Full-body Movement in Numerical Trainings: *A Pilot Study with an Interactive Whiteboard*

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Abstract

In this pilot study, we introduce an effective spatial-numerical training to improve children's arithmetic abilities. We designed this training based on previous successful trainings of spatial-numerical associations (such as number line estimation) and introduced a full-body response movement. Children responded to a number line estimation task presented on an interactive whiteboard by moving their whole body to the left or right. In a pilot study with a small group of children (total sample size N = 27), this experimental training was compared to two control trainings, one training the same task without the full-body movement and one training a different task with full-body movement. The experimental training led to significant improvement in all dependent measures and was most effective in enhancing performance in a spatial-numerical task. Furthermore, full-body movement helped children maintain their performance level in multi-digit addition. We conclude that full-body movement can enhance the efficiency of numerical trainings, which could also be successfully utilized in serious games and incorporated into the classroom.

Keywords: *elementary education, numerical processing, spatial-numerical association, embodied cognition, media in education*

1. Introduction

1.1 The relevance of numerical skills

In recent years, arithmetic abilities have gained in significance for both individual life prospects but also societal interests. On the one hand, deficient arithmetic knowledge has been found to be more detrimental to an individual's life than even poor reading and writing skills [1–3]. On the other hand, societal costs for insufficient numerical competencies are immense, and have exemplarily been reported to add up to 2.4 billion £ per year in the United Kingdom [4, see also 5]. Thus, the reliance of society on depicting and transferring information in numerical form has led to an increased need for means to help individuals improve their arithmetic abilities.

For this reason, the field of numerical trainings and interventions is steadily growing. Especially computer-assisted trainings (such as the *Number Race* [6]; see also [7]) have been shown to positively influence numerical development, even more so when combined with a form of direct instruction [8,9].

Research has recently devoted particular attention to the impact of trainings of basic numerical skills, such as writing numbers, comparing number magnitudes, ordering numbers by size, or estimating the position of a number on a number line. These basic numerical skills constitute the building blocks for more complex arithmetic abilities, and can predict children's future arithmetic abilities [10–12]. Many intervention programs already incorporate basic numerical skills (e.g.,

[7,13] due to reports that basic numerical trainings are particularly effective [8] and can create transfer effects onto more complex areas of mathematics (e.g., [14–16]). In the training study described here, we also trained basic-numerical skills, more specifically the ability to estimate the spatial position of numbers along a number line.

1.2 Basic numerical skills: Number line estimation

Magnitudes and numbers have long been hypothesized to be represented in an ascending order along a left-to-right oriented line that is automatically accessed whenever a number is encountered [17]. On this *mental number line representation*, numbers are spatially coded and reflected in an analogue format. Developmentally, first hints at a spatial left-to-right encoding of numbers have been detected even in preschool children [18] and it has been suggested that the positions of the numbers on the mental number line become more accurate with age and experience [10].

To measure the accuracy of participants' mental number line representation, Siegler and Opfer [19] introduced a *number line estimation task*. In this task, participants are presented with a hypothetical number line (e.g., ranging from 0 to 100) on which they have to estimate the position of a given number (e.g., 37). The accuracy of participants' mental number line representation is then inferred from the distance between their estimations and the actual positions of the numbers.

At the current state of research, it is no longer assumed that this number line estimation task purely measures an underlying representation of number magnitude, or mental number line [20]. Rather, the task is assumed to measure the ability to apply strategies that allow participants to accurately place a number [21]. However, this alternative account does not diminish frequent findings that the number line estimation task is associated with scholastic performance in mathematics. For example, Booth and Siegler [10] found that children with a more accurate number line representation performed better in arithmetic tasks and also learned answers to unfamiliar arithmetic problems more easily. Likewise, Link and colleagues [22] observed associations between number line estimation accuracy and addition and subtraction skills of elementary school children.

It is therefore not surprising that numerous attempts have been made to improve children' number line estimation accuracy (see [23] for an overview). For example, Kucian and colleagues ([24], see also [25]) developed a number line training for children with developmental dyscalculia and found significant improvements in their spatial representation of numbers.

In the current study, we too tried to take advantage of the potential of the number line estimation task for enhancing numerical skills. To this end, we developed and piloted a training in which we attempted to improve on prior trainings by incorporating an *embodied experience* of numbers in accordance with reported associations between the body and numbers (see also [26,27]).

1.3 Associations between numbers and the body

Frequently replicated findings suggest that numbers are associated with bodily experiences, most prominently with finger counting [28,29]. Most children spontaneously use their fingers when learning to count, and it has been reported that these finger counting strategies induce a lasting association between numbers and space that still influences numerical processing in adulthood [30,31]. As a theoretical account for such findings, Domahs and colleagues [30] coined the term *embodied numerosity* in reference to theories of *embodied cognition*, that assume that all human cognition is rooted in sensori-motor processes (see [32] for an overview).

Recent studies suggest that this association between bodily experiences and numerical information is bidirectional, as observed by Shaki and Fischer [33], who had participants perform a random number generation task while walking. They instructed participants to make lateral turns after a couple of steps and produce a number with each step. Participants were more likely to turn to the left after generating a small number and to the right after generating a large number. Similarly, when instructed to turn to the left, they were more likely to generate small numbers than when they instructed to turn to the right and vice versa.

Similar full-body movements have previously already been implemented to enhance spatial-numerical associations in training studies [15,16]. The underlying logic for such trainings is that responding to a numerical task by moving to the left (for small numbers) or right (for large numbers) in accordance with the ordering of numbers on a number line can strengthen the association between space and numbers.

