These factors may impact on the ability of some participants with dyslexia to reason with a verbal strategy.

Participants demonstrating a clear verbal strategy achieved more correct solutions for ES (77%) and EV (83%) problems than those demonstrating a clear spatial strategy, ES (38%) and EV (51%). Post hoc tests showed that verbal reasoners correctly solved twice as many ES syllogisms using a verbal strategy than spatial reasoners. These results suggest that verbal reasoners are better able to apply rules to continue searching for solutions and so achieve more correct syllogisms than spatial reasoners. Rips (1983) posits that reasoners start with an initial representation that remains in place for a short space of time but does not feature in the analysis process. The representation is used to generate a verbal or abstract description of the premises, then the reasoner uses their inherent mental logic to work through the problem. Rules are applied to the problem and if no solution is found then further rules are applied for continued processing. This process is repeated until a solution is found. However, the greater the number of rules to be applied, and consequently the greater number of representations to be generated, results in an increased burden on working memory and leads to the likelihood of errors (Stupple & Waterhouse, 2009). Figure 3.9 shows where both types of reasoners start with almost identical scores in problems that they both find equally difficult to solve.

It is not clear why some participants chose to show workings for some syllogisms and not others. Examination of the remainder of workbooks that contained some workings, but not enough to be included in the analysis, revealed no obvious pattern. One possible reason is that participants were not able to manifest the premises into drawings or shapes, or to articulate them into equations, so resorted to working them in their minds. One spatial participant, who also happened to be dyslexic, reported that she struggles with words and it would have been better using pictures, and that she did not refer to the training booklet at all during the post-training section because it was “too hard”. In fact, she continued to use a spatial strategy for the post-training section as well. Prowse, Turner and Thompson (2009) suggest that confidence levels, the feeling of rightness, and believability of the conclusion (Shynkaruk & Thompson, 2006) can affect performance. Research by Quayle and Ball (2000) found another factor contributing to reduced confidence is increased load on working memory. This may cause the reasoner to resort to belief bias rather than logical reasoning. Confidence was not measured so its effect on performance can only be speculated upon.

Smith-Spark et al. (2003) demonstrated that an increased cognitive load can affect processing in the central executive in working memory. If disruption and impairment in processing occurs when information is moved around the systems in the central executive Smith-Spark et al. (2003), people with dyslexia are likely to spend more time and energy phonologically processing problematic words or trying to recognise a word within the context of familiar words than typical readers (Ramus, 2014; Shaywitz, 2005). The delay in phonological processing causes a decrease in retention of previously decoded words in working memory and if the words are remembered, their meaning are likely to be processed out of order, which can lead to improper comprehension (Mills, 2018) and therefore incorrect outward representation of the verbal or pictorial information.

A limitation of the current study is not employing a specific method for detecting strategies during the pre-test. For example, collecting verbal protocol would have provided confirmation of the participants’ thought processes, possibly indicating why they chose one strategy over another and more importantly, how they decided which problems to show workings for. Another useful method could be the use of psychometric tests such as the GRE Analytic Test and the PFT test used by Monaghan and Stenning (1998). The GRE Analytic Test measures the ability to analyse information and reason logically through problems and would be useful for determining the cognitive level and critical thinking skills of participants. The PFT (paper folding) test is a measure of spatial skills and the ability to visualise solutions to problems. The GRE Analytic Test and the PFT test can help determine a participant's dominant reasoning style and can offer possible clues as to why they did or did not completely follow the experimental trial instructions, as well as predict the predominant strategy they might use. Also, using a larger sample of syllogisms in the pre-test study would provide a better indication of which type of problems engendered one strategy or another for different participants.

The results of the current study partially supported the hypothesis that participants with dyslexia were impaired with the training strategy for solving syllogisms. This has implications for how people with dyslexia are supported in their study materials. Forcing the use of a verbal strategy will make performance worse compared to their peers without dyslexia.

CHAPTER 5: SPATIAL STRATEGIES

5.1. Spatial processing strategies

The aim of this chapter is to consider the effect of a spatial strategy when reasoning with syllogisms. It presents a description and evidence of spatial processing strategies, then goes on to present a study comparing the performance of people with dyslexia and people without dyslexia before and after learning to solve syllogisms using Euler Circles, a diagrammatic method used to reason about relations between terms.

Johnson-Laird, Savary and Bucciarelli (2000) define a strategy as a series of steps taken to solve a problem. Some people have been observed to employ a spatial strategy as one of the steps in the reasoning process (Ford, 1995; Bacon, Handley & Newstead, 2003). A spatial strategy is one where a reasoner creates a visuo-spatially-structured layout of the information in the problem at hand. Research has shown that people imagine a spatial layout when solving linear syllogisms (Byrne & Johnson-Laird, 1989) or create mental arrays of items and relations between items given in premises (De Soto, London & Handel, 1965). It is suggested that this strategy can reduce the load on verbal working memory and it is easier to manipulate than sentential information.

Different theories of reasoning proffer notions about what accounts for errors in solving syllogisms. Mental Models theory suggests that errors occur due to the number of representations the reasoner has to make to solve the problem (Johnson-Laird, 1983) because information has to be stored in memory while further information is added and integrated. Mental rules states that chains of rules are applied to the problem and the more steps required to solve the problem the larger the load on working memory, therefore the greater likelihood of errors (Braine, Reiser & Rumain, 1984). Barrouillet and Lecas (1999) suggest people may reduce working memory load by constructing simplified initial models, leaving some information implicit. The implicit information can be expanded, fleshed out and made explicit if the need arises.

Gilhooly et al. (1993) examined the types of errors participants made in generating conclusions under high memory load (verbal presentation of syllogisms) and low memory load (visual presentation of syllogisms) conditions with one of six dual tasks: articulatory suppression (speaking while being presented with the stimuli), unattended speech (one syllable words, eg cat, played continuously over headphones), verbal random generation (participants required to generate random numbers from 1-9), spatial random generation (participants required to tap keys on a keypad randomly), tapping in a simple pattern (participants required to tap in a simple pattern on a keypad), unattended pictures (line drawn pictures superimposed on a screen). Gilhooly et al. (1993) found the most common errors to be forgetting (middle terms were included in the conclusion), information integration (incorrect conclusions drawn from valid arguments), and incomplete analysis (definite conclusions drawn from syllogisms with no valid conclusions). They suggest that the memory loading affected retention of the terms and their roles rather than the actual problem solving process. Research in the area of working memory in dyslexia (Gould & Glencross, 1990; Smith-Spark, Fisk, Fawcett & Nicolson, 2003; Swanson, Ashbaker & Lee, 1996; Thomson, 1982) suggests that the increased memory load resulting from dual tasks such as finger tapping and digit repetition can have a negative impact on the performance of people with dyslexia compared to those without dyslexia, possibly leading to a greater number of errors.

Kosslyn (1980) argues that the knowledge contained in long term memory is used to generate a surface representation of the problem and this remains active during the reasoning process. The representation can be propositional or analogue. Propositional representations are based on the relationship between two sets of categories (Smyth, Collins, Morris & Levy, 1994), for example, “All poodles are dogs”. Analogue representations are ones in which categories are represented with spatial or visual information (Kosslyn, 1980). An analogue is defined as something that is similar to something else and it can be used instead of the original. According to Kosslyn (1980), when information needs to be retrieved from memory, a search is made using both propositional and analogue representational forms. If the propositional form does not find the answer to the problem, then the analogue form will attempt to find it.

Spatial reasoning serves to preserve explicit or inferred order between several elements, to identify relations between dimensions of elements, and to identify polarity within a dimension of an element (Gattis & Dupeyrat, 2000). Spatial representations are explicit in that we can visualize the order of elements and their relationships. De Soto et al. (1965) claim deduction is based on an internal representation of ordered spatial relations. In other words, implicit concepts are made explicit by the construction of a spatial representation. A reasoner can use the explicit spatial representation to make an inference or judgment about an implicit concept. For example, take the linear syllogism, “Mary is taller than Jane and shorter than Sue”. A reasoner can mentally place the three girls side by side in order of height and, by virtue of the internal spatial representation, can easily solve the question of where Mary fits in the order of height.

Von Hecker, Hahn and Rollings (2016) define spatial processing as a "correlate or mediating mechanism of the experience of coherence". Coherence refers to how well different bits of information fit together to facilitate understanding and evaluation in a way that makes sense to the reasoner. According to Thagard (2000), it is a process of mental balancing where information from all aspects of a problem is integrated together to make some sort of logical sense. Buehner and Humphreys (2010) claim that spatial perception is influenced by causal links, so objects are more likely to be perceived as closer together when they are causally linked than when they are not.

Von Hecker et al. (2016) examined the notion of coherence on spatial perception when solving categorical syllogisms. A categorical syllogism is made up of two premises and a conclusion that describes the nature of the relationship between two categories of members. A categorical proposition asserts that all or some members of one category are included within another category. The syllogism is logically valid if the conclusion follows on from the premises. It is invalid if the conclusion does not follow. The logical necessity of the syllogism determines its coherence. That is, it is necessary for both premises to be true for the syllogism to be logically valid and therefore coherent. For example,

All A are B
All B are C
Therefore, All A are C is coherent as the conclusion is valid.

However,

All A are B
All B are C
Therefore, All C are A is incoherent as the conclusion is invalid.

Von Hecker et al. (2016) hypothesised that if coherence is reflected in spatial reasoning processes then the distance between on-screen presentations of premises should be perceived as closer together for the valid syllogisms than for the invalid syllogisms. To avoid a content effect, they created artificial contexts so previous knowledge contained in the participants' long-term memory would not influence the reasoning process (Kosslyn, 1980). Participants were told they were entering a garden where genetic manipulation had taken place and normal biological rules did not apply, and they were to think of the experience as science fiction. They were presented with 12 syllogisms (six valid and six invalid), with an equal number of quantifiers and logical forms. Each set of valid and invalid syllogisms contained three 'All' and three 'Some' quantifiers in the same logical form.

The participants were allowed as much time as they needed to work on each syllogism but were not allowed to give the solution right away. Next, they were given a spatial task in which they were told to fixate on the gap between the premises where a cross had been, then a string of small x's was presented for 700ms at a distance of 15cm below the premises. For half of the trials the string of x's fit in the gap between the premises and for the other half it would overshoot to the left or to the right by one character. The premises stayed on screen for 1500ms longer and then the participants were asked to indicate if the string of x's overshot or did not overshoot the gap. After providing their response, a new window opened for them to indicate if the syllogism they were working on before the string of x's appeared was valid or invalid.

The results revealed that valid syllogisms were judged as valid more correctly as valid than invalid syllogisms as invalid. The participants were more likely to say the string of x's did not overshoot the gap when the premises in question came from an invalid syllogism than from a valid syllogism, or rather when two words came from

a set of propositions high in coherence than from a set of propositions low in coherence. The data were further analysed in the light of the participants' perception of validity (regardless of whether the syllogisms were valid or invalid) and the results showed a similar pattern. The researchers suggest that the higher coherence of valid syllogisms is indicative of a spatial reasoning process. It should be noted that only the AB/BC figure of syllogism was used in the study and this figure is cited as being more cognitively demanding (Jia, Lu, Zhong & Yao, 2009) than the other three figures, AB/CB, BA/BC and BA/CB. It could very well be that the participants resorted to a spatial strategy due to the difficulty of the syllogism rather than judging it as valid due to coherence. Von Hecker et al. (2016) suggest that reasoners may use spatial simulation to represent coherence between the propositions in a problem, as well as the individual terms featured in the propositions, and that the participants perceived logically valid syllogisms as more coherent than logically invalid ones.
They posit that perception of coherence is dependent on simultaneous consideration of all three propositions rather than just the relationship between the two terms in a single proposition.

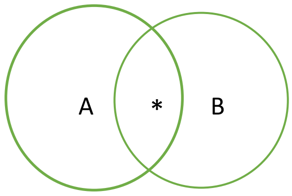
Roberts, Gilmore and Wood (1997) claimed that spatial ability predicts strategy selection in problem solving. They demonstrated this with a compass direction task where participants were asked to determine the compass point at which a person would end up relative to the starting point if the same size steps in the given directions are taken. Figure 5.1 is an example of a compass point direction task. There are two ways to solve the problem. The first is a spatial method that involves generating a spatial representation of each step, one at a time as per the instructions and then identifying the final bearing in relation to the starting point. The second is a cancellation method that requires the participant to cancel out opposite directions through a process of elimination of redundant steps and then deducing the final position from the remaining steps. All participants were pre-tested for verbal and spatial ability. The results revealed an "inverted aptitude-strategy relationship" where participants with low spatial ability used a spatial strategy and participants with high spatial ability used the cancellation method. Verbal ability was found not to be related to strategy selection. Roberts et al. (1997) concluded that the participants with high spatial ability were better at forming accurate representations of the problem and determining that the opposites steps were redundant, thereby enabling them to execute the spatial strategy more successfully than the participants with low spatial ability.

Figure 5.1: Example of the compass point direction task.

One step East
One step East
One step East
One step South
One step West

It has been further suggested that some people may use a form of Euler Circles to solve categorical syllogisms (Stenning & Oberlander, 1994; Ford, 1995; Stenning & Yule, 1997). Euler Circles are diagrammatic representations of sets of items and their relationship to each other. They are a form of spatial reasoning. Figure 5.2 is an example of Euler Circles representing the syllogism premise 'Some A are B'. The circle on the left contains all the members of category A and the circle on the right contains all the members of category B. The area within the overlapping portion contains those members that are common to both categories. Stenning and Oberlander (1995) added the use of an asterisk to denote the necessity in the overlapping portion of the circles. The reasoner would then create a similar diagram for the second premise followed by one that combines both premises to form a conclusion.

Figure 5.2: Example of Euler Circles representing the syllogism premise 'Some A are B'.



According to Larkin and Simon (1987), diagrams can facilitate a faster search and recognition for solutions to a problem compared to sentential representations because several steps in the process can be considered simultaneously.

There are individual differences in whether people seem to use a spatial or a verbal strategy as shown by Ford (1995), rather than use both types of representation as suggested by Kosslyn (1980). The focus of this thesis is the strategies used by people with dyslexia when reasoning with syllogisms. Individuals with dyslexia may be particularly prone to differences in performance with different types of representations.

Bacon, Parmentier and Barr (2013) have demonstrated that increased cognitive load can affect visuospatial performance in people with dyslexia and this can be improved with instructions for reasoning with a visual strategy. While studies using the Corsi Block Test suggest that the visuospatial sketchpad is intact in people with dyslexia in the forwards recall version of the task (Gould & Glencross, 1990; Jeffries & Everatt, 2004; Palmer, 2000), other research suggests that performance on the backwards recall version of the task may rely on functions other than short-term visuospatial sketchpad storage capacity. The difficulty in backwards recall is attributed to the additional demands on the central executive that are necessary to transform the sequence into reverse order (Corsi, 1972; Schofield & Ashman, 1986).

As people with dyslexia show deficits in the executive, Bacon et al. (2013) hypothesised that they would perform less well than people without dyslexic people on backward recall. They presented participants with a computerised version of the Corsi Block Task under both forward and backward recall conditions. Arranged following Corsi's (1972) original array, the squares turned black for 1000 ms, one at a time and with a stimulus-onset asynchrony of 2000 ms, to form the sequences participants were required to remember. The sequences increased in difficulty from two to nine locations, with two trials at each level. The span score was defined as the highest level at which a participant could recall at least one sequence correctly. The Corsi Block Task was followed by a computerised version of the Visual Patterns Test in which each pattern was presented for 3 seconds. The participants' task was to remember these patterns so they could reproduce them immediately afterwards in an empty grid. The results revealed that while participants with dyslexia performed comparably with participants without dyslexia in the forward recall task, they showed deficits in the backward version of the task.

It has been suggested that backward recall involves the encoding and maintenance of locations as a static visual pattern, rather than a sequence (Pickering, Gathercole, Hall & Lloyd, 2001; Vandierendonck, Kemps, Fastame & Szmalec, 2004) and people with dyslexia may compensate for their difficulties with verbal material by using a strategy that converts written information into more 'dyslexia-friendly visual images' (Bacon et al., 2007). Bacon et al. (2013) posit that, when faced with the processing demands of backward recall, participants with dyslexia may resort to their visual abilities instead of a serially based spatial strategy. The researchers noted that participants with and without dyslexia perform equally well when instructed to use a visual strategy.

While research has shown that people with dyslexia tend to adopt visual strategies in reasoning (Bacon & Handley, 2010a, 2010b; Bacon et al., 2007), the nature of the Corsi Block Task might naturally prompt participants with dyslexia to use a sequential recall strategy to match the sequential presentation of the stimuli, thereby creating difficulty in the process of switching from a default serial strategy to a more effective visual approach.

According to Miyake et al. (2000), switching strategies may involve three distinct executive processes: updating, inhibition, and shifting. Updating is the process of monitoring incoming information to check if it is relevant to the task at hand and then revising what is held in working memory and replacing it if necessary. This process requires the reasoner to be actively moving information around in working memory. Smith-Spark, Fisk, Fawcett and Nicholson (2003) demonstrated evidence of an executive deficit in adults with dyslexia in a task where participants were asked to recall the x most recent items in lists of varying lengths. This meant the participants had to keep the first x items in memory and then, if there were more than x items in a list, they had to drop the least recent item and update the contents in their memory by replacing the dropped item with the new addition. The results revealed that the length of the list did not adversely affect the performance of participants with dyslexia, while the longer lists reduced the performance of participants without dyslexia, implying that the central executive does not have much involvement in the task for participants with dyslexia.

Metacognition, which is an individual's awareness and understanding of their thought processes and a feeling of rightness (Ackerman & Thompson, 2017; Thompson, Prowse-Turner & Pennycook, 2011), can influence the level of confidence when performing a task. Furnes and Norman (2015) examined three forms of metacognition (knowledge, skills and experience) in people with dyslexia in a reading exercise for which the dependent variable was memory of the passages. Participants self-reported their metacognitive knowledge and skills, while their metacognitive experiences were assessed by predictions of performance and judgments of learning. The results showed that participants with dyslexia rated themselves lower in knowledge about reading strategies than participants without dyslexia, but no different to participants without dyslexia in their use of deep and surface learning strategies. The results suggest that people with dyslexia have metacognitive insight into their own difficulties with reading and they are also capable of adjusting their expectations in line with their skills.

