The use of a digital dance mat for training kindergarten children in a magnitude comparison task

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Abstract: Previous studies demonstrated that basic numerical skills reliably predict children's future mathematical performance. The spatial representation of numerical magnitude, represented in the form of a mental number line, seems to be of particular importance. Our training program for kindergarten children used a digital dance mat as input device that required children to move their whole body to respond in a magnitude comparison task. By employing such a spatial embodied training method, in a parallel randomized cross-over design, our study with 19 kindergarten children revealed a significant interaction between training condition and repeated exposure to items, implying that children improved more strongly in the dance mat than in the control condition. These results suggest that the use of digital media to train embodied spatial numerical skills may be more effective in basic numerical tasks such as magnitude comparison. We suggest that the involvement of embodied spatial codes, shared by the representation addressed by the task at hand, aids acquisition of task-relevant basic numerical skills.

Basic numerical skills

Arithmetic competencies are important cultural skills, comparable to reading and writing being a fundamental requirement not only for school success, but also for coping with everyday life. At the beginning of their first year of schooling, children's arithmetic skills already differ markedly, and these differences do have long term consequences. It has been repeatedly demonstrated that preschool numerical skills are a good predictor of a child's later arithmetic performance (e.g., Duncan et al., 2007). Findings so far suggest that arithmetic skills and processing of numbers involve various basic numerical competencies that are based on specific types of representations. For instance, the *Triple Code Model* by Dehaene (Dehaene & Cohen, 1995; Dehaene, Piazza, Pinel, & Cohen, 2003) suggested three types of number representations: (1) the visual Arabic number form (written digits); (2) a verbal representation (written or spoken number words); and (3) an analogue or semantic representation of number magnitude (representing the quantitative meaning of numbers). Over the years, the Triple Code Model has been revised several times, adding among other changes a spatial representation of number magnitude in the form of a mental number line that is activated whenever a number is encountered (Dehaene et al., 2003; Nuerk, Graf, & Willmes, 2006). This is illustrated best by the so-called *SNARC* (*S*patial *N*umerical *A*ssociation of *R*esponse *C*odes) *effect* that is usually observed in parity judgement tasks as a systematic interaction between the side of response and number magnitude. In a large number of studies (e.g., Dehaene, Bossini, & Giraux, 1993; Nuerk, Iversen, & Willmes, 2004a; Nuerk, Wood, & Willmes, 2005; see Wood, Willmes, Nuerk & Fischer, 2008 for a meta analysis), subjects have been found to respond faster to small numbers by the left hand and faster to larger numbers by the right hand. Note that in parity judgement, the magnitude of the numbers as such is irrelevant to solving the task. Nevertheless, response patterns suggest that perception of a number automatically activates a spatial mental representation of its magnitude, which cannot be suppressed willingly. The development of the mental number line (as indicated by the presence of a SNARC effect) is regarded as a key requirement for later arithmetic achievement (e.g., Bachot, Gevers, Fias, & Roeyers, 2005) and a precise spatial representation of number magnitude was found to be associated with better actual mathematics achievement and a better ability to learn unknown arithmetical problems (Booth & Siegler, 2008). Therefore, training of such basic numerical representations may be a promising approach. However, before turning to the embodied spatial training program developed for the current study previous approaches on how to train arithmetic capabilities shall be reviewed briefly.

Training arithmetic skills

Griffin, Case, and Siegler (1994) developed *Rightstart*, an intervention program for kindergartens. They were motivated by their observation that children from low-income families enter school with less understanding of mathematical concepts than their middle-class peers. In order to counteract this discrepancy and the resulting disadvantage in these children's later school career, the authors also developed versions of *Rightstart* (later renamed *Number Worlds)* for older age groups (Griffin, 2003). The program consists of game-like exercises on number lines, number comparison and the semantic representation of numbers. It also contains specifically developed board games that children can play in pairs or small groups (see also Ramani & Siegler, 2008). These board games train skills related to counting and visualizing the distance travelled by the figures, thus connecting the semantic and spatial representation of number magnitude. Evaluation studies confirmed a positive effect of the program on arithmetic capabilities of preschoolers (Griffin et al., 1994).

