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Take it of your shoulders: Providing scaffolds leads to better performance on mathematical word problems in secondary school children with developmental coordination disorder

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ABSTRACT

Background: Many children with developmental coordination disorder (DCD) have mathematical problems which are more pronounced for mathematical skills that also require executive functions. Although empirical evidence is missing, math and special education need teachers of children with DCD report difficulties with mathematical word problem solving that can be remediated by providing the children with scaffolds cueing the intermediate steps.
Aims: This study aims to find empirical evidence for the effectivity of such additional support. In addition, we want to investigate whether the difficulties are due to inefficient arithmetic or executive functioning skills.
Methods and Procedures: A DCD and a control group solved word problems with and without scaffolds and conducted a series of tasks measuring calculation and executive skills.
Outcomes and Results: Performance improves when scaffolds are presented to children with DCD. Children with DCD and control children differ on executive functioning tasks but perform similarly on arithmetic tests.
Conclusions and Implications: Providing scaffolds for word problem solving is effective in children with DCD. Scaffolds possibly reduce the required cognitive load, making the problem solvable for DCD children that have reduced executive functioning skills.

What this paper adds?

Previous studies have shown that many children with DCD have problems with mathematical skills, especially with more advanced mathematical skills that also involve executive functioning (memory, inhibition, flexibility). The present study is set up on request of a group of math – and special education need (SEN) teachers of secondary school children with DCD and provides for the first time empirical-pragmatic evidence for the effectivity of scaffolds that cue the intermediate steps of word problem solving. Without such scaffolds, DCD children perform less accurate, which seems to indicate that the solution process is not yet internally regulated. The difficulties with word problem solving in children with DCD are most likely due to lowered executive functioning skills in this group and not so much their mathematical skills, because a comparison of the DCD group with a control group showed differences in executive functioning, but not on an arithmetic tasks.

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1. Introduction

Developmental Coordination Disorder (DCD) is a condition characterized by an impaired ability to acquire and execute movement skills, affecting around 5–6 % of all children, with a higher prevalence in boys (Smits-Engelsman, Jover, Green, Ferguson, & Wilson, 2017). These motor problems start early in life and affect everyday activities such as tying shoelaces, holding, throwing or catching objects. Children with DCD experience difficulties with social participation and are at high risk of developing further physical and mental health problems (Lingam et al., 2012). Importantly, the motor problems do not result from low intelligence, visual impairments or another neurological disorder (American Psychiatric Association, 2014). The motor problems are very heterogeneous among individuals and the etiology and neural basis of DCD remain unclear (Zwicker, Missiuna, Harris, & Boyd, 2012). A recent review of neuroimaging data shows that children with DCD show differences in the brain structure and functions across motor and attention networks involving prefrontal, parietal and cerebellar regions (Wilson et al., 2017).

In addition to these problems with movement skills, it is also well documented that DCD has an impact on academic achievement. Children with DCD perform worse than control children on reading, writing and mathematics tasks (e.g., Alloway, 2007; Alloway & Archibald, 2008; Gomez et al., 2015; Lingam et al., 2012; Pieters, Desoete, Van Waelvelde, Vanderswalmen, & Roeyers, 2012). With respect to mathematics, Vaivre-Douret et al. (2011) claimed that 88 % of the children with DCD also have mathematical problems. Zooming in on the mathematical problems of children with DCD, Pieters et al. (2012) examined a sample of 9 year old children with DCD and compared them with age-matched control children. They observed that children with DCD performed on average worse than control children on both number fact retrieval (i.e., fast retrieval of simple mathematical problems stored in memory, e.g., “3 × 5”) and mental computation (i.e., solving complex calculation that require intermediate steps, e.g., “436 + 71”). Furthermore, these authors noted that children with DCD struggle more with complex tasks that require both complex procedural knowledge and executive functions such as attention and working memory.

In support of this claim, previous studies demonstrated that executive functions are indeed related to math achievement (Bull & Scerif, 2010; Cragg, Sarah, Richardson, Roome, & Gilmore, 2017; Friso-Van Den Bos, Van Der Ven, Kroesbergen, & Van Luit, 2013). Executive functions are typically divided into memory updating, inhibition, and cognitive flexibility (see Miyake et al., 2000). It has been suggested that children with DCD have problems with all of these executive functions (Bernardi, Leonard, Hill, Botting, & Henry, 2017; Wilson et al., 2017). With respect to working memory, Piek, Dyck, Francis, and Conwell, (2007) observed a relation between memory performance and motor skills: children with worse motor skills were equally accurate but slower on a memory recall task. More recently, Bernardi et al. (2017) showed that children with DCD performed worse than control children on a non-verbal working memory task (i.e., odd-one-out), but not on a verbal working memory task (i.e., word recall; see also Leonard & Hill, 2015). Also inhibitory skills seem to be affected in children with DCD. Leonard, Bernardi, Hill, and Henry, (2015) showed that children with DCD performed worse on a non-verbal inhibition task in which hand gestures demonstrated by the experimenter had to be either copied or either inhibited and replaced by another movement. In contrast, a similar verbal inhibition tasks did not reveal such differences. Pratt, Hayley, Adeyinka, and Hill (2014) also observed inhibitory problems in children with DCD, and argued that these problems are moderated by task difficulty, because the children only displayed poorer inhibition skills on the more difficult tasks. Finally, cognitive flexibility, that is the ease with which children can switch to another task or implement other instructions, is also weaker in children with DCD (Bernardi et al., 2017; Wuang, Su, & Su, 2011). For instance, Bernardi et al. (2017) found that children with DCD perform worse than control children performing on a task in which they first have to learn a rule to sort objects to trial and error and then have to switch to another rule. Altogether, these studies demonstrate that children with DCD experience problems with several executive functions, especially manifest in non-verbal and more complex tasks. Moreover, these executive problems are persistent through development as demonstrated in a longitudinal study by Bernardi et al. (2017). It has been argued that executive problems and motor difficulties are closely related, because planning and coordinating movements (e.g., catching a ball) requires accurate anticipation, inhibition of distractive elements and monitoring and correcting movements, or in other words executive control (Saban, Ornoy, & Parush, 2014).

1.1. Mathematical word problems and executive functions

Mathematical word problems refer to word problems from which the information that is presented in the problem needs to be integrated, typically into a mathematical formula, to arrive at a solution of the problem (Boonen, van der Schoot, van Wesel, de Vries, & Jolles, 2013). Mathematical word problems are considered a powerful tool children use to transfer their mathematical skills to everyday situations and are, therefore, a crucial skill to master (Gasco, Villarroel, & Zuazagoitia, 2014).

Solving mathematical word problems requires executive functioning resources, in particular working memory and cognitive flexibility (Desmarais, Osana, & Lafay, 2019). Working memory is involved in all steps of the problem-solving process: information has to be maintained and updated in working memory continuously. At the other hand, cognitive flexibility is needed to switch between different possible solution strategies. For instance, Lubin, Vidal, Lanoë, Houdé and Borst (2013) conducted a study using the negative priming paradigm and observed that more time is needed to solve a target word problem (i.e., the probe) when it was preceded by another word problem (i.e., the prime) in which the correct strategy for the target problem had to be inhibited. This study not only shows the importance of flexible switching between solution strategies, but also the involvement of inhibitory skills.

Because executive functioning is involved of these additional requirements, children typically experience more difficulties when solving such word problems than when solving other mental computations (Verschaffel, Greer, & De Corte, 2000). Indeed, several studies have reported problems with mathematic word problem solving in children with learning disabilities and/or mild intellectual disabilities and have proposed alternative instruction methods for enhancing problem solving performance (e.g., Chung & Tam, 2005; Jitendra & Star, 2011; Montague, 2008). To the best of our knowledge, mathematical word problem solving has not been systematically examined in children with DCD specifically. However, math teachers and special education needs (SEN) teachers (i.e., supportive assistants for individualized instruction) responsible for instructing mathematics to children with DCD in secondary school, bring up that these children experience serious difficulties with solving word problems. This is not so surprising given their problems with executive functioning tasks.

Instructional research has shown that providing a general plan to the children for processing and solving word problems can help to overcome the difficulties with word problem solving. Such a plan typically consists of a series of easy-to-remember steps (e.g., Jitendra & Star, 2011; Montague, 2008). Some of these strategies address the first phases of the solving process (i.e., reading the problem, identifying the question, and determining the problem type). Other strategies deal with latter phases in word problem solving (i.e., determining the mathematical formula, calculating the solution and checking). There are also strategies addressing both phases. For instance, a model by Van Dooren, Verschaffel, Greer and De Block (2006) distinguishes several, iterative steps: (1) children have to understand all relevant information for the word problem, (2) a mathematical model has to be formulated, (3) using this model and through mathematical relations, the result has to be computed, (4) the mathematical result has to be interpreted in terms of the concrete problem, (5) the model has to be re-evaluated by checking whether the result is reasonable given the original situation and (6) the solution needs to formulated (for an overview of these strategies, see Powell & Fuchs, 2018).

Whichever strategy is selected, it is crucial that the teacher models the strategy first and then gradually decreases the level of support (i.e., fading) so that the strategy becomes internally regulated by the student. According to the math and SEN teachers from the children with DCD that were involved in our research, this shift from external regulation towards internal regulation of the strategy is what DCD children struggle with. Therefore, the SEN-teachers still provide the children with DCD with scaffolds, that is additional support cueing all steps of the learned word problem solving procedure (i.e., what is the relevant information; what is the unknown; what is the mathematical formula; compute the formula; check the result; write down your answer).

1.2. The present study

The present study is demand-driven (i.e. set up on request of a group of math – and SEN-teachers) and aims to provide empirical-pragmatic evidence for the effectivity of the scaffolding approach by math- and SEN teachers to overcome difficulties with word problem solving in children with DCD. We examined the performance of secondary school children with DCD and a control group (both aged between 14 and 16 years) on mathematical word problems that were part of their current curriculum (see Appendix 1). The word problems were presented with and without the presence of scaffolds cueing the intermediate steps. The children were first presented with two word problems without scaffolds, after which two new word problems were presented with scaffolds. The performance on both types of word problems was compared. It was *hypothesized that children with DCD would perform better on word problems with scaffolds (compared to word problems without scaffolds). Additionally, it was hypothesized that the difference between both conditions might be smaller in the control group because the solution process should be already internally regulated (H1)*. After the problems with scaffolds, two additional new word problems were presented, again without scaffolds, to verify whether the additional support that was provided with the previous problems, encouraged the children to follow the same strategy on new problems. *It was hypothesized that children would perform better on these last two word problems without scaffolds than on the first two because they could transfer the step-by-step solution strategy to new problems (H2)*. Finally, because word problem solving also relies on mathematical and executive functioning skills, we also investigated the performance of children with DCD and the control group on those skills. In this way, we wanted to examine whether the problems children with DCD experience with mathematical word problems can be related to weaker math skills and/or weaker executive functions. *Here, it was hypothesized that the performance of children with DCD on mathematical and executive tasks would be worse than the performance of the control children (H3)*.

2. Methodology

2.1. Participants

Participants were 25 children with DCD and a control group of 103 children typically developing children 3rd (i.e., 14–15 years old) or 4th (i.e., 15 − 16 years old) grade of secondary school. Both grades are expected to have internalized the intermediate steps for solving word problems. The experimental protocol was approved by the university's ethical committee (G-2018 02 1118). All children and their parents gave consent for participation.

One of the children with DCD whose total score total score on all words problems was < 2SD from the group mean was excluded. The final group of children with DCD group comprised 14 children from 3rd grade and 11 in 4th grade. All DCD children were boys and recruited via the Dominiek Savio Institute (Hooglede-Gits, Belgium), a secondary school for children with neuromotor disorders. They were all diagnosed with DCD in line with the DSM-V criteria (APA, 2014). Some of these children were also diagnosed with a comorbid disorder such as autism, attention deficit hyperactivity disorder or a learning disorder. Sixteen children were in the general secondary education track, nine followed vocational secondary education.

The children in the control group (N = 103) were recruited in two other secondary schools. Five children were excluded because they were diagnosed with dyscalculia (N = 3) or because they were absent at one of the testing moments (N = 2). From the 98 remaining children, seven children were excluded because they were an outlier (> 2 SD above or below average) on one of the computerized tasks. Additionally, two participants, whose total score on all words problems was < 2SD from the group mean, were excluded from further analyses. The final group (N = 89) comprised 53 boys. Fifty-two of the final sample were in 3rd grade. Seventy-three children followed a general secondary education track, 16 were in vocational education. The sex ratio was different in both groups, $Chi^2 = 13.00$, $p < .001$, as the DCD group only contained boys. The ratio of 3rd and 4th -graders was similar, $Chi^2 = 0.14$, $p < .001$, $p = .71$

2.2. Materials

2.2.1. Word problems

Two sets of six word problems were created in collaboration with the math and SEN teachers from Dominiek Savio, for general education and vocational education respectively, with the aim of matching the performance of both groups. All word problems for the children in general education were of the same type, that is comparisons with one unknown variable (e.g., "The brothers Ben and Arne and their sister Emma earned €2055 together. Ben earned €75 more than Arne. Emma earned €7.50 less than half of what her brothers earned. How much did Ben, Arne and Emma earn individually?"). The word problems for the children in vocational education dealt with volumes and surfaces (e.g., "A swimming pool measures 2 × 3 m and is 1.50 m in height. Father is filling the pool with water up to 50 cm from the edge. How many liters of water does the pool contain?"). The children from vocational education were allowed to use a sheet with relevant formulas. All word problems can be found in Appendix 1.

The word problems were bundled in booklets. The first two word problems were presented without scaffolds. No additional support cueing the different steps of the solution process was given, but the children were explicitly instructed to write down all intermediate steps and told that writing down the final answer alone is not sufficient. The following two word problems were presented with scaffolds cueing the necessary intermediate steps. The scaffolds were part of the instructional method of the math- and SEN teachers and in line with models for word problem solving (Van Dooren et al., 2006). Finally, the last two word problems were presented again without scaffolds to investigate whether the solution procedure was transferred to new word problems. The order of the word problems was counterbalanced across participants resulting in three different booklets so that each word problem belonged once to each category (word problems without scaffolds; word problems with scaffolds; word problems without scaffolds - transfer).

Although the word problems were based on the mathematics curriculum of general and vocational education respectively, the mathematics teachers of the children with DCD in the general education track were additionally consulted and asked whether each child would be able to solve the problems constructed for the general education track, because some of the children with DCD received differentiating instruction. If the teacher thought the word problems were too difficult, the word problems for vocational education were used for that child. In this way, five children from the DCD group that were in general education solved the word problems for vocational education. In total, 11 children with DCD solved the word problems for general education and 14 children the problems for vocational education.

2.2.2. Mathematical and executive skills

All mathematical and executive functioning tasks were computerized. E-prime Professional software, version 2.0 (Psychological Software Tools, Pittsburgh, PA, USA) was used for stimuli presentation and the recording of the data. The mathematical tasks tested both preverbal numerical skills and symbolic number skills. Preverbal numerical skills were assessed with a numerosity comparison task. Previous research has demonstrated that the performance on this task is related to individual differences on more advanced symbolic mathematical skills (e.g. Halberda, Mazzocco, & Feigenson, 2008). Acquired symbolic math skills were measured with two arithmetic verification tasks for number fact retrieval and procedural calculation respectively. Pieters et al. (2012) showed difficulties with both forms of calculation in a DCD group. The executive functioning skills we measured comprised inhibitory skills and verbal working memory which we considered the most relevant for solving word problems.

2.2.2.1. Numerosity comparison. In this task, two dot arrays were presented on the left and right side of the screen (coloured in yellow and blue respectively). Children had to decide whether the yellow or the blue dots were more numerous by pressing the 'f' and 'j' button on an AZERTY keyboard. Stimuli were created with an adapted version of the dot generation algorithm by Gebuis and Reynvoet (2011). This algorithm controls for five visual cues across trials: convex hull (i.e., the area subtended by each dot array), total surface area (i.e., the aggregate surface area of all dots in one array), dot item size (i.e., the average diameter of the dots presented in one array), total circumference (i.e., the aggregate circumference of all dots in one array), and density (i.e., surface area divided by convex hull). This is done by creating two types of trials – fully congruent trials and fully incongruent trials. Fully congruent trials are trials in which all visual cues positive correlate with number (i.e., the more numerous dot array has the larger convex hull, larger tot area, larger dot item size, etc.). In contrast, fully incongruent trials are trials where the visual cues negative correlate with number (i.e., the more numerous dot array had the smaller convex hull, less total area, etc). This manipulation ensures that participants base their decision on the number of dots, and not on their physical properties.

Each trial started with a centrally-positioned fixation cross for 500 ms after which the dot arrays were presented for 500 ms. After that, a black screen was presented. Responses could be given during stimulus presentation or during the presentation of the black screen. All dot arrays contained between 10 and 40 dots and could have six different ratios (i.e., 1.11, 1.14, 1.20, 1.25, 1.50, and 2.00). For each ratio, six congruent and six incongruent trials were presented, resulting in a total of 72 trials, presented in two blocks with a small break in between. Five practice trials preceded the experimental trials. Feedback was provided in the practice trials. No feedback was given on the experimental trials.

2.2.2.2. Arithmetic verification tasks. Two arithmetic verification tasks were administered – single-digit multiplication and multipledigit subtraction task.

The stimuli for the *single-digit multiplication task* consisted of ten unique multiplication problems (i.e., all operands larger than 4 and no ties), presented correctly (e.g., 4 × 6 = 24), incorrectly where the solution is unrelated to the multiplication table (e.g., e.g., 4 × 6 = 25), and incorrectly with the solution related to the multiplication table (e.g., e.g., 4 × 6 = 28). Participants had to indicate whether the presented multiplication problem was correct or incorrect by pressing “j” and “f” on an AZERTY keyboard. Each trial began with 600 ms fixation cross, followed by the multiplication problem, presented until response. The next trial started after 1500 ms intertrial interval. Before the actual experiment, participants were presented with five practice trials (with feedback), followed by 40 randomly presented experimental trials (without feedback). In half of these trials, the presented solution was correct, while in the other half incorrect.

In the *multi-digit subtraction task*, there were twelve unique subtraction problems, presented either correctly (e.g., 32 − 15 = 17) or incorrectly (e.g., 32 − 15 = 27). The solution for half of these problems required borrowing (e.g., 32 − 15 = 17), while the other half did not (e.g., 69 − 31 = 38). The participants had to decide whether the presented subtraction problem was correct or not by pressing “j” and “f” on an AZERTY keyboard. The structure of the trial was identical to the single-digit multiplication task. Prior to the task, five practice trials with feedback were provided, followed by 36 randomly presented experimental trials without feedback (correct trials were presented twice[1]).

2.2.2.3. Inhibitory skills. Participants completed a Stroop task to measure cognitive inhibition and a Go/No-Go task measuring motor inhibition. The order of the tasks was counterbalanced across participants.

In the *Go/No-Go task*, participants were presented with a picture of a horse and a picture of a bird. The picture of the horse constitutes a "Go" stimulus, while the image of the bird was a “No-go stimulus”. Consequently, participants were instructed to press “SPACE” whenever they saw a horse, and to withhold their response when they saw a bird. Each trial started with a 500 ms centrally-positioned fixation cross. Then, the stimulus was presented for 90 ms, followed by a black response screen presented for 750 ms. Afterwards, the next trial started.

Prior to the task, each participant received three practice trials with feedback. Next, participants completed 48 randomly presented experimental trials without feedback (75 % Go-trials).

In the *Animal Stroop task*, two animal pictures were simultaneously presented on the screen (e.g., a bear, a butterfly, a rabbit and an elephant). The images of the animals could be either congruent (e.g., a big image of a bear and small picture of a butterfly) or incongruent (i.e., a big image of a butterfly and a small picture of a bear) to the actual physical size of the animal. Participants were instructed to judge which animal was larger in real life by pressing “j” and “f” on an AZERTY keyboard. Each trial started with 500 ms fixation cross, followed by the picture pair, presented until response. After that, the next trial started. The task began with five practice trials with feedback provided, followed by 36 experimental trials (50 % congruent), without feedback.

2.2.2.4. Forward digit span task. The forward digit span task is a subtest of the Wechsler Adult Intelligence Scale–Fourth Edition (WAIS-IV; Wechsler, 2008). In this task, the examiner reads out loud number string in an increasing length (min = 2; max = 9). The participant is asked to remember the string in the same order. The participant is given two trials for each length (e.g., two trials to recall five-digit strings). The task ends when the child makes mistakes on both trials of a certain string length. The individual score of each child is the largest span they could accurately recall.

2.3. Procedure

All children with DCD were tested individually by their regular SEN teachers during one of the weekly planned sessions. All SEN teachers were invited first to an information session during which they received clear instructions on how to conduct the experimental tasks and were asked to strictly adhere to these instructions. The children with DCD were examined during one of their individual sessions with their SEN teacher. First, the children solved the word problems. If the SEN teacher noticed that the child struggled with one of the word problems, the child was encouraged to read the word problem carefully again, but no further additional support was given. When the word problem was too difficult even after encouragement, the SEN teacher instructed the child to go to the next word problem after about seven minutes. Then, all computerized tasks were administered in the same order: first the dot comparison task, followed by the multiplication task, the subtraction task, the go/no-go task and Stroop task. In between tasks a short break was provided. Finally, verbal short term memory was measured. The entire session took about 60 min.

The data from the control group was collected in two different time slots. In a first time slot, the students conducted the word problems collectively during math class, supervised by a graduate student. After a short introduction, the children were instructed to start with the first word problem, and only go to the next when they had finished the previous one. Every seven minutes they were instructed to go to the next word problem, if they did not do so spontaneously. When the children had questions, the child was instructed to read carefully again the question, but no additional support was provided. In the second time slot, all other tasks were administered in small groups of three students in a separate room at school using three laptops. Each task was shortly introduced and then the task was started by the graduate student. The order of the tasks was the same as in the DCD group. Each session ended with the forward digit span task which was administered individually.

[1] Due to a programming error, incorrect trials were presented only once resulting in unequal proportions of correct and incorrect trials.

2.4. Data-analysis

A scoring scheme for each word problem was developed by the mathematics and SEN teachers from the Dominiek Savio Institute. A correct end result was not sufficient to receive the maximum score. Instead, the children also had to conduct all intermediate steps. This approach also mirrors the grading of word problems in regular math classes.

All word problems from the children with DCD were scored by two graduate students who designed and collected the data. This resulted in a satisfactory intraclass correlation coefficient, *ICC* = .85, 95 % *CI* [.83, .87]. The word problems from the control group were corrected by one graduate students. To check the reliability of the scores, a random sample of 15 booklets was also scored by the second graduate student, again resulting in a satisfactory *ICC* = .93, 95 % *CI* [.88, .97]. Not every word problem required the same number of intermediate steps. This also resulted in a different total score for each word problem (min. 3 and max. 5 points). To compare between conditions, scores on each word problem were rescaled to 5. Then, for each child, three scores were computed by summing the scores for the first two of word problems without structure, the two word problems with structure and the last two word problems without structure respectively.

As we mentioned already, both sets of word problems (general education track and vocational education track) were part of the current curriculum of both groups. In this way, we expected that the mathematical word problem solving scores should be similar in both groups. This was confirmed with an independent samples *t*-test on the total scores (i.e., sum of all word problem scores) of both sets of problems (total score general education, $M = 15.55$; vocational education, $M = 14.77$; $t(111) = .64$; $p = .52$). Therefore, educational track was not considered as an additional between subject factor[2] .

The first hypothesis, that is *children with DCD benefit from the presence of scaffolds cueing the intermediate solution steps more than control children*, was evaluated with a repeated-measures ANOVA on the word problem scores with word problem type (no scaffolds vs scaffolds) as within-subjects factor and group (DCD vs control). as between-subjects factor. To examine the second hypothesis, that is *children with DCD will transfer the solution strategy to new problems*, another repeated measures ANOVA was conducted with the first two (no scaffolds) and last two word problems (no scaffolds – transfer) as a within-subjects factor and group (DCD vs control) as between-subjects factors.

For the dot comparison task, the multiplication task and the subtraction task overall accuracy was computed. To measure inhibitory skills, the following indexes were used. For the go/no-go task the percentage of commission errors (i.e., responses on a no-go trial) was computed. For the Animal Stroop task, the interference effect, that is the RT difference between incongruent and congruent trials. Finally, it has been argued that also in the dot comparison task inhibitory skills are involved (Gilmore, Keeble, Richardson, & Cragg, 2015). More specifically, to respond correctly on an incongruent trial, non-numerical cues need to be inhibited, which resembles performance in a Stroop task. Therefore, here too, an interference effect was computed by subtracting the accuracy on incongruent from the accuracy on congruent trials. Finally, the forward digit span was equal to the largest span of numbers that a child could correctly remember. To verify our third hypothesis (i.e., *performance of children with DCD on mathematical and executive functioning skills will be worse than controls*), we conducted series of independent samples t-tests on all these outcome measures comparing children with DCD and control children.

3. Results

Participant`s average performance in the word problem tasks and on the cognitive measures is depicted in Table 1.

3.1. Word problems

With respect to our first hypothesis, there was main effect of word problem type, $F(1111) = 4.81$ $p = .037$, $\eta_p^2 = .04$, showing that the scores on word problems without scaffolds lower than the scores on word problems with scaffolds. There was no main effect of group, $F(1111) = 2.55$, $p = .11$, $\eta_p^2 = .02$, and there was no significant interaction, $F(1111) = 1.74$, $p = .19$, $\eta_p^2 = .02$. Given the focus on children with DCD of our hypothesis, we examined whether this group significantly benefitted from the scaffolds, which was the case, $t(23) = 2.22$; $p = .018$ (one-sided). The score of the control children on the word problems with scaffolds was not better than on the problems without scaffolds, $t(88) = 0.84$; $p = .20$ (one-sided).

Comparing the first and last two word problems (without scaffolds vs without scaffolds – transfer; Hypothesis 2) yielded no main effect of word problem task, $F(1111) = 0.93$, $p = .34$, $\eta_p^2 = .008$, but there was main effect of group, $F(1111) = 4.57$, $p = .035$, $\eta_p^2 = .04$, suggesting that children with DCD scored higher than control children. There was no significant interaction, between word problem task and group, $F(1111) = 0.33$, $p = .57$, $\eta_p^2 = .003$.

3.2. Numerical and mathematical abilities

No differences were found between both groups on the performance on the dot comparison task, $t(111) = .17$; $p = .87$, the multiplication verification task, $t(111) = .21$; $p = .83$, and the subtraction verification task, $t(111) = .45$; $p = .65$.

[2] The results were the same when educational track was entered as an additional between-subject factor in the ANOVA

Table 1
Mean participant`s performance on the word problem, math and inhibitory control tasks with their corresponding standard deviation (SD), depicted per group and educational track. Mean accuracies (proportion correct responses) are depicted for the dot comparison, multiplication, and subtraction tasks. The performance in the Go/No-Go task is measured in terms of commission error (CE) – the proportion of errors in the no-go trials. Stroop interference effect reflects the difference (in ms) between the incongruent and congruent trials in the Stroop task. Dot congruency reflects the difference between congruent and incongruent trials in the dot comparison task.

	Typically developed control children (*N* = 89)		Children with DCD (*N* = 24)	
Educational track	General (*N* = 73)	Vocational (*N* = 16)	General (*N* =11)	Vocational (*N* =13)
Word problem tasks				
Without structure	4.95 (2.54)	4.27 (1.80)	5.49 (1.86)	4.82 (2.49)
With structure	5.20 (2.81)	4.64 (2.92)	5.96 (1.93)	6.59 (2.05)
Without structure-transfer	5.16 (2.43)	3.96 (1.94)	5.72 (3.27)	5.71 (2.96)
Numerical and math abilities				
Dot comparison task (overall)	0.66 (0.07)	0.61 (0.05)	0.65 (0.08)	0.66 (0.08)
Multiplication task	0.90 (0.10)	0.81 (0.09)	0.88 (0.06)	0.87 (0.11)
Subtraction task	0.88 (0.10)	0.85 (0.12)	0.88 (0.06)	0.85 (0.11)
Executive functioning skills				
Forward Digit span task	7.08 (0.92)	6.43 (0.96)	5.46 (0.93)	5.69 (0.86)
Go/No-Go (CE)	0.45 (0.22)	0.49 (0.25)	0.28 (0.25)	0.28 (0.19)
Dot congruency	0.26 (0.26)	0.38 (0.29)	0.46 (0.25)	0.45 (0.26)
Stroop interference	43 (45)	63 (56)	29 (43)	50 (66)

3.3. Executive functioning skills

Children with DCD had a lower working memory span than control children as measured by the forward digit span, $t(111) = 6.46$; $p < .001$. DCD children also had a larger dot congruency effect than controls, $t(111) = 2.85$; $p < .01$, indicating they were more intered by the non-numerical cues in the numerosity comparison task. The interference effect as measured with the animal stroop task did not differ in both groups, $t(111) = .51$; $p = .62$. Finally and unexpected, children with DCD made less commission errors in the go/no-go task than control children, $t(111) = 3.44$; $p < .001$.

4. Discussion

The present study examined whether providing scaffolds cueing the different steps for word problem solving had a positive impact on the word problem solving performance of children with DCD. Previous research has shown that this method is effective for children with mathematical learning problems and children with mild intellectual deficits (Powell & Fuchs, 2018). Although no research has been conducted in a sample of children with DCD, math and SEN teachers consider this additional support also essential for helping children with DCD to solve word problems. However, empirical evidence, supporting this intuition based on experience of teachers, is lacking. Providing such evidence is crucial though, given the fact that the regular math curriculum does no longer foresee such scaffolds in children from 3rd and 4th grade, that is the current sample, because the goal is to obtain a shift from external to internal regulation for word problem solving strategies by fading the additional support. Children with DCD, however, seems to struggle with this shift towards internal regulation. Therefore, we conducted an empirical-pragmatic study in which we examined the advantage of scaffolds for word problem solving in children with DCD and in typically developing control children (H1). We also verified whether the presentation of these scaffolds on a word problem is sufficient to apply the strategy on new problems (i.e., transfer – H2). Finally, we examined whether the difficulties in word problem solving could possibly be situated in either mathematical or executive functioning skills (H3).

To the best of our knowledge, the current study is the first to provide evidence that also children with DCD benefit from the presence of scaffolds that cue the intermediate solution steps (i.e., what is the relevant information; what is unknown; what is the mathematical formula; compute the formula; check the result; write down your answer in a sentence). Children with DCD performed better when such scaffolds were present. Although the analyses an additional contrast showed that the difference between word problems with and without scaffolds was only significant in the DCD group and not the control group, the enhancement due to the scaffolds was not statistically different in both groups. Indeed, Table 1 shows that also the control group benefits from the additional support given during word problem solving. This comes not as a surprise given that the remediation strategy is not uniquely developed to help children with DCD, but all children with word problem solving difficulties (see Powell & Fuchs, 2018 for an overview). As a consequence, also control children can benefit from these scaffolding technique, especially those who are underperforming on word problem solving. This is supported by the observation of a significant negative correlation between the scores on the first two word problems and the gain score (i.e. score on word problems with scaffolds minus score on first two word problems without scaffolds), $r(89) = -.49$; $p < .001$, in the control group.

There was no evidence for the hypothesis that children would perform better on new word problems *without scaffolds* after having encountered word problems *with* scaffolds (i.e. transfer). Because all children have learned to solve these word problems by applying such a general strategy, it was expected that the scaffolds would be sufficient to re-activate the learned solution process on new problems. Apparently, scaffolds on only two word problems were not sufficient to trigger the solution process and additional practice is needed in some children to establish an internally regulated word problem solving strategy.

With respect to the third hypothesis, no differences were observed between children with DCD and control children on preverbal numerical and arithmetic (i.e., multiplication and subtraction) skills. This is different than in the study of Pieters et al. (2012) who observed problems with fact retrieval and procedural calculation in DCD children which were on average 9 years old. The current sample of DCD children is between 14 and 16 years old. Fact retrieval and procedural calculation are typical skills from primary school and the accuracy on such problems is possibly no longer affected in older children with DCD. By contrast however, DCD children experienced more interference in the numerosity comparison task and had a lower working memory score. This is in line with previous studies showing that executive functioning in children with DCD is deficient (e.g., Bernardi et al., 2017; Piek et al., 2007). Unexpectedly, children with DCD made fewer commission errors in the motor inhibition task. This is not consistent with the observations of Bernardi et al. (2017) who found that children with DCD performed worse on a motor inhibition task. However, both tasks to measure motor inhibition clearly differ: whereas in the current study participants had to refrain from pressing when a particular object was shown on 25 % of the total amount of trials (go/no-go task), participants in the study from Bernardi et al. (2017) had to copy hand gestures in one condition or to inhibit the hand gesture and replace it by another in another condition. The inconsistent results could in part be explained by the fact that the latter task is clearly more difficult, especially given the motor problems of children with DCD. Pratt et al. (2014) indeed argued that poorer inhibition skills are typically found on more difficult tasks. Although the executive functioning performance could not be directly related to the word problem performance (there were not enough word problems to obtain a reliable score), given the involvement of executive processes in word problem solving and the deficient executive processes in children with DCD, there is a strong possibility that these latter difficulties underlie the word problem solving difficulties in these children.

The present results can nicely be integrated within the cognitive load theory (Sweller, 1988), an influential theory in the domain of learning and instruction. According to this theory, information has to be processed first in the working memory, which has a limited capacity and duration, before it can be stored in the long-term memory. Cognitive load is induced when learners have to process new information in order to construct new knowledge and learning is most efficient when the cognitive load is optimal, that is not too low or too high. The total cognitive load experienced by the learner is determined by intrinsic load on the one hand and extraneous load on the other. Intrinsic load refers to the complexity of the information that needs to be processed. The extraneous load is determined by the way the information is presented. In addition, the optimal cognitive load is also dependent on the individual characteristics of the learner, like experience or processing capacity of the learner (Sweller, van Merriënboer, & Paas, 2019). Executive functioning, which is affected in children with DCD, has a negative impact on the processing capacity of learners. As a result, the optimal cognitive load in children with DCD is lower than in control children. Presenting the word problems with scaffolds, cueing a step-by-step solution of the word problem, is a way to reduce the cognitive load. Such a reduction in cognitive load is necessary to bridge the gap between the cognitive load induced by a word problem and the optimal cognitive load of children with DCD which is needed for accurate word problem solving.

The current study exhibits some unexpected findings and has certain limitations which are in part due to the empirical-pragmatic approach of this study in which we wanted to strive for as much ecological validity as possible (i.e., using word problems that were part of the current curriculum, examine the DCD children within the foreseen support time frame). This that led to particular design choices that may have obscured some differences in the data. First, in contrast to what could be expected based on input from math teachers and SEN-teachers (note that this study was actually designed to systematically examine the observations of teachers that children with DCD have difficulties solving word problems), the children with DCD did not perform worse on the word problem task compared to the control children. One of the possible reasons for this finding could be the different testing situations in both groups. The testing situation mimicked the actual situation of both groups during math classes. Children with DCD were tested individually during one of their regularly planned math supporting sessions with the SEN teacher and regularly encouraged to continue by the SEN teacher if they made not a lot of progress on a specific problem. The control children, by contrast, were tested in group during one of their math classes and did not receive individual encouragements, possibly resulting in reduced motivation. Another limitation of the study is that we could not directly relate executive functioning scores to the performance on mathematical word problems because the reliability of the word problem solving test was too low. This is because word problems that were part of the current curriculum of 14 − 16 year old children (i.e., word problems with one unknown variable in general education and word problem about surfaces/volumes in vocational education – see Appendix 1). The children needed quite a lot of time to solve a word problem and hence, only a few word problems could be presented, resulting in a low reliability of the word problem solving test. Both limitations could possibly be resolved in future research by examining the performance of DCD and control children in group on simple word problems that need to be verified (e.g., "Ann has 25 marbles, she has 5 marbles more than John: John has 20 marbles?"; see Lubin et al., 2013). More problems could be presented, resulting in a more reliable index and the chance that children with DCD become frustrated when they have to solve such problems alone will also be reduced. A final limitation of this study is that children with DCD and their control peers were not compared on the entire spectrum of executive functions. In this study, we focused on verbal short-term memory (i.e., forward digit span) and inhibition (i.e., Go/No-Go and Stroop task), which are involved in solving the word problems presented in this study. Future studies, however, should consider also measuring cognitive flexibility that also appears to play an important role in word problem solving (Desmarais et al., 2019). Similarly, also reading skills could be compared in further research, which could also affect performance in word problem solving.

To conclude, for the first time, the current study provided empirical evidence showing that scaffolds cueing the different intermediate steps of word problem solving, positively affects the performance in children with DCD. The scaffolds possibly reduce the cognitive load induced by a word problem, and may compensate for the poorer executive functioning skills in children with DCD.

CRediT authorship contribution statement

Bert Reynvoet: Conceptualization, Methodology, Software, Data curation, Writing - original draft, Writing - review & editing. **Mila Marinova:** Data curation, Writing - original draft, Writing - review & editing. **Delphine Sasanguie:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing.

Appendix 1

Mathematical word problems (translated to English) that were used for the general education track (type: one unknown variable)

1 If I add 20 to the half of a number, the sum is 10 less than the triple of that number. What is the number?
2 A trader mixes rice of €2/kg with rice of €1.65/kg. For each part of the first type of rice, he takes four parts of the second type. In total he paid €43. How much kg he has of the second type of rice?
3 A washing machine uses up to 1.5 time more watt/h than a coffee machine. A dish machine uses 180 W less than a washing machine. When all three machines are on, total use is 3070 W/h. How much does each machine uses?
4 If I add €12 to a third of my total savings, I have sufficient money to buy a book of €25. How much savings do I have?
5 The length of a classroom is 0.4 m less than the double of its width. The perimeter is 40 m. what are the length and width of the classroom?
6 The brothers Ben and Arne and their sister Emma earn €2055 together. Ben earned €75 more than Arne. Emma earned €7.5 less than the half of the total of her two brothers. How many did each earn?

Mathematical word problems (translated to English) that we used for the vocational education track (type: area and volume – a sheet with formulas could be used)

1 A classroom is 6 m wide, 8 m long and 2 m high. How much air (in liter) is there in the class? and how much oxygen is there, if you now that air contains 20 % oxygen.
2 Hanne makes a terrarium in a jar with a cylinder shape. The jar has a radius of 8 cm and is 20 cm high. Hanne is filling the jar with potting soil up to 5 cm of the top. How much potting soil does the jar contain?
3 Charlotte would like to have a terrace in her garden. the garden has a total surface of 10 m by 20 m. How much acres does the garden measure? and how much acres will the terrace be, if you know that Charlotte will use 60 % of the garden for her terrace?
4 A pool measure 2 by 3 m and is 1.5 m deep. Father is filling the pool with water up to 50 cm of the top edge. How much water (in liter) does the pool contain?
5 On the table there is a cylindrically shaped vase with a radius of 4 cm and 20 cm high. What is the total surface of the vase? And how much dm^2 paper do you need if you want to decorate half of the vase with paper?
6 In the zoo there is a new aquarium in the shape of a cube with an edge of 2 m. The aquarium is fileld with water up to 10 cm of the top edge. How much water (in dm^3) is needed?

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