Research suggests that people with dyslexia tend to use a spatial strategy when solving syllogisms compared to people with non-dyslexia (Bacon & Handley, 2010). Some have made the claim that people with dyslexia have greater visuospatial skills that compensate for their language difficulties (Galaburda, 1993; Miles, 1993). Metacognition of difficulties may play a part in strategy selection when solving problems.

5.2. Study: Performance of participants with dyslexia and participants without dyslexia after being taught to solve syllogisms using Euler Circles

The current study compared the performance of people with dyslexia and people without dyslexia before and after learning to solve syllogisms using Euler Circles. It was expected that people with dyslexia would perform better than people without dyslexia after being trained on a spatial strategy.

5.2.1. Method

Participants

Participants were 31 Lancaster University undergraduate students: with dyslexia (10 female, 6 male) and without dyslexia (10 female, 5 male) with mean age 19 years (SD = 1.8). The mean age of the participants with dyslexia was 20 years (SD = 1.8) and the participants without was 19 years (SD = 1.5). Participants without dyslexia were recruited via Sona, the department's online participant recruitment system. Self-reported participants with dyslexia were recruited through advertisements placed on Job Shop on the Lancaster University Students Union website, notices in the stairwell of the Psychology building, and via Sona. On behalf of the researcher, the Student Support office kindly contacted students who were recorded by the university as having been officially assessed as dyslexic, either by provision of evidence to the Disabilities Office of a diagnosis by a medical professional or educational psychologist. Due to time and resource constraints, and the multiple parts of the study, participants were not tested for IQ. In addition, research studies that have reported IQ scores have found no difference between participants with dyslexia and participants without dyslexia (Smith-Spark & Fisk, 2007). Participants with dyslexia and participants without dyslexia who were not psychology majors were paid £13.50 across both sessions. Psychology majors were given course credit.

Materials

Raven's Standard Progressive Matrices was used as a test of general cognitive ability in order to ensure a comparable level of cognitive ability between participants.

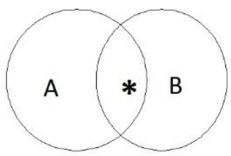
The pre-training workbook consisted of 12 syllogisms using neutral premise terms that were not related to each other (e.g. Some of the weavers are historians). All 12 syllogisms were taken from Ford's (1995) study and were selected based on the level of difficulty for the participants in her study: four that were shown to be easiest for verbal reasoners (EV, that is participants in Ford's study that indicated they solved the syllogisms with a verbal based strategy), four that were easiest for spatial reasoners (ES, i.e., participants who reported using spatial based strategies), and four that were equally difficult for both types of reasoners (HSV). See Appendix 2 for the list of syllogisms used in the pre-training workbooks. The 12 syllogisms were randomly sorted, resulting in three different pre-training workbooks. Each syllogism appeared on a separate page with a clear space for workings and lines at the bottom of the page for writing out the solution(s). There was a separate line for each possible answer form (e.g. All…………… are…………..; Some………… are not…………; etc) to ensure participants correctly formatted their solutions. Accuracy was recorded as having placed the correct terms in the correct space. Not all participants filled out the answer format as instructed. Some participants wrote sentences or phrases to explain their solution, some wrote more than one solution, but most wrote only one solution. As long as one of the proffered solutions was correct it was accepted as accurate regardless of how it was displayed. For example, for the syllogism All B are A, some B are C, if a subject wrote “some A are C [correct] but also all C are A [not correct]” then that problem was counted as correct.

The training booklet was a step by step guide that demonstrated how to solve each of three syllogisms using Euler Circles. Each premise was represented separately with a diagram and a written explanation of how the circles are or are not combined, as well as how placement of the asterisk is used to denote where there is certainty that something exists. The third diagram in each example demonstrates how both syllogisms are combined to show the correct solution. Again, this was followed by a written explanation of how the asterisks “survive”. The correct solution was provided for each example. The examples were all formats that appeared in the pre-training and post-training workbooks. See Appendix 5 for a copy of the training booklet. The training process was derived from Stenning and Oberlander’s method (1995). Figure 5.3 shows one of the examples in the training booklet.

Figure 5.3: Example problem from the training booklet.

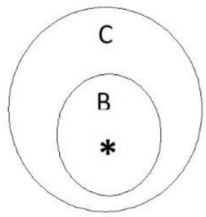
An easy way of solving syllogisms is by using Euler Circles. In logic, these are circles used to represent the terms of categorical statements. For example, take the syllogism
Some A are B
All B are C

Some A are B is represented as:



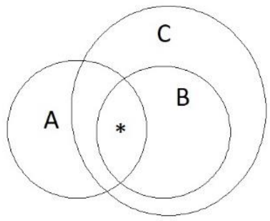
The diagram shows that some As are Bs, but also some As might not be Bs, and some Bs might not be As. We put a * where we know there is at least something (in the overlap between the A and the B). Remember, we are only concerned with facts that we already know about the premises.

All B are C is represented as:



In this diagram, the B is inside the C, indicating that all Bs are also Cs. The diagram also shows that some of the Cs may not be Bs. We put a * where we are sure that something exists.

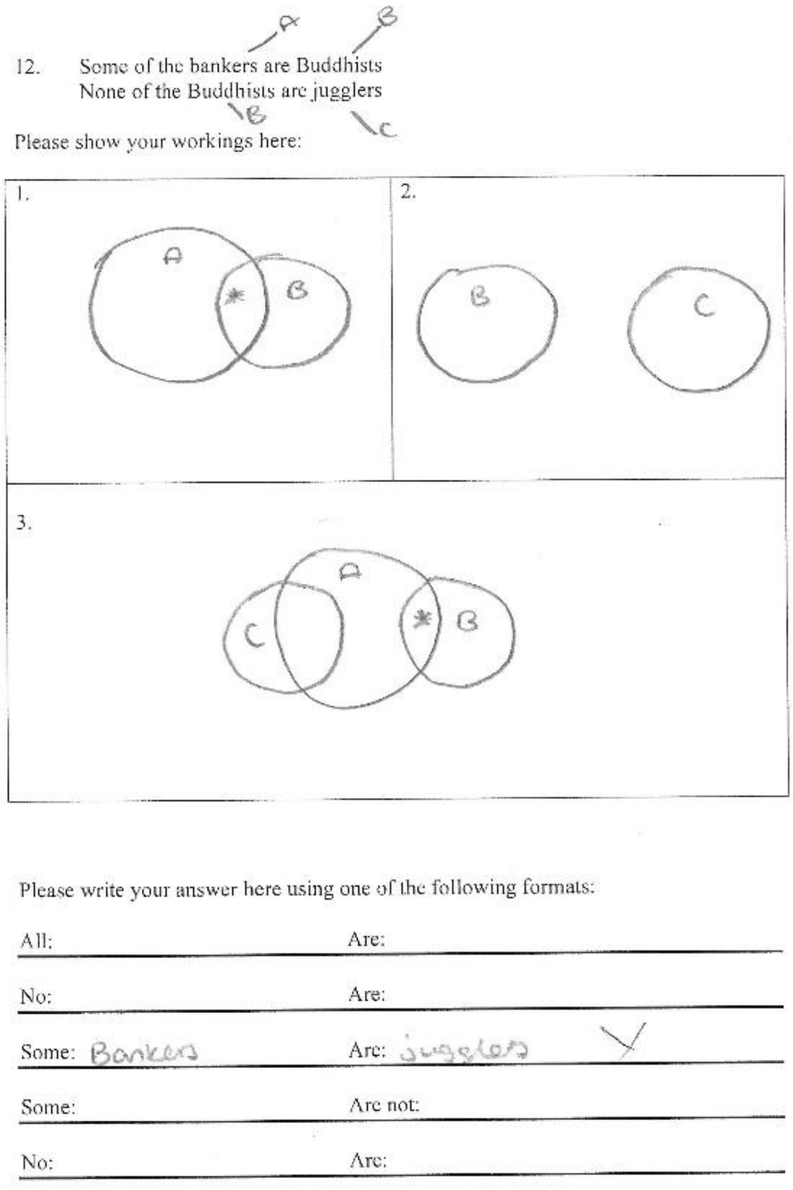
The next step is to combine the two diagrams. Draw the pictures so the B circles overlap, and then make the A and C circles overlap wherever possible from the original diagrams. Then decide whether any of the asterisks "survive" – they survive if they're in an area that isn't cut by the other circle.



The * from Some A are B is in an unchanged region, so we keep it. The * from All B are C is in a changed region, so we don't keep it. Since we can only use information we are certain of, the only logical conclusion we can draw from diagram is that some of the As are also Cs. Therefore, the solution is Some A are C.

The post-training workbook consisted of 12 syllogisms in the same forms as those in the pre-training workbook. The terms used, however, were different so as to prevent any interference from the pre-training set of syllogisms. It was felt that some participants may remember the terms from the pre-training set and this may influence their solution or strategy. The post-training terms were also taken from the syllogisms used in Ford's (1995) study. The random order was kept the same as the pre-training workbook to try and maintain as much control as possible, so each post-training workbook had a matching pre-training workbook. Each syllogism in the post-training workbook appeared on a separate page with four numbered boxes, instead of a single blank space, for workings and lines at the bottom of the page for writing out the solution(s). See Appendix 8. The boxes were included to encourage use of the step by step method of solving the syllogisms. The steps were to draw a representation of premise one in the first box, then draw a representation of premise two in the second box, then the final drawing that combines both premises to form the conclusion goes in the third box. Figure 5.4 is an example of a participant's workings in the post-training workbook.

Figure 5.4: Example of a participant's workings in the post-training workbook.



An Olympus digital voice recorder was used to record each participant's verbal protocol in the pre-training and post-training sessions. A stop watch was used to record solution times.

Design

A 2 x 2 x 3 mixed design was used. The between-subjects factor was dyslexic status (dyslexia, non-dyslexia) and the within-subjects factors were training (pre-training v post-training) and problem type (HSV, ES, EV). The dependent measures were the number of syllogisms solved correctly and the time taken to solve each one.

Procedure

Participants were tested in two sessions lasting approximately one hour each. The Raven's Standard Progressive Matrices was administered in groups of no more than four in the first session and took approximately 45 minutes per participant. The problem solving task was administered individually in the second session within seven days of the first session. The participants were presented with the pre-training workbook containing 12 randomised syllogisms. They were asked to say aloud their workings and write them on the spaces provided in the workbooks. Their verbal protocol was recorded with an Olympus digital voice recorder. The solution time for each syllogism was recorded using a stopwatch. The turning of the page was used as an indication of completion of each syllogism.

Upon completion of the pre-training workbook, participants were presented with the training booklet. They were allowed as much time as they needed to study the material and to ask the researcher questions for clarification. Immediately after the training session, the participants were presented with the post-training workbook containing 12 randomised syllogisms in the same order as the pre-training workbook, but with different premise terms. The procedure was exactly the same as for the pre-training session, except that they were asked to draw their workings in the numbered boxes provided instead of using the open space on each page.

5.2.2. Results

An independent samples t-test was conducted on the data from the Ravens Standard Progressive Matrices to determine if there were any group differences between the participants with dyslexia and those without dyslexia. The results indicated that participants with dyslexia and participants without dyslexia were of similar cognitive ability. The overall mean raw score was 40.13, with SD = 4.43 (dyslexic: M = 39.19, SD = 4.97; non-dyslexic: M = 41.13, SD = 3.66), indicating an age equivalent of 18 years. The independent samples t-test revealed t (29) = -1.23, p = .23, d = -0.44.

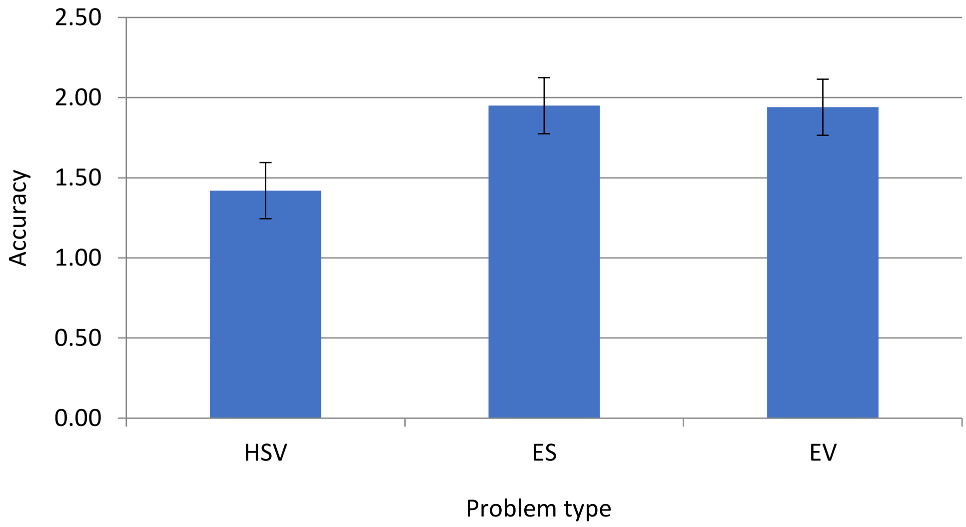
The mean score for all correctly solved syllogisms was combined within each condition so each participant ended up with one average score for each of HSV, ES and EV. The mean number of correct solutions is displayed in Table 5.1.

Table 5.1: Mean number of correctly solved syllogisms. The figure in parentheses is the standard deviation.

	Pre-training		Post-training	
Syllogism Type	Dyslexia	Non-dyslexia	Dyslexia	Non-dyslexia
HSV	.22 (.27)	.43 (.24)	.28 (.27)	.48 (.29)
ES	.44 (.25)	.53 (.23)	.53 (.22)	.45 (.25)
EV	.50 (.27)	.63 (.27)	.36 (.18)	.45 (.25)

A 2 x 2 x 3 mixed design ANOVA was performed on the mean number of correctly solved problems with problem type (ES, EV, HSV) and training (pre-training, post-training) as within-subjects factors, and dyslexic status (dyslexia v non-dyslexia) as between-subjects factor. This revealed a main effect of problem type, $F(2,28) = 8.98$, $p < .05$, $\eta\rho^2 = .24$. The number of correctly solved syllogisms was higher for ES problems (M = 1.95, SD = .95) and EV problems (M = 1.94, SD = 1.04) than for HSV problems (M = 1.42, SD = 1.14). See Figure 5.5.

Figure 5.5: Overall mean number of correctly solved syllogisms.

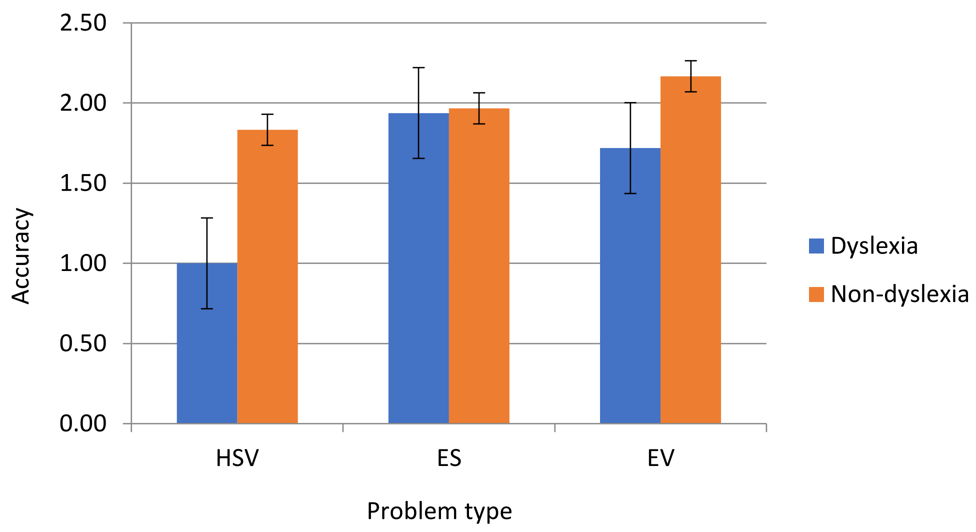


The main effect of training was not significant $F(1, 29) = .904$, $p = .35$, $\eta\rho^2 = .03$. The between-subjects main effect, dyslexia v non-dyslexia, was not significant, $F(1, 29) = 3.29$, $p = .08$, $\eta\rho^2 = .10$. Overall, participants without dyslexia correctly solved more problems (M = 1.99, SD = 1.02) than those with dyslexia (M = 1.55, SD = .98), but not significantly so.

The results also showed a significant interaction between problem type x dyslexia, $F(2, 28) = 3.87$, $p < .05$, $\eta\rho^2 = .16$. Figure 5.6 demonstrates that participants with dyslexia scored lower (M = 1.00, SD = 1.09) than participants without dyslexia

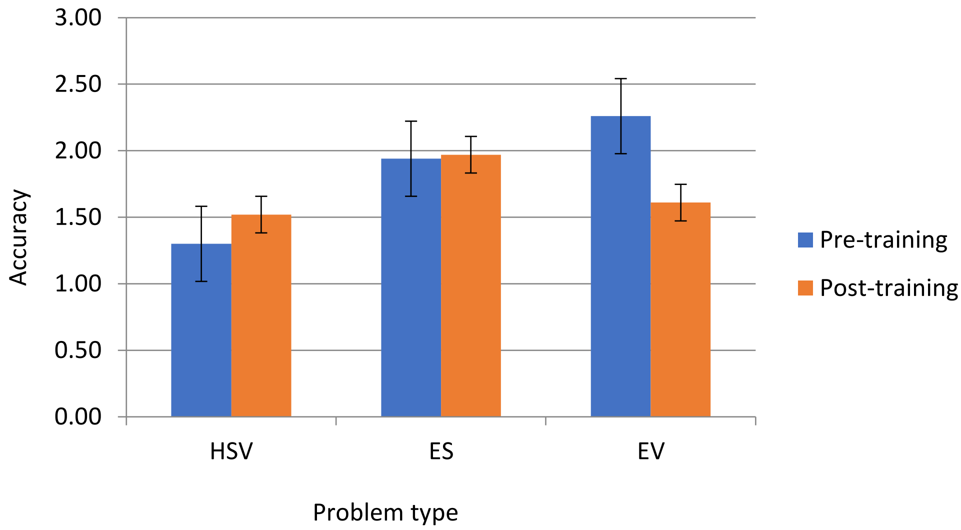
(M = 1.83, SD = 2) on HSV problems. Participants with dyslexia also scored lower on EV problems (dyslexic: M = 1.72, SD = .91; non-dyslexic: M = 2.17, SD = 1.03). Both participants with dyslexia and participants without dyslexia were evenly matched on ES problems (dyslexic: M = 1.94, SD = .94; non-dyslexic: M = 1.97, SD = .96).