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1.4 Embodied numerical trainings and their application in educational settings

Fischer, Moeller, Bientzle, Cress and Nuerk [15] were among the first to investigate the interdependency of numbers and physical space by training kindergarten children in a number magnitude comparison task (deciding whether a number was smaller or larger than another number). To create a sensori-motor experience of numbers and space, Fischer and colleagues [15] used a *digital dance mat* as input device. Children stood on this digital dance mat and responded by moving their whole body to the right or left, depending on whether a presented number was larger (thus to the right on the mental number line) or smaller (to the left on the mental number line) compared to a reference number. They observed greater training effects in comparison to a control training with no full-body movement in both a number line estimation task and a counting task.

In a follow-up study, Link and colleagues [16] aimed to train number line estimation even more directly by having first-graders walk to the position of a number line that was taped to the floor. They then received feedback from an experimenter, who measured the distance between children's estimates and the correct position. This training combined the presentation of a number line on the floor with a full-body response corresponding to the direction of said number line. To measure children's estimates, they were recorded with a Kinect™ Sensor. In a control condition with no full-body movement, children performed the same task with their finger on a tablet PC. The authors found greater improvement in number line estimation as well as an addition task after the embodied compared to the control condition.

So far, these prior trainings highlighted the potential benefits of full-body trainings of spatial-numerical associations. However, what cannot be concluded from the studies so far is to what extent the training effects were caused by motivational effects (such as enjoyment of the games, see [34]). Both walking along a number line as well as jumping on a dance mat might be more interesting and fun to children compared to performing the same task on a tablet PC. This potential media confound could not be detected in the prior study designs. However, this media influence might not be trivial and might account for some of the findings.

Another important factor to consider in the prior studies is the applicability of the trainings in actual scholastic education. Although digital media are more and more integrated into education, digital dance mats [15] have not yet found their way into the classroom. Additionally, the jumping movement on the dance mat cause a lot of noise, thereby disturbing the entire class. The number line walking training developed by Link and colleagues [16] has the drawback that the setup takes up a lot of space, and that a teacher would have to supervise the training at all times, seeing as the feedback is given by the experimenter who measures the correct distance by hand.

However, more and more classrooms are equipped with interactive whiteboards. These are more and more replacing traditional chalkboards because they can be used as a conventional whiteboard, and also work as a projection device. Due to their considerable width, children should have to walk along the interactive whiteboard when writing on it, thereby making the interactive whiteboard a promising new candidate for embodied trainings that could also be implemented in the classroom.

1.5 The current study

We designed an *experimental training* on an interactive whiteboard, which combined a training of a number line estimation task with full-body movement along the whiteboard, thereby constituting the embodied condition. To detect possible motivational effects, we went beyond prior embodied training studies [15,16] and designed two control conditions instead of one (see Figure 1) to discern effects of the trained task from motivational media effects. In the *task-matched control training*, we combined a training of a number line estimation task with a manual response on a tablet PC, thus controlling whether effects were caused by the spatial-numerical task. In contrast, in the *media-matched control training* we combined a non-spatial colour discrimination task with a full-body response format, thus controlling whether effects were caused merely by the motivational aspects of the digital medium.
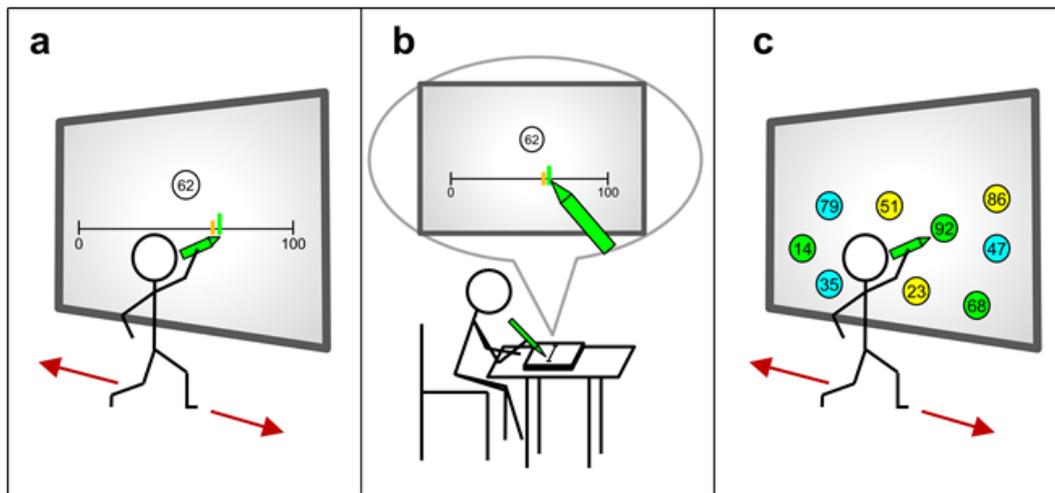
Figure 1. Training setup in the three training conditions. 1(a) Experimental training condition, 1(b) Task-matched control condition, 1(c) Media-matched control condition

In order to expand on previous findings on embodied trainings, we chose second-graders as the target group. These children were already tall enough to reach the interactive whiteboard, yet young enough to still profit from a number line estimation training. Also, second-graders are already capable of performing a wide variety of numerical and arithmetic tasks, which was important because we were interested in vertical transfer effects (e.g., [35]) of the training to more difficult tasks. In particular, we were interested in transfer to more complex multi-digit arithmetic procedures. Children are only taught the number range up to 100 during the course of second grade (as indicated by a still non-linear representation of number magnitude, e.g., [19]). Therefore, a training of this number range in combination with a training of an extension of this range up to 1000 could be particularly beneficial to help children expand their knowledge of numbers, thus helping them comprehend upcoming scholastic content.

