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ORIGINAL ARTICLE

Visualisation to support children with attention-deficit/hyperactivity disorder learning to solve mathematical word problems: A randomised controlled trial

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Abstract

This randomised controlled trial experimental study compared the effectiveness of using two different types of visualisation – *self-constructed visualisation* (SCV) and *passively received visualisation* (PRV) – to help children with attention-deficit/hyperactivity disorder (ADHD) solve mathematical word problems. While SCV refers to drawings that children create to help solve given word problems, PRV refers to pre-made images that accompany word problems. Twenty children with ADHD in Kuwait, aged nine to 11 years, were randomly assigned to either the SCV or PRV group, where they were taught to use either SCV or PRV to solve word problems across 20 daily one-to-one sessions. The results showed that regardless of the visualisation type, children's word problem-solving ability significantly improved. Children with ADHD should thus be encouraged to use visualisation to help make the word problem-solving process more accessible to them.

KEYWORDS

attention-deficit/hyperactivity disorder (ADHD), constructionism, passively received visualisation (PRV), self-constructed visualisation (SCV), visualisation

Key points

- The findings showed that both types of visualisation – self-constructed visualisation (SCV) and passively received visualisation (PRV) – can help children with ADHD learn how to solve word problems in mathematics, despite the difficulties experienced by these children in processing textual information.
- The study also found that children's performance following SCV was significantly better than their pre-test performance, and they maintained this level of performance for a further month following SCV. This suggests that SCV has long-lasting benefits. PRV did not appear to show long-lasting benefits.
- Teachers should be made aware of the benefits of using visualisation with children who have special needs or learning disabilities, giving the technique more attention as part of their overall pedagogy.

INTRODUCTION

Mathematical word problems can be defined as descriptions of circumstances involving one or more problems that can be solved by performing appropriate mathematical operations on given numerical information (Verschaffel et al., 2010, 2020). As word problems are often presented in everyday contexts, they represent the interaction between mathematics and real life (Moleko, 2021). Solving word problems involves multiple mathematical thinking processes, for example, understanding, planning, calculations and verification (Csíkos & Szitányi, 2019). Such processes present specific challenges to children who have difficulty concentrating, or who cannot plan their actions easily, as in the case of children with attention-deficit/hyperactivity disorder (ADHD). Moreover, children with ADHD also tend to exhibit reading difficulties (Kofler et al., 2018). This can be problematic for them, as word problems demand a fairly high degree of reading comprehension (Csíkos & Szitányi, 2019), and Trakulphadetkrai et al. (2020) have shown that limited reading comprehension and poor vocabulary knowledge can increase difficulties encountered by children when solving word problems.

Considering these challenges, the current study sets out to ascertain the effectiveness of using visualisation as a tool for helping children with ADHD solve word problems. The rationale for this study's focus on visualisation is that it could help make solving word problems more accessible to children with language-processing difficulties while keeping them focused on their task. Specifically, the study sets out to compare the effectiveness of two types of visualisation, that is, *self-constructed visualisation* (SCV) and *passively received visualisation* (PRV). While the former is taken to refer to children' own drawings that they create to assist them in solving word problems, the latter refers to ready-made images that accompany word problems. As solving word problems is a common mathematical task (Csíkos & Szitányi, 2019), it is thus imperative that we ensure that we have a good understanding of how children with ADHD can be best supported when engaging in this type of mathematical task.

The following sections will now expand on the conceptualisations of ADHD, mathematics learning challenges for children with ADHD and the role of visualisation as a mathematics learning tool.

CONCEPTUALISATIONS OF ADHD

ADHD is widely considered to be a hereditary disorder, affecting around 5.29% to 7.1% of schoolchildren worldwide (Evans et al., 2018; Neudecker et al., 2019; Young & Smith, 2017). It is characterised by three key behavioural characteristics, namely, inattention, hyperactivity and impulsivity (Evans et al., 2018; Neudecker et al., 2019; Young & Smith, 2017). According to Schultz (2011), although ADHD is perceived to be similar to attention deficit disorder (ADD), the absence of hyperactivity in ADD implies that ADHD sufferers have other special needs, due to the impulsive nature that can accompany their inattentiveness.