Figure 5.6: Interaction between problem type x dyslexia.



The results also revealed a significant interaction between training x problem type, $F(2, 28) = 5.52$, $p < .01$, $\eta\rho^2 = .16$. The number of correctly solved HSV problems was lower in the pre-training condition (M = 1.3, SD = 1.10) than in the post-training condition (M = 1.52, SD = 1.18), and almost identical for ES problems in both the pre-training (M = 1.94, SD = .96) and post-training (M = 1.97, SD = .95) conditions. However, the number of correctly solved EV problems was much lower in post-training (M = 1.61, SD = 1.09) than pre-training (M = 2.26, SD = 1.10), indicating that training affected the way in which the participants reasoned with the problems. See Figure 5.7.

Figure 5.7: Interaction between training x problem type.



A paired samples t-test revealed that participants performed worse on problems that were easiest for verbal reasoners after training (M = 1.61, SD = .88) than before training (M = 2.26, SD = 1.09), $t(30) = 2.87$, $p < .05$, d = .66. While participants performed slightly better on problems that were easiest for both types of reasoners after training (M = 1.52, SD = 1.18) than before training (M = 1.29, SD = 1.10), $t(30) = -1.16$, $p = .88$, they were relatively equal on problems that were easiest for spatial reasoners before training (M = 1.94, SD = .96) and after training (M = 1.97, SD = .95), $t(30) = -.15$, $p = .26$.

There was no significant interaction between training x dyslexia, $F(1, 29) = 1.21$, $p = .28$, $\eta\rho^2 = .04$ or between training x problem type x dyslexia $F(2, 58) = .81$, $p = .45$, $\eta\rho^2 = .03$.

The data were further analysed to examine the nature of the interactions between problem type x dyslexic status and training x problem type. A separate 2 x 2

ANOVA was conducted for each problem type (HSV, ES, EV) with the within-subjects factors as training (pre-training, post-training) and the between-subjects factor as dyslexic status (dyslexia, non-dyslexia). The results of each analysis are presented separately.

EV (Syllogisms that are easiest for verbal reasoners)

There was a significant main effect of training, $F(1, 29) = 8.04$, $p < .05$. There was an overall reduction in accuracy from pre-training (M = .56, SD = .27) to post-training (M = .40, SD = .22). There was no significant effect of dyslexia, $F(1, 29) = 2.76$, $p = .11$. There was also no significant interaction between training and dyslexic status, $F(1, 29) = .14$, $p = .71$.

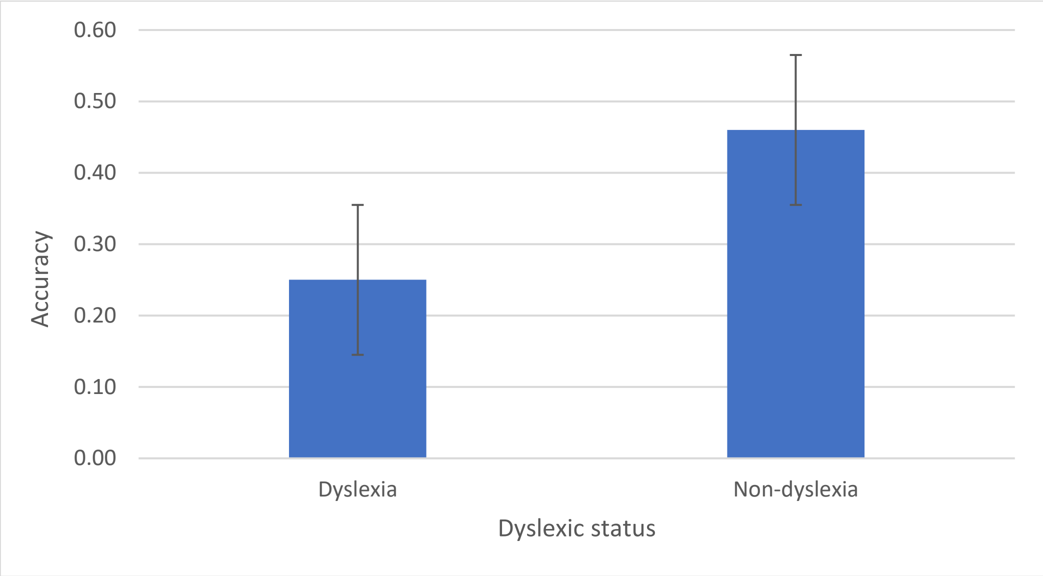
ES (Syllogisms that are easiest for spatial reasoners)

There was no significant main effect of training, $F(1, 29) = .01$, $p = .92$, or of dyslexic status, $F(1, 29) = .01$, $p = .92$. There was no significant interaction between training and dyslexic status, $F(1, 29) = 2.88$, $p = .10$.

HSV (Syllogisms that are equally difficult for verbal and spatial reasoners)

There was a significant main effect of dyslexic status, $F(1, 29) = 6.28$, $p < .05$. Participants without dyslexia solved almost twice as many syllogisms correctly (M = .46, SD = .27) than participants with dyslexia (M = .25, SD = .27). See Figure 5.8. There was no significant main effect of training, $F(1, 29) = 1.28$, $p = .27$. There was no interaction between dyslexic status and training, $F(1, 29) = .02$, $p = .90$.

Figure 5.8: Main effect of dyslexic status.



5.2.3. Additional analysis of reasoning strategy

The pre-training workbooks were inspected for evidence of a particular reasoning strategy in order to determine whether participants who had a particular strategic approach (verbal or spatial) might be affected differently by training to use a spatial method. The same criteria as explained in Chapter 3 were applied. To count as clear evidence of a strategy the participant was required to present with at least four problems showing workings in a verbal or spatial strategy as described by Ford (1995). Eight out of the 31 participants demonstrated a clear verbal strategy (5 with dyslexia, 3 without dyslexia), while three demonstrated a clear spatial strategy (0 with dyslexia, 3 without dyslexia). The remaining 22 participants either showed no workings at all, or not enough to determine a clear strategy, so were classified as undefined and their data was not included in the analysis.

It is interesting that so few participants showed a clear strategy compared with Bacon et al. (2007). However, Bacon et al. (2007) do not indicate exactly how many of the 40 participants wrote down their protocol. They only mention 4 that used a mixed strategy and 3 that were unidentified. They showed examples of 4 participants' protocols. They used 2 sets of problems (8 syllogisms with sporting terms and 8 with Welsh terms) but did not state how many had to be shown per set to identify a clear strategy. The differences may be due to the use of sporting/Welsh terms in Bacon et al.'s (2007) syllogisms, or a more constrained set of syllogism types in the current study. The data were not analysed by dyslexic status as there were fewer than four participants in three out of the four conditions. The data for the verbal and spatial participants were analysed in a 2 x 2 x 3 ANOVA in an explorative analysis. The within-subjects factors were training (pre-training, post-training) and syllogism type (HSV, ES, EV). The between-subjects factor was reasoning strategy (clear verbal or clear spatial). The dependent variable was the mean number of correctly solved syllogisms. Table 5.2 shows the mean performance across all conditions.

Table 5.2: Mean accuracy across all conditions. Standard deviation is shown in parentheses.

Syllogism Type	Verbal Strategy		Spatial Strategy	
	Pre-training	Post-training	Pre-training	Post-training
HSV	.28 (.28)	.38 (.23)	.41 (.14)	.75 (.25)
ES	.50 (.27)	.47 (.28)	.58 (.14)	.67 (.14)
EV	.65 (.27)	.28 (.16)	.75 (.25)	.50 (.25)

There was no main effect of training, $F(2, 18) = .12$, $p = .74$ or of syllogism type, $F(2, 18) = 1.56$, $p = .24$. The only significant result was an interaction between training x syllogism type, $F(2, 18) = 7.05$, $p < .01$, $\eta\rho^2 = .44$. The interaction for this subset is similar to that of the larger set. Training had a detrimental effect on performance for EV problems, as was also shown in the analysis of the entire data set (see Figure 5.7 above).

5.2.4. Discussion

The present study compared the performance of people with dyslexia and people without dyslexia before and after learning to solve syllogisms using a spatial strategy, more specifically a method based on Euler Circles. To this end, I examined whether individuals demonstrated evidence of using a verbal or spatial strategy (Ford, 1995) and how this might be affected by learning a strategy that may be compatible or incompatible to what they presently used. The hypothesis is that if people with dyslexia are predominantly spatial reasoners (Bacon & Handley, 2010) they would perform better on problems that are easiest for spatial reasoners than on problems that are easiest for verbal reasoners.

The results are consistent with existing research that suggests individuals tend to favour a verbal or spatial strategy (Ford, 1995). The results of the present study revealed an interaction of problem type x dyslexia, where participants with dyslexia performed worse than participants without dyslexia on both EV and HSV problems but were evenly matched on ES problems. This gives credence to the notion that people with dyslexia tend to favour a spatial strategy (Bacon & Handley, 2010). Interestingly, inspection of the pre-training workbooks for those that showed their workings revealed that none of the participants with dyslexia demonstrated clear spatial strategy but five of them demonstrated a clear verbal strategy. The poorer performance of participants with dyslexia compared to participants without dyslexia on problems that are equally difficult for both spatial and verbal reasoners, as well as problems that are easiest for verbal reasoners, suggests that they may be applying inappropriate strategies to solve these types of problems. Having to solve the syllogism as well as producing written workings, seemed to have affected their ability to write or draw what they were thinking. In addition, the introduction of a training regime could be seen as the introduction of a dual task paradigm where the participants were expected to learn a new skill and use it to solve a series of problems. Swanson, Ashbaker and Lee (1996) suggest that high processing demands can lead to deficits on both verbal and visuospatial working memory in people with reading disabilities. Other research suggests that visuospatial memory deficits come to the forefront only when the task at hand requires the person to engage with it verbally (Gould & Glencross, 1990; Thomson, 1982).

If participants with dyslexia do not have sufficient verbal working memory capacity for problem solving, they may choose the easiest strategy, which is not necessarily the right one for them. The more models required to build the conclusion, the more strain on their working memory, resulting in a failure to search for all possible alternatives (Johnson-Laird, 1983). Therefore, the more difficult the problem the more likely errors are to occur.

Training slightly improved the overall performance on problems that are equally difficult for verbal as well as spatial reasoners but had a detrimental effect on performance on problems that are easiest for verbal reasoners. There was no discernible difference for problems that are easiest for spatial reasoners. This is demonstrated in the analysis of data from participants that showed clear evidence of a verbal strategy. The reduction in accuracy for EV problems was approximately 45% from pre-training to post-training. Teaching the spatial strategy did not have an overall positive effect on participants and was not particularly helpful for the participants with dyslexia. It appears to make problems that are easier with a verbal strategy harder to solve. Therefore, the strategy in the way it is being taught impacted the approach to learning but did not promote problem solving. It is possible that strategy style rather than dyslexic status impacts upon problem solving.

Considering the evidence presented by participants demonstrating a clear verbal or spatial strategy, as indicated in the overall results, there is an almost complete reversal in performance from pre-training to post-training on problems that are easiest for verbal reasoners. It may be the case that individuals who possess lower spatial ability may be less able to form accurate representations of the problems (Roberts, 1997) so would be negatively affected by having to work with a spatial strategy. Some participants may be capable of switching strategies and the training enabled them to see the problems from a different perspective. In fact, some participants were observed writing the conclusion first and then drawing the diagrams of the method in order to match that conclusion. In some instances, they appeared to realise the conclusion was incorrect so revised the workings and amended the previously written conclusion. It may be argued that they were simply satisfying the demands of the study by filling in the required parts of the workbook, though there is some evidence overall of the effect of the training strategy on syllogism performance after compared to before the training – for the group as a whole, the training affected problem solving.

There are some limitations to the present study. There was no verbal or written protocol recorded so it is not known in many cases what strategy was being used in the pre-training session. Despite the instructions, many participants did not show their workings. Inspection of each workbook revealed that, 11 out of 31 participants showed a clear strategy. In keeping with the composition of the stimuli, the clear strategy was judged as at least four instances of the same strategy in the pre-training workbook, i.e. at least four problems showing workings of either a verbal or a spatial strategy as described by Ford (1995). Eight participants showed a clear verbal strategy, rewriting the premises as mathematical equations and drawing arrows or symbols to indicate relationships between terms. Three participants demonstrated a clear spatial strategy, drawing shapes such as circles to indicate relationships between terms. Four participants demonstrated a mixed strategy. One participant demonstrated a clear verbal strategy throughout and interestingly had drawn circles for the first few problems in the booklet but never filled them in with terms. As the circles were drawn underneath the verbal workings, this suggests that they may have started with one strategy then thought about trying a different one before deciding to stick with the original plan.

Another limitation is the inequality of syllogism figures used in the study. Figure 5.9 shows the distribution of figures in the pre-training and post-training workbooks. AB/CB and BA/BC are the only figures that are common to all conditions. A Fisher's exact test resulted in $p = .689$, so the distribution of figures was not significantly different across the categories of syllogism. Future research can consider a study that balances the figures across all conditions.

Figure 5.9: Distribution of syllogism figures in the training booklets.

Figure	HSV	ES	EV
AB/BC	0	1	2
BA/CB	0	0	1
AB/CB	1	1	0
BA/BC	3	2	1

The study partially supported the hypothesis that participants with dyslexia differ to participants without dyslexia in the way they reason with syllogisms. It was expected that people with dyslexia should perform better after training on a spatial strategy. The results revealed that, as expected, both types of reasoners were affected by problems that are equally difficult for both (Ford, 1995). The results also showed a significant interaction between problem type and dyslexia. Participants with dyslexia scored lower on HSV and EV problems than participants without dyslexia but were evenly matched on ES problems.

The results also revealed a significant interaction between training and problem type. The number of correctly solved HSV problems was lower in pre-training. ES was identical in pre and post training and EV was lower in post-training. Further testing confirmed HSV improved after training. So, it might have made some problems easier with a new strategy, either with a new strategy for some reasoners or made some problem types easier with a different strategy. Training did not have any impact on dyslexia as demonstrated by the lack of interaction between training and dyslexic status.

Further analysis confirmed EV was worse after training. HSV was affected by dyslexic status. It is possibly the case that if people with dyslexia are hindered by phonological difficulty and verbal working memory capacity, they were not able to adopt the new strategy, whereas people who were not affected by these things could.

Exploratory work with a clear strategy confirmed earlier finding that training had a detrimental effect on performance of EV problems. That is, training in a spatial strategy hindered the performance of participants who tend toward a spatial strategy on problems that are easier to solve with a verbal strategy.

CHAPTER 6: EYE TRACKING

6.1. Eye movements and problem solving

Eye tracking has been widely used in the research of cognitive processes, such as memory, attention, language, problem solving and decision making (Thomas & Lleras, 2007; Knoblich, Ohlsson & Raney, 2001; Espino, Santamaria, Meseguer & Carreiras, 2005). The information from eye tracking research can be used to infer that cognitive processing has taken place (Rayner, 1998). Despite the name eye tracking, the focus of this type of research method has been largely on when the eyes remain still rather than when they are actually moving (Yeh, Tsai, Hsu & Lin, 2014). It is felt that eye movements not only reflect what we are thinking, but they can also influence how we think (Thomas & Lleras, 2007).

The main types of eye movements in reading and information processing are saccades and fixations. Saccades are the rapid movement of the eyes between fixation points. Saccades occur when reading a passage or looking at a scene or object. Some studies have shown that cognitive processes are suspended during a saccade (Irwin & Carlson-Radvansky, 1996; Sanders & Houtmans, 1985; Sanders & Rath, 1991; Van Duren & Sanders, 1992 & 1995). According to Uttal and Smith (1968), no new information is gained during a saccade due to the rapid movement of the eyes. Fixations, which last around 200-300ms, are the period of time when the eyes remain still between saccades. The general assumption is that the fixation is the focus of attention and its duration is the processing effort at that location (Holmqvist, Nystrom, Andersson, Dewhurst, Jarodzka & Van de Weijer, 2011). A greater number of overall fixations implies a less efficient search (Goldberg & Kotval, 1999), more fixations in one area suggests that particular area is more important to the viewer than other areas (Poole & Ball, 2005), longer fixations in an area can signify processing difficulty (Rayner, 1998), and concentrated fixations tend to be considered focused and efficient (Cowen, Ball & Delin, 2002). Focused attention helps maintain information in memory and in retrieving information from memory (Theeuwes, Belopolsky & Olivers, 2009) which is essential for efficient information processing in working memory.

Research suggests a strong relationship between what someone is looking at and what they are thinking about, as well as fixation between duration and the amount of processing (Just & Carpenter, 1976; Rayner, 1978, 1998). Ballard, Hayhoe, Pook and Rao (1997) suggest longer fixation times can mean deeper processing and short fixation times serves to re-encode information about the problem into working memory. They point out that re-encoding does not necessarily mean further processing. The problem solver may have "abandoned or overcome attention allocation" and just rearranged their representation to process the information from a different angle.

Research indicates that readers tend not to fixate in the blank spaces between sentences (Abrams & Zubir, 1972; Rayner, 1975). In addition, eye movements seem to be different for silent reading and reading aloud. Fixations are longer for silent reading (Levy-Schoen, 1981). When the text is more difficult saccades decrease while fixations and regressions increase (Jacobson & Dodwell, 1979; Rayner & Pollastek, 1989). Regression in reading is the process of going back to re-read a passage. Dillon (1985) suggests that the examination of eye fixations provides more direct information about the processes of problem solving than is possible through the analysis of test scores. She posits that the pattern of eye fixations is a good indicator of the strategy being used to solve a problem. However, standard testing can fall prey to participants not clearly understanding the nature of the task or the instructions, forgetting or not paying attention to relevant information, using irrelevant methods or just guessing answers. Dillon's previous research also suggests that people with different cognitive abilities processed problems differently. She demonstrated that people with different abilities differed in strategy, individual differences accounted for significant amounts of variance in performance, and that stimuli can be manipulated to elicit different strategies. Berthge, Carlson and Weidl (1982) found that scanning patterns of third grade children solving the Coloured Progressive Matrices Test varied depending on the testing conditions.