In 2003, Samara and Clements developed a computer program, *Building Blocks,* for children of kindergarten age (see also Clements, Battista, Samara, & Swaminathan, 1997; Clements & Battista, 1989; Clements & Meredith, 1993). The underlying instructional approach is genuinely constructivist and constructionist (cf. Papert, 1980): Children are expected to understand numerosity by manipulating objects systematically. The computer program allows a variety of manipulations and visualizations that support children's understanding of numbers. They can move objects – comparable to the board game – and this movement leaves traces that visualize distances and thus the spatial and semantic meaning of numbers (see also the training program *number race*; Wilson et al., 2006a; Wilson, Revkin, Cohen, & Dehaene, 2006b). Summative evaluation of this program confirmed that the children's numeric achievement improved by almost 1 standard deviation (Clements & Sarama, 2007).

Embodied cognition

One hypothesis of the present study is that the development of the spatial magnitude representation can be supported by motor processes. This assumption is based on findings on *embodied cognition*. In traditional theories of cognitive science, perception and action planning were regarded as two separate processes, and cognitive processes were thought to be exclusively based on mental representations. The possibility of a connection between cognition and action was largely ignored for a long time and thus, influences of action-related processes on the perception of information, and the influence of perception processes on motor action were highly underestimated. However, more recent embodied cognition approaches specifically address these possible connections. For instance, Hommel, Müsseler, Aschersleben, and Prinz (2001) propose a framework that is based on the assumption that the contents of cognition and action plans are encoded in a common architecture of representation, and integrated in a joint task-oriented network.

The most basic elements of this *Theory of Event Coding* (TEC) are so-called *feature codes* that represent all features of an event. These refer to different aspects or phenomena of a specific task which they represent. Certain *features* do not refer specifically and exclusively to one stimulus or response, but process sensory input from various different sensory systems and modulate activities of different motor systems. According to TEC, an event will activate several different feature codes, each of which modulates one specific aspect of perception *and* action. Processes of perception and action interact in the jointly shared representational medium of encoding when *features* of perception and motor functions overlap. Feature codes of both perceived information and action plans are then integrated in the same representational medium when they become part of an *event code*. Hommel and colleagues assume that event codes are accumulations of feature codes and that their temporary integration will depend on the respective context and task. Many features of events in the environment exist in different sensory modalities, so restrictions of one modality may be compensated by taking into account and integrating information from another modality. A task is thus solved more easily the more features stimulus and response have in common. On this basis, we can make assumptions about the supportive role of motor skills in learning. We expect target-oriented motor movements, combined with external representations of stimuli (in this case: of numerical magnitude) to lead to an integration of the respective *feature codes*. Thus, a joint representational architecture for number perception and motion will be built. While Hommel and colleagues inferred evidence for their theory from various empirical studies they did not take into consideration the specific connection between number magnitude processing and motor skills, or *embodied numerosity*. However, various empirical findings do suggest that such a connection exists. In many cultures, parts of the body – mostly hands and fingers – are used to represent numbers (cf. Menninger & Broneer, 1992). Furthermore, even adult number processing appears to be closely linked to finger counting (e.g., Domahs, Krinzinger, & Willmes, 2008; Noël, 2005; Wood, Willmes, Nuerk, & Fischer, 2008; Fischer, 2008) and the motor system of grasping (e.g., Badets, Andres, Di Luca, & Pesenti, 2007; Moretto & DiPellegrino, 2008).This indicates that numerosity is not only represented mentally, but also bodily, and that a corresponding connection between motor skills and number processing exists.