There are differing views on what causes ADHD. For some, ADHD is a neurodevelopmental disorder caused by disparities in the development of the brain's anatomy, adversely affecting the mental development of those affected, including their ability to organise and focus (Arnold et al., 2020; Bozinovic et al., 2021; Visser et al., 2020). However, recent studies, such as Michaud's (2021), are unable to determine conclusively that ADHD learning difficulties shown in some children are, in fact, caused by neurodevelopmental disorders. Furthermore, Smith (2017, p. 767) criticises the prevalent perspective that ADHD is a universal phenomenon found in all human populations across time and place, and argues – based on his analysis of ADHD's emergence in Canada, the UK, Scandinavia, China and India – for a reconceptualisation of ADHD as a social construct, that is, 'a product of local historical, cultural and political factors'. His view echoes that of Hamed et al. (2015, p. 2), who highlight that people:

> from different cultural and ethnical backgrounds may have different views and perceptions of behavioural norms and when to consider behaviour inappropriate or indicative of a clinical disorder such as ADHD.

This sociological perspective on ADHD, therefore, highlights the issue with using widely adopted ADHD diagnostic tools, such as the American Psychiatric Association's *Diagnostic and statistical manual of mental disorders, fifth edition* (DSM-5; APA, 2013) and the World Health Organisation's *International classification of diseases, tenth edition* (ICD-10; WHO, 1992), which are to some extent based on subjective behavioural assessment.

CHALLENGES FOR CHILDREN WITH ADHD WHEN SOLVING WORD PROBLEMS

Word problems are frequently used as a distinct genre of mathematical task (Csíkos & Szitányi, 2019). They allow children to apply the mathematical knowledge that they learn in the formal classroom setting to meaningful everyday contexts (Pongsakdi et al., 2019). This is crucial in mathematics learning, as it helps children to contextualise abstract mathematical concepts in contexts that are relevant and meaningful to them. However, as noted in the introductory section, it can be argued that children with ADHD may find solving word problems more challenging than children without ADHD for two key reasons; namely, the complexity involved in maintaining focus while engaging in multiple mathematical thinking processes; and in reading and understanding the textual information presented in word problems.

Concerning the first challenge, solving word problems involves multiple mathematical thinking processes, for example, understanding, planning, calculation and verification (Csíkos & Szitányi, 2019). Such processes can present specific problems for children who have difficulty concentrating or who cannot plan their actions easily, as in the case of children with ADHD. To a large extent, these challenges are caused by the fact that children with ADHD have poorer working memory than their typically developing peers (Alloway & Cockcroft, 2014). Drawing from Miyake and Shah (1999), Trakulphadetkrai et al. (2020, p. 477) define working memory as 'the mental space that is involved in the controlling, regulating, and maintaining of relevant information needed to achieve complex cognitive tasks'. Thus, having poor working memory can limit one's mental ability to engage in the various thinking processes required to solve word problems.

Concerning the second challenge, as word problems are textual in nature, it requires children to be able to read and understand textual information efficiently. This argument is supported by Trakulphadetkrai et al.'s (2020) findings, which conclude that children's ability to solve word problems can be predicted by their language ability and reading comprehension skills. It can thus be quite challenging for children with ADHD to solve word problems as they also experience reading difficulties, at least in part, due to their poor working memory (Kofler et al., 2018).

Given the aforementioned challenges, and given that solving word problems is a common mathematics teaching and learning tool, being able to support children with ADHD to solve word problems successfully is thus crucial. The current study will now argue that using visualisation can help to address these specific mathematics learning challenges as experienced by children with ADHD.