Eye tracking has become one of the most popular methods of studying human visual attention based on the eye-mind assumption (Just & Carpenter, 1980). The eye-mind assumption is the notion that the eye is fixated on a word for the duration of time it takes the reader to process the word. Scan path patterns demonstrate cognitive strategies used in goal-oriented tasks (Gandini, Lemaire & Dufau, 2008). Hegarty, Mayer and Green (1992) used eye-tracking to examine the comprehension process and the strategies for solving mathematics word problems. They found that key information such as numbers and variable names to solving problems were fixated longer and were critical in determining the solution.   Verschaffel, De Corte and Pauwels (1992) also used eye-tracking techniques to examine word problem solving and indicated that students made more comprehension reversal errors (e.g., addition used while subtraction was the correct strategy) when the order of the terms in the relational statement was not consistent with the preferred order. Research has also shown that prior knowledge and expertise had influences on allocating visual attention on relevant information in comprehending conceptual graphics (Canham & Hegarty, 2010; Cook, Wiebe & Carter, 2008). Recognising, selecting, and processing the relevant information is essential for successful mathematics word problem solving.

6.2. Insight problem solving

Knoblich, Ohlsson and Raney (2001) argue that attention is allocated in different ways to each part of a problem and this is influenced by the initial representation of that problem. A problem contains values and operators. The values are generally considered to be variable and the operators are considered to be constant. Difficulties may arise due to an inappropriate (Knoblich et al., 2001) or incomplete (Kaplan & Simon, 1990) representation of the problem and this may lead to an incorrect strategy for solving it. The problem solver may end up simply staring at it hoping for some sort of inspiration. Knoblich et al. (2001) refer to this as an impasse.

Functional fixedness has been cited as one of the reasons for the impasse. This is where prior knowledge of a similar problem influences thought processes in assessing the problem at hand (Duncker, 1945; Keane, 1989). Another reason is mental ruts, where repeated exploration of unsuccessful search paths increases activation of those same paths (Smith, 1995), which is essentially the problem solver just trying the same unsuccessful approach repeatedly and never achieving the correct solution.

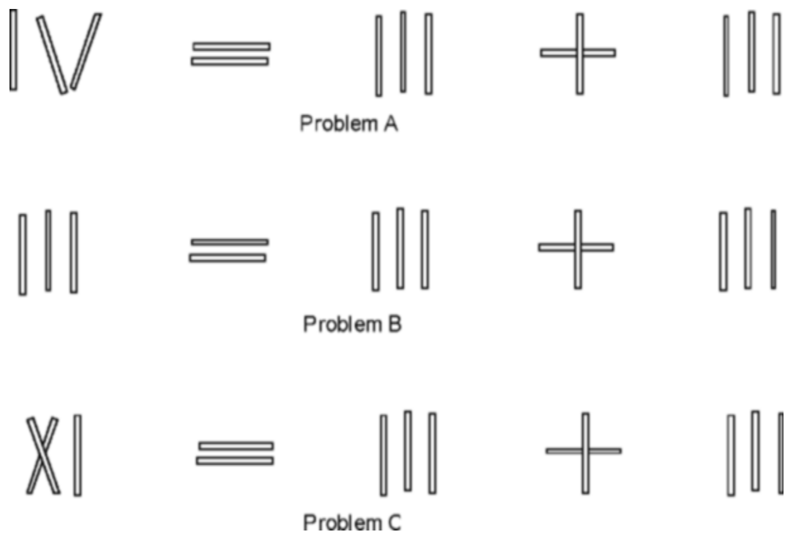
In some instances, solving a problem may require thinking outside of the box or employing insight. Insight involves the ability to mentally detach the components of the problem (Knoblich, Ohlsson, Haider & Rhenius, 1999) and revise the representation. In other words, to see the problem in a whole new light. The problem solver must relax the constraint placed on the components, usually the operator (Ohlsson, 1992). Insight only happens when the representation changes, when the problem solver is willing and able to ignore prior or assumed knowledge and see things differently.

Knoblich, Ohlsson and Raney (2001) studied insight problem solving using the matchstick problem. This particular problem was used because it was easier to determine which component the participants were fixating on at any given point in time. It was felt that the matchsticks would activate the participants' prior knowledge of maths which in turn will bias the assessment of the problems, rendering it difficult for the participants to "detach a component that has no meaning of its own". They further suggest that an impasse only occurs after initial explanation of the problem so the duration of eye fixation should increase for difficult problems, and the length of fixation should be similar for successful and unsuccessful problem solvers. They used eye tracking as research indicates that what a person is looking at tends to be what they are processing (Just & Carpenter, 1976).

Participants in their study were presented with three incorrect mathematical statements expressed in Roman numerals with the matchsticks. They were required to correct the statements by moving only one matchstick. Figure 6.1 shows the statements that were used in the study. Problem A required the value of the result (shown on the left side of the equation) to be changed. This could be accomplished by moving the stick in IV to the right of the V to make it VI. Problem B required the operator to be changed and this could be accomplished by replacing the second plus sign with an equal sign. Problem C required the decomposition of the X and this could be accomplished by shifting the left-slanted stick to further to the left so the value becomes a V. The problems were presented in random order with a time limit of five minutes for each one. If the solution was incorrect they had to continue working on the problem until the correct solution was found or the time ran out. The dependent variables in this study were the frequency of solution during a five-minute interval, the solution time for problems solved, and the position and the duration of each fixation on the display.

If the values are viewed as variable and the operators as constant, then the focus in the initial exploratory phase should be on the values rather than the constants. Since the values have to change in order to solve the problem then the participant should demonstrate a longer fixation time overall on the values and this should increase over time due to a faulty representation. Impasses were expected in Problem B and Problem C only. This should last only until constraint is relaxed on the operators.

Figure 6.1: Problems used in insight study (Knoblich et al, 2001)



The results revealed that Problem B was solved significantly less often than Problem A and Problem C. Problem C was solved significantly less often than Problem A. With respect to solution times, Problem A was solved significantly faster than Problem B and Problem A was solved significantly faster than Problem C. Problem C was solved significantly faster than Problem B.

With regards to eye tracking data, only fixations longer than 100ms were included. The problem solving process was divided into three equal portions for each participant and then aggregated across all of the participants. The results indicated that the overall fixation duration was higher in Problems B and C than in Problem A, and the mean fixation duration increased steadily across intervals in Problems B and C, but remained constant after the second interval in Problem A. These results appear to agree with the hypothesis that the participants faced more impasses in Problems B and C than in Problem A.

In a similar vein to the matchstick problem, syllogisms require manipulation of the terms in each premise to draw a conclusion. How easy or difficult the task is depends on several factors such as the figure of the syllogism or the style of the reasoner. Observing the eye movements of reasoners can provide valuable information about the reasoning process.

6.3. Eye movements and embodied solutions

Grant and Spivey (2003) suggest cognitive processing and eye patterns are linked, that the pattern of eye movements can influence spatial reasoning "by way of an implicit eye movement–to–cognition link where successful participants moved their eyes in a pattern that embodied the solution". Using Duncker's (1945) radiation problem, they demonstrated that participants who successfully solved the problem within 10 minutes had spent more time looking at the tissue area than those who were unable to solve it without hints. Duncker's radiation problem asks participants to suppose they are doctors faced with a patient who has a malignant tumor. It is inoperable and there is a ray that can destroy the tumor but the intensity of the ray will also destroy healthy tissue as well. The task is to work out how to destroy the tumor while preserving the healthy tissue. The pattern of eye movements of the successful participants followed a path that embodied the solution.

Thomas and Lleras (2007) took this a step further to examine whether forcing an eye movement pattern that embodied the solution to the problem could make participants more successful. They used a tracking task to occasionally guide their participants' eye movements while attempting to solve Duncker's (1945) radiation problem. The tracking task was to identify a digit among letters within the problem diagram. The participants were allocated to one of four groups: an embodied-solution group where their eyes were guided across the skin areas, focusing on the pattern that embodies the laser path; an areas-of-interest group that were only guided to the same areas as the embodied-solution group but with far fewer instances of crossing the skin areas; a repeated skin-crossing group that were guided between the same two points without focusing on the skin areas; and a tumour–fixation group which served as the control group by looking only at the tumour.

The researchers hypothesised that if skin-crossing saccades heavily influenced cognition of the problem then the embodied-solution group should perform best. If simply directing the eyes to the relevant areas is sufficient then the embodied-solution and the areas-of-interest groups should perform best. If skin-crossing helps but has no bearing on embodiment, then the embodied-cognition and the repeated-skin-crossing groups should perform best. If guiding the eyes has no influence on embodiment then all groups should perform similarly.

The results showed that the embodied-solution group were more likely to solve the radiation problem than all the other groups. This supported the notion that eye movement patterns can influence thought in spatial reasoning tasks and is most effective when the guidance embodies the solution. This is further evidenced in a study by Litchfield, Ball, Donovan, Manning and Crawford (2010) demonstrating that novice radiologists were better able to identify nodules after being shown the search patterns of more experienced colleagues.

In another study, Susac, Bubic, Kaponja, Planinic and Palmovic (2014) observed 40 students while they tried to rearrange algebraic equations. These researchers found a correlation between the number of fixations and the efficiency of problem solving, suggesting that more efficient participants had developed adequate strategies. Their results indicate that eye tracking data provide insights into implicit cognitive processes and can be used as an indirect measure of cognitive load and level of difficulty for participants and could also be a useful way of assessing problem solving strategies during the task. They reported that scan path analysis provided an objective measure of the frequency of participants' checking the offered solution during the equation rearrangement. Similarly, Tai, Loehrb and Brighamc (2006) suggest that eye-gaze tracking may potentially be a useful approach to furthering understanding of students' problem-solving behaviours. In particular, "eye movements may be useful in discriminating different levels of expertise on complex academic tasks within groups of students who have similar levels of performance" (Tai et al., 2006, p. 189).

Research has shown that a figural effect occurs when drawing conclusions from syllogisms (Chater & Oaksford, 1999; Dickstein, 1978; Polk & Newell, 1995; Wetherick & Gilhooly, 1990) and this is most prominent for Figure 1 and Figure 2. The figural effect is the tendency to create solutions in the same form as the premise containing the subject. The reasoner states the conclusion in the order the premises were presented and in which the terms were used to construct the mental representation of those premises. These figures relate to the relative order of the terms in the syllogism premises, and are:

Figure 1: AB/BC
Figure 2: BA/CB
Figure 3: AB/CB
Figure 4: BA/BC

The figural effect is that Figure 2 tends to generate more answers in the C-A pattern while Figure 1 generates more answers in the A-C pattern. In addition, Figure 1 syllogisms are generally processed faster than Figure 2 syllogisms (Espino, Santamaria & Garcia-Madruga, 2000).

Several theories abound about the cause of figural effects in the processing of syllogisms. The process may be dependent on how and when the elements of the problem are represented in the mind of the reasoner. According to the Probability Heuristic Model (PHM, Chater & Oaksford, 1999), the min-heuristic selects the quantifier and the attachment heuristic selects the order of end terms in the conclusion, therefore the figure does not affect the difficulty of the task because the conclusion has already been determined. In contrast, the Mental Models theory (Johnson-Laird & Bara, 1984) claims that figure does affect the difficulty of the task and this occurs when separate representations of the premises are combined in order to solve the problem. They suggest Figure 1 is easier because the middle term is adjacent in both premises and Figure 2 is harder because it requires the reasoner to rearrange the representation, either by changing the order of the terms within the premises or the order of the premises themselves.

Espino, Santamaria, Meseguer and Carreiras (2005) used eye tracking to investigate if the level of difficulty and the figure of the syllogism affects the processing time. As Mental Models Theory indicates, there can be an early process effect where the figure affects the difficulty due to initial representations having to be reviewed and additional representations having to be created, or as PHM indicates, a late process effect where figure has an effect only after all other factors have determined the mode or quantifier.

Espino et al. (2005) examined First Pass Time (the sum of duration of fixations in a given part of a sentence during the initial reading of the passage), comparing it with the Total Reading Time (the sum of the duration of all the fixations in a given part of a sentence). First Pass Time relates to early processes around the initial viewing of the premises, while Total Reading Time relates to the later processes relates around the total time taken to draw a conclusion (Rayner, Sereno, Morris, Schmauder & Clifton, 1989).

The dependent variables in the study were First Pass Time v Total Reading Time. Participants were presented with 8 problems: 4 each of Figure 2 (BA/CB) and Figure 1 (AB/BC) problems, with 8 additional syllogisms serving as fillers. The test problems were 4 simple (two of each figure) and 4 complex (two of each figure) models. The complex models always included negative quantifiers. The problems were presented individually in random order and participants were required to press a key when they reached a conclusion and give a verbal answer to the experimenter.

The results for First Pass Time showed no significant effects or interactions of difficulty or type of figure. However, there was an effect of type of figure for the second premise. Participants took longer to read the second premise in Figure 2 than in Figure 1. This result supports the notion that the figural effect occurs as a result of additional processing of the second premise. The shorter reading times for the second premise in Figure 1 syllogisms suggests that reasoners can integrate the information of the second premise more quickly in Figure 1 syllogisms than in Figure 2 syllogisms.

The results for Total Reading Time showed reliable effects of difficulty for the first premise. Participants took less total time in solving simple problems than complex problems. The second premise showed reliable effects of difficulty and of type of figure. Participants took less total time for simple problems than for complex problems and they took less total time for Figure 1 problems than for Figure 2 problems. The results may have also been affected by the fact that the complex problems always included negative quantifiers.

With regards to accuracy, participants gave more correct conclusions to simple than to complex problems and they gave more correct conclusions to Figure 1 than to Figure 2 problems. In addition, there was an interaction between figure and difficulty. Participants gave more correct conclusions to Figure 1 simple problems than to Figure 2 simple problems. There was no effect for complex problems.

The results of this study are more in keeping with Mental Models Theory that suggests a figural effect is caused by reasoners rearranging their mental representations of models in order to solve the syllogism. The close proximity of the middle term in both premises makes it easier to process those syllogisms as there is no need to rearrange the representations. It is easy to construct the first premise then immediately integrate the information from the second premise (Johnson-Laird, 1983). For the Figure 2 problem they would have had to construct the second premise then review the arrangement for the first premise in light of the new information, thus adding processing time. This effect cannot be explained by PHM.

Jia, Lu, Zhong and Yao (2009) further distinguished between evaluation and generation of conclusions in an eye-tracking study of syllogism solving. The effect appears to be the reverse when participants are asked to evaluate a conclusion rather than generate one of their own. Participants in their study were asked to evaluate whether a given conclusion in ninety Figure 2 (BA/CB) and ninety Figure 1 (AB/BC) syllogisms were true or false. Two important factors in their study were early and late processes. Early processes were defined as the duration of the fixation from the time the participant entered the area of interest and left it for the first time. Late processes were defined as the sum of the duration of all fixations except the first one. Interestingly, they found the Figure 1 syllogisms were more cognitively demanding than the Figure 2 syllogisms. The early processes were longer for the major premise and the conclusion of Figure 1 than Figure 2. The late processes were longer for the major premise, minor premise and the conclusion of Figure 1 than Figure 2. These findings suggested there were differences in figural effects between evaluation and generation of conclusions. Figure 1 appeared to engender a backward-chaining process that was more cognitively demanding than Figure 2 that appeared to engender a forward-chaining process.

Eye tracking studies have revealed a lot of valuable information in terms of strategies that people use for problem solving, with the possibility of different strategies being exhibited through different regions of the syllogism problems, and in terms of the processes around figural effects. An interesting question is how this method of study can be used to determine which type of syllogistic problems are easier to solve with verbal or spatial strategies.

6.4. Study examining eye movements while solving syllogisms

The aim of the current study was to examine eye movements of participants while solving a set of 12 categorical syllogisms with valid conclusions to identify where attention is focused during the reasoning process (Espino et al., 2005), and if they were influenced by the level of difficulty or the figure of the syllogism (Jia et al., 2009). The syllogisms used in the study were those identified by Ford (1995) as being easiest for spatial reasoners (ES), easiest for verbal reasoners (EV), and equally difficult for both spatial and verbal reasoners (HSV). Each syllogism was separated into eight areas of interest, one for each of the quantifiers and terms in each premise. Treating each quantifier and each term as a separate area of interest made it possible to track which part of the premise attention was allocated to at any point during the experimental trials. It was expected that participants would be affected more by the figural effect than the level of difficulty.

Observing eye movements while solving syllogisms can show where, if any, impasses occur (Knoblich et al., 2001), and if there is an impasse, what type of problem is it more likely to occur with. Hegarty et al. (1992) found key information such as numbers and variable names were fixated longer and were critical in determining solutions. Therefore, I consider the possibility that the pattern of fixation on problems with varying levels of difficulty (ES, EV and HSV) as well as the figure of the syllogism (AB/BC, AB/CB, BA,BC, BA,CB) can identify which parts of the premises are most important for deducing a conclusion for verbal or spatial reasoners. The hypothesis is that reasoning strategy would be affected more by the figure of the syllogism than by the level of difficulty of the syllogism.

6.4.1. Method

Participants

Participants were 23 Lancaster University students with a mean age of 23 years (SD = 5.3). They were recruited by Sona, the research participation system used by the Department of Psychology, and by posting notices around the university campus. They were paid £7 for participation. None of the participants took part in the previous studies in this thesis. Four participants were tested but the data was not included in the analysis as it had not been collected effectively due to computer malfunction, resulting in the final n = 19.

Materials

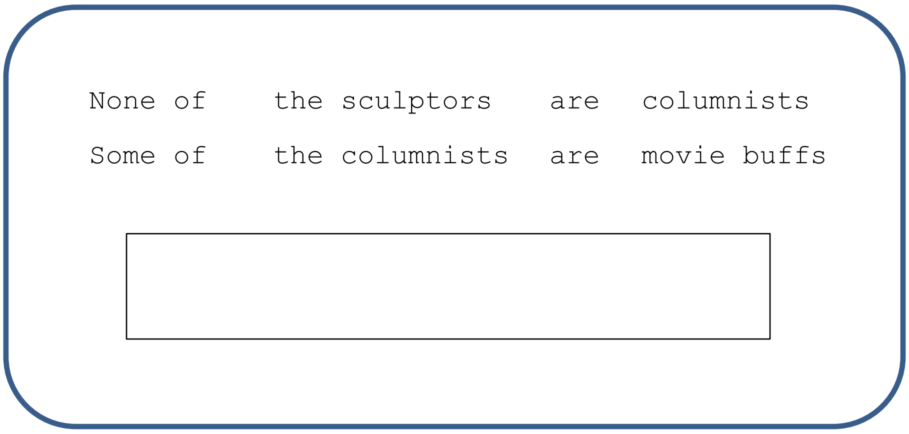
A shortened form of the Raven's Standard Progressive Matrices (Bilker, Hansen, Brensinger, Richard, Gur & Gur, 2012) was used as a test of general cognitive ability in order to test for the effect of non-verbal cognitive ability between participants.