Media for embodied cognition

Different new digital media provide input formats that enable an *embodied interaction* (Romero, Good, Robertson, du Boulay, Reid, & Howland, 2007; Dourish, 2001). Such interfaces have been developed in recent years mainly for computer games. For example, *digital dance mats* require subjects to move their whole body by stepping on different fields of the mat in a specific succession. Games using dance mats have become widespread as part of the Sony Playstation® 2 (PS2) or Microsoft XBOX. Low-price versions of dance mats are now available in supermarkets, and can be connected to any computer via USB. In addition, the so-called *Wii* hit the market in 2006. This gaming console includes a handheld pointing device that does not work by activating defined fields, but by moving a controller which contains sensors detecting movements, thus registering the player's position and actions. More recent systems of the same type detect movements and gestures via web cams (Hoysniemi, 2006; Moeslund & Hilton, 2006; Fitzgerald et al., 2006).

Comparable interfaces for embodied interaction have already been applied for games involving motion (e.g., Reidsma, Nijholt, Poppe, Rienks, & Hondorp, 2006), but also for training of physical fitness (e.g., Hartnett, Lin, Ortiz, & Tabas, 2006) and health education programs (e.g., Watters et al., 2006). In the U.S. dance mats were used in more than 760 schools in the context of physical education, hoping to achieve a long-term effect on the students' health behavior (Business Wire, 2006). To our knowledge, dance mats have never been used in a specifically instructional context before. We believe, though, that this input device that is including spatial and motor input components has potential for training the spatial representation of numbers. Additionally, digital dance mats have a high motivational potential. Children have fun training and moving with them, and they are thus particularly suitable for use in kindergarten and primary school.

The current study

Based on the considerations described above, we expected that an embodied spatial-numerical training realizing shared features in both presentation and response format should be more effective in leading to a more pronounced decrease in error rates and response latencies. The specificities of the training program we developed will be described below.

We trained children on a magnitude comparison task in two conditions using different presentation and response formats. In the experimental (dance mat) condition, additional presentation of a number line and a spatial response format that required motor input supported children's performance. We designed the control (tablet PC) condition so that neither presentation nor response format involved explicit spatial information. In both conditions, we used two types of presentation material: Arabic numerals and assemblies of squares, which were presented inside a larger square to be perceived as an entity. Prior to the task, children were instructed not to count the squares in the assemblies but to estimate how many there were. To avoid giving the children perceptual cues, non-numeric factors of the assemblies were kept constant (as proposed by Xu & Spelke, 2000). For example, the white surface covered by black squares and thus, the luminosity of the stimuli was held constant in all items of the assembly variation.

Experimental condition: Dance mat

At the beginning of each trial, children stood on the central field of the dance mat. Tasks were projected onto the floor with a data projector directly in front of them (see Figure 1). The presented tasks consisted of lines that had either numbers (*0* and *10* or *0* and *20*) or square assemblies (0 and 10 or 0 and 20 squares) marking the endpoints. Between the endpoints, one number/square assembly was marked as a standard for comparison. The children had to compare the magnitude of a second number/assembly that was presented above the line with the magnitude of the standard and to judge whether its position on the line was left or right of the standard. Responses were given by stepping on the left field of the mat with both feet when the number's/assembly's location was to the left and on the right field when it was to the right of the standard.

Figure 1: Experimental set-up in the dance mat condition.

Control condition: Tablet PC

In the control condition, the same magnitude comparison task was administered in a different setup. The control condition's function was to provide a comparable task that involved new media as well, but did not provide as much of a strong connection between action and perception. Children were shown two numbers that were vertically aligned on the monitor of a tablet PC. In contrast to the dance mat condition, children merely had to touch the bigger number with an electronic pen. The same stimuli in pseudo-randomized order were used in the control and experimental condition. Figure 2 shows the stimulus formats used in both conditions (separated by type of presentation material) on the example of the comparison between 3 and 7.

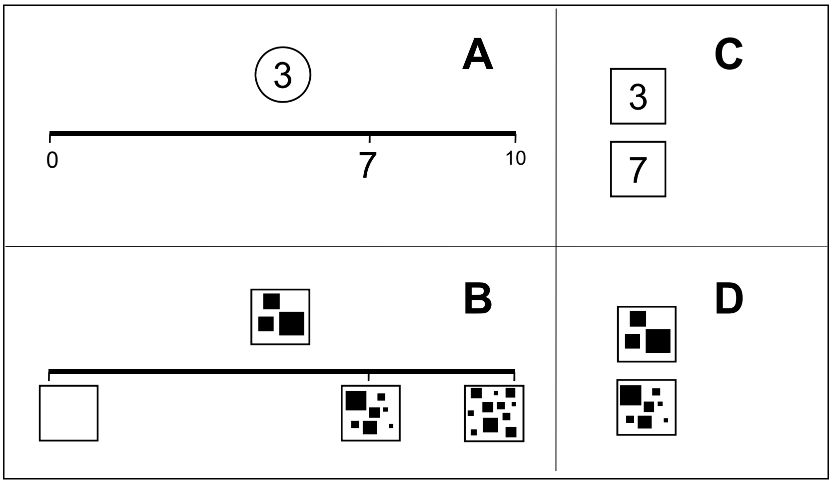

Figure 2: Examples of stimuli in both types of presentation material in the dance mat condition (with **A.** Arabic numbers and **B.** square assemblies) and in the tablet PC condition (with **C.** Arabic numbers and **D.** square assemblies).

Procedure and Design

We chose a parallel randomized cross-over design to provide all children with the possibility of training with the dance mat, meaning that half of the children first received dance mat and then tablet PC training, while for the other half the order of training conditions was reversed.

The data presented in this paper were part of a large scale study. For reasons of brevity, the current article will address the results of the magnitude comparison task only. In this large-scale study, we also varied whether numbers/square assemblies had to be compared to a variable or fixed standard (with fixed standard magnitudes being either 5 or 10). In the scope of this paper, we will focus on items on which magnitudes had to be compared to a variable standard, because these items – unlike items with a fixed standard – were presented twice each and allowed for an evaluation of children's improvement from the first to the second time of an item's presentation. This way, we could analyze whether children improved similarly over training in either condition or whether one condition yielded a higher improvement than the other.

Each child received three training sessions with the dance mat and three sessions with the tablet PC, which consisted of 64 to 72 items each. The items of the first training session of either condition consisted of magnitudes ranging from 0 to 10, the items of the second session from 0 to 20, and every third session comprised half of the items of the first and half of the items of the second session (i.e., comparisons to a variable standard only). The six training sessions were carried out individually with each child on six different days within a period of three weeks. Training sessions took approximately 10 to 15 minutes per child and were administered before noon in rooms of the kindergarten. When a child missed or could not participate in a training session, the missed session was – if possible – carried out on some other day.

Participants

Preschool children from two kindergartens participated in the study. The parents of 27 children gave their written consent. Because of prolonged illness or absence, 5 children dropped out of the study. Children were randomly assigned to the two conditions, 11 children were first trained on the dance mat and 11 started with the tablet PC. Subsequently, 3 children's data sets had to be excluded from the analysis due to absence in one training session that could not be carried out at a later point or poor understanding of task instructions, leaving the complete data sets of 19 children – 8 girls, 11 boys –, aged between 60 and 79 months, for analyses. Mean age of the children included in the analysis was M = 70.74 (SD = 6.06) months and did not differ between the two experimental conditions.

Results

To analyze the learning effects of training with the dance mat as compared to training with the tablet PC, we compared children's improvement in accuracy (rates of correctly solved items) and reaction times between conditions on items that were presented twice. Improvement was computed by subtracting performance of all children at the first time of presentation from their perfomance at the second time of presentation separately for each item. Since means of reaction times differed between the two conditions due to the very different response formats, z-standardized reaction times were used to ensure comparability of conditions. Reaction times were only computed for correct trials. Children's rates of correctly solved items were arcsine transformed prior to all analyses to approximate normal distribution. We then conducted Analyses of Variance comparing each child's improvement in accuracy and reaction time between the two conditions (F_1). Furthermore, we analyzed the data across items (F_2). Where it was necessary, one-sided *t*-tests (i.e., t_1 and t_2, respectively) were used to evaluate our directed hypotheses.

Children's Performance

First, we conducted ANOVAs on children's improvement in accuracy and on their decrease in reaction time with *condition* and *material* (digits or square assemblies) as within subject factors. We further tested for the predicted differences between the two conditions by means of one-sided *t*-tests. As expected, we found that children's z-standardized reaction times decreased significantly more in the dance mat than in the tablet PC condition [$t_1(18) = 6.19$, $p < .001$, tested one-sided; ANOVA: $F_1(18) = 24.14$]. Likewise, there was a significant main effect of condition on rates of correctly solved trials [$t_1(18) = 2.14$, $p < .05$; $F_1(18) = 2.94$], indicating that children's increase of accuracy from the first to the second time of presentation was larger in the dance mat than in the tablet PC condition (see Figure 3). We found a marginally significant main effect of material on accuracy [$F_1(18) = 3.18$, $p = .08$] that would have reached significance if tested one-sided, but no significant effect of material on reaction times [$F_1(18) = 2.32$, $p = .14$]; and there was no significant interaction between material and condition in either accuracy or reaction times [both $F_1(18) < 1$]. This lack of significant interactions implies that the differences between the conditions were not mainly caused by one type of material, but that children improved similarly on items consisting of both digits and square assemblies.

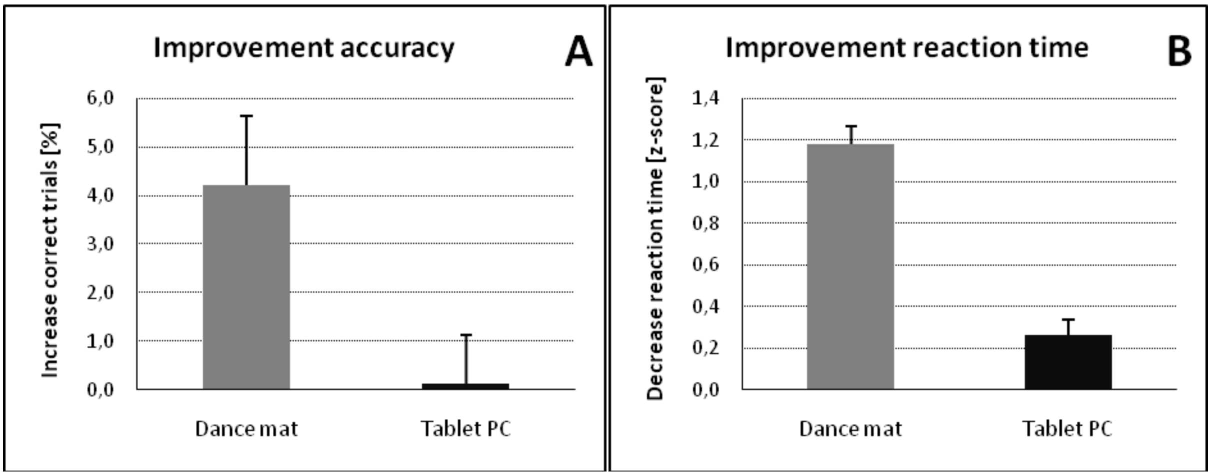

Figure 3: Comparison of children's improvement in **A.** accuracy and **B.** reaction time in the dance mat and tablet PC condition.

Item analysis

For the Item analysis, repeated measures ANOVAs were conducted, this time with *condition* as the repeated measures factor and *material* as the between subject factor. Again, hypothesized differences were examined by use of one-sided *t*-tests. We found a significant main effect of condition on rates of correctly solved trials [$t_2(67) = 2.66$, $p < .01$; ANOVA: $F_2(1,67) = 5.54$], as well as on reaction times [$t_2(67) = 4.20$, $p < .001$; $F_2(1,67) = 16.03$]. *Material* was found to have a marginally significant main effect on accuracy [$F_2(1,67) = 3.48$, $p = .06$] and no significant main effect on reaction times [$F_2(1,67) = 1.74$, $p = .19$]. Again, material and condition did not interact significantly in either accuracy or reaction times [both $F_2(1,67) < 1$].

Subjective evaluation

At the end of the study, we interviewed parents and kindergarten staff on their impression of the training. Both groups agreed that the children enjoyed both the dance mat and tablet PC training, but that children had more fun on the dance mat. Most children talked about the project at home and in the kindergarten; some of them spent more time on mathematical tasks than before. Parents and kindergarten teachers had the impression that the level of difficulty was adequate for the children's age and abilities, and the kindergarten staff approved of the idea of using the dance mat for future projects.

Discussion

The present study showed that the magnitude comparison task can be trained in kindergarten children and that improvement in the magnitude comparison task is larger when this task is trained using an embodied spatial-numerical approach. Performance of children improved significantly more in the dance mat condition than in the tablet PC condition on both reaction times and accuracy. This superiority of the dance mat training was found in analysis of children's performance and also persisted when an item analysis was conducted. These results provide further support for Hommel et al.'s (2001) theory of event coding, indicating that the mental number line representation is indeed more strongly activated when presentation and response format share more features. In the present case mainly spatial attributes are enforced by motor movements and the presentation of the to-be-compared numbers on a number line. Thus, in accordance with Hommel et al., features of stimulus and response seem to be processed as parts of the same event code. Also, the lack of a significant interaction between condition and material (digits or square assemblies) speaks for a generalizability of the positive effects of the dance mat training across different types of stimulus material.

It should also be noted that our computations yielded marginally significant main effects for material (digits or square assemblies) on accuracy that would have reached significance had we employed a one-sided test. However, we did not have any expectations as to which material would produce higher training effects than the other. A trend was found for means of improvement to be higher on items consisting of digits than on items consisting of square assemblies. This might be due to the distinct nature of Arabic digits that allowed for children to remember them more accurately than square assemblies, which children were instructed to process only in an approximate manner. Thus, children might have remembered Arabic digits, but not patterns of square assemblies.

One might argue that the tasks we used were too demanding for kindergarten children, since the German curriculum for the last year of kindergarten states that children should be able to recognize the regular dice patterns. At the time they enter school, the children are thus expected to be familiar with the numbers from 1 to 6. The tasks used in the training program of the current study presenting magnitudes from 0-20 exceeded this level by far. However, since chance level of success was 50 percent on all the tasks, children did not experience failure too often keeping their motivation at a very high level. Furthermore, the fact that significant differences in learning outcome were observed between the two conditions when items were presented only twice argues for the high potential of the dance mat as a training medium for basic numerical skills.

A differentiation of which processes precisely differentiate the two training conditions should be the aim of further studies. In the present experiment, the dance mat and tablet PC condition differed in various features of both perception and action. The dance mat condition was combined with presenting the tasks in number line form, and children had to respond by using motor skills to move their whole body to one side or the other. In the tablet PC condition, items were presented without external representation of the number line, and the response format did not ask for any movement to the left or right. So, from the present study, the question remains whether it were either differences of perception *or* action that led to the performance difference between dance mat and tablet PC condition, or if it was the combination of these two features.

Furthermore, it would be of interest whether the improvements in children's performance on the magnitude comparison tasks may be transferable to other domains of numerical knowledge. We examined children's performance in pre- and posttest transfer measures, namely a number line estimation task and a standardized arithmetic test battery. These results, however, will be published separately and will therefore receive no further discussion in this paper. Seeing as children improved significantly more in both transfer measures in the dance mat than in the tablet PC condition, these transfer effects do enforce the assumption that children profit more from the dance mat than training.

Taken together, the present study showed that a digital dance mat can be used effectively for training of the spatial representation of number magnitude. Bearing in mind that the spatial representation of number magnitude is an important basic competence that reliably predicts later mathematics achievement (Booth & Siegler, 2008), training of this competency would be desirable in preschool education. Moreover, since subjective ratings clearly favoured the dance mat over the tablet PC as well, we conclude that exercise with the dance mat presents a possibility of such training that children experience as a highly motivating game.

On a general level, this study indicates that the theory-guided use of modern media improves learning even in basic tasks and thus supports the idea that multi-media tools can be an important mediator of learning success even in kindergarten children. Moreover, this study lends support to the idea that the inclusion of bodily experiences to represent abstract concepts may not only be helpful to represent those abstract concepts but that embodied cognition also aids their acquisition.

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