To measure training success, we tested children before and after training on multiple arithmetic tasks. Overall, we expected a linear increase of training efficiency with increasing systematic association of numbers and space in the training conditions. That means that we expected the greatest improvement in the experimental condition, followed by the task-matched control condition (due to the numerical content of the task), with the media-matched control condition causing the least improvement (due to the non-numerical content of the task).

2. Materials and Methods

2.1 Participants

Thirty-two second-grade children participated in the study. Parents' written informed consent and children's oral informed consent were obtained before the beginning of the study. Five children were excluded from data analysis due to chance level performance in one or more of the dependent measures. None of the remaining 27 children (12 girls; mean age 7 years 10 months; range 7 years 1 month – 8 years 6 months) exhibited obvious attentional or verbal difficulties. All children were familiar with numbers up to 100.

2.2 Design and Procedure

The study was conducted in one individual session per child. Each child received training in two of the three conditions (the experimental and either the task-matched or media-matched control condition). Therefore, children were divided into four groups, two of which started with the experimental training (both n = 7), one that started with the task-matched (n = 6), and one that started with the media-matched control training (n = 7). Training conditions were then switched, so that the first two groups now completed either the task-matched or media-matched training, whereas the other two groups now completed the experimental training. To assess possible improvements induced by the training, children were tested on dependent measures prior to the first training (t1), in between trainings (t2), and after the second training (t3).

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However, due to the long duration of the study (approx. 90 minutes), children's motivation and concentration decreased substantially after the first training. This resulted in a considerable overall decline in all children's performance. Therefore, the second training session was not included in the analysis. Instead, only improvement from before (t1) to after the first training session (t2) was analyzed. This resulted in an unbalanced distribution of children over the training conditions, because the two groups who started with the experimental training were collapsed into a larger group with n = 14 children.

Each training condition took approximately 15 minutes and consisted of 80 training items: 40 in the number range 0-100 and 40 in the number range 0-1000. Training started with the number range 0-100, after which children took a short break before continuing with the 0-1000 range. Items were presented in a randomized order within each range. Children received feedback during the training, but not the testing sessions. From t1 to t2, training and assessment took approximately 60 minutes.

2.3 Training Conditions: Tasks and Digital Media

In the two spatial numerical task conditions (experimental and task-matched control condition, see Figure 1a and 1b), children had to perform a *number line estimation task* in which they estimated a given number's position on a number line of which only the endpoints were marked (either 0-100 or 0-1000). The same items were used in the two training conditions. As feedback, the correct position of the given number was presented for 3 seconds simultaneously with children's estimate (see Figure 1), allowing children to see how far their estimate was from the correct position. Children's estimates were not classified as correct/incorrect or good/bad to avoid discouragement. Rather, children were given the correct position on every trial to allow them to improve their estimate on the next trial (in the style of Knowledge of Correct Response feedback, [36,37]). In the media-matched control condition, we used a *color discrimination task*. Children saw a display of nine randomly distributed colored circles, all of which contained irrelevant numbers (ranging from 0-100 or 0-1000), and were instructed to tap the green circles in any order with an electronic pen. As feedback, correctly tapped green circles disappeared, whereas incorrectly tapped circles remained on the display.

In the two full-body response conditions (experimental and media-matched control condition, see Figure 1a and 1c), tasks were presented on an interactive whiteboard (screen size: 165.7cm x 125.7cm) that was wide enough to elicit a full-body response movement. In the task-matched control condition, tasks were presented on a tablet PC (screen size: 28.6cm x 21.5cm) without full-body response movement. On both media, children responded directly on the screen with an electronic pen.

To sum up, in the experimental training condition (see Figure 1a), the number line estimation task was presented on the interactive whiteboard to highlight spatial attributes in both presentation and response. Number lines were 153.5cm long. In the task-matched control condition (see Figure 1b), the number line estimation task was presented on the tablet PC on which number lines were 26.5cm long. In the media-matched control training (see Figure 1c), the color discrimination task was presented on the interactive whiteboard. Circles were randomly distributed across the lower two thirds of the screen along a width of 153.5cm, so children had to move unsystematically to reach all of them.

2.4 Dependent Measure Tasks

At pretest (t1) and posttest (t2), children were tested on four different tasks (presented in balanced order) that assessed improvements in different areas of arithmetic proficiency. To avoid any memory effects from t1 to t2, three different item sets (A, B, and C) were created for each task. These item sets were matched in numerical magnitude and difficulty and were administered in a Latin square balanced order, so that each child received different item sets at t1 and t2 (for example, participant 1 received set A at t1 and set B at t2, participant 2 received set B at t1 and set C at t2, and so on).

2.4.1 Paper and pencil number line estimation task: Analogous to the trained task, children had to estimate the positions of numbers on number lines ranging from 0-100 and from 0-1000 (18 items per range). Number lines were 30cm long and thus longer than number lines presented on the tablet

PC (26.5cm), but shorter than number lines presented on the interactive whiteboard (153.5cm). This task was included to measure whether children's number line estimation improved in a different format (paper and pencil without feedback) on number lines of different physical length.

2.4.2 Speeded multi-digit addition: In the addition task, children had to solve as many multi-digit addition problems as possible within 90 seconds. This task was included to measure whether the training induced transfer effects onto more complex arithmetic operations.

2.4.3 Three-digit number comparison: Children were presented with three-digit number pairs on a tablet PC, and had to choose the numerically larger number by pressing either the left or right touch-pad key (24 items in total). Order of item presentation was randomized. We included this task to assess improvement of children's understanding of three-digit number magnitude and place-value integration.

2.4.4 House number task: In this task, children were presented with a three-digit reference number and a display of three numbers, from which they had to choose the one number that was numerically closest to the reference number. The task was presented on a tablet PC and responded to by checking the selected option with an electronic pen. The order of item presentation was randomized. The task was embedded in a cover story about house numbers on a *number street*. To prohibit children from resorting to calculation strategies, we set a time limit of 10 seconds per item. With this task, we aimed to measure children's understanding of place-value integration.

As dependent measures, we calculated the deviation of children's estimates from the actual position of the number in percent (as proposed by Siegler & Opfer [19]) in the paper and pencil number line estimation task. In the three other tasks, error rates served as dependent measures.

3. Results

3.1 Analysis

Prior to all analyses, error rates were arcsine standardized to approach normal distribution. Also, we calculated performance changes for each dependent measure by subtracting each child's percent deviation/errors before training from their percent deviation/errors after training (t2-t1). These measures of performance change reflected the repeated measure design of the study. Children who started out at 0 % errors in any dependent measure (13 in the addition task and 4 in the number comparison task) had to be excluded from the analysis in the respective dependent measure because they could not improve any further in terms of accuracy. Exclusion of these children did not change the descriptive pattern of the results.

The analysis was then conducted in two steps: First, we analyzed whether there was a significant improvement or decline of performance in any of the dependent measures. To do so, we used t-tests to analyze whether the performance changes were significantly different from zero in the three training conditions. Performance levels at t1 and t2 as well as performance changes from t1 to t2 are depicted in Table 1.

In a second step, to determine whether children improved more or less in either of the training conditions, we analyzed performance changes from t1 to t2 in a between-subject approach comparing the three training conditions. Because we had an exact hypothesis about the pattern of our results, we applied the analytic procedure of evaluating specific contrasts in multiple regression analysis ([38], see [39] for an example of the application). The benefit of this procedure is that we can directly test our very specific assumption that children would improve most in the experimental condition, less in the task-matched control condition, and even less in the media-matched control condition. Therefore, we first created a contrast that described the hypothesized rank ordering of the means by assigning contrast weights to each condition. This led to the first contrast A (1 0 -1). Because the procedure requires as many contrasts in a design as there are degrees of freedom [39], we created one additional contrast that was orthogonal to the first one. This contrast was supposed to capture residual systematic variance between the compared groups after the variance explained by the contrast of interest had been removed. Thereby, we ensured that the first contrast parsimoniously and accurately described the rank ordering of means [38]. In our design, the only mathematically accurate orthogonal contrast to the first contrast A was contrast B (-1 2 -1). In terms of interpretation, this second contrast reflects a result pattern where the task-

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matched control condition differs from the two other groups. The two contrasts were entered simultaneously as independent variables in a multiple regression analysis. A result was considered consistent with our hypothesis when the following two conditions were satisfied: (1) contrast A was statistically significant, and (2) contrast B was not statistically significant. Effect sizes are reported as R^2_{change}, which describes the change in explained variance by entering each contrast into the regression model.

3.2 Improvement from t1 to t2

In the experimental condition, t-tests revealed significant improvements in all dependent measures: the number line estimation task [$t(13) = -2.44$, $p < .05$, $d = .65$], the number comparison task [$t(10) = -2.01$, $p < .05$, $d = .51$]; the house number task [$t(13) = -1.98$, $p < .05$, $d = .51$], and the addition task [$t(6) = -2.28$, $p < .05$, $d = .70$].

In the task-matched control condition, children improved significantly in the number comparison task [$t(5) = -2.49$, $p < .05$, $d = .96$] and the house number task [$t(5) = -2.28$, $p < .05$, $d = .94$], but not in the other dependent measures (both $t < 1.34$, all $p > .27$).

There was no significant improvement in any dependent measure in the media-matched control condition (all $t < 1.42$, all $p > .29$). See Table 1 for performance changes in the dependent measures.

Table 1. Children's mean performance (standard deviations) in % at pretest (t1) and posttest (t2) as well as performance changes from t1 to t2 in the three groups.

	t1	t2	t2-t1
Number line Task (% deviation)			
Experimental (n = 14)	12.74 (5.92)	9.6 (4.13)	-3.14 (4.82)*
Task-matched Control (n = 6)	11.11 (4.34)	9.59 (3.71)	-1.52 (3.80)
Media-matched Control (n = 7)	11.25 (2.8)	12.02 (2.67)	0.77 (2.97)
Addition (% errors)			
Experimental (n = 7)	29.29 (16.36)	20.35 (22.39)	-8.93 (12.81)*
Task-matched Control (n = 4)	11.57 (3.28)	22.97 (19.07)	11.4 (17.40)
Media-matched Control (n = 3)	10.18 (4.02)	6.73 (5.92)	-3.44 (2.68)
Number comparison (% errors)			
Experimental (n = 11)	9.28 (8.46)	6.06 (8.56)	-3.22 (6.28)*
Task-matched Control (n = 6)	12.85 (9.63)	6.25 (6.45)	-6.6 (6.90)*
Media-matched Control (n = 6)	9.03 (4.69)	7.29 (9.29)	-1.74 (8.98)
House number task (% errors)			
Experimental (n = 14)	31.43 (8.72)	25.71 (12.62)	-5.71 (11.28)*
Task-matched Control (n = 6)	40 (20.4)	31.33 (12.75)	-8.67 (9.27)*
Media-matched Control (n = 7)	36 (19.46)	32.57 (11.41)	-3.43 (17.19)

* $p < .05$.

Note that improvement is reflected in negative values (in a decrease of deviation/error rates). The changes in numbers of participants between tasks result from the exclusion of children with error rates of 0% in the pretest.

3.3 Regression analysis of planned contrasts

Contrast A (1 0 -1), which reflected our hypothesized result pattern, reached significance in the number line estimation task [$F(1,24) = 4.01$, $p < .05$, $R^2_{change} = .14$], whereas contrast B did not [$F(1,24) = .03$, $p = .87$, $R^2_{change} = .00$]. This indicates that children in the experimental group indeed improved more than children in the task-matched control group, which in turn improved more than children in the media-matched control group. The alternative orthogonal contrast B (-1 2 -1) reached significance in the addition task [$F(1,11) = 5.73$, $p < .05$, $R^2_{change} = .32$], whereas contrast

A did not [$F(1,11) = .23$, $p = .64$, $R^2_{change} = .01$]. This means that in comparison to children in the two whiteboard conditions, whose error rates remained constant, children's error rates in the task-matched control condition actually increased from t1 to t2. Neither contrast A nor contrast B reached significance in the two other dependent measures (all F < .37, all p > .55). See Figure 2 for the significant contrast patterns.
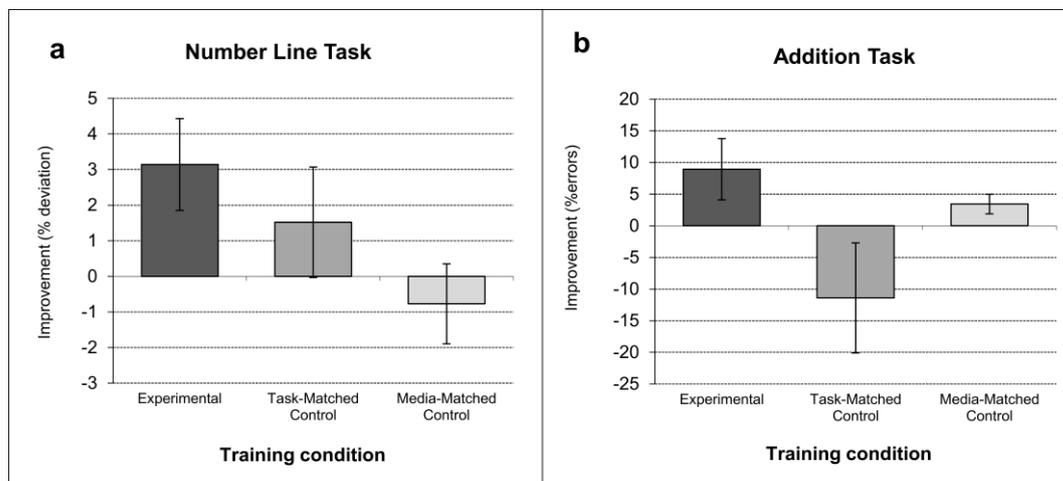

Figure 2. Children's performance changes (means and SEM) by condition in the number line and addition task. 2(a) Mean improvement of deviation (in %) between estimated and correct positions of numbers in the number line task. 2(b) Mean improvement of error rates (in %) in the speeded addition task

3.4 Performance during number line trainings

To evaluate whether children's differential improvements in the experimental and task-matched control condition could be due to differences in training performance, we analyzed the training data. Children's performance in the number line estimation task during training differed between the 0-100 range and the 0-1000 range [$t(19) = -3.80$, $p < .001$, $d = -1.66$], with children deviating more from the correct position in the 0-1000 (10.85%) than in the 0-100 range (5.75%). However, children's estimation performance during training did not differ between the experimental (7.92%) and the task-matched control condition (9.20%), $t(18) = -.69$, $p = .50$, $d = -.32$.

4. Discussion

The goal of this study was to examine whether an embodied training of number line estimation could improve children's arithmetic performance beyond either a training of a spatial-numerical task without bodily movement, or a bodily training without a spatial-numerical task. In doing so, we complemented prior studies suggesting a benefit of spatially presented tasks [14] by adding a spatial response format to further help improve children's arithmetic competencies.

We expected that a training incorporating the most pronounced spatial attributes in both stimulus and response should create the greatest training effects. Generally, our hypothesis was confirmed: (i) Children in the experimental condition reached the level of significant improvement in all dependent measures, whereas children in the task-matched control condition (number line estimation on a tablet PC) improved only in two of them, and children in the media-matched control condition (colour discrimination task on an interactive whiteboard) did not improve at all. (ii) When comparing the three groups, we observed that in the paper and pencil number line estimation task children benefitted most from the experimental training and least from the media-matched control training. (iii) Furthermore, we found a previously unreported media effect in the addition task. Performance of children in the task-matched control condition actually decreased after the training compared to the other two training groups. This finding might reflect a beneficial effect of the full-body movement and its motivational appeal. Because the addition task was the only task requiring children to actually perform a complex arithmetic operation, it presumably posed strong demands on executive functioning and might have been most susceptible to decreases

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in children's motivation and concentration. This effect, although not consistent with our hypotheses, can be taken as encouragement for theory-driven use of digital media in arithmetic learning.

4.1 Theoretical and practical implications

Just like previous studies [15,16], we showed that an embodied spatial-numerical training can improve children's performance more than other training setups. In particular, the increase of training success with increasing spatial-numerical associations highlights the importance of spatial attributes for arithmetic learning.

We believe that this study enriches the results of the previous embodied training studies, suggesting that the observed effects were not merely driven by motivational effects, but by a combination of a spatial-numerical task with a spatial full-body response movement (see [40] for a critical examination of the motivational effects of interactive whiteboards). However, by expanding on the prior design with a second control group, we showed that motivational effects also play a role in embodied trainings that make use of new and exciting digital media, and should be considered in future studies.

This study also has practical implications for education. Our results suggest that by not just using digital media, but by using them in a theory-driven approach, digital media can help children learn more efficiently than conventional training methods. These effects could further be increased by coaching teachers in order to improve their ability to apply technology into their teaching [41]. Furthermore, bodily movement seems to be beneficial for maintaining children's motivation and concentration, which in turn poses opportunities to support children with mathematical difficulties or attentional problems. This finding is in line with research on the implementation of physically activating games (or *exergames*) in education [42]. As more and more schools are being equipped with interactive whiteboards, such trainings could also be instated in schools and the current results suggest that it may be effective even at a low level of intensity.

4.2 Limitations

Seeing as the current study was a pilot study to test the potential of interactive whiteboards for numerical trainings, there are a number of limitations that need to be discussed. The original design of two training sessions on one day was not successful because the participating second graders were not capable of upholding their concentration and motivation for such an extended period of time. Therefore, an alternative design with trainings conducted over multiple sessions as employed in prior studies [15,16] seems more advisable for follow-up studies.

Moreover, significant improvement differences between the groups were only observed in two of the four dependent measures. This can be accounted for by some of the methodological characteristics of the pilot study, such as the short training duration (15 minutes on average), the uneven distribution of children over the training conditions, the overall small number of participants, and the choice of very strict control conditions. Therefore, the descriptively greater improvement in the experimental condition may not have reached significance in all dependent measures.

The small sample size and uneven distribution of participants among the training conditions also does not yet allow for a wide generalizability of the results, therefore calling for follow-up experiments with larger samples. Nevertheless, the results are encouraging because even at a short training duration and with small sample sizes, the spatial-numerical embodied training led to improvements in all of the dependent measures. Thus, our training shows potential even after only 15 minutes and thus, we are confident that it could evoke even more differential improvements when implemented for a longer period of time.

4.3 Future Directions

The promising results of the current study even with a small number of participants and strict control conditions call for further investigations of embodied numerical training. To substantiate our present findings and the findings of prior studies [15,16], we believe that some points would be worth addressing in future research.

For one, the control conditions implemented in the current study were designed specifically to answer our main research questions. However, different types of responses and tasks could be differentiated in future studies. For example, we implemented a condition utilizing the same digital medium (interactive whiteboard) as the experimental condition, but a different task (color discrimination). In this media-matched control condition, task presentation did not contain any systematic spatial features, and the task content was of a non-numerical nature. Still, it would be possible to incorporate a task that is presented in a similarly non-spatial format but requires processing of numerical information, such as simple addition or multiplication fact retrieval (e.g., [43]). By incorporating such a task, it could be inferred whether the spatial nature of the number line estimation task created a greater benefit for embodied training because of its correspondence to the specific response movement.

Conversely, a task that does not contain numerical information but is presented in a spatially oriented fashion could offer insights into the role that numerical information played in the greater success of our training. One exemplary task that is very comparable to number line estimation in its spatial presentation is a line bisection task in which participants have to mark the supposed midpoint of a horizontally oriented line. By using such a task, the specific benefit of the numerical content could be extracted.

On another note, like many experimental studies, the current study was not conducted in a traditional educational setting. The material has not yet been evaluated in a real educational context, and could be enriched by input from educational practice. This could help shape and improve the current program and materials in a way that makes them more suitable for practice.

With regard to the relevance of the current study for serious game development, it would be interesting to further develop the training software. In the current pilot, the game-based elements were limited, with the training taking on more of a computer-enhanced learning scenario [44]. Because the feedback during the training was neutral in that it only showed the correct result, the positive reinforcement during the training was given by the experimenter, who encouraged children and gave them content-independent positive feedback for staying focussed and trying their best. To elevate the training from a computer-supported training to a serious game, it would be possible to incorporate the reinforcement into the learning environment, for example in the form of a point system, or by adding an avatar that children could interact with. If the training were to be applied in a scholastic content, this would enable children to perform the training more independently and also increase their flow experience during the game [45]. Also, it could help children to stay on task longer by making the training more captivating and engaging (see e.g., [46]).

5. Conclusion

In this study, we showed that the number line estimation task is a promising candidate for a serious game that can be successfully implemented on an interactive whiteboard. Not only did a short training lead to improvements in different tasks, it also did so without any motivating graphics or a reward system.

However, game-based versions of the task are also possible and have already been implemented. For example, Kiili and colleagues ([47], this issue) presented a handheld game on a tablet called *Semideus*, in which positions of integers and decimals have to be estimated on a number line. In this game, children control a character called Semideus, who collects coins for correctly solved items, has to avoid traps, and race a goblin to reach the coins in time. Such studies highlight the fact that number line estimation tasks can be implemented in a game-based setting and on different types of digital media, as also demonstrated in a prior study with the Kinect™ Sensor [16].

The current data suggest that employing an embodied spatial-numerical training can improve numerical capabilities more markedly than control trainings. This finding highlights the applicability of embodiment in functional cognitive training approaches by use of digital media. Therefore, in our view, this study calls for a wider use of the embodiment concept for systematic cognitive trainings not only of mathematics, but also other fields of education.

Acknowledgements

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References

[1] Bynner, J., Parsons, S., Does Numeracy Matter? Evidence from the National Child Development Study on the impact of poor numeracy on adult life, London: The Basic Skills Agency, 1997.

[2] Parsons, S., Bynner, J., Does Numeracy Matter More?, London: National Research and Development Centre for Adult Literacy and Numeracy, 2005.

[3] Bynner, J., Parsons, S., New Light on Literacy and Numeracy, NRDC National Research and Development Centre for adult literacy and numeracy, 2006.

[4] Gross, J., Hudson, C., Price, D., The Long Term Costs of Numeracy Difficulties, London: Every Child a Chance Trust and KPMG, 2009.

[5] Butterworth, B., Varma, S., Laurillard, D., Dyscalculia: from brain to education., Science, Vol. 332, Nr. 6033, 1049–1053, 2011. doi:10.1126/science.1201536

[6] Wilson, A.J., Revkin, S.K., Cohen, D., Cohen, L., Dehaene, S., An open trial assessment of "The Number Race", an adaptive computer game for remediation of dyscalculia., Behavioral and brain functions : BBF, Vol. 2, 20, 2006. doi:10.1186/1744-9081-2-20

[7] Räsänen, P., Salminen, J., Wilson, A.J., Aunio, P., Dehaene, S., Computer-assisted intervention for children with low numeracy skills, Cognitive development, Vol. 24, 450–472, 2009. doi:10.1016/j.cogdev.2009.09.003

[8] Kroesbergen, E.H., Van Luit, J.E.H.H., Mathematics Interventions for Children with Special Educational Needs: A Meta-Analysis, Remedial and Special Education, Vol. 24, Nr. 2, 97–114, 2003. doi:10.1177/07419325030240020501

[9] Xin, Y.P., Jitendra, A.K., The effects of instruction in solving mathematical word problems for students with learning problems: A meta-analysis, The Journal of Special Education, Vol. 32, Nr. 4, 207–225, 1999. doi:10.1177/002246699903200402

[10] Booth, J.L., Siegler, R.S., Numerical magnitude representations influence arithmetic learning, Child Development, Vol. 79, Nr. 4, 1016–1031, 2008. doi:10.1111/j.1467-8624.2008.01173.x

[11] Holloway, I.D., Ansari, D., Mapping numerical magnitudes onto symbols: The numerical distance effect and individual differences in children's mathematics achievement, Journal of Experimental Child Psychology, 2009. doi:10.1016/j.jecp.2008.04.001

[12] Moeller, K., Pixner, S., Zuber, J., Kaufmann, L., Nuerk, H.-C., Early place-value understanding as a precursor for later arithmetic performance - A longitudinal study on numerical development, Research in Developmental Disabilities, Vol. 32, Nr. 5, 1837–1851, 2011. doi:10.1016/j.ridd.2011.03.012

[13] Krajewski, K., Nieding, G., Schneider, W., Kurz- und langfristige Effekte mathematischer Frühförderung im Kindergarten durch das Programm „Mengen, zählen, Zahlen", Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie, Vol. 40, Nr. 3, 135–146, 2008. doi:10.1026/0049-8637.40.3.135

[14] Ramani, G.B., Siegler, R.S., Reducing the gap in numerical knowledge between low- and middle-income preschoolers, Journal of Applied Developmental Psychology, Vol. 32, Nr. 3, 146–159, 2011. doi:10.1016/j.appdev.2011.02.005

[15] Fischer, U., Moeller, K., Bientzle, M., Cress, U., Nuerk, H.-C., Sensori-motor spatial training of number magnitude representation, Psychonomic bulletin & review, Vol. 18, Nr. 1, 177–183, 2011. doi:10.3758/s13423-010-0031-3

[16] Link, T., Moeller, K., Huber, S., Fischer, U., Nuerk, H.-C., Walk the number line – An embodied training of numerical concepts, Trends in Neuroscience and Education, Vol. 2, Nr. 2, 74–84, 2013. doi:10.1016/j.tine.2013.06.005

[17] Dehaene, S., Bossini, S., Giraux, P., The mental representation of parity and number magnitude, Journal of Experimental Psychology: General, Vol. 122, Nr. 3, 371–396, 1993. doi:10.1037/0096-3445.122.3.371

[18] Opfer, J.E., Furlong, E.E., How numbers bias preschoolers' spatial search, Journal of Cross-

Cultural Psychology, Vol. 42, Nr. 4, 682–695, 2011. doi:10.1177/0022022111406098

[19] Siegler, R.R.S., Opfer, J.J.E., The development of numerical estimation: Evidence for multiple representations of numerical quantity, Psychological science, Vol. 14, Nr. 3, 237–243, 2003. doi:10.1111/1467-9280.02438

[20] Barth, H.C., Paladino, A.M., The development of numerical estimation: Evidence against a representational shift, Developmental science, Vol. 14, Nr. 1, 125–135, 2011. doi:10.1111/j.1467-7687.2010.00962.x

[21] Link, T., Huber, S., Nuerk, H.-C., Moeller, K., Unbounding the mental number line - new evidence on children's spatial representation of numbers, Frontiers in Psychology, Vol. 4:1021, 2014. doi:10.3389/fpsyg.2013.01021

[22] Link, T., Nuerk, H.-C., Moeller, K., On the relation between the mental number line and arithmetic competencies, The quarterly journal of experimental psychology, Vol. 67, Nr. 8, 1597–1613, 2014. doi:10.1080/17470218.2014.892517

[23] Moeller, K., Fischer, U., Nuerk, H.-C., Cress, U., Computers in mathematics education – Training the mental number line, Computers in Human Behavior, Vol. 48, 597–607, 2015. doi:10.1016/j.chb.2015.01.048