The test stimuli consisted of 12 syllogisms with neutral premise terms that were not related to each other (e.g. Some of the weavers are historians). All 12 syllogisms were taken from Ford's (1995) study and were selected based on the level of difficulty for the participants in her study: four that were shown to be easiest for verbal reasoners (EV), four that were easiest for spatial reasoners (ES), and four that were equally difficult for both types of reasoners (HSV). All 12 syllogisms had valid conclusions. See Appendix 3 for the list of syllogisms.

The syllogisms were presented in random order on a 57.5cm (23”) HPs2331a computer monitor with resolution 1024 x 768. Eye movements were recorded with a Tobii Pro X60 table mounted eye tracker at a rate of 60Hz, with a maximum gaze angle of 35 degrees. Participants sat approximately 50cm away from the monitor but were free to adjust their position slightly to ensure that the eye tracker picked up their eye movements. The syllogisms were displayed in the centre of the monitor screen. Each premise was divided into four areas of interest (AOIs), for a total of eight AOIs. Each AOI was either a term or a quantifier in each of the premises. For example, in the syllogism ‘None of the sculptors are columnists’, AOI1 is ‘None of’, AOI2 is ‘the sculptors’, AOI3 is ‘are’, and AOI4 is ‘columnists’. AOI5-AOI8 followed the same pattern.

The first premise was positioned 8cm from the top of the screen, with each AOI in that premise positioned a minimum of 2cm away from the previous one. The space for each AOI was governed by the length of the longest phrase. The second premise was positioned 12cm from the top, 4cm below the first premise, with each subsequent AOI positioned directly under its counterpart in the first premise, for example AOI5 was positioned directly under AOI2. All AOIs were displayed in font size Courier New 18, with black letters on a white background. Figure 6.2 shows the layout of the AOIs.

Figure 6.2: Presentation layout of the syllogisms during experimental trial. Each block of word(s) represents an AOI. For example, AOI1 = None of, AOI2 = the sculptors.



Design

A repeated measures design was used. The within-subjects factors were problem type (HSV, ES, EV) and AOI (AOI1, AOI2, AOI3, AOI4, AOI5, AOI6, AOI7, AOI8) in the analysis of verbal versus spatial problem strategy. For the analysis by Figure, the within-subjects factors were Figure (AB/BC, AB/CB, BA/BC, BA/CB) and AOI (AOI1, …, AOI8). The dependent variables were the looking proportion (proportion of the total time of fixations in any AOI) of each AOI and the response times for level of difficulty and figure of syllogisms.

Procedure

Participants were tested individually in one session lasting approximately 60 minutes. The shortened form of Raven’s Standard Progressive Matrices test was administered first, followed immediately by the problem-solving task.

Instructions for the problem-solving task were presented on paper and participants were given the opportunity to ask questions before proceeding to the second part of the study. The instructions were as follows:

> You are taking part in an investigation about how people use information in order to draw conclusions. You will be solving a series of syllogistic reasoning problems. A syllogistic problem consists of two premises (statements), for example:
>
> Some B are A
> All B are C
>
> Your task is to determine the conclusion (if any) which follows logically from these. A logical conclusion is a conclusion which must be true, if the premises are true. In this example, notice that the B appears twice, once in each premise, and the A and C are non-repeated terms. You are to draw a conclusion about these non-repeated terms. The conclusion must be in one of the following forms, where the question mark stands for a non-repeated term in the problem.
>
> All ? are ?
> No ? are ?
> Some ? are ?
> Some ? are not ?
> None ? are ?
>
> For example, Some teachers are tap dancers
> All teachers are bookworms
>
> Conclusion: Some of the bookworms are tap dancers, or
> Some of the tap dancers are bookworms
>
> Feel free to write or draw anything that helps you.
>
> When you have reached your conclusion, simply type that conclusion clearly in the box provided on the computer monitor. You do not need to position the cursor as anything you type will automatically go in the box.

The Tobii Pro X60 eye tracker was calibrated at the start of each session. This was followed by online instructions for progression through the session on the computer. Each trial began with the presentation of a central fixation cross in the centre of the computer screen. After five seconds the cross disappeared, and a problem appeared with a box underneath for the participant to type their conclusion. Participants were allowed to study the problem for up to two minutes. A two-minute time limit was used as the results from Experiment 1 in Chapter 3 showed that no participant required prompting for a response within that time frame. The longest response in that experiment was 118.90 seconds. If participants in the current study had not typed a conclusion within that time frame, a message appeared above the problem to tell them their two minutes were up and to type their conclusion in the box provided. They were then given a further two minutes to type a conclusion. After typing their conclusion, they were required to press ‘0’ to move on to the next problem.

6.4.2. Results

The results for the shortened version of the Ravens Standard Progressive Matrices showed a mean of 5.2 and standard deviation of 1.3 across all participants.

The total number of times each AOI was looked at was calculated as the mean of the proportion of the total amount of looking time across all eight AOIs for each syllogism. The data were collated by problem type or by figure according to the analysis. The results of each analysis are presented separately.

Problem type x AOI

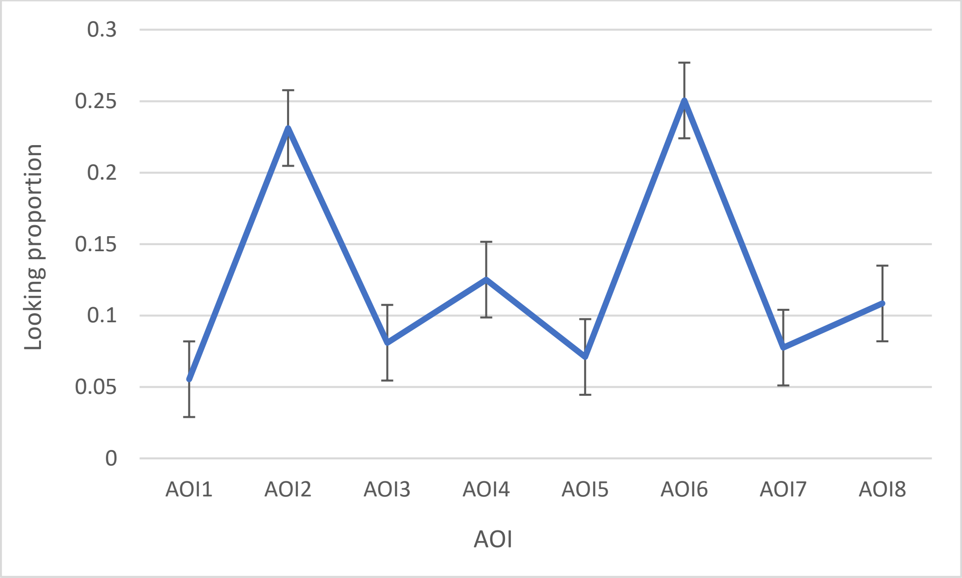
A 3 x 8 repeated measures ANOVA was conducted on the data collated by problem type. The within-subjects factors were problem type (HSV, ES, EV) and AOI (AOI1, AOI2, AOI3, AOI4, AOI5, AOI6, AOI7, AOI8). The dependent variable was the proportion of looking time for each AOI. Table 6.1 shows the looking proportion for each problem type x AOI.

Table 6.1: Looking proportion for problem type x AOI. The standard deviation is in parentheses.

AOI	HSV	ES	EV	Overall
AOI1	.05 (.04)	.05 (.03)	.06 (.03)	.05 (.03)
AOI2	.19 (.05)	.25 (.06)	.25 (.05)	.23 (.05)
AOI3	.09 (.04)	.06 (.03)	.08 (.04)	.08 (.04)
AOI4	.14 (.06)	.13 (.05)	.11 (.05)	.13 (.05)
AOI5	.07 (.05)	.06 (.03)	.08 (.05)	.07 (.04)
AOI6	.24 (.07)	.27 (.10)	.25 (.07)	.25 (.08)
AOI7	.11 (.06)	.07 (.03)	.06 (.04)	.08 (.04)
AOI8	.10 (.07)	.12 (.09)	.11 (.07)	.11 (.08)

There was a significant main effect of AOI, $F(7,126) = 42.86$, $p < .001$. The first term in each premise (AOI2 and AOI16) was looked at twice as long as the second term in each premise (AOI14 and AOI18). See Figure 6.3.

Figure 6.3: Overall looking proportion of AOI for problem type.



There was a significant interaction between problem type x AOI, F(14,252) = 4.40, $p < .001$. This was due to significant differences between problem type in AOI2, AOI3, AOI4 and AOI7. See Table 6.2 for details.

Table 6.2: *p*-values of pairwise comparisons between problem type x AOI.

	HSV v ES	HSV v EV	ES v EV
AOI1	1.000	.717	.231
AOI2	.006**	.004**	1.000
AOI3	.003**	.707	.043*
AOI4	.726	.006**	.359
AOI5	.483	1.000	.917
AOI6	.203	1.000	.707
AOI7	.023*	.012*	1.000
AOI8	.431	.675	1.000

Note: * significant at .05 level; ** significant at .01 level. The alpha level has been corrected for multiple comparisons using Bonferroni.

HSV x ES: The proportion of looking is greater for the first term in premise 1 (AOI2) in ES (M = .25) than in HSV (M = .19). The proportion of looking for the second quantifier in premise 1 (AOI3) was greater in HSV (M = .09) than ES (M = .06). The looking proportion for the second quantifier in premise 2 (AOI7) was also greater for HSV (M = .11) than for ES (M = .07).

HSV x EV: The proportion of looking for the first term in premise 1 (AOI2) is greater in EV (M = .25) than in HSV (M = .19). The proportion of looking for the second term in premise 1 (AOI4) is greater in HSV (M = .14) than in EV (M = .11). The proportion of looking for the second quantifier in premise 2 (AOI7) is greater in HSV

(M = .11) than for EV (M = .06). This suggests a longer processing time for premise 2 for problems that are difficult to solve with a verbal or spatial strategy.

ES x EV: The proportion of looking for second quantifier in premise 1 (AOI3) is greater in EV (M = .08) than in ES (M = .06).

In post hoc tests, the results displayed in Figure 6.4 are as follows:

EV (Syllogisms that are easiest for verbal reasoners)

The looking proportion for the first term in premise 1 and premise 2 is identical (M = .25), as well as for the second term in premise 1 and premise 2 (M = .11). The first term in each premise was looked at 56% more than the second term in each premise.

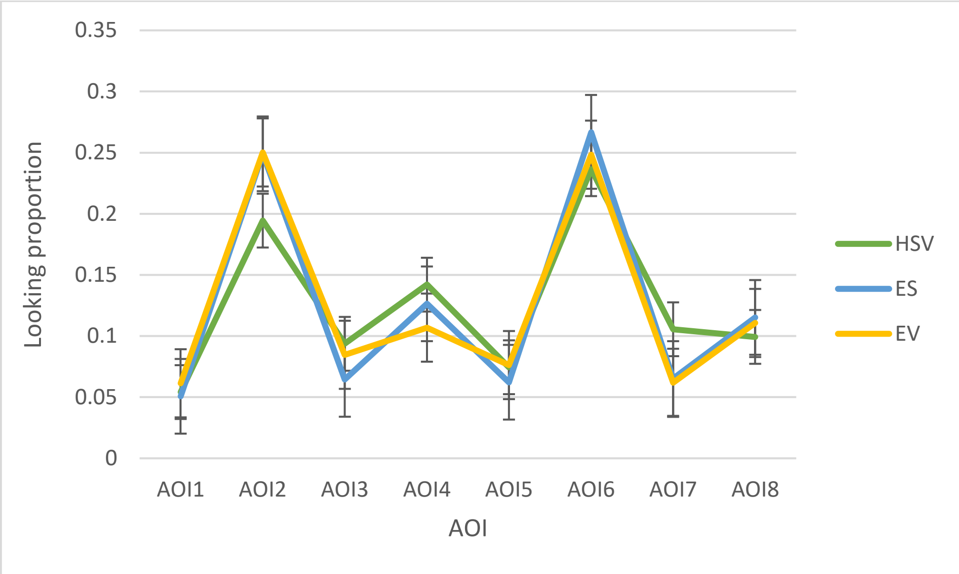
ES (Syllogisms that are easiest for spatial reasoners)

The looking proportion for the first term in premise 1 (M = .25) was almost identical to the first term in premise 2 (M = .27), as well as the second term in premise 1 (M = .13) and premise 2 (M = .12).

HSV (Syllogisms that are equally difficult for verbal and spatial reasoners)

The looking proportion for the first term in premise 1 was 20% smaller (M = .19) than for the first term in premise 2 (M = .24). The looking proportion for the second term in premise 1 was greater (M = .14) than for the second term in premise 2 (M = .10).

Figure 6.4: Looking proportion for problem type x AOI.



Response Times

A one-way repeated measures ANOVA was conducted. The within subjects factor was problem type (HSV, ES, EV) and the dependent variable was the response time. Interestingly, the overall response time for HSV problems was quicker (M = 43437ms) than for ES (M = 47702ms) and for EV (47982ms) problems. See Figure 6.5. A Shapiro-Wilk's test and a visual inspection of the histograms, normal Q-Q plots and box plots showed that the response times for each level of difficulty were not normally distributed, with each level demonstrating $p < .001$. The data were transformed using Log10. The main effect for response time was not significant, $F(2,152) = 1.12$, $p = .33$.

Figure 6.5: Response times for problem type.

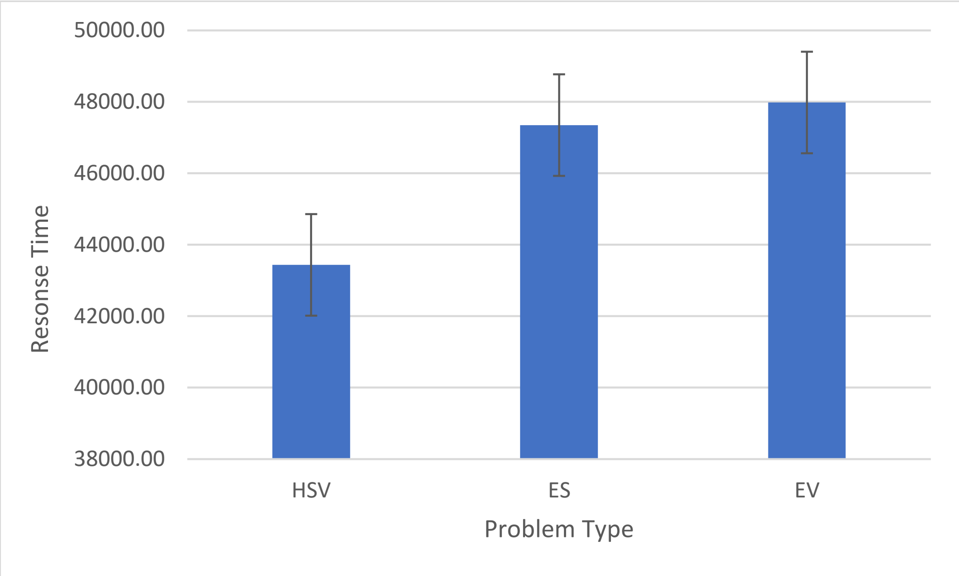


Figure x AOI

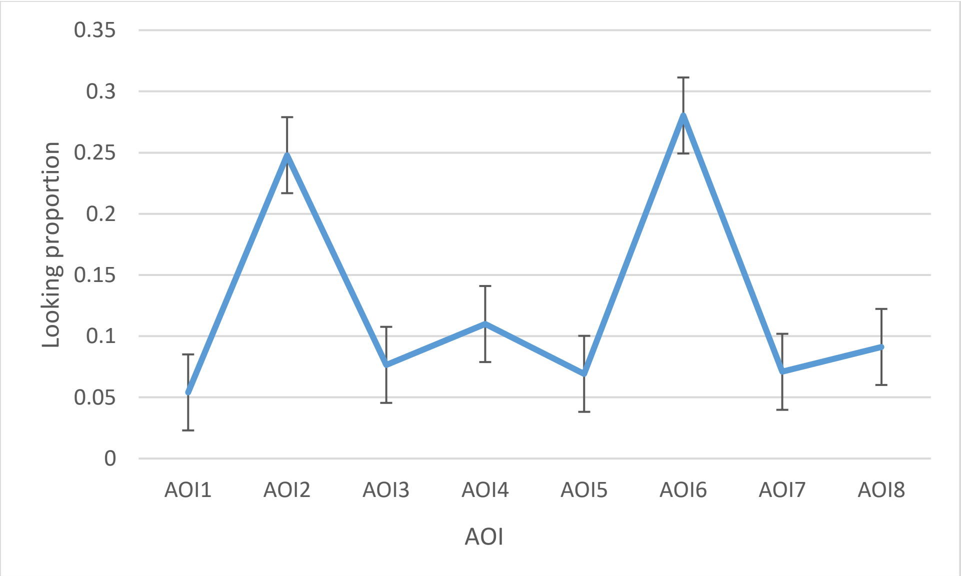
A 4 x 8 repeated measures ANOVA was conducted for the data collated by figure of the syllogism. The within-subjects factors were figure (AB/BC x BA/BC x AB/CB x BA/CB) and AOI (AOI1 x AOI2 x AOI3 x AOI4 x AOI5 x AOI6 x AOI7 x AOI8). The dependent variable was the looking proportion for each AOI. Table 6.3 shows the looking proportions for each figure x AOI.

Table 6.3: Looking proportions of figure x AOI. The standard deviations are in parentheses.

AOI	AB/BC	BA/BC	AB/CB	BA/CB	Overall
AOI1	.06 (.03)	.06 (.04)	.05 (.04)	.05 (.04)	.05 (.04)
AOI2	.27 (.06)	.18 (.04)	.32 (.09)	.22 (.07)	.25 (.07)
AOI3	.06 (.03)	.09 (.04)	.09 (.04)	.07 (.04)	.08 (.04)
AOI4	.09 (.05)	.16 (.06)	.07 (.04)	.12 (.07)	.11 (.06)
AOI5	.06 (.03)	.08 (.04)	.06 (.04)	.07 (.05)	.07 (.04)
AOI6	.27 (.01)	.21 (.07)	.31 (.11)	.33 (.09)	.28 (.07)
AOI7	.05 (.03)	.10 (.04)	.06 (.03)	.07 (.06)	.07 (.04)
AOI8	.14 (.12)	.12 (.09)	.04 (.03)	.06 (.05)	.09 (.07)

There was a significant main effect of AOI, $F(7,126) = 67.78$, $p < .001$. The first term in each premise (AOI2 and AOI16) were looked at approximately twice as long as the second term in each premise (AOI14 and AOI18). See Figure 6.6.