VISUALISATION AS A MATHEMATICS LEARNING TOOL

Visualisation is crucial to mathematics learning as it can support the mathematical thinking process (Arcavi, 2003). Bruner (1966) proposed three modes of representation to aid learning: the enactive mode (learning through actions and concrete objects), the iconic mode (learning through visual aids) and the symbolic mode (learning through symbols and languages). According to Bruner (1966, p. 49):

> it may be possible to by-pass the first two stages. But one does so with risk that the learner may not possess the imagery to fall back on when his symbolic transformation fails to achieve a goal in problem solving.

Representing mathematics situations visually can give meaning to and help solve word problems (Bruter, 2013; Hanna & Villiers, 2012). In addition, visualisation can assist with recall because images are generally easier to remember than abstract concepts (Bruter, 2013; Schäfer, 2021). Moreover, visualisation can help improve children's mathematical understanding by enhancing their cognitive ability through the development of mental images (Bruner, 1966; Giaquinto, 2011; Schäfer, 2021; Skemp, 1989).

However, some scholars are critical of the use of visualisation to support mathematics learning. Tversky (2010), for example, argues that images can be confusing for children if they cannot comprehend the meaning of a given image. Likewise, Gates (2018) adds that it is not always easy to discern what some given images are supposed to represent. Thus, the clarity of the images is critical, or else they will be useless.

Passively received visualisation (PRV) and self-constructed visualisation (SCV)

The current study focuses on two types of visualisation: *passively received visualisation* (PRV) and *self-constructed visualisation* (SCV), which were coined by the study's authors.

Passively received visualisation (PRV)

In the context of the current study, PRV is taken to refer to ready-made images that accompany word problems. For example, a ready-made image that could accompany the word problem: '*Hamad went to the theme park. Hamad played four games and for each game, he won two prizes. How many prizes did Hamad win altogether*?' could be an image of four groups of two toys. Using such images may be considered as a means of teaching and learning through visualisation, which helps make unfamiliar material more familiar for children (Taber, 2018). In addition, images can make complex conceptual or abstract knowledge available to children by providing a clear picture of the concepts and removing the confusion (Dongwi & Schäfer, 2019; Taber, 2018). Many researchers affirm that visual images (that is, PRV in the case of the current study) can positively influence mathematics learning and change children's attitudes towards mathematical concepts (Arcavi, 2003; Bjuland, 2007; Gal & Linchevski, 2010). These researchers have found that the use of these visual images in teaching and learning environments can complement the teaching of any mathematical concept and enhance higher thinking in problem solving.

Using images to teach and learn mathematics can have its limitations. As previously mentioned, Gates (2018) argues that it is not always easy to work out what images are supposed to represent. Furthermore, Ozdamli and Ozdal (2018), for example, found that teachers do not always want to use visual representations of mathematical concepts, because it can be time-consuming for them to find or create these visual representations and it adds to their workload.

Self-constructed visualisation (SCV)

In the context of this study, SCV is taken to mean images that children construct themselves to assist them in solving word problems. As noted in the previous section, the idea here is that such visualisation renders the processing of textual information more accessible to children.

In essence, the concept of SCV is linked to the act of drawing, which can be defined as constructing an image or an external visual representation of information, so as to make it easier to grasp the information (Carney & Levin, 2002; Van Meter et al., 2006). A research gap exists in the use of drawing for teaching, especially among children with ADHD, for whom poor working memory appears to be a major challenge (Clark et al., 2007; Young et al., 2007). The few empirical studies that provide some evidence that drawing can be used to improve working memory via visual sensory parts of the brain include Meade's (2019) study of 210 undergraduate students at a university in Canada, which found that the use of drawing to represent given words is more effective than just writing out those words in helping the participants to recall the words later. Although Meade's study involved participants who are older than those in the current study, and despite the study's focus on recall of information, it can still be argued that using drawing (and hence SCV in the context of this study) to represent the words (and hence the mathematical situations) in given word problems has the potential to make the word problem-solving process more accessible.

However, the process of drawing is not without issues. Leutner et al. (2009), for example, argue that the process of drawing can lead to high cognitive load; that is, learners can be overwhelmed by the amount of information to be simultaneously processed (Paas et al., 2004). This could help explain Yaoukap et al.'s (2019) argument that some children may find it difficult to engage in the process of drawing.

In summary, SCV and PRV represent two similar – and yet different – approaches to solving word problems. Specifically, while both approaches are visual in nature, the PRV approach relies on children using ready-made visualisations or images that accompany given word problems to help them solve the problems. The SCV approach, on the other hand, relies on children constructing their own visualisation or images themselves to represent mathematical situations in given word problems as a strategy to solve the problems. It can thus be argued that children using the SCV approach engage in the mathematical problem-solving process much more actively than their PRV-using counterparts who just passively rely on the visualisations or images that are presented to them as part of the word problems. Specifically, to be able to represent any given word problems visually, children using SCV would first have to ensure that they actually understand the problems and what is being asked. Then they would have to decide, for example, which type of visualisation would best represent the mathematical situations found in the given problems; for instance, whether to use pictorial representation, which is essentially a drawing that represents the objects as closely as possible (for example, drawing two apples to represent two apples that are described in a given word problem), or the more abstract kind (for example, drawing two rectangular bars or two dots to represent the two apples). Moreover, children using SCV would then have to ensure the accuracy of the numerical information as represented in their drawings. These areas of consideration represent the additional cognitive steps that children would have to go through when using the SCV approach to solve mathematical word problems, while their PRV-using counterparts arguably do not have to go through these additional cognitive steps.

There is also a theory that may help explain why the SCV approach could be more effective than the PRV approach, and this theory will be discussed in the next section.

CONSTRUCTIONISM AS THE STUDY'S UNDERPINNING THEORY

The current study's underpinning theory is constructionism, which offers a nuanced divergence from constructivism (Halpenny & Pettersen, 2014). Constructivism, of which Piaget was a pioneer, is a psychological learning theory, which essentially maintains that learners construct their own knowledge and understanding based on their experiences of the world, while internalising their ideas (Halpenny & Pettersen, 2014). In constructionism, the emphasis is on *externalisation*: the cognitive process whereby learners externalise their current understanding by creating a 'public artefact' that can be examined and probed by others (Papert, 1993). In the current study, such public artefacts take the form of SCV, where the children project their understanding of given word problems by creating images. These images, from the child's perspective, appropriately represent the problems presented to them. Such a process of active externalisation is key to constructionism, and when incorporated into the mathematics learning process (for example, through SCV), it arguably makes learning more effective, compared to using PRV or no visualisation at all.

AIM OF THE CURRENT STUDY

To the best of our knowledge, no previous empirical studies have set out to compare the effectiveness of PRV and SCV as strategies to help children with ADHD solve word problems. It is this research gap that the current study sets out to address. Therefore, the current study sets out to the answer the following research question: to what extent do PRV and SCV help children with ADHD solve mathematical word problems?

METHODS

Research context

The current study is situated in Kuwait, where children with different types of special educational needs are included in state-funded schools; for example, children with Down syndrome, hearing and vision impairments, autism, and with other learning disabilities (for example, dyslexia, dyscalculia and ADHD) (Ministry of Education, 2006). Kuwait has adopted an inclusive education system as part of a broader national strategy, because providing inclusive education is implied in the religious mandate that forms a significant part of the policy-making process in the region (Weber, 2012). Al-Manabri et al. (2013) also highlight that inclusive education is part of Kuwaiti mainstream education to help ensure that learning institutions in the country provide equal opportunities for all children.

However, the implementation of inclusive education to accommodate children with special educational needs is often negatively perceived by learning institutions and communities in the Middle East, including Kuwait. For example, Al-Manabri et al. (2013) have argued that children with special educational needs were perceived in the Arab world as holding the rest of the class back, delaying the progress of learning, and asking inappropriate or irrelevant questions. This is arguably one of the reasons why the Kuwaiti Ministry of Education decided to open two special schools for children with learning disabilities (a boys' school in 2013 and a girls' school in 2014 in Mubarak Al-Kabeer Educational Governorate) (Alzamil et al., 2021) so that the special learning needs of these children could be catered for specifically.

Sampling and sample size

Children were selected from two state-funded special needs schools for children with learning disabilities in Kuwait. Schools in Kuwait are gender-segregated. Therefore, one of the participating schools was all-female and the other was all-male. Children from both schools who were diagnosed with ADHD in the nine- to 11-year-old age group were invited to participate in the study. (The reason for choosing this age group, and not a younger age group, is because very young children can find the process of drawing difficult when compared to their older counterparts; Rellensmann et al., 2017.) Overall, 20 children (eight girls, 12 boys) were found to fit these selection criteria and agreed to take part in the study. Their parents also gave consent for their children to take part in the study.

It is worth noting that the current study's girls-to-boys ratio of 1:1.5 noticeably differs from the girls-to-boys ratio found in other countries. For example, Novik et al. (2006) found that of the 1478 children who were diagnosed with ADHD across ten European countries, only 231 of them were girls and the rest were boys, yielding the girls-to-boys ratios ranging from 1:3 to 1:16 according to country. Salem et al.'s (2014) study of 70 Kuwaiti children diagnosed with ADHD found the girls-to-boys ratio to be around 1:3.5 (that is, 20 girls, 30 boys). It is thus acknowledged that the gender ratio in this study does not reflect the more typical gender ratios found in other studies.

Research design

The current study adopted a randomised controlled trial design with two groups of children (PRV and SCV). Each group comprised four girls and six boys who were randomly allocated to it. Every child in these two groups attended daily one-to-one 30-min sessions for four weeks (totalling 20 sessions), led by the first author (Details of the sessions can be found in the following section).

An experimental intervention was designed to investigate the effectiveness of two specific types of visualisation (PRV and SCV) on helping children with ADHD solve word problems. The intervention was conducted on the two groups of children: the intervention group (SCV) and the comparison group (PRV). In an experimental research design, the purpose is to control and measure changes in one or more variables (independent variables) in order to investigate the effect of these changes on other variables (dependent variables) (Pandey & Pandey, 2015). In the current study, the independent variable was the type of visualisation (PRV or SCV) used to solve word problems. The dependent variable was the children' ability to solve word problems as measured in their test scores. The study's hypotheses were:

> *Null hypothesis*: There will be no statistically significant differences in the ability of children with ADHD (across both the SCV and PRV groups) in solving word problems.
>
> *Alternative hypothesis*: There will be statistically significant differences in the ability of children with ADHD (across both the SCV and PRV groups) in solving word problems.

The intervention was conducted during the first term of the academic year in Kuwait (September to mid-January). In September and October 2018, the study took place in the girls' school, while in November and December 2018, it took place in the boys' school.

Before the data collection began, children in the intervention group (SCV) received a one-to-one introductory session for 15 min from the first author to ensure that they understood the purpose of the intervention, and were clear on what was meant by solving word problems through drawing. This was achieved by giving the children one example of a word problem where they were encouraged to think of how the problem could be represented visually, and allowing them to attempt to create a drawing to try to represent the given problem. This introductory session was not offered to children in the PRV cohort due to the fact that they would not be using the SCV approach in their sessions.

Research instruments

Children across the two groups completed the same tests: a pre-test, a post-test and a delayed post-test (administered one month after the post-test). In addition, the children across the two groups completed four interim tests: one after every five daily one-to-one sessions (see Table 1 for further clarification of the experimental design). These interim tests served as a means to measure how the children developed over the course of the 20 daily sessions.

Decisions about the questions to be used as part of the daily sessions and in the tests were informed by mathematics teachers from both participating schools. Their agreement was necessary to ensure that the word problems used in the sessions and tests corresponded to their schools' curriculum. In the context of the current study, the teachers advised that the mathematical focus should be on multiplication and division.

Each daily one-to-one session (30 min each) for the SCV or PRV children involved them solving six word problems. Children in the SCV group were asked to solve these by visually representing mathematical situations in the given word problems through drawing, while children in the PRV group were asked to solve the same problems by relying on given images that accompanied the problem. The researcher did not interfere when the children were trying to solve the given word problems during the sessions. The only help received by the children during the sessions was when some of them needed assistance from the first author to read out some mathematical word problems.

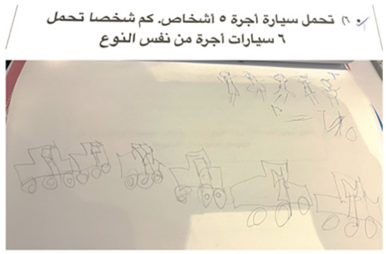
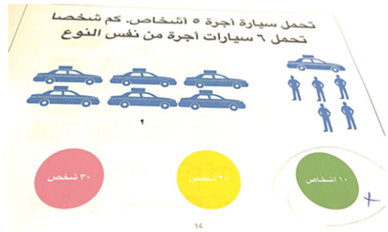
There were six word problems in each test. The first two problems were the easiest, the middle two problems were of medium difficulty, and the last two problems were the most difficult. The rationale for ordering the problems from the easiest to the most difficult was to help reduce the likelihood of test takers abandoning the test altogether (Anaya et al., 2022). Examples of the word problems, and how the children solved the word problems using SCV and PRV, are illustrated in Table 2.

TABLE 1 Design of the experiment.

	Pre-test	Test 1	Test 2	Test 3	Test 4	Post-test	Delayed Post-test
SCV							
10 children (4 girls; 6 boys)		After 5 sessions	After 10 sessions	After 15 sessions	After 20 sessions		One month after the post-test
PRV							
10 children (4 girls; 6 boys)		After 5 sessions	After 10 sessions	After 15 sessions	After 20 sessions		One month after the post-test

Abbreviations: PRV, passively received visualisation; SCV, self-constructed visualisation.

TABLE 2 Examples of three word problems from one of the sessions (as translated from Arabic).

Word problems (three examples)	Example from one of the SCV children	Example from one of the PRV children
1. Hamad went to the theme park. Hamad played four games and for each game, he won two prizes. How many prizes did Hamad win altogether?		
2. If you know that one taxi can fit only five people, then what is the maximum people that can fit in six taxis?		
3. Salwa has 15 dinars to spend across five days. How many dinars can Salwa spend equally per day for those five days?		

Abbreviations: PRV, passively received visualisation; SCV, self-constructed visualisation.

Data analysis

As noted, the experiment was designed to investigate the effectiveness of two specific types of visualisation (PRV and SCV) on helping children with ADHD solve word problems. An independent sample *t*-test was applied to compare the mean scores of the two different independent groups' performance on the pre-test, post-test and delayed post-test. Although the study's sample size is small (N=20), this does not affect the test results. De Winter (2013), for example, argued that the *t*-test can be performed even with a sample size of two as long as the Type I error rate did not exceed the nominal value of 5%. As the *t*-test is a parametric test, the normality hypothesis was tested, and the data were normally distributed. Moreover, the paired sample *t*-test was also used to ascertain whether differences in the pre-test, post-test and delayed post-test scores can be observed within each group.

RESULTS

The independent-samples *t*-test was used to compare the test scores of the two groups of children to ascertain which type of visualisation treatment would be more effective in helping them solve word problems. As shown in Table 3, there was no statistically significant difference in the test scores of the two groups of children in any of the tests. The effect sizes of the intervention in the post-test (d=0.38) and the delayed post-test (d=0.47) scores were small.

Separately, the paired-samples *t*-test analysis shows a statistically significant difference between the pre-test and post-test for the PRV group, highlighting that children in the PRV group did significantly better on the post-test compared to the pre-test by an average increase of 2.30 points (see Table 4). Additionally, a statistically significant difference was also found between their performance on the post-test and delayed post-test (which was administered one month after the post-test). Interestingly, the PRV children somehow performed significantly worse on the delayed post-test than they did on the post-test by an average decrease of 1.70 points.

The same analysis was performed on the SCV group's dataset as shown in Table 5, which reveals that the SCV children performed significantly better on their post-test when compared to their pre-test by an average increase of 1.70 points (compared to the average increase of 2.30 points in the PRV group noted in the previous paragraph). Furthermore, no statistically significant difference was found in the children's performance between the post-test and the delayed post-test, which arguably can be seen as a more positive outcome in relation to their counterparts in the PRV group who – as stated in the previous paragraph – performed worse, to a statistically significant extent, in their delayed post-test compared with their post-test.

DISCUSSION AND CONCLUSION

The current study set out to examine the extent to which two types of visualisation (SCV and PRV) can cater to the mathematics learning needs of children with ADHD, specifically in helping them solve word problems.

The findings showed that both groups performed significantly better on their post-test compared to their pre-test. To an extent, this finding is unsurprising, as earlier studies have found that children with special needs and children in general benefit from using visualisation in mathematics learning (Garderen et al., 2014; Tsai & Yen, 2013). What is arguably surprising is the fact that children in the SCV group did not significantly outperform their PRV counterparts at the post-test. This is surprising because according to Papert (1993), children are thought to learn more effectively when they have opportunities to externalise (or *project out*) their thinking and understanding by creating a public artefact (which in the case of the current study is the drawings created by children in the SCV group). One potential explanation for why there was no significant difference in the post-test performance between the two groups of children could be due to the fact that both groups used the concept of visualisation. Despite the nature of visualisations used by the two groups (SCV and PRV) differing, it seems that both groups equally increased their ability to process the complexity of both the contextual and numerical information in the given word problems, thereby equally improving their word problem-solving ability.

The study also found that while the SCV children's performance on their post-test was significantly better than on their pre-test, there was no statistically significant difference in the SCV children's performance on their post-test and their delayed post-test. Arguably, this can be interpreted quite positively, in that the SCV children's ability to solve word problems with the help of SCV appeared to be sustained even a month after the data collection period. The PRV children's performance is even more interesting. Specifically, while the PRV children's post-test performance was significantly better than their pre-test performance, their delayed post-test performance was statistically significantly *worse* than their post-test performance. Unlike their SCV peers, the PRV children's word problem-solving ability (using the PRV approach) was not sustained after the data collection period. In fact,

TABLE 3 Descriptive statistics and comparison between SCV and PRV for test performance.

Group	*N*	Mean	Standard deviation	Standard error mean	Sig. (2-tailed)
Pre-test					
PRV	10	0.60	0.843	0.267	0.773
SCV	10	0.70	0.675	0.213	
Test 1					
PRV	10	2.40	1.578	0.499	0.741
SCV	10	2.20	1.033	0.327	
Test 2					
PRV	10	3.10	1.729	0.547	0.372
SCV	10	3.80	1.687	0.533	
Test 3					
PRV	10	3.20	1.317	0.416	0.535
SCV	10	3.60	1.506	0.476	
Test 4					
PRV	10	3.20	0.789	0.249	0.289
SCV	10	3.80	1.549	0.490	
Post-test					
PRV	10	2.90	1.287	0.407	0.408
SCV	10	2.40	1.350	0.427	
Delayed post-test					
PRV	10	1.20	1.229	0.389	0.306
SCV	10	1.80	1.317	0.416	

Abbreviations: PRV, passively received visualisation; SCV, self-constructed visualisation.

TABLE 4 Paired-sample *t*-test – PRV group.

	Paired differences							
				95% Confidence interval of the difference				
	Mean	Standard deviation	Standard error mean	Lower	Upper	*t*	df	Sig. (2-tailed)
Pair 1								
Pre-test – post-test	−2.300	1.494	0.473	−3.369	−1.231	−4.867	9	0.001
Pair 2								
Post-test – delayed post-test	1.700	1.829	0.578	0.392	3.008	2.940	9	0.016

Abbreviation: PRV, passively received visualisation.

TABLE 5 Paired sample *t*-test – SCV group.

