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Dyslexia and syllogistic reasoning in adults: differences in strategy usage

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# Abstract

People with dyslexia have been found to prefer spatial over verbal strategies when performing word-based syllogistic reasoning tasks that require self-generated responses. The current research investigated whether this was also the case for pictorially-based syllogisms, when responses were required to either concrete or abstract stimuli, and when multiple-choice answers were presented. Adults with and without dyslexia, matched for non-verbal ability, were presented with sets of isomorphic reasoning problems in which the stimuli were either concrete words, abstract words, concrete shapes or abstract pictograms. As expected, there was no group difference in reasoning accuracy. Unlike previous findings, the adults with dyslexia preferred to use a mixed verbal and spatial strategy and performed better with this strategy, while the individuals without dyslexia preferred a verbal strategy and performed more successfully when employing this strategy. The provision of answer options to facilitate strategy change in individuals with dyslexia is discussed.

Keywords: Dyslexia; Cognitive Strategies; Adults

# Introduction

Developmental dyslexia (henceforth, dyslexia) is typically characterised by specific impairments in spelling, reading and writing which cannot be accounted for by general learning difficulties or factors such as low socioeconomic status, emotional background or low intelligence (e.g., Beech, 1994; Lyon, Shaywitz & Shaywitz, 2003). In addition to difficulties with literacy-related skills, broader cognitive impairments have also been identified in dyslexia and these have been found to persist into adulthood. For example, dyslexia-related problems with working memory and executive functioning have both been reported in adults (e.g., Brosnan et al., 2002; Smith-Spark & Fisk, 2007; Smith-Spark, Henry, Messer, Edvardsdottir & Zięcik, 2016). The current paper focused on a further important type of cognition in adults, namely reasoning, in which dyslexia-related differences in strategy choice have been found (Bacon, Handley & McDonald, 2007). Previous work in the area was extended in several ways. Firstly, strategy choice was explored in response to either words or images when reasoning deductively. Secondly, problem materials were used that were either concrete or abstract in nature. Thirdly, the participants were given answer options from which to select their response rather than asking them to generate their own conclusions. Fourthly, intra-individual variation in strategy choice was investigated at a finer-grained level than previously undertaken in the reasoning literature.

 Deductive reasoning, wherein a conclusion is derived from factually true information, has been widely measured using syllogisms. Syllogisms are formed of two statements (consisting of a general statement, or major premise, and a supporting statement, or minor premise) which contain information about three categories (e.g., A, B, C) and include quantifiers (*all, some, no, some…not*). When attempting to solve syllogisms, individuals are asked to assume that the information presented in the premises is true. For example, individuals might be asked to provide the response to the conclusion “Some artists are…” when given the major premise “*All artists are bankers*” and minor premise “*All bankers are clowns*”. To answer such problems, individuals must work out the type of relationship that exists between the non-repeated terms “artists” and “clowns” by using the middle term “bankers”. The conclusion contains both the subject (clowns) and the predicate of the conclusion (bankers).

There are three common methods to administer syllogisms experimentally. The first method is to provide two premises and to ask the participant to work out the conclusion (e.g., Bacon, Handley & Newstead, 2003). The second method is to provide one conclusion and ask the participants to decide whether the given conclusion necessarily follows from the premises (e.g., Copeland, 2006). The third method is to provide multiple-choice answer options from which the participants should choose their response (e.g., Johnson-Laird & Bara, 1984). The use of the latter method has been found to result in similar levels of performance to the self-generation of the conclusion by participants (Dickstein, 1978; Hardman & Payne, 1995).

Individual differences have been found to exist in both the selection and use of reasoning strategies to solve problems (e.g., Ford, 1995; Gilhooly, Logie & Wynn, 1999; Roberts & Newton, 2003). A strategy is essentially a self-selected set of procedures that is used to achieve a goal. If through trial and error, individuals recognise that a particular strategy is not working, then they may amend or change their strategy using a new set of procedures (Roberts & Newton, 2001). Evidence for individual differences in strategy use was provided by Galotti, Baron and Sabini (1986). They found that good reasoners were more likely to discover the two sums rule - that where both premises contained the quantifier ‘some’, the conclusion can never be valid- and thus eliminate the need to reason. Seminal work by Ford (1995) found inter-individual differences in strategy preference, with verbal reasoners argued to reason by ‘swapping’ the verbal terms around within the premises, whereas spatial reasoners tend to use more abstract representations of the relationships between the terms within the syllogism, such as Euler’s circles. To illustrate these different strategic approaches, examples of verbal and spatial reasoning strategies are presented in Fig. 1.