Figure 6.6: Overall looking proportion for AOI of syllogism figure.



The F value for the main effect of figure is not available as the data was collated by proportion so each syllogism type will be the same in terms of its means. There was a significant interaction between figure x AOI, $F(21,378) = 10.59$, $p < .001$. This was due to significant differences between the figures in AOI2, AOI3, AOI4, AOI6, AOI7 and AOI8. See Table 6.4 for details.

Table 6.4: *p*-values of pairwise comparisons between figure x AOI.

	AB/BC v BA/BC	AB/BC v AB/CB	AB/BC v BA/CB	BA/BC v AB/CB	BA/BC v BA/CB	AB/CB v BA/CB
AOI1	1.000	.535	1.000	.541	1.000	1.000
AOI2	.000**	.626	.052	.000**	.125	.010**
AOI3	.000**	.005**	1.00	1.000	.011*	.291
AOI4	.000**	.549	.464	.000**	.020*	.029*
AOI5	.962	1.000	1.000	1.000	1.000	1.000
AOI6	.061	1.000	.166	.001**	.000**	1.000
AOI7	.000**	.514	.627	.011*	.730	1.000
AOI8	1.000	.006**	.042*	.003**	.022*	.245

Note: * significant at .05 level; ** significant at .01 level

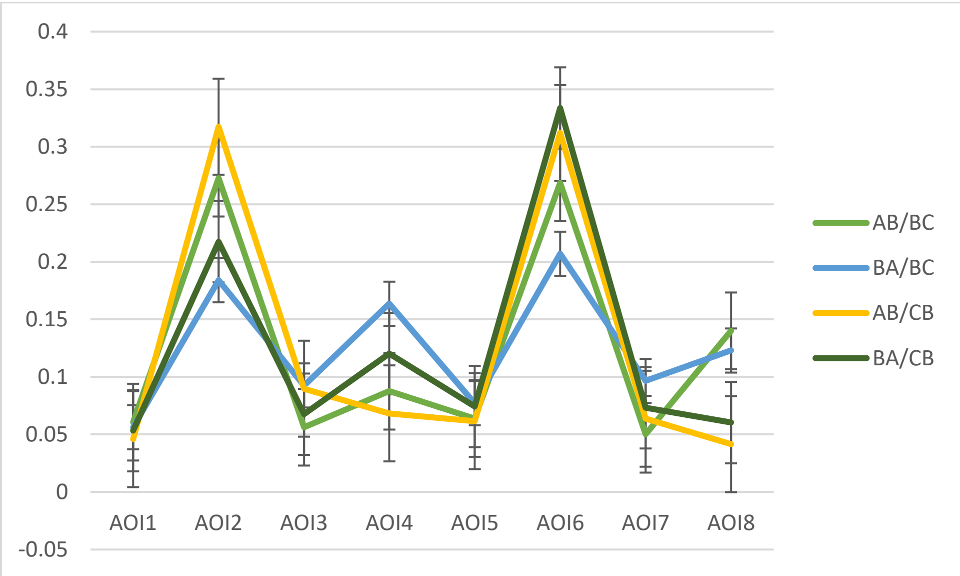
AB/CB: The looking proportion for the first term in premise 1 (M = .31) was equivalent to that of the first term in premise 2 (M = .31). The looking proportion for the second term in premise 1 (M = .07) was slightly higher than for the second term in premise 2 (M = .04).

BA/BC: The looking proportion for the first term in premise 1 is (M = .18) was similar to the first term in premise 2 (M = .20). However, there was a reverse effect for the second term in premise 1 (M = .16) and premise 2 (M = .12).

BA/CB: The looking proportion for the first term in premise 2 was higher (M = .33) than for the first term in the first premise 1 (M = .21). The opposite occurred for the second term. The looking proportion for the second term in premise 1 was twice as long (M = .12) than for the second term in premise 2 (M = .06).

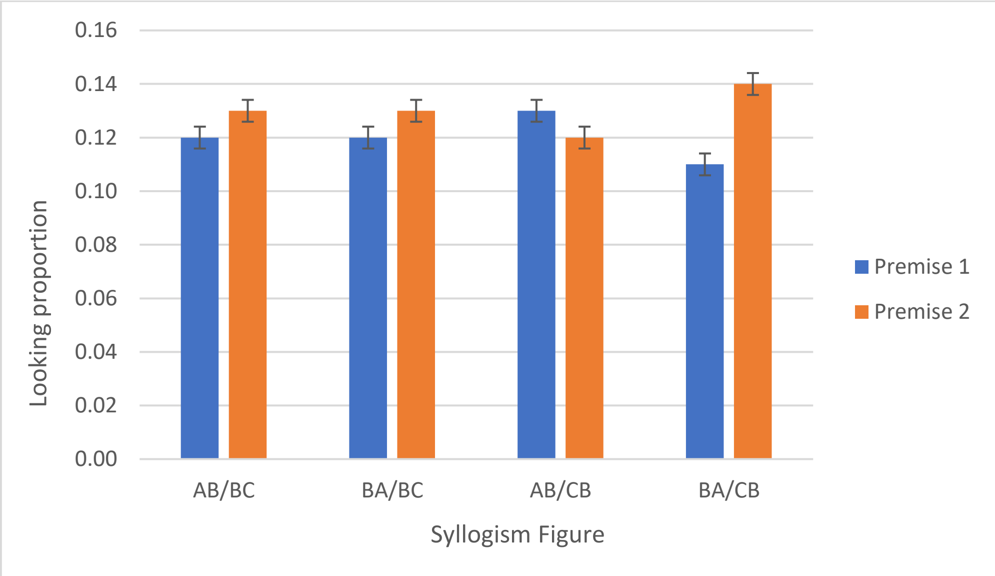
AB/BC: The looking proportion of the first term in premise 1 (M = .27) was similar to the first term in premise 2 (M = .27). The looking proportion of the second term in premise 2 (M = .14) was higher than for the second term in premise 1 (M = .09). See Figure 6.7.

Figure 6.7: Looking proportion for figure x AOI.



Collapsing the results across all AOIs for each figure shows opposing patterns for the symmetrical figures, AB/CB and BA/BC, and an identical pattern for AB/BC and BA/BC. See figure 6.8. This suggests that the terms in premise 1 of AB/BC are switched to make the figure symmetrical and consequently is less cognitively demanding. Overall, premise 2 is looked at more than premise 1 in the BA/CB figure.

Figure 6.8: Collapsed results across all AOIs for each syllogism figure.

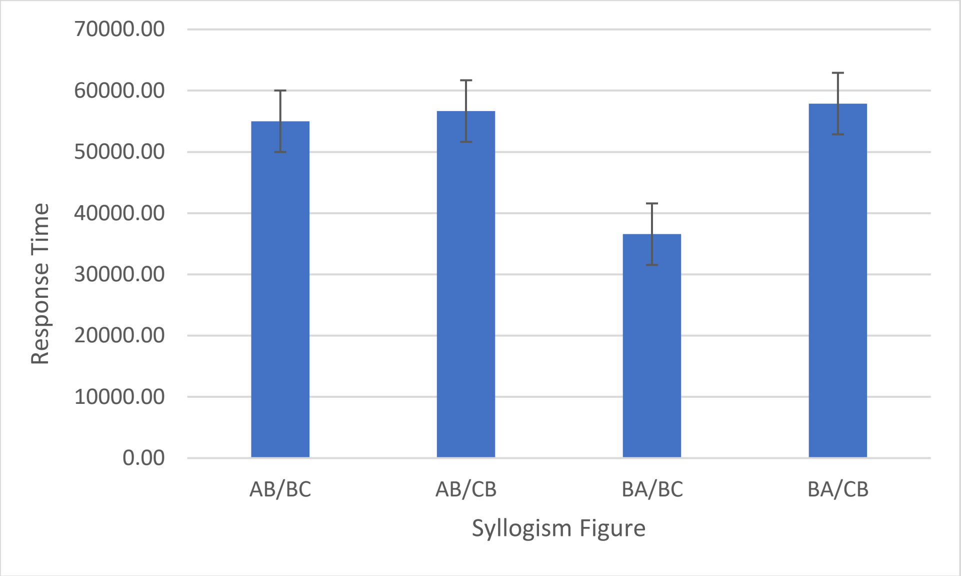


Response Times

There was a main effect of response times, $F(3,54) = 2.93$, $p < .05$. The response time for BA/BC was quicker (M = 36567ms) than for AB/BC (M = 55005ms), AB/CB (M = 56671ms) and BA/CB (M = 57886ms). See Figure 6.9.

For AB/BC problems, participants produced more A-C (68%) responses than C-A (47%). For the BA/CB problems, they produced more C-A responses (79%) than A-C (21%) responses.

Figure 6.9: Response times for syllogism figure.



6.4.3. Discussion

The aim of the current study was to examine eye movements of participants while solving a set of 12 categorical syllogisms with valid conclusions to identify reasoning strategies, and if they were influenced by the level of difficulty or figure of the syllogism. The syllogisms used in the study were those identified by Ford (1995) as being easiest for spatial reasoners, easiest for verbal reasoners, and equally difficult for both spatial and verbal reasoners. Each syllogism was separated into eight areas of interest, one for each of the quantifiers and terms in each premise. Treating each quantifier and term as a separate area of interest made it possible to track which part of the premise attention was allocated to at any point during the experimental trials. It was expected that participants would be affected more by the figural effect than the level of difficulty of the syllogisms.

The looking patterns for problem type (HSV, ES and EV) and figure (AB/BC, AB/CB, BA/BC and BA/CB) are almost identical, suggesting that attention is divided between terms based on the figure rather than the level of difficulty of the syllogisms. The greater proportion of looking was allocated to the first term in each premise, on average twice as much as for the second term in each premise. Surprisingly, a small proportion of looking time was allocated to the quantifiers. Knoblich et al. (2001) found in their matchstick experiment that prior knowledge of arithmetic biased people to seeing the values as variable, so the focus of attention tended toward the values rather than the operators. The current study suggests a similar pattern where the focus of attention was primarily on the terms rather than the quantifiers. For each respective syllogism figure, the quantifiers will be the same regardless of the level of difficulty or whether the participant is using a spatial or verbal strategy. If the preferred response for that figure is C-A, then participants are likely switching the terms in premise 2 as well as the premise order, thereby increasing cognitive demand. The key information for participants appeared to be the terms (Hegarty, Mayer & Green, 1992). They appear to view the quantifiers just long enough to establish the nature of the link between the terms. In addition, it is possible there may be an element of belief bias occurring where the participants are reasoning about the relationship between the literal meaning of the terms instead of logically between the sets of characteristics. For example, the syllogism ‘All of the engineers are sculptors, All of the engineers are alcoholics’ elicited a smile from some participants. Also, some participants queried whether the relationship was general or specifically about a group of people in a room, suggesting they were using their implicit knowledge of the terms to guide their workings. However, while the looking pattern is similar for problem type and figure of the syllogism, the proportion of attention differed.

Normal reading would result in few returns (Jacobson & Dodwell, 1979; Rayner & Pollastek, 1989) to AOIs that are above or to the left of current position, and so the eyetracking data goes beyond the patterns that would be observed in a standard reading study.

There was an interaction between problem type x AOI, with the significant differences due to AOI2, AOI3, AOI4 and AOI7 (See Table 6.1). Pairwise comparisons between HSV v ES and HSV v EV problems suggests a longer processing time for premise 2 for problems that are difficult to solve with a verbal or spatial strategy. The results support previous research that fixations increase for difficult problems (Stupple & Ball, 2007). More attention seems to be paid to the operators/quantifiers rather than the values for problems that are equally difficult to solve with a verbal or spatial strategy. According to Knoblich et al. (2001), the focus in the initial stage of reasoning should be on the values and fixations should increase for difficult problems.

Collapsing the results across all AOIs for each figure showed opposing patterns for the symmetrical figures, AB/CB and BA/BC (See Figure 6.7). Premise 1 garnered more attention in the AB/BC figure, while premise 2 garnered more attention in the BA/BC figure. In keeping with other research, the terms are switched around equably between premises 1 and 2 of these figures (Ford, 1995; Espino & Santamaria, 2013). If we consider A-C to be the preferred response, as well as the first-in-first-out theory for the conclusion, then for AB/CB the terms in premise 2 are switched to make the middle term contiguous, thereby increasing the looking proportion for premise 1 as this needs to be reassessed in the light of the new order of terms. The first-in-first-out theory works on the assumption that working memory operates on a first in and first out basis, the evidence being that lists tend to be easier to recall by the order in which the items were presented (Broadbent, 1958). Applying this theory to syllogisms, the implication is that conclusions are stated based on the order in which the terms were used to construct representations of the premises. Likewise, for BA/BC the terms in premise 1 are switched, increasing the looking proportion in premise 2 during reassessment of the problem. Interestingly, there is an identical pattern between the asymmetrical syllogisms, AB/BC and BA/BC. This supports the notion that the terms in premise 1 of BA/BC are switched to make the middle term contiguous.

Premise 2 is looked at more than premise 1 in the BA/CB figure, lending support to the Stupple and Ball (2007) finding of longer inspection times for BA/CB which leads to increased processing times when the middle terms are not contiguous. If the preferred response for this figure is C-A, then participants are likely switching the order of the premises (making CB premise 1 and BA premise 2) to make the middle term contiguous, resulting in the added process of reassessing the problem and thereby increasing the cognitive load. Jia et al. (2009) point out that figural effects tend to occur when participants are required to generate their own solution rather than evaluate one that is given to them.

Another factor to consider is the time constraints imposed on the experimental trials. Imposing a time limit of two minutes per problem may have been a source of increased pressure for some participants, possibly inducing a shift from logical to belief bias reasoning (Evans & Curtis-Holmes, 2005) or matching (Gilhooly, 2005). Heuristic processes come to the forefront when time and cognitive resources are limited (Evans & Curtis-Homes, 2005).

While participants were not assessed for the reasoning strategy style, it is interesting to note that HSV problems (43436.8ms) were solved 8.3% faster than ES problems (47701.61ms) and 9.5% faster than EV problems (47982.28ms). With regards to the figure of the syllogism, response time was fastest for BA/BC

(36566.59ms). It was 33.5% faster than AB/BC (55004.88ms), 35.5% faster than AB/CB (56671.11ms), and 36.8% faster than BA/CB (57886.26ms). It should also be noted here that of the 12 syllogisms used in this study, six were the figure BA/CB and three of those were in the HSV category. One possible explanation for this is that participants settle on the first reasonable solution that seems valid to them.

The current study was limited by the uneven distribution of figure type. The set of syllogisms used in the study was the same that was used in the verbal and spatial strategies studies. The criteria for selection resulted in a pool of three AB/BC, two AB/CB, six BA/BC, and one BA/CB figures. The aim of the study was to examine eye movements while solving the same types of syllogism problems as all other studies in this thesis. While it creates a limitation in the study, maintaining consistency across all studies means less likelihood of other factors affecting interpretation of the results. There needs to be further research using equal numbers of each figure type. While the looking pattern is similar for all figure types, providing strong indication of how attention is allocated across all problems in the study trials, the data will be more robust with a larger pool of stimuli.

The current study supported the hypothesis that looking proportion is influenced by the figure of the syllogism but did not support the hypothesis that it is influenced by the level of difficulty. Examining the syllogisms by areas of interest has aided in distinguishing those problems which relate to different problem solving strategies, in particular verbal and spatial strategies. Future research can consider tracking the eye movement path across the premises as this can provide further information about which types of problems are better solved by a verbal or a spatial strategy, and go even further to look at how this may differ for different types of reasoners, such as those with dyslexia and those without dyslexia .

CHAPTER 7: SUMMARY AND CONCLUSION

My thesis explored the differences in reasoning strategies, comparing the performance of people with dyslexia and people without dyslexia. In particular, in a series of studies I examined the way people with dyslexia and people without dyslexia reason when solving syllogisms and the effects of training to solve them with a different strategy. The aim of my research is to contribute to the understanding of reasoning, strategy selection and problem solving, and the development of intervention strategies for problem solving for people with dyslexia.

The main theme running through the thesis is based on a pioneering study by Ford (1995) that identifies two groups of reasoners – verbal and spatial. She found that verbal reasoners tended to treat syllogisms like mathematical problems, re-writing them as equations, substituting words with letters and using arrows to indicate relationships between the terms of the premises. Spatial reasoners, on the other hand, tended to use shapes in different spatial relationships to represent different classes and their relationships. Bacon at al. (2007) furthered research in the area to show that people with dyslexia tended towards a spatial strategy. The introduction outlined the background to research on the theories of reasoning, as well as dyslexia and learning strategies.

Chapter 2 examined individual differences in reasoning strategies, observing figural effects and belief bias. This chapter featured two experiments. The first experiment investigated strategy selection and figural effects, comparing the performance of participants with dyslexia and participants without dyslexia, with the aim of determining whether there are differences in the strategies that both groups use and if they are affected by the figure of the syllogism. The second experiment used a sentence-picture verification task and a syllogism solving task to examine belief bias.

The results of the study supported previous research that people do tend to reason with a verbal or spatial strategy. It showed that people with dyslexia are affected by the figure of the syllogism. However, it failed to support the hypothesis that there is a difference in strategy between people with dyslexia and people without dyslexia.

Chapter 3 compared the performance of participants with dyslexia and participants without dyslexia after being taught a verbal, rule-based strategy for solving syllogisms. While the initial results showed that training on a verbal strategy improved performance of participants without dyslexia but had a detrimental effect on participants with dyslexia, post hoc tests showed the effect to be only for problems that are easiest for spatial reasoners. Closer inspection of those participants that showed evidence of a clear verbal or spatial strategy suggested that the difference in performance is perhaps more a function of strategy rather than dyslexic status. If people with dyslexia are predominantly spatial reasoners (Bacon et al., 2007), it would be difficult to distinguish them from spatial reasoners without dyslexia under these conditions. While spatial participants without dyslexia may be affected by the verbal training, the assumption is that this is due to being made to use a strategy they would not normally choose in the first instance. A similar assumption can be made for participants with dyslexia, with the added suggestion of a phonological deficit affecting the reasoning process (Snowling, 2000). Therefore, forcing participants with dyslexia, who are predominantly spatial reasoners (Bacon et al., 2007), to work with a verbal strategy may exacerbate the effects of this deficit, more so when visuospatial memory deficits are thought to come to the forefront only when the task at hand requires them to engage with it verbally (Gould & Glencross, 1990; Thomson, 1982).