	Paired differences							
				95% confidence interval of the difference				
	Mean	Standard deviation	Standard error mean	Lower	Upper	*t*	df	Sig. (2-tailed)
Pair 1								
Pre-test – post-test	−1.700	1.636	0.517	−2.871	−0.529	−3.285	9	0.009
Pair 2								
Post-test – delayed post-test	0.600	1.350	0.427	−0.366	1.566	1.406	9	0.193

Abbreviation: SCV, self-constructed visualisation.

it somehow got noticeably worse. One conjecture for this interesting finding may be attributed to PRV children's lack of opportunities to actively construct their own visualisation as part of their word problem-solving strategy; this lack of opportunities may have hindered their ability to retain their word problem-solving ability one month after the post-test. Unintentionally, this specific finding thus perhaps highlights a cognitive benefit of the SCV approach (as underpinned by Papert's, 1993 constructionism theory), namely, that children's active construction of visualisation can help them retain their word problem-solving ability over a period of time.

Limitations of the study

The current study has some limitations. First, it would have generated more insightful findings by having three groups of children instead, namely, the SCV group, the PRV group and a third group of children whose word problems would not come with any accompanying images and who would need to use ‘traditional’ method of solving word problems instead (such as written calculation methods). The inclusion of this third group would have revealed how the SCV and PRV children performed on their tests compared to their counterparts in the ‘business-as-usual’ peer group.

Second, the limitations of time (that is, just one month to apply the intervention) and a small sample size played a critical role in the quality of the data collected in this study. Research conducted over a longer period could have revealed stronger and more enduring effects of the intervention. Moreover, if the sample size had been bigger, the results could be interpreted more robustly.

Moreover, we could have interviewed the children in the study in relation to their responses to the given word problems. This would have revealed more insights into their thinking, and it would have added more depth to our analysis. Unfortunately, due to the study's time constraints, it was not possible to conduct such interviews.

Finally, the children were not tested on their general mathematics and reading ability levels before conducting the intervention. Establishing children's general mathematics and reading ability levels, and using this information to help ensure that each of the two groups (SCV and PRV) was made up of a similar proportion of children with the different mathematics and reading ability levels, would have made the research design fairer and more reliable.

Implications of the study

The findings of this study suggest that the use of visualisation – whether PRV or SCV – could help children with ADHD learn how to solve word problems, despite the difficulties experienced by these children in processing textual information (Kofler et al., 2018). Teachers should therefore be made aware of the benefits of using visualisation with children who have special needs or learning disabilities, and give the technique more attention as part of their overall pedagogy. In particular, teachers could make visualisation explicit in their mathematics lesson plans, especially when children are asked to solve word problems. In relation to SCV specifically, one key advantage of children using SCV rather than PRV when solving word problems is that teachers could use the children's drawings as a formative assessment tool to assess their current level of mathematical understanding. Moreover, when children who use SCV still struggle to solve word problems, their drawings can be used as a diagnostic tool by the teacher to try to understand what may have caused the difficulty.

Future research directions

The focus of the current study has been on using visualisations – a form of written communication – to make solving word problems more accessible to children with ADHD. It would be interesting to explore the extent to which alternative forms of communication (for example, oral communication through the use of the dialogic teaching strategy – a strategy that harnesses the power of talk to foster children's thinking; Alexander, 2020) – could help reduce the cognitive overload that children with ADHD may experience when solving word problems using traditional written methods.

As previously noted, ADHD is characterised by three key behavioural characteristics, namely, inattention, hyperactivity and impulsivity (Evans et al., 2018; Neudecker et al., 2019; Young & Smith, 2017); it would thus also be useful to ascertain the extent to which the use of visualisation (both SCV and PRV) could help to address these characteristics of children with ADHD when they are solving word problems.

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CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

DATA AVAILABILITY STATEMENT

Access to the study's research data is available to the research team only due to the wording used on the study's information sheets and consent forms.

ETHICS STATEMENT

The study received ethical approval from the University of Reading's Institute of Education.

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