INSERT FIGURE 1 ABOUT HERE

Newton and Roberts (2000) used a task in which people were given sets of compass point directions (e.g., one step north, one step west, etcetera). The task required the participant to state where they would end up, relative to their starting position, if they were to take equally sized steps as instructed. Newton and Roberts found that their participants tended to use a spatial reasoning strategy when solving the task. Furthermore, the participants did not voluntarily change strategy on a subsequent task, unless they were shown and instructed to use a more efficient strategy. Full feedback, in which the participants were told the correct answer on a trial-by-trial basis, led to the discovery and use of a better reasoning strategy than partial or no feedback. Newton and Roberts argued that the likely explanation for the participants discovering a more optimal strategy was that providing full feedback on incorrect responses resulted in the participants allocating additional time to validate alternative strategies and to decide to use the most efficient one.

Once a strategy has been selected, it is still possible for people to consider alternative strategies but research has found that they are reluctant to do so. Roberts, Taylor and Newton (2007) investigated the reluctance of individuals to change strategy even when faster and more accurate strategies were available. When subsequently interviewed, one of the views expressed by those participants who had shown a reluctance to change was that they disliked the new style of representing the problem, even though they knew that the strategy was faster and more accurate. Roberts et al. found that three additional factors needed to be considered in order to encourage strategy change. Firstly, incentives to encourage higher accuracy levels helped persuade participants to change strategy. Secondly, people who were reluctant to change strategy often found the new strategy difficult to perform. Thirdly, those who chose to stick with a more cognitively demanding initial strategy were more likely to make errors with that very same strategy.

As well as the evidence in favour of individual differences in both reasoning ability and reasoning strategy preference, there is also some evidence to suggest group differences in strategy use in some neurodevelopmental disorders such as autism spectrum disorder (Król & Król, 2019) and dyslexia (e.g., Bacon et al., 2007), the focus of the current paper. Given this focus, broad indicators of dyslexia-related differences in strategy use will firstly be considered, before the evidence relating specifically to strategy use in syllogistic reasoning is addressed.

Using the Corsi Block Span task, Bacon, Parmentier and Barr (2013) found dyslexia-related differences in strategy change. Under more cognitively taxing task demands, their adult participants without dyslexia opted to change recall strategy, resulting in better performance. Conversely, the group with dyslexia did not change strategy, making task demands more taxing than they should have been. When the group with dyslexia received explicit instructions to change strategy and acted upon these instructions, the accuracy of their performance was comparable with the group without dyslexia. Bacon et al. argued that this difference in strategy change did not result from dyslexia-related memory problems. Instead, they proposed that it was linked to dyslexia-related executive functioning deficits in task-switching, the result of which was that the participants with dyslexia failed to suppress irrelevant incoming information and, thus, did not switch to a more effective strategy.

With regard to the latter impairment, Smith-Spark and Fisk (2007) found that the recall accuracy of individuals with dyslexia on the first half of a spatial working memory span task was lower relative to the group without dyslexia than on the second half of the test. The authors proposed that the novelty of the task required the adults with dyslexia to use more executive processing than those without dyslexia when first exposed to the task demands and were slower to set up cognitive schemata in order to process it. They linked this slowness to the Supervisory Attentional System (SAS) within Norman and Shallice’s (1986) model of the control of action. The SAS is responsible for coordinating, integrating and controlling the processing of information, using attentional resources to modulate behaviour. It is drawn upon when task novelty is high or the required sequence of actions needed for performance is poorly learned. Varvara, Varuzza, Sorrentino, Vicari and Menghini (2014) have also argued for an SAS deficit based on data from children with dyslexia.

Broad problems with strategy use and change in dyslexia are thus suggested by several studies. More particularly, and of direct relevance to the focus of the current study, dyslexia-related differences in strategy use in syllogistic reasoning have been considered by Bacon et al. (2007). They administered concrete syllogisms in the form of either English terms (e.g., “cook”) or abstract syllogisms using Welsh terms (e.g., “yluk”). These terms were situated within premises expressed in English. The Welsh terms were unknown to the problem solvers and, therefore, were not semantically meaningful. Overall, university students with dyslexia were found to perform comparably to students without dyslexia when solving the syllogisms. However, at a finer-grained level, the individuals with dyslexia solved significantly more syllogisms correctly involving the more abstract Welsh terms than syllogisms involving concrete English terms, whereas the group without dyslexia did not show a difference in performance between the two types of syllogisms. Bacon et al. also found that their participants with dyslexia tended to use a spatial reasoning strategy, regardless of the presentation type, while the participants without dyslexia tended to use a verbal strategy. The authors proposed that this difference in strategy preference supported Knauff and Johnson-Laird’s (2002) visual-impedance hypothesis. Knauff and Johnson-Laird presented transitive inferences under different conditions. The authors found that their visual condition impeded reasoning with longer latencies required to generate solutions. Knauff and Johnson-Laird argued that visually rich representations may yield additional, but irrelevant, information that is not needed to reach a conclusion, thereby placing an unnecessary additional load on working memory resources and slowing the reasoning process as a result. With regard to their own results, Bacon et al. proposed that the presentation of visually rich concrete English terms within the premises impeded the ability of the individuals with dyslexia to reason effectively. They argued that, due to the well-documented working memory impairments in adults with dyslexia (e.g., Smith-Spark et al., 2003; Smith-Spark & Fisk, 2007), any additional and unnecessary visual information would load disproportionately on already stretched working memory resources and this, coupled with the load placed on resources when manipulating information during problem solving, would impact negatively on performance.

Bacon et al. (2007) thus identified dyslexia-related differences in syllogistic reasoning strategy usage and explained the preference for a spatial approach in terms of working memory resource limitations. Bacon and Handley (2010) also found no group difference in accuracy between adults with and without dyslexia in transitive reasoning. They also reported a preference for a visual-spatial strategy in the group with dyslexia which differed from the abstract-spatial strategy favoured by the adults without dyslexia. Bacon and Handley argued that visual and semantic processes compensate for dyslexia-related deficits in phonological and verbal memory when reasoning.

To the best of the authors’ knowledge, no further research on reasoning in adults with dyslexia has been published (for a recent study involving children with dyslexia, see Panagiotidou, Serrano & Moreno‐Ríos, 2019). The current study, therefore, aimed to extend this very small corpus of research to examine strategy use in syllogistic reasoning using a verbal and written protocol methodology. Both verbal and pictorial terms were presented. For each of these types of term, the stimuli were either semantically meaningful or abstract.

The verbal terms were presented in either the English or Finnish language. The terms expressed in English thus had obvious semantic meaning to the native English-speaking participants. The terms expressed in Finnish, on the other hand, were unknown to the participants but would still be recognised as word-like letter strings. The Finnish language was chosen as it is a member of the Uralic language family rather than being a member of the Indo-European family and, thus, the word-like letter strings would seem much less familiar to English-speaking participants than Welsh. However, as Finnish has a very transparent orthography (e.g., Borleffs, Maassen, Lyytinen & Zwarts, 2017) and is based on the Latin script, it is not difficult for non-reading-impaired English speakers to read Finnish words (Suomi, Toivanen & Ylitalo, 2008).

The pictorial terms were presented as either easily nameable shapes or abstract pictograms (which were in the form of Mandarin Pinyin characters). The participants were required to be naïve Mandarin Pinyin and, moreover, the characters could not be named easily, whereas the pictures in the form of shapes could be named readily (e.g., “square” or “house”). A further variation from Bacon et al.’s study was that the participants were provided with multiple-choice options from which to choose their answer to each syllogism rather than them being required to generate their own conclusions. Hardman and Payne (1995) found that the use of a multiple-choice format led to increased performance over self-generated conclusions and is, therefore, a valid methodology to use in reasoning research. Additionally, McKendree and Snowling (2011) found that multiple-choice formats do not disadvantage students with dyslexia. Multiple-choice options have the potential to assist adults with dyslexia by reducing the load on their lowered working memory resources (e.g., Smith-Spark & Fisk, 2007). Finally, individual differences in strategy choice were investigated at a finer-grained level of detail than previous work (Bacon et al., 2007; Ford, 1995), which categorised problem solvers as verbal or spatial reasoners overall. Intra-individual variation in the extent to which participants adopted a single strategic approach or moved between different strategies over the course of testing was, thus, explored.