There is evidence of verbal working memory impairments in people with dyslexia, while spatial memory appears to remain relatively intact (Smith-Spark, Fisk, Fawcett & Nicolson, 2003). Working memory capacity is an important consideration for the results in this thesis. Deficits in short term working memory (Ackerman & Dykman, 1993; Brunswick, McCrory, Price, Frith & Frith, 1999; McDougall & Donohoe, 2002; McLoughlin, Fitzgibbon & Young, 1994; Plaza, Cohen & Chevrie-Muller, 2002) and high processing demands can lead to deficits on both verbal and visuospatial working memory in people with reading disabilities (Swanson, Ashbaker & Lee, 1996). Further study needs to distinguish between participants with dyslexia who are spatial reasoners and participants without dyslexia who are spatial reasoners.

Chapter 4 compared the performance of participants with dyslexia and participants without dyslexia after learning to solve syllogisms using a spatial strategy based on Euler Circles, more specifically, a strategy developed by Stenning and Oberlander (1995). This strategy was identical to the verbal strategy in terms of the stages required in the algorithm so it can be seen to be computationally equivalent. However, the representations were different. They were based on spatial rather than verbal information. In the study reported in this Chapter, participants with dyslexia performed worse than participants without dyslexia on problems that are easiest for verbal reasoners and on problems that are equally difficult for both verbal and spatial reasoners, supporting the notion that people with dyslexia tend to favour a spatial strategy (Bacon et al., 2007). The results demonstrated that while training slightly improved the overall performance on problems that are equally difficult for verbal as well as spatial reasoners, it had a detrimental effect on performance on problems that are easiest for verbal reasoners. There was no discernible difference in performance on problems that are easiest for spatial reasoners. It appears that using a spatial strategy made problems that are easier with a verbal strategy harder to solve. With regard to the effect on problems that are equally difficult for both verbal and spatial reasoners, the training enabled some participants to see problems from a different perspective and understand, whether explicitly or implicitly, that the strategy they were using originally was inappropriate for the problem at hand and so were able to make the switch. Overall, teaching the spatial strategy impacted learning but did not promote problem solving.

Chapter 5 used the study of eye movements to ascertain where attention was focused while solving the syllogisms. The key questions here were whether the pattern of eye movements can provide insight into the reasoning process and whether the pattern was affected by the level of difficulty or the figure of the syllogism. Interestingly, I found that the focus of attention was more on the terms in the premises than the quantifiers. This suggested that the values (Knoblich et al., 2001) are more important than the quantifiers to the reasoning process. Interesting also was the fact that the pattern of proportions of fixations to different regions of the syllogisms was the same regardless of the level of difficulty or the figure of the syllogism.

While the studies in Chapter 2 failed to support the hypothesis of difference in strategies between participants with dyslexia and participants without dyslexia, the study in Chapter 3 revealed that a difference becomes apparent when the focus is on specific types of problems and when guidance is provided for how to solve them. When the element of free choice was taken away and participants were no longer able to work around individual constraints, for example working memory limitations or automatisation deficits in the central executive (Smith-Spark et al., 2003), significant differences came to the forefront. An introduction of extra cognitive load for some participants can cause disruption and impairment in processing, hindering the ability to learn new things.

Automatisation is the process of learning to do something and then practicing it until it becomes automatic. For a new skill to become automatic, the learner must gather the necessary information and then practice the skill until it sets in their memory (Anderson, 1982). Moores, Nicolson and Fawcett (2003) found teenagers with dyslexia performed significantly worse than participants without dyslexia in speed and accuracy in a shifting attention task. The shifting attention task required more cognitive resources to complete because the target had to be kept in memory while the participant continued to perform the focus task. Solving syllogisms requires representations of the premises to be stored in memory while processing possible solutions. This may account for the silence of some participants in the studies in this thesis who stated that they could not think and write at the same time. An overloaded system would shut down some parts in an attempt to maximise the efficiency of the remaining parts. This would afford the participant space to consciously compensate (Nicolson & Fawcett, 1990) in the performance of the task.

Metacognition and a feeling of rightness (Ackerman & Thompson, 2017; Thompson, Prowse-Turner & Pennycook, 2011) can influence whether a conclusion is accepted as valid or invalid or not. A lack of confidence in the solution that was generated whether, or not, it is correct can prompt an individual to seek alternative solutions. This can be seen in participants that write an answer, sit back and stare at it for a while, then either draw their workings to match the answer, or draw workings then erase the original answer and rewrite it to match the workings. The feeling of rightness is thought to follow fast and autonomous Type 1 processing (Thompson et al., 2011) and this prompts the reasoner to move to analytic Type 2 processing.

There are some limitations in the studies presented in this thesis. The studies in chapters 3 and 4 relied on participants demonstrating either a verbal or spatial strategy via the workings in their booklets. However, many of them failed to show any workings at all and some showed workings for odd problems but showed no discernible pattern. It would be useful for future research to test for verbal and spatial abilities first, for example using psychometric tests such as the GRE Analytic Test and the PFT test employed by Monaghan and Stenning (1998), which can first classify reasoners, before determining their behaviour in syllogisms, or their response to different intervention strategies. The GRE is a complex task and does reflect different strategic approaches to reasoning problems in participants. The PFT is about spatial ability and would be good to use. However, the focus for my work is the effect of training interventions on performance. Ideally, a broad suite of tests would be used, but practically, focusing on the training interventions meant a limit to the number of cognitive tests that could be included alongside the syllogism sessions. Therefore, in this instance, it was better not to use the GRE and PFT to “diagnose” aptitudes/styles of learning.

Another limitation, which holds for chapter 5 as well, is the number of syllogisms presented for each figure. There were not enough samples in each category. Testing participants on all 27 syllogisms with a valid conclusion can be used as a way of identifying reasoning strategies among participants with dyslexia and participants without dyslexia, as well as providing more robust data to determine if any individual differences exist, such as figural effects and belief bias. A better examination of figural effects can be accomplished with a larger sample of syllogisms that are counterbalanced across all four figures.

The studies in this thesis were conducted in English using university students so is therefore limited by the English vocabulary and sentence structures. Results will likely differ with stimuli in a different language that has a very different form and grammatical structure to English, for example Japanese and Korean have topic markers and subject markers with no equivalent in English, as well as using characters rather than letters. What might be significant in English may not be significant in another language by virtue of its grammatical structure. Similarly, university students will have achieved a higher learning ability while progressing through the educational system. Some university students with dyslexia may have learned coping strategies (Miles, 1993) to help them overcome any difficulties they faced during their educational journey.

The present research has shown supporting evidence for the notion that people tend to reason with a verbal or spatial strategy when solving syllogisms, and that people with dyslexia tend towards a spatial strategy. It has gone further to show that while there are no major differences in the way people with dyslexia and people without dyslexia reason, there are subtle differences in those that tend toward a spatial strategy and the differences most likely relate to manipulation of verbal information, driven by difficulties associated with a phonological deficit (Snowling, 2000) and working memory capacity (Smith-Spark et al., 2003). It has extended research in the area by introducing training in verbal and spatial strategies that may have been different to the strategy initially used by the participants, and has shown that training affected the performance of the tasks.

The research has also shown that the pattern of eye movements while solving syllogisms can provide valuable information about the reasoning process. Considerations for future research are comparing the pattern of eye movements of people with dyslexia to people without dyslexia, and the effects of training on the patterns. Would people look at problems differently with a better understanding of the nature of the task? Knowing that there is an expected method, whether it is the one they initially use or one they are taught to use is likely to change how they approach the task.

Another consideration for future research is discourse study. This can take the form of embedding reasoning problems in passages of text to determine how dyslexia might affect problem solving in real world settings. For example, prior beliefs might have a greater impact when the problem is more ‘normal’ than a syllogistic one.

The development of intervention strategies for people with dyslexia must consider the learning styles of individuals and their approach to problem solving, and indeed the difficulties they may face due to issues such as working memory capacity, phonological deficits and automatisation. Rather than assuming that all characteristics of dyslexia apply to all people with dyslexia there must be acknowledgement that there are many combinations of characteristics. Strategies must be flexible enough that they can be adjusted to suit the individual.

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APPENDICES

Appendix 1: Examples of participant information sheet,

consent form and debrief sheets

Participant Consent Form (Used for all studies)

Title of Study: Strategies in Reasoning

Before signing this form you should have been given a sheet labelled "Participant Information Sheet". If you have not already read this please do so before continuing with this form.

Please sign and date this form if you are willing to take part in this experiment, and, if so, for the data that you provide to be used anonymously in reports arising from this study.

You have the right to withdraw from the study at any time without giving a reason and with no adverse consequences. Involvement in this study must be of your own free will. If you are unsure about anything mentioned in this form please ask the researcher present for help.

Please print the following information:

Name of Participant ………………………………………………… Age ………..

Have you ever been diagnosed with, or told you had, dyslexia? ……………………..

Degree ………………………………………………………………………………

Address of Participant ……………………………………………………………..

……………………………………………………………

Please tick this box if you are happy to be contacted for future studies ☐

Signature of Participant ……………………………………… Date ……………

Signature of Experimenter………………………………………. Date ……………

Please feel free to get in contact with me if you have any questions about any aspects of this research. (k.rawlins@lancaster.ac.uk) or, alternatively, my supervisor Prof Padraic Monaghan (p.monaghan@lancaster.ac.uk)

Participant Information Sheet (Used for studies in Chapter 3)

Title of study: Strategies in Reasoning

Researcher: Kay Rawlins

Contact details: k.rawlins@lancaster.ac.uk

Participation in this study is voluntary therefore you have the right to withdraw from the study at any time without having adverse consequences. No explanation need be given.

Aim of the Study: The main aim of the research project is to examine how people reason and the different types of learning strategies that people use. We are particularly interested in whether there are different learning approaches for people with and without dyslexia.

The study will take approximately 60 minutes.

First you will be asked to look at patterns with a piece cut out of it and try to find the matching piece from a set.

Second is a problem solving task to be completed on a computer. You will be asked to determine the conclusion from information presented in two sentences about logical relations.

Participation in this study is confidential; all data will be analysed and stored anonymously, therefore no one will be individually identifiable.

Should you have any complaints regarding this research you can contact the Head of Department, Prof Charlie Lewis or telephone 01524 593470.

Participant Information Sheet (Used for studies in Chapters 4 and 5)

Title of study: Strategies in Reasoning 2

Researcher: Kay Rawlins

Contact details: k.rawlins@lancaster.ac.uk

Participation in this study is voluntary therefore you have the right to withdraw from the study at any time without having adverse consequences. No explanation need be given.

Aim of the Study: The main aim of the research project is to examine how people reason and the different types of learning strategies that people use. We are particularly interested in whether there are different learning approaches for people with and without dyslexia.

The study will be conducted over two sessions, each taking approximately one hour.

In the first session you will be asked to look at a pattern with a piece cut out of it and try to find the matching piece from a set. Upon completion of this task, we will arrange a date and time for the second session.

The second session will be done in 3 parts. First is a problem solving task done in a paper booklet. You will be asked to determine the conclusion from information presented in two sentences about logical relations.

This will be followed by a short training session, in the form of a booklet that demonstrates a particular method for problem solving.

Finally, there will be another problem solving task done in a paper booklet. The problems are similar to those you will have previously seen. Once again, you will be asked to determine the conclusion from the information presented.

Participation in this study is confidential; all data will be analysed and stored anonymously, therefore no one will be individually identifiable.

Should you have any complaints regarding this research you can contact the Head of Department, Dr Linden Ball at l.ball@lancaster.ac.uk or telephone 01524 593470.

Participant Information Sheet (Used for study in Chapter 6)

Title of study: Strategies in Reasoning

Researcher: Kay Rawlins

Contact details: k.rawlins@lancaster.ac.uk

Participation in this study is voluntary therefore you have the right to withdraw from the study at any time without having adverse consequences. No explanation need be given.

Aim of the Study: The main aim of the research project is to examine how people reason and the different types of learning strategies that people use. We are particularly interested in whether there are different learning approaches for people with and without dyslexia.

The study will be conducted in one session taking approximately one hour (60 minutes) on a non-invasive desktop eye-tracker.

You will be presented with two sentences on a computer monitor and asked to determine the conclusion about their logical relations from information presented.

Participation in this study is confidential; all data will be analysed and stored anonymously, therefore no one will be individually identifiable.

Should you have any complaints regarding this research you can contact the Head of Department, Prof Kate Cain (k.cain@lancaster.ac.uk) or telephone 01524 593990.

Participant debriefing sheet (Used for studies in Chapter 3)

Researcher's name: Kay Rawlins

Title of study: Strategies in Reasoning 2

Aim of the study:

Ford (1995) suggests that people solve problems in very different ways. She identified two groups of reasoners – verbal and spatial. She found verbal reasoners tended to treat the syllogisms like mathematical problems, re-writing them as equations, substituting words with letters and using arrows to indicate relationships between the terms of the premises. Spatial reasoners, on the other hand, tended to use shapes in different spatial relationships to represent different classes and their relationships.

Dyslexia has been widely accepted as a consequence of phonological deficit, the way the brain codes or 'represents' the spoken attributes of words (Snowling, 2000). People with dyslexia have difficulty with tasks that require short-term memory processing such as mental arithmetic, writing and learning new information. Research suggests that people with dyslexia tend to conceptualise information in a visuospatial rather than a verbal way (Von Karolyi, Winner, Gray and Sherman, 2003). Bacon, Handley and McDonald (2007) demonstrated that people with dyslexia tend to adopt a spatial strategy when solving syllogisms, while people without dyslexia tend to adopt a verbal strategy.

The aim of this study is to contribute to the understanding of reasoning, strategy selection and problem solving. The focus is on the strategies people with dyslexia employ when solving syllogisms, compared to people without dyslexia, as well as the effect of learning a new strategy on the way they solve syllogisms. The main objective is to develop an intervention strategy for problem solving for people with dyslexia.

Outline of the study design:

The first part of the study was the Raven's Standard Progressive Matrices test which was used only as a test of general intellectual ability. This was followed by a problem solving task in which participants were asked to determine a conclusion from information presented in two sentences about logical relations. Below is an example:

Premises: Some lawyers are dancers; All dancers are poets.
Correct conclusion: Some lawyers are poets.

There are no risks associated with any part of this experiment; it does not involve any interventions or deception. Your personal data (name and age) will be immediately separated from the experimental data and it will not be possible to link this data back to you.

Please do not show or discuss this study with anyone else as this could affect future results.

Participant debriefing sheet (Used for studies in Chapters 4 and 5)

Researcher's name: Kay Rawlins

Title of study: Strategies in Reasoning

Aim of the study:

Ford (1995) suggests that people solve problems in very different ways. She identified two groups of reasoners – verbal and spatial. She found verbal reasoners tended to treat the syllogisms like mathematical problems, re-writing them as equations, substituting words with letters and using arrows to indicate relationships between the terms of the premises. Spatial reasoners, on the other hand, tended to use shapes in different spatial relationships to represent different classes and their relationships.

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The aim of this study is to contribute to the understanding of reasoning, strategy selection and problem solving. The focus is on the strategies people with dyslexia employ when solving syllogisms, compared to people without dyslexia, as well as the effect of learning a new strategy on the way they solve syllogisms. The main objective is to develop an intervention strategy for problem solving for people with dyslexia.

Outline of the study design:

The study consisted of a problem solving task in which participants were asked to determine a conclusion from information presented in two sentences about logical relations. Below is an example:

Premises: Some lawyers are dancers; All dancers are poets.
Correct conclusion: Some lawyers are poets.

This was followed by a brief training session introducing a method for solving similar problems, and then participants were asked to complete another problem solving task which was similar to the previous task.

There are no risks associated with any part of this experiment; it does not involve any interventions or deception. Your personal data (name and age) will be immediately separated from the experimental data and it will not be possible to link this data back to you.

Please do not show or discuss this study with anyone else as this could affect future results.

Participant debriefing sheet (Used for the study in Chapter 6)

Researcher's name: Kay Rawlins

Title of study: Strategies in Reasoning

Aim of the study:

Ford (1995) suggests that people solve problems in very different ways. She identified two groups of reasoners – verbal and spatial. She found verbal reasoners tended to treat the syllogisms like mathematical problems, re-writing them as equations, substituting words with letters and using arrows to indicate relationships between the terms of the premises. Spatial reasoners, on the other hand, tended to use shapes in different spatial relationships to represent different classes and their relationships.

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The aim of this study is to contribute to the understanding of reasoning, strategy selection and problem solving. The focus is on the strategies people with dyslexia employ when solving syllogisms, compared to people without dyslexia, as well as the effect of learning a new strategy on the way they solve syllogisms. The main objective is to develop an intervention strategy for problem solving for people with dyslexia.

Outline of the study design:

The study consisted of a problem solving task in which participants were asked to determine a conclusion from information presented in two sentences about logical relations. Below is an example:

Premises: Some lawyers are dancers; All dancers are poets.
Correct conclusion: Some lawyers are poets.

A desktop mounted eye-tracker was used to determine where participants focused their attention while solving the problems, as well as how long the focus was on certain parts of the problems.

There are no risks associated with any part of this experiment; it does not involve any interventions or deception. Your personal data (name and age) will be immediately separated from the experimental data and it will not be possible to link this data back to you.

Please do not show or discuss this study with anyone else as this could affect future results.