[24] Kucian, K., Grond, U., Rotzer, S., Henzi, B., Schönmann, C., Plangger, F., et al., Mental number line training in children with developmental dyscalculia, NeuroImage, Vol. 57, Nr. 3, 782–95, 2011. doi:10.1016/j.neuroimage.2011.01.070

[25] Käser, T., Baschera, G., Kohn, J., Kucian, K., Richtmann, V., Grond, U., et al., Design and evaluation of the computer-based training program Calcularis for enhancing numerical cognition, Frontiers in psychology, Vol. 4, 489, 2013. doi:10.3389/fpsyg.2013.00489

[26] Fischer, U., Link, T., Cress, U., Nuerk, H.-C., Moeller, K., Math with the dance mat: On the benefits of embodied numerical training approaches, In: Lee V, editor, Learning Technologies and the Body: Integration and Implementation in Formal and Informal Learning Environments, New York: Routledge, p. 149–163, 2015.

[27] Moeller, K., Fischer, U., Link, T., Wasner, M., Huber, S., Cress, U., et al., Learning and development of embodied numerosity., Cognitive processing, Vol. 13, Nr. Suppl 1, S271–S274, 2012. doi:10.1007/s10339-012-0457-9

[28] Butterworth, B., The Mathematical Brain, London: Macmillan, 1999.

[29] Fuson, K.C., Children's counting and concepts of number, New York: Springer, 1988.

[30] Domahs, F., Moeller, K., Huber, S., Willmes, K., Nuerk, H.-C., Embodied numerosity: Implicit hand-based representations influence symbolic number processing across cultures, Cognition, Vol. 116, Nr. 2, 251–266, 2010. doi:10.1016/j.cognition.2010.05.007

[31] Fischer, M.H., Finger counting habits modulate spatial-numerical associations, Cortex, Vol. 44, Nr. 4, 386–392, 2008. doi:10.1016/j.cortex.2007.08.004

[32] Wilson, M., Six views of embodied cognition., Psychonomic bulletin & review, Vol. 9, Nr. 4, 625–636, 2002. doi:10.3758/BF03196322

[33] Shaki, S., Fischer, M.H., Random walks on the mental number line, Experimental brain research, Vol. 232, Nr. 1, 43–49, 2014. doi:10.1007/s00221-013-3718-7

[34] Giannakos, M.N., Enjoy and learn with educational games: Examining factors affecting learning performance, Computers and Education, Vol. 68, 429–439, 2013. doi:10.1016/j.compedu.2013.06.005

[35] Resnick, L., Resnick, D., Assessing the thinking curriculum: New tools for educational reform, In: Gilford BR, O'Connor MC, editors, Changing assessments, Boston: Kluwer Academic, p. 37–75, 1992.

[36] Erhel, S., Jamet, E., Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness, Computers and Education, Vol. 67, 156–167, 2013. doi:10.1016/j.compedu.2013.02.019

[37] Corbalan, G., Kester, L., van Merriënboer, J.J.G., Dynamic task selection: Effects of feedback and learner control on efficiency and motivation, Learning and Instruction, Vol. 19, Nr. 6, 455–465, 2009. doi:10.1016/j.learninstruc.2008.07.002

[38] Abelson, R.P., Prentice, D.A., Contrast tests of interaction hypothesis, Psychological Methods, Vol. 2, Nr. 4, 315–328, 1997. doi:10.1037/1082-989X.2.4.315

[39] Niedenthal, P.M., Brauer, M., Robin, L., Innes-Ker, A.H., Adult attachment and the perception of facial expression of emotion, Journal of personality and social psychology, Vol. 82, Nr. 3, 419–433, 2002. doi:10.1037//0022-3514.82.3.419

[40] Torff, B., Tirotta, R., Interactive whiteboards produce small gains in elementary students' self-reported motivation in mathematics, Computers and Education, Vol. 54, Nr. 2, 379–383, 2010. doi:10.1016/j.compedu.2009.08.019

Fischer U., Moeller K., Huber S., Cress U., Nuerk H.C., Full-body Movement in Numerical Trainings: A Pilot Study with an Interactive Whiteboard

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[41] Jang, S.J., Integrating the interactive whiteboard and peer coaching to develop the TPACK of secondary science teachers, Computers and Education, Vol. 55, Nr. 4, 1744–1751, 2010. doi:10.1016/j.compedu.2010.07.020

[42] Kiili, K., Perttula, P.T.A., Exerbraining for Schools: Combining Body and Brain Training, Procedia Computer Science, Vol. 15, Nr. 0, 163–173, 2012. doi:10.1016/j.procs.2012.10.068

[43] Dehaene, S., Cohen, L., Cerebral pathways for calculation: Double dissociation between rote verbal and quantitative knowledge of arithmetic, Cortex, Vol. 33, Nr. 2, 219–250, 1997. doi:10.1016/S0010-9452(08)70002-9

[44] Susi, T., Johannesson, M., Backlund, P., Serious Games – An Overview, University of Skövde, Sweden, 2007

[45] Kiili, K., De Freitas, S., Arnab, S., Lainema, T., The design principles for flow experience in educational games, Procedia Computer Science, Vol. 15, Nr. DECEMBER, 78–91, 2012. doi:10.1016/j.procs.2012.10.060

[46] Corti, K., Games-based Learning; a serious business application, PIXELearning Limited. 2006.

[47] Kiili, K., Devlin, K., Perttula, T., Tuomi, P., Lindstedt, A., Using video games to combine learning and assessment in mathematics education. International Journal of Serious Games, Vol. 2, Nr. 4, December 2015.