In line with the findings of Bacon et al. (2007), individuals with and without dyslexia were not expected to differ in overall reasoning ability. Instead, the focus was on the finer-grained level of the strategy adopted by individual participants when they answered syllogistic reasoning problems correctly. At this level, it was hypothesised that the individuals with dyslexia would demonstrate an overall preference for adopting spatial reasoning strategies in response to both concrete and abstract terms when reasoning syllogistically. In contrast, the individuals without dyslexia were expected to show a preference for verbal strategies. Consistent with the expected pattern of results with word stimuli, it was also predicted that the group with dyslexia would demonstrate significantly more frequent use of a spatial strategy than the group without dyslexia when successfully solving syllogisms.

# Method

Participants

Forty native English-speaking university students took part in the study (overall mean age = 26 years, *SD* = 7). There were 20 participants with dyslexia (7 males, 13 females; mean age = 28 years, *SD* = 7) and 20 participants without a diagnosis of dyslexia (2 males, 18 females; mean age = 25 years, *SD* = 6). The participant groups did not differ significantly in age. Table 1 shows the mean ages of the groups, together with their mean scores on the baseline measures (all of which are described below) and the inferential statistics relating to each measure. All the participants confirmed that they had no prior knowledge of Finnish or Mandarin Chinese. They were either awarded course credits or an honorarium for their participation. Prior to testing, each participant in the group with dyslexia provided the researcher with an educational psychologist’s report confirming his or her dyslexia diagnosis.

Baseline Measures

All the participants were given a series of baseline measures to ensure the validity of their assignment to one or other of the two participant groups. Full Raven’s Progressive Matrices were used to measure non-verbal ability (Raven’s Matrices; Raven, Raven & Court, 1993) and they were adapted to be presented on an IBM-compatible computer. The test involved five sets of 12 reasoning puzzles that became progressively more difficult to solve.

As a further check on the validity of the participant groupings, several measures sensitive to the presence of dyslexia were also administered. The nonsense word reading passage, the forward and backwards digit span, the one-minute reading test and the one-minute writing test were administered from a well-established dyslexia screening tool designed for use with adults, namely the Dyslexia Adult Screening Test (DAST; Fawcett & Nicolson, 1998).

The spelling age of each participant was determined using the spelling element of the Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993). This test consisted of 50 English words to spell which increased in difficulty as the task progressed. It was administered following the standardised instructions. The participants were awarded one point for each correct spelling. A total score of 42 or more indicated a spelling age of greater than 17 years of age. All participants in the group without dyslexia had spelling ages greater than 17 years, while 11 of the participants with dyslexia had spelling ages below the adult range.

Visuospatial working memory was tested using the Block Recall test from the Working Memory Test Battery for children (WMTB-C; Pickering & Gathercole, 2001). The participant was seated in front of a square board with nine identical fixed blocks placed randomly on it. The researcher sat opposite the participant. The researcher tapped the top of specific blocks in a sequence. The participant was required to replicate the sequence by tapping the blocks in the same order. The test was administered following the standardised instructions. The experimental task consisted of nine sets of six different block sequences to recall. The number of blocks that were presented before recall was required increased from one to nine blocks over the course of the task. Testing was terminated when the participant made four consecutive errors in one particular block. One point was given for each correct response. The visuospatial span score was calculated as being the highest number of blocks recalled correctly.

 Unrelated *t*-tests were used to analyse the baseline measures data. No significant group difference was found in scores on the Raven Standard Progressive Matrices (Raven, Raven & Court, 1993), suggesting that the groups were well matched for non-verbal reasoning ability. The individuals with dyslexia were found to be significantly poorer on the DAST nonsense word reading passage, the backwards digit span, the one-minute reading test and the one-minute writing test, as well as on the WMTB-C (Pickering & Gathercole, 2001) and the WORD spelling test (Wechsler, 1993). Thus, the group with dyslexia showed the phonological processing, working memory, reading, spelling and writing deficits typically associated with the condition. However, no statistically significant group differences were found on the DAST forward digit span task and the Block Recall task (Pickering & Gathercole, 2001) in line with previous findings on short-term memory in adults with dyslexia (e.g., Smith-Spark, Fisk, Fawcett & Nicolson, 2003; Vasic et al., 2008). Table 1 shows the inferential statistics and group mean scores on each of the background measures.

 INSERT TABLE 1 ABOUT HERE

Materials

The syllogism types selected were the same as those used by Bacon et al. (2003) but the actual words forming the terms differed. Each syllogism had two premises, with three terms being employed. One of the terms was repeated, being used in the first premise and, once again, in the second premise (Term B). The other two terms were unrelated (Terms A and C). When combining information presented in the premises, the participants were required to work out the relationship between the two unrelated terms. The form taken by each syllogism is shown in Fig. 2. Bacon et al. (2007) raised the concern that their participants may have reduced the terms within the syllogisms that were presented to single letters. To avoid this concern in the current study, words which began with the same letter were used for Terms A, B and C in each of the concrete and abstract word syllogism trials.

INSERT FIGURE 2 ABOUT HERE

Four counterbalanced types of syllogism were presented. There were eight trials of each type, giving a total of 32 trials. For the different syllogism types, Terms A, B and C were replaced with i) concrete words (which were English words with obvious semantic meaning to native English speakers; such as “surfers”), ii) abstract word forms (being Finnish words with no semantic meaning for English language speakers; such as “lehtori”), iii) 2D concrete shapes (consisting of semantically meaningful shapes that can be represented in English, such as a triangle) and iv) 2D abstract symbols (constituting Mandarin Chinese Pinyin character symbols that cannot be semantically represented readily in English, such as the character). The order of presentation of each of the four types of syllogisms was randomised.

Each syllogism yielded conclusions using one of four different types of quantifiers. These qualifiers were ‘all’ ‘some’, ‘none’ and ‘no valid conclusion’. The practice trial consisted of four isomorphic syllogisms, one of each trial type. For each individual concrete word and abstract word syllogism trial, the terms used were matched for word length. The terms used in the concrete words condition were also matched for imageability and word frequency using the MRC Psycholinguistic Database (Coltheart, 1981).

A video camera was used to record the participants’ actions and verbal and written protocol for analysis of strategy usage. To ensure anonymity, the lens of the camera was so aimed as never to record the participants’ faces during testing.

Design

Strategy use was determined by the first author coding the video recordings. Following the approach of Ford (1995) and Bacon et al. (2007), verbal strategies were defined as a participant demonstrating how they would move the repeated word from one statement to another by pen, pointing or discussing the moving of terms. Verbal strategies also included combining the quantifiers to provide an answer (e.g., “The first and second statement start with ‘All’, so the answer must be ‘All’”). Spatial reasoning strategies were defined as any problem-solving behaviour which included the use of symbolic aids, such as drawing circles. If the participants partly used two strategies or followed up one strategy by using another strategy to confirm their answer, then this was recorded as a mixed strategy. If no discernible strategy was apparent, the approach was recorded as “non-identifiable”. The dependent variable was the number of correct responses given by the participants on the syllogisms presented. In order to test for potential researcher bias in categorising the strategies used, an independent rater, naïve to the hypothesis, randomly self-selected 50% of the data across all participants to analyse strategy usage. The independent rater was unaware of the participant’s dyslexia status.

A Chi-square analysis was used to investigate overall accuracy between the groups regardless of strategy choice. Correct and incorrect answers were calculated for strategy type to investigate the intra-individual variation of strategies used.

The percentage of trials on which participants chose a verbal, spatial or mixed strategy (regardless of the accuracy of their response) was calculated to explore intra-individual variation in strategy choice.

A three-way log-linear analysis was used to investigate the association between participant group (levels: individuals with dyslexia and individuals without dyslexia), syllogism type (levels: concrete words, abstract words, concrete shapes and abstract symbols) and strategy choice (levels: spatial, verbal and mixed reasoning strategy). Further Chi-square analyses were undertaken to explore any significant interactions identified by the log-linear analysis.

Procedure

 The study was granted full ethical approval by the authors’ host institution. Testing was conducted on an individual basis. Once informed consent was obtained from the participant, the baseline measures were administered in an initial session. In the second session, the first of four booklets containing the syllogisms was placed in front of the participant. The participant was then asked to read the instructions. While pointing to the practice syllogism, the researcher explained that the problems were made up of two statements and that those two statements were connected by one term. The participant was asked to work out whether the other two unrepeated terms were connected in any way. The practice syllogisms involved one isomorphic example being presented in four different forms: abstract words, concrete words, abstract pictograms and concrete shapes. The participant was reminded to continuously verbally express their workings on each problem and to write them down in the spaces provided in the answer booklets.

Once the participant was familiar with the task, he or she was asked to solve each syllogism at his or her own pace, using any problem-solving method that “worked” for him or her. The participant was once again reminded to verbalise his or her reasoning processes continuously and to record his or her working out in the answer booklets provided for each syllogism type. The participant was encouraged to take breaks as required during testing.

After completion of the tasks, each participant was debriefed.

# Results

Overall reasoning accuracy performance

A Chi-square test indicated that there was no association between participant group and the total number of syllogisms answered correctly, χ2(1, N = 1280) = 1.58, *p* = .208.

The percentages and the number of responses for correct responses by syllogism type and participant group are presented in Table 2. There was no association between participant group and the number of correct answers produced in response to the different syllogism types, χ2 (3, N = 776) = .103, *p* = .992.

INSERT TABLE 2 ABOUT HERE

Reasoning strategy choice

A concordance rate of 92% in determining the strategy type used by the participants was obtained between the first author and the independent rater who was naïve to the study aims.

Intra-individual variation in overall strategy choice

The data on intra-individual variation in strategy use by participant group are presented in Fig. 3 and Fig. 4. All but two participants showed intra-individual variation in their choice of strategic approach to solving the individual syllogistic reasoning trials. Regardless of the accuracy of their response, the participants with dyslexia used a verbal strategy on 23% of the syllogisms that they answered. In comparison, the participants without dyslexia used a verbal approach on 50% of the syllogisms presented. The group with dyslexia used a mixed approach on 56% of the trials, whereas the group without dyslexia used a mixed strategy on 37% of the syllogistic reasoning problems. Overall, both the group with dyslexia (16%) and the group without dyslexia (6%) were less likely to use a spatial approach alone.

INSERT FIGURE 3 ABOUT HERE

INSERT FIGURE 4 ABOUT HERE

Reasoning strategy use on problems answered correctly

The three-way log-linear analysis produced a final model with a likelihood ratio of χ2 = .00, *p* = 1. There was no significant three-way participant group x syllogism type x strategy choice interaction in the number of reasoning problems correctly solved, χ2 = 6.57, *p =* .363. However, the model indicated that the two-way interactions were significant (participant group x strategy choice, χ2 = 93.63, *p < .*001; syllogism type x strategy choice, χ2 = 20.00, *p* = .003). Two further Chi-square analyses were, therefore, performed to explore these significant two-way interactions.

There was a significant difference between the observed and the expected frequency of correct answers by participant group and strategy choice, χ2(2, N = 753) = 87.64, *p* < .001. The group with dyslexia were more likely to answer syllogisms correctly using a mixed reasoning strategy and less likely to answer them correctly using a spatial reasoning strategy. On the other hand, the group without dyslexia was more likely to answer more trials correctly using a verbal reasoning strategy. The data are presented in Fig. 5.

INSERT FIGURE 5 ABOUT HERE

There was a significant association between syllogism presentation and strategy choice, χ2 = 16.95, *p =* .009. Regardless of group membership, the participants tended to use a mixed strategy when correctly solving syllogisms with concrete words, abstract words and pictograms but they tended to use a verbal strategy when successfully solving the syllogisms which involved concrete shapes. The data are presented in Fig. 6.

INSERT FIGURE 6 ABOUT HERE

# Discussion

The current study investigated the use of strategies by adults with and without dyslexia when reasoning syllogistically, manipulating both the mode in which the terms were presented (i.e., verbal or pictorial) and the level of semantic meaningfulness attached to the terms used (i.e., concrete or abstract). Answer options were presented to the participants, rather than requiring them to generate their own conclusions. The two participant groups were found to be well matched for nonverbal ability on the Raven’s Matrices (Raven, Raven & Court, 1993). The main findings can be summarized as follows: i) no difference was found between the group with dyslexia and the group without dyslexia in the overall number of syllogisms answered correctly and this result was consistent with the results of Bacon et al. (2007) and Bacon and Handley (2010), ii) group differences in reasoning strategy usage were uncovered, with the group without dyslexia tending to favour a verbal approach while the group with dyslexia tended to employ a mixed verbal and spatial strategy, and iii) nearly all participants showed variation between trials in their choice of strategy. These latter two findings will now be considered in more detail.

Strategy choice was examined using verbal and written protocol analysis, with a 92% level of agreement being found between the first author and an independent rater when independently scoring the strategy choice data. As hypothesised, the group without dyslexia showed an overall preference for a verbal reasoning strategy across all syllogism types when producing correct answers. These results also support Bacon et al.’s (2007) findings. However, the group with dyslexia was found to perform better overall using a mixed reasoning strategy for all syllogism types. The increased use of a mixed reasoning strategy for the group with dyslexia differed from Bacon et al.’s findings in which only 20% of the participants with dyslexia were reported to have used a mixed verbal and spatial strategy. In the current study, which had the same *N* as that of Bacon et al., 70% of the participants with dyslexia used predominantly a mixed strategy overall.

There is a need to explain why the choice of a mixed strategy proved particularly beneficial to the group with dyslexia. The use of a mixed verbal and spatial strategy could have aided their reasoning, especially when using English terms or terms that drew upon semantic processing, by reducing the load placed on verbal working memory resources, a well-documented area of difficulty in adults with dyslexia (e.g., Smith-Spark & Fisk, 2007; Smith-Spark, Henry et al., 2016). This, in turn, may also have reduced the possibility of the visual impedance effect occurring (as argued by Bacon et al., 2007). However, while this argument may particularly help to explain the findings when the terms of the syllogisms were either concrete English or shapes, it does not explain why an overall mixed strategy type preference for the group with dyslexia was found in the current study, while Bacon et al. (2007) found that individuals with dyslexia showed an overall preference for a spatial strategy.

One possible explanation for the difference in strategy preferences between those reported by Bacon et al. (2007) and those found in the current study is that the two studies differed in the style in which the syllogisms were presented. In the current study, the use of multiple-choice answer options allowed the participants to select the answer option that they believed to be correct. Conversely, the participants in Bacon et al.’s study were required to form their own conclusions to the problems that were presented and this is likely to be more demanding cognitively. When given multiple-choice answer options, it is possible that the participants who employed a verbal strategy may have simply mapped their conclusion directly on to the answer options available to them. Conversely, the participants who used a spatial strategy may have needed to adapt the options on offer to fit their spatially generated conclusion. The offering of multiple-choice answer options may have provided feedback in the form of confirming a conclusion generated by the participants.

While using a different type of reasoning task from that employed in the current study, Newton and Roberts (2000) found that the type of feedback offered to participants had an effect upon strategy discovery. A task which encouraged an obvious strategy but also allowed an alternative, less salient but more optimal strategy was presented. Full feedback, in which the participants received feedback about their response accuracy and were told the correct answer, was more likely to lead to strategy discovery than partial feedback where just the accuracy of responses was fed back to the participants. Newton and Roberts’ results could help to explain why the use of answer options in the current study encouraged strategic flexibility in the participants with dyslexia, acting as a form of internal feedback that allowed for strategy discovery, leading to the use of an initial strategy and then the use of a further strategy to confirm the answer originally generated. Answer options may thus have facilitated strategy change to allow the participant to evaluate the conclusion(s) reached. Moreover, if the answers that they generated using the spatial reasoning strategy matched those produced using the verbal reasoning strategy, then this may have boosted their confidence in using the alternative strategy

In the absence of answer options which suggest alternative solutions, other approaches to solving problems may not be as evident to adults with dyslexia as they are to adults without dyslexia. The dyslexia-related difficulties with voluntarily or readily shifting strategy (Bacon et al., 2013) might reflect a broader problem with executive functioning in disengaging from one task or strategy to engage in another (e.g. Smith-Spark et al., 2016). As stated previously, the SAS (Norman & Shallice, 1986) allows an individual to break out from his or her ongoing cognition. Smith-Spark and Fisk (2007) have argued for SAS dysfunction in dyslexia (see also Varvara et al., 2014). Relating this theoretical point to the results of the current study, the use of answer options may have acted as an effective prompt to allow individuals with dyslexia to disengage from reasoning using one particular strategy to engage successfully with another strategy, thereby compensating for a shortfall in the ability to self-initiate strategy change. The provision of answer options may thus have provided a well-defined problem space within which the participants could work, helping the participants to consider how to start answering the problem as they would understand how the end goal might look. This stands in contrast to conditions in which individuals are asked to generate their own answers without any idea of how the answer may look (e.g., Bacon et al., 2007). Such an understanding of the problem space would also have aided the participants with dyslexia to evaluate their own conclusion(s) and to compensate for metacognitive problems such as those identified by Meltzer (1991). The answer options may, therefore, have aided participants with dyslexia to change strategy by allowing them to use one strategy and then to compare their conclusion with the answer options available, thus permitting the individuals with dyslexia to accept or reject their original conclusions with a greater degree of confidence. The use of a mixed strategy may, therefore, have provided the participants with dyslexia with a form of ‘cognitive comfort’ in their reasoning ability.

Further to this, the use of a verbal protocol analysis in Bacon et al.’s (2007) study alongside the self-generation of answers may have increased the load on phonological processing resources. This may be especially true for individuals with dyslexia, due to their phonological processing problems (e.g., Vellutino, Fletcher, Snowling & Scanlon, 2004) and it may also partly explain why individuals with dyslexia may have naturally opted for a spatial strategy in Bacon et al.’s (2007) study. Ramus and Szenkovits (2008) have argued that phonological representations are largely intact in individuals with dyslexia but that phonological processing deficits become apparent when short-term memory resources are drawn upon, when tasks require time constraints or when information is in conscious awareness. In addition to the process of reasoning itself, both Bacon et al.’s study and the current research drew on phonological processing by requiring participants to read the syllogisms, keep this information in working memory and then provide constant verbalisation and written protocol on solution(s). These multiple cognitive demands would be likely to place a comparatively higher cognitive load on the participants with dyslexia as a result of their difficulties in these areas (see similar points, for example, by Nicolson & Fawcett, 1990, and Smith-Spark, Henry, Messer & Zięcik, 2017).

Consistent with previous research (e.g., Ford, 1995; Galotti et al., 1986; Newton & Roberts, 2000), individual differences in reasoning strategies have once more been found and different groups have been shown to favour the use of different strategies overall. However, of equal importance is the finding of intra-individual differences, namely that within each group and within many individuals there is evidence of a variety of different strategies being employed. In the current study, the majority of reasoners adopted a mixed approach to their strategy usage, with very few adopting a single strategy and remaining with it for all trials. This finding is of great importance for future research in the area of strategy choice in reasoning. For tasks where there is a great deal of strategic flexibility, this needs to be reported carefully. To only include participants using a single strategy might render the majority of the data collected redundant, yet to report overall strategy tendency as representative might obfuscate the actual findings. Studies of strategy usage need to have greater exactness in the way in which strategy choice or preference is reported since overall tendency is different from overall preference per se.

To conclude, the results of the current study raise questions as to how best to present problems to individuals with dyslexia when they are learning new skills or attempting new tasks. If the answer options do indeed act as a cue to individuals with dyslexia to consider alternative strategies (which may facilitate performance), then these findings have both theoretical and pedagogical implications. The use of answer options may offer a level of scaffolding (Wood, Bruner & Ross, 1976) which may help individuals with dyslexia to effect a change of reasoning strategy. These cues may act as an aid to reasoning performance, making it more likely that individuals with dyslexia would disengage from one strategy to engage in another and, thus, provide them with a means of compensating for impairments in cognitive flexibility (Bacon et al., 2007; Smith-Spark & Fisk, 2007). Consideration, therefore, needs to be given to the way in which problems are presented to people with dyslexia. This knowledge should be applied in pedagogic settings with answer options being employed to encourage greater flexibility in reasoning to benefit all reasoners, regardless of any diagnosis of dyslexia.

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