Appendix 2: List of syllogisms used in the belief bias study

Abstract	Neutral	Belief bias	Correct answer
All B are A Some B are C	All of the politicians are potters Some of the politicians are chess players	All of the mammals are goats Some of the mammals are cows	Some A are C, or Some C are A
Some B are not A All B are C	Some of the doctors are not singers All of the doctors are intellectual	Some snakes are not poisonous All of the snakes are cobras	Some C are not A
All B are A All B are C	All of the engineers are sculptors All of the engineers are alcoholics	All of the trees are oak All of the trees are pine	Some C are A Some A are C
All B are A All C are B	All of the weavers are gardeners All of the vegetarians are weavers	All of the mammals are tigers All of the animals are mammals	All C are A
No B are A All C are B	None of the bankers are Buddhists All of the jugglers are bankers	None of the reptiles are scaly All snakes are reptiles	No C are A No A are C
No A are B Some C are B	None of the pianists are mechanics Some of the experts are mechanics	None of the daffodils are yellow Some flowers are yellow	Some C are not A
Some A are B No C are B	Some of the clubbers are pilots None of the rock climbers are pilots	Some roses are red None of the flowers are red	Some A are not C
No A are B All C are B	None of the chess players are bookbinders All of the dancers are bookbinders	None of the ostriches are flying All of the birds are flying	No A are C No C are A

Appendix 3: List of syllogisms used in the pre-training workbooks and in the eye tracking study

No	Syllogism	Easiest for
1	All of the psychologists are gymnasts Some of the psychologists are not skaters	Both
2	All of the engineers are sculptors All of the engineers are alcoholics	Both
3	None of the bankers are tennis club members Some of the bankers are gymnasts	Both
4	Some of the soccer players are not professors All of the blood donors are professors	Both
5	All of the politicians are potters Some of the politicians are chess players	Spatial
6	Some of the playwrights are stamp collectors All of the playwrights are bookworms	Spatial
7	All of the teetotallers are reporters Some of the artists are not reporters	Spatial
8	None of the sculptors are columnists Some of the columnists are movie buffs	Spatial
9	None of the butchers are wine drinkers Some of the foreigners are butchers	Verbal
10	Some of the weavers are historians None of the historians are tennis club members	Verbal
11	All of the bookworms are doctors None of the doctors are beekeepers	Verbal
12	Some of the florist are not football fans All of the florists are skydivers	Verbal

Appendix 4: List of syllogisms used in the post-training workbooks

No	Syllogism	Easiest for
1	All of the zookeepers are surfers Some of the zookeepers are not homeowners	Both
2	All of the lawyers are athletes All of the lawyers are comedians	Both
3	None of the rock climbers are pilots Some of the rock climbers are clubbers	Both
4	Some of the poets are not prize winners All of the hikers are prize winners	Both
5	All of the secretaries are football fans Some of the secretaries are soccer players	Spatial
6	Some of the vegetarians are teachers All of the vegetarians are stamp collectors	Spatial
7	All of the wine drinkers are biologists Some of the potters are not biologists	Spatial
8	None of the chess players are bookbinders Some of the bookbinders are dancers	Spatial
9	None of the librarians are skaters Some of the sculptors are librarians	Verbal
10	Some of the bankers are Bhuddists None of the Bhuddists are jugglers	Verbal
11	All of the vegetarians are gardeners None of the gardeners are weavers	Verbal
12	Some of the doctors are not singers All of the doctors are intellectual	Verbal

Appendix 5: Verbal strategy training booklet

Example 1:

An easy way of solving syllogisms is by examining the relationship between the terms of the premises. For example, take the syllogism

Some A are B
All B are C

Some A are B is represented as A & B, which means there's at least something that's an A and a B. There might still be some A that are not B, and some B that are not A, but we are only concerned with facts that we know about the premises.

All B are C is represented as B → C. This means that if you're a B, you're also a C. But there might also be C that are not B, we just don't know.

So, now we've got:

A & B
B → C

The next step is to see if we can apply a rule to join the two representations together. We can break down the A & B into an A, and a B: A, B

Then, the next stage is to see if we can put either the A or the B with the B → C ("if you're a B you're also a C") representation.

In this case, we can:

From B and B → C, we can get C

So, we now have A, B, C. So, we can now get rid of the B:

A, C.

We can only use information we're certain of, that we have an A that's also a C, we don't know that all A are C, or all C are A. So the conclusion is: Some A are C.

Example 2:

All B are A
Some B are not C

All B are A is represented as B → A ("if you're a B you're also a C").

Some B are not C is represented as B & ¬ C. The ¬ C means that it's not a C. We know that some B are not C, but it could also be that some B are C, and some C are not B. But we don't know this for sure.

The next step is to combine the two representations:

B → A
B & ¬ C

Breaking down the B & ¬ C:
¬ C, B
putting together the B and the B → A
B, B → A, gives A

So, we have ¬ C, B, A

We can get rid of the B, so we have ¬ C, A. We don't know for sure that no A are C, or no C are A, so the conclusion is: some A are not C.

Example 3:

No B are A
All B are C

No B are A is represented as B →¬ A ("if it's a B then it's not an A")[1]

All B are C is represented as B → C ("if it's a B then it's a C").

The next step is to combine the two representations.

Let's start with B → ¬ A.
If we know someone's a B, then we can work out they are also ¬ A.
So, we can get ¬ A, B.
Putting the B together with B → C, gives us C.
So, we have ¬ A, B, C.
We can't assume that no A are C, or no C are A. So we conclude: some C are not A.

[1] Note that you can write No B are A as B →¬ A *or as* A →¬ B, whichever helps most. In this example, B →¬ A is most useful because we can get the B to link to go with B → C.

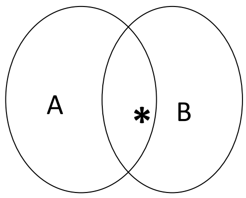
Appendix 6: Spatial strategy training booklet

Example 1:

An easy way of solving syllogisms is by using Euler Circles. In logic, these are circles used to represent the terms of categorical statements. For example, take the syllogism

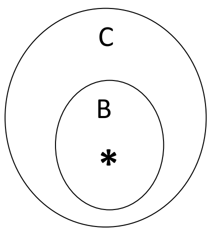
Some A are B
All B are C

Some A are B is represented as:



The diagram shows that some As are Bs, but also some As might not be Bs, and some Bs might not be As. We put a * where we know there is at least something (in the overlap between the A and the B). Remember, we are only concerned with facts that we already know about the premises.

All B are C is represented as:

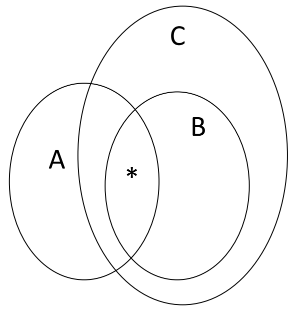


In this diagram, the B is inside the C, indicating that all Bs are also Cs.

The diagram also shows that some of the Cs may not be Bs.

We put a * where we are sure that something exists.

The next step is to combine the two diagrams. Draw the pictures so the B circles overlap, and then make the A and C circles overlap wherever possible from the original diagrams. Then decide whether any of the asterisks "survive" –



The * from Some A are B is in an unchanged region, so we keep it.

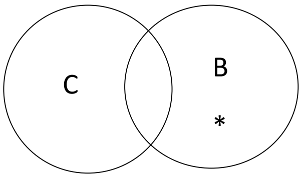
The * from All B are C is in a changed region, so we don't keep it.

Since we can only use information we are certain of, the only logical conclusion we can draw from diagram is that some of the As are also Cs.

Example 2:

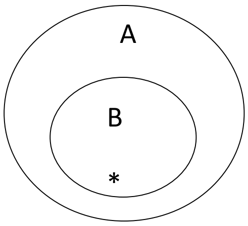
All B are A
Some B are not C

Some B are not C is represented as:



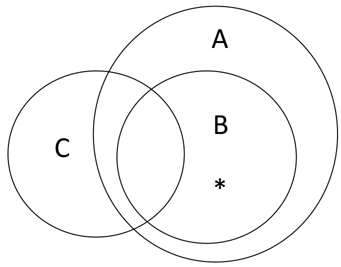
The diagram shows that some Bs are not Cs, but also some Bs might be Cs, and some Cs might not be Bs.

All B are A is represented as:



In this diagram, the B is inside the A, indicating that all Bs are As.

The next step is to combine the two diagrams so that the common term B overlaps, then see where the * ends up.



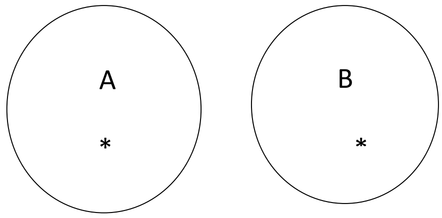
The * from All B are A is in a changed region so we don't keep it.

The * from Some Bs are not Cs is in an unchanged region so we keep it.

Example 3:

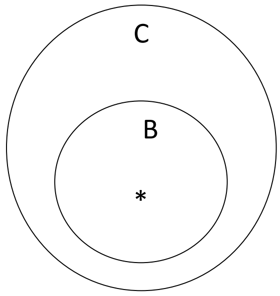
No B are A
All B are C

No B are A is represented as:



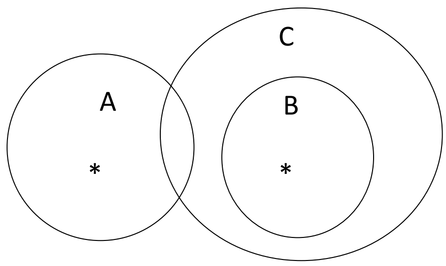
In this diagram, the circles are drawn separately to show that none of the As are Bs.

All B are C is represented as:



This diagram shows that all of the Bs are Cs.

The next step is to combine the two diagrams then see where the * ends up.



The * in the A circle is in a changed region, so we don't keep it.

Appendix 7: Pre-training workbook

You are taking part in an investigation about how people use information in order to draw conclusions. You will be solving a series of syllogistic reasoning problems. A syllogistic problem consists of two premises (statements), for example:

Some B are A
All B are C

Your task is to write down the conclusion (if any) which follows logically from these. A logical conclusion is a conclusion which must be true, if the premises are true. In this example, notice that the B appears twice, once in each premise, and the A and C are non-repeated terms. You are to draw a conclusion about these non-repeated terms. The conclusion must be in one of the following forms, where the question mark stands for a non-repeated term in the problem.

All ? are ?
No ? are ?
Some ? are ?
Some ? are not ?
None ? are ?

For example, Some teachers are tap dancers
All teachers are bookworms

Conclusion: Some of the bookworms are tap dancers, or
Some of the tap dancers are bookworms

As we are trying to find out how people solve these problems, it is vital that you 'think aloud' while you are working out your answers. Please speak out loud while solving each problem to explain to the experimenter how you reached your conclusion. There should not be any silent periods on the tape. We also need a written record of your work. Therefore it is also vital that you use the pen and the space below the statements to show any working out that you use to help you solve the problems. Feel free to write or draw anything that helps you. When you have reached your conclusion, simply state that conclusion clearly in writing. You will be timed with a stopwatch. You will have 2 minutes for each problem. Do not refer to previous problems once you have completed them.

1. Some of the florists are not football fans
All of the florists are skydivers

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

2. None of the sculptors are columnists
Some of the columnists are movie buffs

Please show your workings here:

Please write your answer here using one of the following formats:

All: ________________ Are: ________________

No: ________________ Are: ________________

Some: ________________ Are: ________________

Some: ________________ Are not: ________________

No: ________________ Are: ________________

3. All of the politicians are potters
Some of the politicians are chess players

Please show your workings here:

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

4. Some of the weavers are historians
None of the historians are tennis club members

Please show your workings here:

Please write your answer here using one of the following formats:

All: ______________________ Are: ______________________

No: ______________________ Are: ______________________

Some: ______________________ Are: ______________________

Some: ______________________ Are not: ______________________

No: ______________________ Are: ______________________

5. Some of the playwrights are stamp collectors
All of the playwrights are bookworms

Please show your workings here:

Please write your answer here using one of the following formats:

All: ______________________ Are: ______________________

No: ______________________ Are: ______________________

Some: ______________________ Are: ______________________

Some: ______________________ Are not: ______________________

No: ______________________ Are: ______________________

6. All of the engineers are sculptors
All of the engineers are alcoholics

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

7. None of the butchers are wine drinkers
Some of the foreigners are butchers

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

8. All of the bookworms are doctors
None of the doctors are beekeepers

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

9. Some of the soccer players are not professors
All of the blood donors are professors

Please show your workings here:

Please write your answer here using one of the following formats:

All: ______________________ Are: ______________________

No: ______________________ Are: ______________________

Some: ______________________ Are: ______________________

Some: ______________________ Are not: ______________________

No: ______________________ Are: ______________________

10. All of the psychologists are gymnasts
Some of the psychologists are not skaters

Please show your workings here:

Please write your answer here using one of the following formats:

All: ____________________ Are: ____________________

No: ____________________ Are: ____________________

Some: ____________________ Are: ____________________

Some: ____________________ Are not: ____________________

No: ____________________ Are: ____________________

11. All of the teetotallers are reporters
Some of the artists are not reporters

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

12. None of the bankers are tennis club members
Some of the bankers are gymnasts

Please show your workings here:

Please write your answer here using one of the following formats:

All: ______________________ Are: ______________________

No: ______________________ Are: ______________________

Some: ______________________ Are: ______________________

Some: ______________________ Are not: ______________________

No: ______________________ Are: ______________________

Appendix 8: Post-training workbook (Verbal)

You are taking part in an investigation about how people use information in order to draw conclusions. You will be solving a series of syllogistic reasoning problems. A syllogistic problem consists of two premises (statements), for example:

Some B are A
All B are C

Your task is to write down the conclusion (if any) which follows logically from these. A logical conclusion is a conclusion which must be true, if the premises are true. In this example, notice that the B appears twice, once in each premise, and the A and C are non-repeated terms. You are to draw a conclusion about these non-repeated terms. The conclusion must be in one of the following forms, where the question mark stands for a non-repeated term in the problem.

All ? are ?
No ? are ?
Some ? are ?
Some ? are not ?
None ? are ?

For example, Some teachers are tap dancers
All teachers are bookworms

Conclusion: Some of the bookworms are tap dancers, or
Some of the tap dancers are bookworms

As we are trying to find out how people solve these problems, we need a written record of your work. Therefore it is vital that you use the pen and the space below the statements to show any working out that you use to help you solve the problems. Feel free to write or draw anything that helps you. When you have reached your conclusion, simply state that conclusion clearly in writing. Do not refer to previous problems once you have completed them.

1. Some of the doctors are not singers
   All of the doctors are intellectual

Please show your workings here:

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

2. None of the chess players are bookbinders
Some of the bookbinders are dancers

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

3. All of the secretaries are football fans
Some of the secretaries are soccer players

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

4. Some of the bankers are Buddhists
None of the Buddhists are jugglers

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

5. Some of the vegetarians are teachers
All of the vegetarians are stamp collectors

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

6. All of the lawyers are athletes
All of the lawyers are comedians

Please show your workings here:

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

7. None of the librarians are skaters
Some of the sculptors are librarians

Please show your workings here:

Please write your answer here using one of the following formats:

All: ______________________ Are: ______________________

No: ______________________ Are: ______________________

Some: ______________________ Are: ______________________

Some: ______________________ Are not: ______________________

No: ______________________ Are: ______________________

8. All of the vegetarians are gardeners
None of the gardeners are weavers

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

9. Some of the poets are not prizewinners
All of the hikers are prizewinners

Please show your workings here:

Please write your answer here using one of the following formats:

All: Are:
___

No: Are:
___

Some: Are:
___

Some: Are not:
___

No: Are:
___

10. All of the zookeepers are surfers
Some of the zookeepers are not homeowners

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

11. All of the wine drinkers are biologists
Some of the potters are not biologists

Please show your workings here:

Please write your answer here using one of the following formats:

All: ______________________ Are: ______________________

No: ______________________ Are: ______________________

Some: ______________________ Are: ______________________

Some: ______________________ Are not: ______________________

No: ______________________ Are: ______________________

12. None of the rock climbers are pilots
Some of the rock climbers are clubbers

Please show your workings here:

Please write your answer here using one of the following formats:

All:	Are:
No:	Are:
Some:	Are:
Some:	Are not:
No:	Are:

Appendix 9: Post-training workbook (Spatial)

You are taking part in an investigation about how people use information in order to draw conclusions. You will be solving a series of syllogistic reasoning problems. A syllogistic problem consists of two premises (statements), for example:

Some B are A
All B are C

Your task is to write down the conclusion (if any) which follows logically from these. A logical conclusion is a conclusion which must be true, if the premises are true. In this example, notice that the B appears twice, once in each premise, and the A and C are non-repeated terms. You are to draw a conclusion about these non-repeated terms. The conclusion must be in one of the following forms, where the question mark stands for a non-repeated term in the problem.

All ? are ?
No ? are ?
Some ? are ?
Some ? are not ?
None ? are ?

For example, Some teachers are tap dancers
All teachers are bookworms

Conclusion: Some of the bookworms are tap dancers, or
Some of the tap dancers are bookworms

As we are trying to find out how people solve these problems, it is vital that you 'think aloud' while you are working out your answers. Please speak out loud while solving each problem to explain to the experimenter how you reached your conclusion. There should not be any silent periods on the tape. We also need a written record of your work. Therefore it is also vital that you use the pen and the space below the statements to show any working out that you use to help you solve the problems. Feel free to write or draw anything that helps you. When you have reached your conclusion, simply state that conclusion clearly in writing. You will be timed with a stopwatch. You will have 2 minutes for each problem. Do not refer to previous problems once you have completed them.

1. Some of the doctors are not singers
All of the doctors are intellectual

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

2. None of the chess players are bookbinders
Some of the bookbinders are dancers

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

3. All of the secretaries are football fans
Some of the secretaries are soccer players

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: ______________________ Are: ______________________

No: ______________________ Are: ______________________

Some: ______________________ Are: ______________________

Some: ______________________ Are not: ______________________

No: ______________________ Are: ______________________

4. Some of the bankers are Buddhists
None of the Buddhists are jugglers

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

5. Some of the vegetarians are teachers
All of the vegetarians are stamp collectors

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

6. All of the lawyers are athletes
All of the lawyers are comedians

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

7. None of the librarians are skaters
Some of the sculptors are librarians

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

8. All of the vegetarians are gardeners
None of the gardeners are weavers

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

9. Some of the poets are not prizewinners
All of the hikers are prizewinners

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: __________ Are: __________

No: __________ Are: __________

Some: __________ Are: __________

Some: __________ Are not: __________

No: __________ Are: __________

10. All of the zookeepers are surfers
Some of the zookeepers are not homeowners

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

11. All of the wine drinkers are biologists
Some of the potters are not biologists

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are:

12. None of the rock climbers are pilots
Some of the rock climbers are clubbers

Please show your workings here:

1.	2.
3.	

Please write your answer here using one of the following formats:

All: Are:

No: Are:

Some: Are:

Some: Are not:

No: Are: