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INTERVENTION STUDY

Embodied Learning Activities Focusing on Letter-Sound Knowledge Increase Spelling Performance in 1st Grade Children with Low and High Reading Ability

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Abstract

The study aimed to investigate the effect of embodied learning on children's literacy skills and whether the activities were particularly beneficial for children at risk for reading difficulties. We conducted a randomized controlled trial during 4 weeks for grade 1 children (n = 52, age = 7.1). Children were randomly assigned to receive regular classroom teaching (CON) or to receive teaching focusing on letter-sound couplings with the use of the body (i.e., movement-phonemes) (MOVE). Children were evaluated on letter knowledge, word reading, and spelling performance before the intervention (T1) and after the intervention (T2). A significantly improvement for MOVE compared to CON from T1 to T2 was observed in children's ability to name letter-sounds ($p < 0.001$), conditional sounds ($p < 0.001$), and for spelling performance ($p = 0.002$). Within CON and MOVE, children were divided into low (LP) and high performers (HP) based on word reading performance at baseline. A significantly higher improvement for LP in MOVE was observed compared to LP in CON from T1 to T2 in letter-sounds ($p < 0.0001$), conditional letter-sounds ($p < 0.0001$), and for spelling performance ($p = 0.037$). No differences were observed between LP-MOVE and HP-MOVE. Our results demonstrate that a short intervention based on movement-phonemes increase children's letter knowledge and spelling performance. The results also demonstrate that LP and HP have similar improvements and therefore, this type of activities are not particularly beneficial for children at risk for reading difficulties. We suggest that this teaching method could be beneficial for all school children at this age.

Keywords Embodied learning · Embodied cognition · Academic learning · Children · Spelling performance · Literacy skills · Reading performance · Letter-sound knowledge · Movement

Extended author information available on the last page of the article

Introduction

It is of significant importance to ensure a good school start for children with a gradual introduction to academic content. Reading is an important basic competence acquired during early education years. A primary objective of education is the development of literacy skills, and during the first year of school, children's success in learning to read and write is a strong indicator of later success in school (Juel, 1988). A review by Buckingham et al., (2014) found that children are more likely to remain poor readers if they begin school as poor readers, especially children with low socioeconomic status (Buckingham et al., 2014). It is important to support children in the development of reading skills during early childhood, as it is likely to benefit their schooling and later work life (McGee et al., 2002; Savolainen et al., 2008).

As a first step in learning to read and spell words in alphabetic orthographies, children must become familiar with the basic alphabetic principle and learn to connect phonemes in spoken words with graphemes in written words (Ehri, 2008). Accordingly, phoneme awareness and letter knowledge measured before the outset of formal reading instruction are unique predictors of later reading and spelling abilities (Caravolas et al., 2012; Furnes & Samuelsson, 2009; Hulme et al., 2012; Kirby et al., 2008; Melby-Lervåg et al., 2012; Schatschneider et al., 2004). Moreover, a clear link between limited letter knowledge at school entry and later reading difficulties has also been reported (Torppa et al., 2006). It is therefore important to develop educational approaches that would facilitate the acquisition of early literacy skills. The current study aimed to implement an intervention in a school setting to boost the development of literacy skills specifically regarding children with literacy-related difficulties in early education.

The intervention used in the present study was developed based on previous research on efficient educational instruction for early school years (Damsgaard et al., 2020, 2022). Firstly, it has been reported that children profit from a systematic approach to early literacy instruction. This includes phonics, a literacy teaching method where children are explicitly taught the connections between phonemes and graphemes (Ehri et al., 2001; National Reading Panel, 2000). Phonics as a method is especially relevant for our aims because it has been found that children who enter school with limited pre-reading skills (i.e., phoneme awareness and letter knowledge) benefit more from systematic and explicit phonics-based instruction than children with well-developed skills (Buckingham et al., 2014). However, the use of the phonics approach in Danish language must be carefully considered. Danish is challenging for learners due to its irregular orthography including standard and conditional pronunciations of letters (Elbro, 2014; Juul & Sigurdsson, 2005). Based on these irregularities, some Danish teaching materials offer comprehensive letter knowledge instruction and sometimes introduce more than one sound correspondence for each letter (Jacobsen & Veber Nielsen, 2011). Accordingly, in the present study, we implemented an intervention based on a synthetic phonics approach covering both standard and conditional pronunciations of letters. The approach used in the study as well as the results are also relevant to English, which has similarly irregular orthography (Seymour et al., 2003).

Our approach was also inspired by research and theories focused on the benefits of embodied cognition on academic performance. Very briefly, embodied cognition describes how our body and environment are related to cognitive processes. Thereby, the mind is integrated into the body sensorimotor systems (Barsalou, 1999). One theoretical explanation for the benefits of embodied learning activities might be that movement, cognition, and learning are closely connected (Barsalou, 2008; Geary, 2008) and the engagement of the motor system reinforces encoding in addition to just observing, listening, pronunciations, and mental visual representations, known as the enactment effect (Gallagher & Lindgren, 2015).

Embodied cognition in this context involves the use of movement in close connection with the learning content and is therefore termed "embodied learning" (Macedonia, 2019). The way movement is used and combined with academic content varies across studies. A study by Mavilidi and colleagues from 2015 investigated the effects of gross motor movements (whole- body activities) and fine motor movements (arms and hands) in connection with foreign language (when learning Italian) on vocabulary learning (Mavilidi et al., 2015). Here, the authors found greater learning benefits in groups of children who performed either gross movements or fine movements while learning compared to children in the control group (limited amount of movement). In addition, the gross movement group was found in two vocabulary tests. This could indicate that gross movements in a language teaching context are more effective than fine movements. This is in line with our recent study on early literacy skills, where children (age 6 years) had the greatest long-lasting effect (17–22 weeks after end-intervention) on letter-sound knowledge, when performing whole-body movements compared to fine movement and no movement group. Children in the fine movement group who used arms and hands while learning also improved their letter-sound knowledge more than the no movement group. Bara and Bonneton-Botté, (2018) suggested that children at the age of five find it easier to learn by gross motor movements, as fine motor movement skills develop more slowly than gross motor skills (Bara & Bonneton-Botté, 2018). In general, only a limited number of studies have addressed the specific benefit of embodied learning activities on literacy skills. In addition to the aforementioned study by Damsgaard et al., 2022, studies by Botha & Africa and Bara & Bonneton-Botté implemented school-based interventions with a close coupling of movements and literacy content (e.g., drawing letters with the arms and walking the outline of letters), and showed significant effects on spelling performance and word recognition skills (Bara & Bonneton-Botté, 2018; Botha & Africa, 2020).

It is, however, not yet clear whether embodied learning may have a different effect on academic achievement and cognitive functioning dependent on children's baseline literacy performance (low and high performers). One study that has shed light on this matter reported findings from a motor enriched learning intervention for math education where children with average performance achieved the greatest educational gains compared to low-performing children (Beck et al., 2016). These findings emphasize the need to consider how the extent of bodily engagement during learning tasks impacts cognitive load, since the low-performing children might have fewer mental resources available to benefit from the motor enriched activities. This is in line with Paas and Sweller who suggested that embodied exercises must

not require too much cognitive effort to avoid the risk of cognitive overload (Paas & Sweller, 2012). Therefore, in order to optimize the beneficial effects of embodied learning interventions, researchers must focus on selecting an appropriate level of bodily engagement, especially when interventions are targeted at children with low baseline academic performance (Damsgaard et al., 2022; Skulmowski & Rey, 2018). We speculate that a carefully designed embodied learning intervention with simple movements and minimal effort could prove the most beneficial for those children who achieve low baseline performance in early literacy education. This way, the intervention would induce beneficial encoding and retrieval embodiment effects while ensuring an optimal level of cognitive effort expenditure and task difficulty that these children can comfortably manage (Madan & Singhal, 2012). We expect that children who are already performing at an average baseline level would also benefit from the intervention but perhaps with a smaller effect because they have reduced potential for improvement compared to low performing children.

In a previous study from our research group, we found a significant improvement in early literacy skills of grade 0 children following an 8-week embodied learning intervention for letter-sound coupling with letter-related movements (Damsgaard et al., 2022) . The present study furthers our previous work via an attempt to optimize the intervention length. We used some of the same tasks and exercises but over a shortened period of 4 weeks. An intervention that requires less time is arguably more feasible for school applications as it uses less teaching time and can be easier to implement around the standard curriculum. This is also the first attempt to understand how the effects of our intervention could differ depending on children's baseline literacy performance and whether it could boost learning gains for those children who experience difficulties with the acquisition of early literacy skills after 1 year at school (grade 0).

The study addresses the following two questions:

1) Does teaching condition (teaching focusing on embodied learning activities and regular classroom teaching) result in significant group differences in early literacy gains?

More specifically, we investigated whether 25 min three times per week for 4 weeks with embodied learning activities significantly improved children's knowledge of standard and conditional letter sounds compared to regular classroom teaching. Moreover, we also investigated whether the intervention had a transfer effect on children's spelling and word reading.

2) Is the potential effect of embodied learning activities in early literacy instruction determined by different baseline levels in word reading performance?

More specifically, we investigated if children categorized as low performers in word reading at baseline experienced a higher beneficial effect of the embodied learning intervention compared to low performing children receiving standard classroom teaching measured as improvement in letter-sound knowledge (direct

training effect) and spelling and word reading performance (transfer effects). To investigate if movement was most effective for low performers, a comparison between low and high performers who had received embodied learning teaching was performed.

Methods

Study Design and Participants

The study was a randomized controlled trial with one intervention group and one control group. Sixty-seven children aged 6–7 were recruited from one elementary school in Copenhagen. After obtaining written consent from the parents, fifty-three children were included in the present study (age = 7.1 ± 0.3) (see Table 1 for demographics and Fig. 1 for flow diagram). No demographics differences between the groups were observed.

Within each class, the teacher initially ranked the children from the highest to the lowest performer in reading based on the teachers' subjective impression of the children's reading abilities. Based on the ranking, they were randomly assigned, before baseline assessment, to either receive embodied learning activities in pairs with focus on letter-sound coupling for 4 weeks, three times a week for 25 min with movements (MOVE) or regular teaching in the classroom without any influence of the research project beside assessment (CON). The ranking system was performed to ensure an equal number of high and low performers in reading within MOVE and CON (see Table 1). The pairs were conducted based on children with same ranking within the two groups (MOVE/CON) to avoid major reading differences within the pairs.

The study was approved by the local Ethical Committee at the University of Copenhagen (protocol: 504-0032/18-500) and complied with the Helsinki Declaration II.

Table 1 Demographics of the two groups (CON, MOVE)

	CON	MOVE
Participants (*n*)	29	24
Age (years)	7.10 ± 0.3	7.09 ± 0.4
Height (cm)	126 ± 4.0	128 ± 4.4
Weight (kg)	24.8 ± 3.3	25.0 ± 4.2
BMI (kg/m^2)	15.6 ± 1.6	15.2 ± 2.1
Sex (% girls)	64	56
Bilingualism (% bilingual)	39	28
Dominant hand (% right)	89	92
Letter naming fluency	42 ±14.4	48 ± 14.6

Data reported as mean ± SD. No significant statistical between-group differences were observed for any of the measures

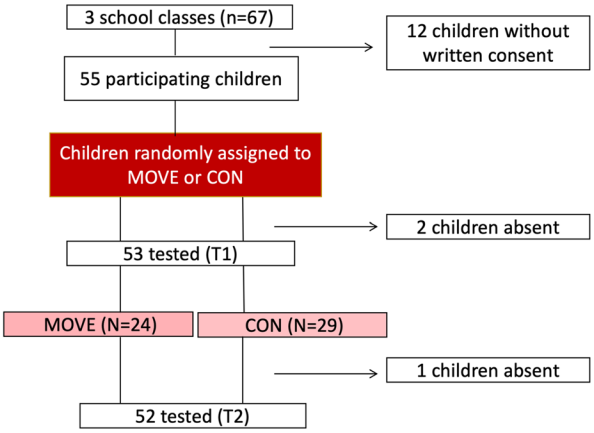

Fig. 1 A flow diagram of the present study. Three school classes participated in the study. Fifty-five children were included in this study after obtaining written consent from the parents and were randomly assigned either to be exposed to teaching 3×25 min for 4 weeks with embodied learning with focus on phoneme knowledge, or to undergo their regular school program without any influence from the research team. All children were tested before (T1, n=53 children) and after (T2, n=52 children) the 4-week intervention

Intervention Condition

The intervention focused on the acquisition of letterforms, letter-sound correspondences, reading, and spelling short words (see Table 2 for overview). Children were taught to make specific whole-body movements to letter-sounds (movement phonemes) and had to use these movements in different types of activities. Movement phonemes were executed from left to right, following the reading direction. The movements were associated with objects or living creatures (e.g., the movement coupled to the sound "s" was associated with a snake). Crisp sounds were coupled with quick movements and high pitch phonemes had movements above lower pitch phonemes of the same letter. The intervention material was developed based in the research-founded Danish teaching material, Fandango Mini, which is recognized by several preschool teachers in Denmark (Jacobsen & Veber Nielsen, 2011).

During the 4-week intervention period with three 25-min sessions per week, children were introduced to 25 letters (form, standard sounds, and selected conditional sounds). The activities were delivered by a trained instructor and children participated in pairs of two. Three pairs entered the room and circulated between the activities in pairs. When relevant, the children were given positive and corrective feedback (both verbally and bodily) during the activities by a supportive instructor.

In our previous work, we provided a detailed explanation of activities including whole-body and hand movements with positive effects on important pre-reading skills (e.g., letter recognition and letter-sound knowledge) and motivation (Damsgaard et al., 2020, 2022; Gejl et al., 2021). In the present study, we used a subset of these activities (see Table 2).

Table 2 Overview of activities and trained letter-sounds for week 1 to 4

	Activity 1	Activity 2	Activity 3	Activity 4	Activity 5
Week 1					
Session 1	Intro to the letters and movement-phonemes of the week: a, b, e, k, l, o, s, t, å	Letter-sound relay: Children run to the end of the room. Grab a letter. Run back to the group and make the letter-sound and movement-phoneme. Teammates must guess the letter based on the sound and movement-phoneme	Alphabet chaos: The alphabet is presented on a screen but in the wrong order. The children must order the letters correctly. As they touch the screen with the correct letter, they should make the movement-phoneme to the letter and the sound(s)	Become a letter: Instructor says a letter sound aloud and makes the movement-phoneme. The children listen to the sound and try to form the letter by using the body in pairs	Miming: Instructor reads a letter aloud. Children write the letter on a big blackboard. Afterwards, they find an animal that starts with the letter and mime it. The teammate guesses the animal
Session 2	Repetition of the letters from session 1	Letter salad: Instructor reads aloud one word at a time. Children listen to the words, distinguish the letter-sounds and write the letters on the blackboard while making the movement-phonemes to the letters. In the end, the whole word would be written on the blackboard. The children say the letter-sounds and make the movement-phonemes for all letters of the word in the end	Vowels against consonants. At the smart board, children search for vowels in a mix of vowels and consonants. They make movement-phonemes and say the letter sound(s) of the vowel	Guess the word. In pairs, the children get a note with a word and a matched picture of the word. One child must spell the word while pronouncing the letter sounds and making the movement-phoneme. The other child must guess the word	Sound duel. The children stand with their backs to each other. The instructor reads a word aloud. The children have 3 s to find the first letter sound in the word and think of the correct movement-phoneme. At the count of 3, they turn around and say the sound and show the movement

Table 2 (continued)

	Activity 1	Activity 2	Activity 3	Activity 4	Activity 5
Session 3	Repetition from sessions 1 and 2	Rime-twister. On a game board 1×1 m with 16 fields, 8 written words and 8 pictures illustrated. One child reads a word aloud and puts a hand or a foot on the written word. The other child finds the rhyming picture matching the word. This continues until all words are taken	Find the alphabet On a screen, the alphabet is presented in lines, but random letters are mixed in. The child needs to first find "a," then "b," then "c," and so on among all the other letters across the lines so that in the end, the alphabet occurs in the correct order	The hidden word Children make a new word out of a word. They insert a new letter in front of or at the end of the original word, so it becomes a new word (e.g., oat + g = goat). One child uses movement-phonemes while spelling the word. The other child must guess the word	
Week 2	Same structure as week 1. Focus letters of the week: d, f, g, i, m, n, r, u				
Week 3	Same structure as week 1. Focus letters of the week: c, h, j, p, v, y, æ, ø				
Week 4	Same structure as week 1. Focus letters of the week: all letters from week 1, 2 and 3.				

The instructors were asked to keep a written log of attendance for each child and to which degree they followed the protocol and the planned activities.

Control Condition

Children in the control condition followed the normal classroom teaching with their teacher and were not influenced by the research team beside the test procedures. Children were taught phoneme knowledge based on the Danish teaching material "Fandango Mini" (Jacobsen & Veber Nielsen, 2011). Fandango Mini is based on a synthetic phonic approach and is scheduled as a 20-week systematic course covering both standard and conditional pronunciations of the letters. The lessons were carried out by the teachers. Furthermore, the teachers used "The First Reading – The Letter Book" as supplementary materials for improving basic understanding of letter-sounds, words, and word reading (Borstrøm & Petersen, 1998).

Test Procedures

To evaluate the effects of embodied learning on children's letter knowledge, word reading, and spelling performance, the children were assessed before (T1) and after (T2) the 4 weeks intervention. The assessment was conducted at the school by trained instructors.

Information about age, dominant hand, height, weight, sex, and bilingualism were collected prior to baseline measures (T1).

Measures

Standardized Test

Two tests were performed to evaluate children's spelling performance and word reading.

Standardized Spelling Task The test evaluated children's spelling performance and was administrated strictly according to the manufacturer's description (Juul, 2019). The test is commonly used in educational practice in Denmark. The test consisted of 17 words (preceded by two practice items) that were read aloud one at a time for the children. The participants had to spell out the words. The length of the words differed from two letters to seven letters and became gradually more difficult. Test reliability is 0.89 (α, Cronbach's alpha) (Juul, 2019).

The test outcome was the number of correctly spelled words and was used as a measure of transfer effect.

Standardized Word Reading The test assessed children's word reading ability (Juul & Møller, 2010) and was administrated strictly according to the manufacturer's

description. The test is commonly used in educational practice in Denmark. Within 4 min, children had to read as many words as possible. The test is a multiple choice with four drawings for each printed word. Each child had to read the word and choose the matching drawing. Test reliability is 0.80 (α, Cronbach's alpha) (Juul & Møller, 2010). The test outcome was the number of correctly read words in 4 min and was used as a measure of transfer effect.

Word Reading

One additional test assessed children's word reading.

Reading Test Without Pictures The test consisted of 16 untrained words presented on a laptop screen. The words were presented one at a time with different lengths (four 2-letter words, four 3-letter words, four 4-letter words, four 5-letter words) for up to 16 s or until an answer was given. Two versions of the test were delivered with a different set of words used in each. One conducted at baseline and one conducted post-intervention. The child was instructed to read the word and say it aloud. The instructor registered the answers as correct or incorrect by pressing a green or red bottom on the keyboard, respectively. If incorrect or no answers were given within the time limit, a new word appeared on the screen. If incorrect or no answers were provided for all four 2-letter words, the test ended. The test was previously used to assess children's word reading performance (Damsgaard et al., 2022; Malling et al., 2021) and the internal consistency of the two test versions evaluated by the Kuder-Richardson formula 20 has previously been reported at 0.896 (95% CI 0.887–0.905) and 0.891 (95% CI 0.881–0.900; (Malling et al., 2021) for versions 1 and 2, respectively. Test reliability is 0.86 (α, Cronbach's alpha). The test outcome was the number of correctly read words, and it was used as a measure of the transfer effect.

Letter Knowledge

Three tests evaluated children's letter knowledge.

Letter Naming To evaluate children's letter knowledge, a Danish version of the DIBELS Letter Naming Fluency test was used which consisted of 12 rows of 10 letters (mixed upper and lower case) on a piece of paper (Good & Kaminski, 2002; Poulsen & Jensen, 2015). The child was asked to name as many letters as possible in 1 min while pointing at each letter. Wrong letter-names were registered by the instructor. If the child did not name a letter within 3 s, the instructor said the letter name and encouraged the child to name the next letter. Prior to commencing the test, the child was provided with a row of 10 letters as practice. The total number of all correctly named letters was used as a baseline measure of children's letter knowledge and the children were only tested at T1.

Naming of Letter-Sounds (Including the Use of Movement) To evaluate children's knowledge of letter-sounds, they were asked to pronounce the sounds of seven

letters ("a," "d," "e," "o," "r," "u," and "v"). The seven letters have several pronunciations in Danish. In total, the test assessed seven standard letter-sounds and eight conditional letter-sounds. The trained instructor read aloud the letter-names one at the time. The child was standing while answering and thereby had the chance to make movements to the sounds. For every letter-sound, responses were registered as correct/incorrect/missing. The test result was the number of correct letter-sounds pronounced (1) in total, (2) as standard letter-sounds, and (3) as conditional letter-sounds. The test was used as a measure of direct training effect. The test was previously used to assess children's pre-reading skills (Damsgaard et al., 2022) and the internal consistency of the test evaluated by the Kuder-Richardson formula 20 was reported at 0.73 (95% CI 0.72–0.75; (Malling et al., 2021). Test reliability is 0.82 (α, Cronbach's alpha).

Letter-Sound Matching To assess children's letter-sound knowledge, a multiple-choice test was performed on paper. In total, 15 letter-sounds were read aloud one at a time by an instructor. The children were instructed to choose which letter out of four possible letters that matched the letter-sound (preceded by one practice trial). The 15 sounds represented both standard and conditional pronunciations of the letter "e," "o," "a," "u," "r," and "v." The internal consistency of the test has been evaluated by the Kuder-Richardson formula 20 to 0.67 (Malling et al., 2021). Test reliability is 0.98 (α, Cronbach's alpha). The test outcome included the number of correct letter-sound matches in total, standard pronunciations, and conditional pronunciations. The test was used as a measure of direct training effect.

Subgroup Division

To investigate whether embodied learning effects could boost the development of literacy skills specifically regarding children with literacy-related difficulties in early education, we divided children into "low performers" and "high performers" based on their performance at baseline in the standardized reading test (number of correct read words). Children below the median (>21) were categorized as low performers (n=26) and children above the median (<21) were categorized as high performers (n=25). As mentioned earlier, the teacher ranking only helped the research team to some degree to ensure even distribution of low and high performers in the two groups. If children did not complete the standardized reading test, they were not included in the subgroup division. In total, 27 out of 29 children in CON and all children in MOVE completed the test and were analyzed based on the subgroup division criterion.

Statistical Analyses

All statistical analyses were performed in R Studio (RStudio, 2020).

Baseline characteristics, including demographics, were compared between the intervention and control group using ANOVA (one-way analysis of variance) for continuous variables and chi-square test for categorical measures.

To investigate whether teaching conditions (MOVE/CON) result in a significant group difference in early literacy gains (research question 1), between-group differences in word reading, spelling performance, and letter knowledge were analyzed using a linear mixed model including CON and MOVE as groups and time were T1 and T2. To account for the cluster structure and the repeated measures in the data, "subject" was set as a random effect and "age" as a fixed effect since children's letter knowledge is known to be age dependent. Model validation was based upon visual inspection of residual plots. Between group analyses were made based on improvement in performance from pre-intervention (T1) to post-intervention (T2) in the literacy tests (naming letter-sounds, letter-sound matching, standardized spelling task, the standardized reading task, and reading test without pictures). *p*-values were adjusted for multiple comparisons with the single-step method, based on the R package "multcomp" (Hothorn et al., 2016).

The effects of the categorization as low and high performers (research question 2) were investigated using linear mixed model with groups as CON and MOVE, time as T1 and T2 and subgroups as "low" and "high." Between-group analyses were made based on improvement in scores from pre-intervention (T1) to post-intervention (T2) for low performers and high performers, respectively. *p*-values were adjusted for multiple comparisons with the single-step method, based on the R package "multcomp" (Hothorn et al., 2016).

Effect sizes (Cohen's *d*) were calculated using the mean differences in performance divided by the pooled standard deviations (Cohen, 2013). Cohen's *d* effect sizes in the range of 0.2–0.35 were considered small, 0.35–0.65 moderate, and > 0.65 large (Cohen, 2013). Results from all inferential tests were interpreted as significant for *p*-values < 0.05.

Results

Literacy Performance at Baseline

The baseline assessment results (T1) for all children in the study were consistent with our previous research (Malling et al., 2021). Taken together, all children scored on average 45 points on the letter naming fluency, 23.6 on the reading, and 9.24 on the spelling tests. This indicates that the study sample is typical for that age group (Juul & Møller, 2010; Malling et al., 2021). Baseline performance scores per intervention group are presented in Table 3. There were no statistical differences in baseline performance between the two intervention groups (MOVE and CON).

The assessment of baseline measures (T1) for groups of children categorized as low and high performers in word reading confirmed appropriate representativeness of the groups. Children categorized as low performers had an average score of 12.15 in reading and 6.44 in spelling, which is lower compared to the average scores for that age group based on reports from previous research (Juul, 2019; Malling et al., 2021). For letter naming fluency, the score of 38.32 is normal for the age groups compared to earlier research in that age group (Malling et al., 2021).

Table 3 Test scores pre-intervention (T1) to post-intervention (T2) for CON and MOVE

Measure	CON (*n*=29)		MOVE (*n*=24)	
	T1	T2	T1	T2
Standardized test				
Standardized spelling task (No. correct, max=17)	9.3 ± 4.0	9.6 ± 4.0	9.2 ± 4.4	11.7 ± 4.0[a]
Standardized word reading (No. correct in 4 min)	20.4 ± 9.9	32.9 ± 11.9	27.0 ± 19.9	39.5 ± 21.2
Word reading				
Word reading test without pictures (No. correct, max = 16)	8.1 ± 3.5	10.4 ± 3.7	9.6 ± 5.0	10.2 ± 4.3
Letter knowledge				
Letter naming fluency (No. correct within 1 min)	42.3± 14.4	48.2± 14.5	48.1±16.5	51.0 ± 18.5
Naming of letter-sounds (No. correct, max = 15)	7.5 ± 1.8	8.0± 1.8	7.6 ± 2.3	12.1 ± 2.0[a]
Naming of letter-sounds (No. correct, max = 7): standard	6.5 ± 0.7	6.6 ± 0.8	6.5 ± 1.4	6.9 ± 0.4
Naming of letter-sounds (No. correct, max = 8): conditional	1.1 ± 1.5	1.4 ± 1.6	1.2 ± 1.4	5.2 ± 1.7[a]
Letter-sound matching (No. correct, max = 15)	11.6 ± 1.4	12.1 ± 1.5	11.4 ± 2.2	12.7 ± 1.9
Letter-sound matching (No. correct, max = 7): standard	6.7 ± 0.5	6.8 ± 0.5	6.5 ± 1.6	7.0 ± 0.2
Letter-sound matching (No. correct, max = 8): conditional	4.9 ± 1.2	5.3 ± 1.2	4.9 ± 1.4	5.8 ± 1.8

Data reported as mean ± SD. [a]Significant difference from CON

The opposite was seen for children categorized as high performers with a letter naming score of 52.25 in letter naming fluency, 35.52 in reading performance, and 12.05 for spelling, which is above the average for that age group based on reports from previous research (Juul, 2008, 2019). Baseline performance scores per performance group are presented in Table 4.

Effect of Teaching Condition

To investigate the *direct training effects* of teaching condition (MOVE/CON) on letter-sound knowledge post-intervention, analysis was performed on the following test: naming letter-sounds and letter-sound matching.

Between-group analysis showed a significantly larger improvement in all letter-sound from T1 to T2 for MOVE compared to CON ($p < 0.001$, mean = 3.9, 95% CI (2.8, 4.9), $d = 2.0$). There was also a significantly larger improvement for conditional sounds in MOVE compared to CON ($p < 0.001$, mean = 3.5, 95% CI (2.6, 4.3), $d = 2.3$) (Fig. 2).

Table 4 Performance for low and high performers for CON and MOVE pre-intervention (T1) and post-intervention (T2)

Measure	Low performers				High performers			
	CON (*n*=14)		MOVE (*n*=12)		CON (*n*=13)		MOVE (*n*=12)	
	T1	T2	T1	T2	T1	T2	T1	T2
Standardized test								
Standardized spelling task (No. correct, max=17)	6.9±3.3	6.9± 3.0	6.0±3.2	8.7±3.2[a]	11.9±3.0	12.1±2.8	12.2±2.9	14.5±2.1[b]
Standardized word reading (No. correct in 4 min)	12.9 ±5.3	26.1±9.5	11.3±6.3	23.3±10.1	29.1± 5.8	39.8±16.7	41.5±10.2	54.2±16.7
Word reading								
Word reading test without pictures (No. correct, max = 16)	6.2±3.3	8.9±3.1	6.3±4.6	7.5±3.9	10.4±2.5	12.5±2.4	12.6±3.3	13.2±2.3
Letter knowledge								
Letter naming fluency (No. correct within 1. min)	35.1±16.2	44.5±16.8	41.9±15.2	44.8±11.1	50.0±8.1	48.8±18.1	53.9±11.7	57.2±22.6
Naming of letter-sounds (No. correct, max = 15)	7.2±1.3	7.6±2.0	6.6±2.6	11.2±2.3[a]	8.0±2.3	8.4±1.9	8.6±1.4	13.1±1.0[b]
Naming of letter-sounds (No. correct, max = 7): standard	6.4±0.8	6.5±0.8	5.9±1.9	6.8±0.6	6.6±0.5	6.5±0.9	7.0±0.3	7.0±0.5
Naming of letter-sounds (No. correct, max = 8): conditional	0.9±1.0	1.1±1.5	0.7±1.2	4.4±1.9[a]	1.4±2.1	1.9±1.7	1.6±1.5	6.1±0.9[b]
Letter-sound matching (No. correct, max = 15)	11.5±1.1	11.3±1.8	10.0±2.3	11.7±2.1[a]	11.8±1.6	12.7±0.8	12.7±1.1	13.6±1.2
Letter-sound matching (No. correct, max = 7): standard	6.7±0.5	6.5±0.7	6.0±.1.5	6.9±0.3	6.8±0.6	6.9±0.3	7.0±0.0	7.0±0.0
Letter-sound matching (No. correct, max = 8): conditional	4.7±1.1	4.8±1.4	4.7±1.1	4.8±1.9	5.0±1.5	5.8±0.8	5.7±1.1	6.6±1.2

Data reported as mean ± SD. [a]Significant difference in improvement between low performers in MOVE vs. CON from T1 to T2. [b]Significant difference in improvement between high performers in MOVE vs. CON from T1 to T2. [c]Significant difference in improvement between low performers in MOVE vs. high performers in MOVE

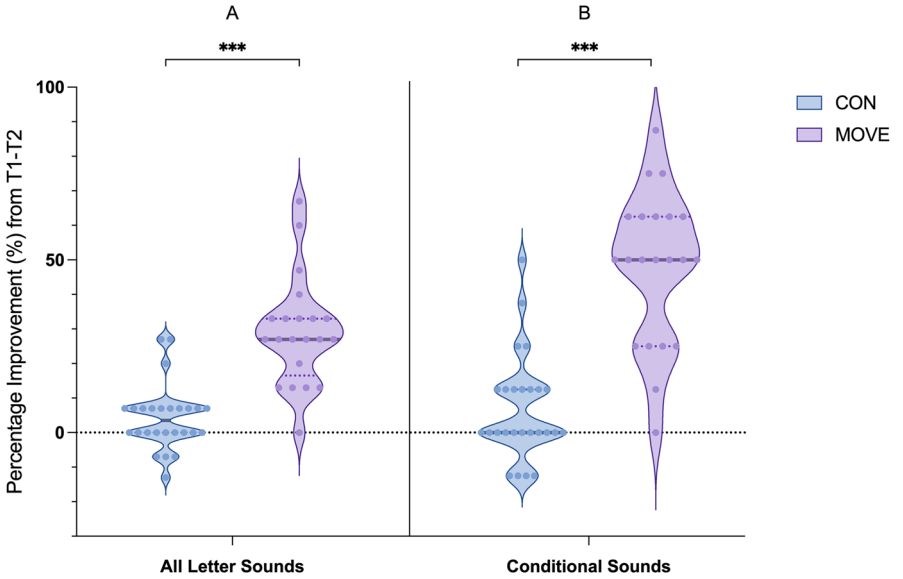

Fig. 2 Improvement in percentage from T1 to T2 (delta score) in children's ability to pronounce letter-sounds for a given letter. **A** illustrates significant (***) increase for MOVE compared to CON for all letter-sounds (both standard and conditional). **B** illustrates significant increase for MOVE compared to CON for conditional letter-sounds (***). Filled dots, individual points. Only complete data points are illustrated. Within the violins, the filled lines indicate the mean and stacked lines indicate quantiles. *, $p < 0.05$, **, $p < 0.01$, ***, $p < 0.001$

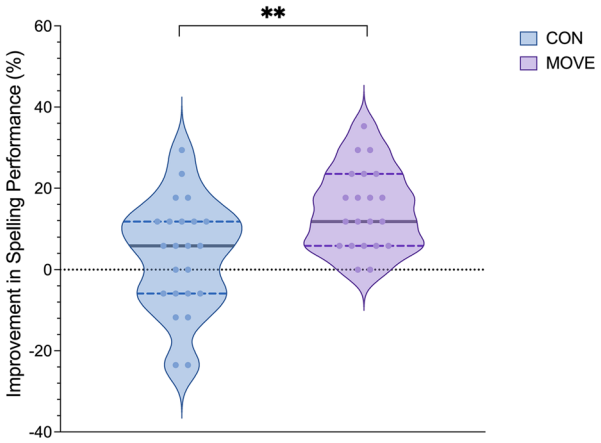

Fig. 3 Improvement in percentage for children's spelling performance from pre-intervention to post-intervention. A significant difference between CON and MOVE was observed from T1 to T2 (**). The stacked line indicates 0% improvement. Filled dots, individual plots. Only complete data points are illustrated. Within the violins, the filled lines indicate the mean, and the stacked lines indicate quantiles. *, $p < 0.05$, **, $p < 0.01$, ***, $p < 0.001$

To investigate the *transfer effect* to spelling and reading, between-group analysis was performed on the standardized spelling task, the standardized reading task, and reading test without pictures.

The analysis showed significant improvement for MOVE compared to CON from T1 to T2 (p = 0.002, mean = 2.0, 95% CI (0.8, 3.2), d = 1.3) in spelling

performance only (Fig. 3). No other significant differences were observed regarding standardized reading task or reading test without pictures.

Effect of Baseline Levels in Word Reading

To explore further whether the sub-group of children with lower baseline word reading performance (low performers) had a higher learning outcome when performing embodied learning for 4 weeks compared to low performers participating in normal classroom teaching, analyses were performed for the naming of letter-sounds and letter-sound matching (*direct training effect*) as well as the standardized spelling task, standardized reading task, and reading test without pictures (*transfer effects*).

Between-group analyses revealed a significantly higher improvement for low performers in MOVE compared to low performers in CON from T1 to T2 in all letter-sounds ($p < 0.0001$, mean = 4.1, 95% CI (2.6, 5.6), $d = 2.2$), conditional letter-sounds ($p < 0.0001$, mean = 3.4, 95% CI (2.2, 4.5), $d = 2.2$) (*direct training*

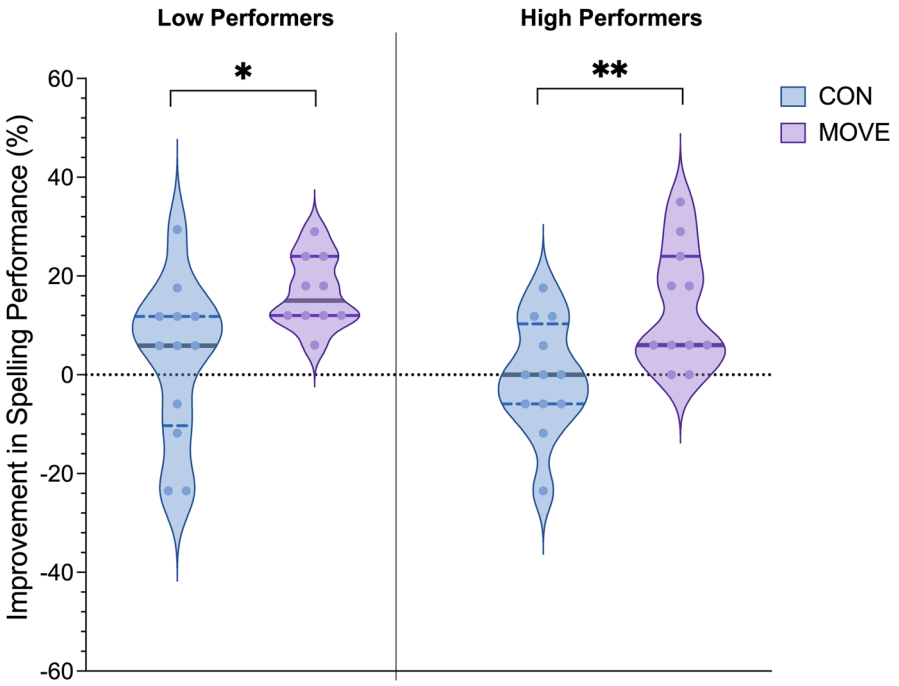

Fig. 4 Improvement in percentage for children's spelling performance from pre-intervention to post-intervention based on children's reading performance at baseline (low/high performers). A significant difference between CON and MOVE for low performers was seen from T1 to T2 (*) and for high performers compared between CON and MOVE (**). The stacked line indicates 0% improvement. Filled dots, individual plots. Only complete data points are illustrated. Within the violins, filled lines indicate the mean and stacked lines indicate quantiles. *, $p < 0.05$, **, $p < 0.01$, ***, $p < 0.001$

effects) and for spelling performance (*transfer effect*) (p = 0.037, mean = 1.8, 95% CI (0.1, 3.5) d = 0.8) (Fig. 4).

For high performers, a significant difference was observed for MOVE compared to CON in all letter-sounds (p < 0.0001, mean = 3.9, 95% CI (2.4, 5.5), d = 2.0), conditional letter sounds (p < 0.0001, mean = 3.8, 95% CI (2.5, 5.0), d = 2.5) (*direct training effects*), and spelling performance (*transfer effect*) (p = 0.006, mean = 2.4, 95% CI (0.7, 4.0), d = 1.1). No other significant differences were observed regarding word reading performance.

No significant differences were observed between low and high performers within the MOVE group, indicating that the embodied learning intervention is beneficial both for low and high performers.

Discussion

In this present study, we find that embodied learning with a focus on letter-sound knowledge for only 4 weeks, 3 times a week for 25 min (in total 5 h) can improve children's early literacy skills compared to regular classroom teaching. More specifically, we found a direct training effect on children's letter-sound knowledge and a transfer effect on their spelling performance. This is in line with previous research on the effects of embodied learning interventions including direct training effect on letter-sound knowledge (Damsgaard et al., 2022) and transfer effect on spelling (Botha & Africa, 2020). However, three patterns of results need further discussion:

Firstly, the intervention effect on letter-sound knowledge was mainly seen on conditional letter-sounds. This pattern could be explained by the ceiling effect (Ho & Yu, 2015) for standard letter-sounds and the floor effect for conditional letter-sounds at T1 for both groups (CON and MOVE) and matches the order in which children usually acquire the sounds of letters. Initially, children acquire the standard sounds of the letters, which widely parallels the names of the letters (Treiman et al., 1998). Usually, children need to know the standard sounds of the letters before acquiring the conditional sounds (Elbro, 2013). Children can learn conditional sounds either directly or indirectly by mapping the spelling of words with their pronunciation while reading. As indicated by the floor effect, most children had no prior knowledge of conditional letter-sounds, and so, children needed to learn and recognize these sounds as alternative pronunciations of the letters during the intervention. This effect can be explained by the meaningful integration of movements to the learning task (Skulmowski & Rey, 2018), which enhances the child's ability to understand, differentiate, and recall the letter-sounds.

Secondly, a transfer effect was seen on word spelling but not on word reading. To observe a transfer effect from T1 to T2 on word reading and spelling, the children participating in the 4-week intervention would have had to acquire letter-sound knowledge proficiency and translate their newly gained knowledge into both a basic word reading strategy and a basic word spelling strategy. When *reading* a new word, children are taught to look at the graphemes from left to right and to pronounce each corresponding phoneme in turn. Then, they blend the phonemes to say the whole word. When *spelling* a new word, children are taught to identify the phonemes and

then write the graphemes that represent the phonemes. Accordingly, word reading and word spelling have been labeled "reversible processes" (Rose, 2006). As students learn regularities beyond the level of simple grapheme–phoneme correspondences, their alphabetic working knowledge expands and accelerates the development of both reading and spelling strategies (Ehri, 2014).

However, it might be the case that the children in the present study did not have had sufficient practice of *phoneme blending* during the intervention period to profit from their enhanced letter-sound knowledge when reading words. While some intervention activities involved word reading to some extent, perhaps further practice and more focus on the processes of identifying individual sounds in a word, putting the sounds together, and saying the word that is made would be required, and so, transfer effects could potentially be found later in the school year. Correspondingly, many studies have tried to investigate short-term effects of movement on reading and found small or non-significant effects (Alvarez-Bueno et al., 2017; de Greeff et al., 2018; Macedonia, 2019; Singh et al., 2019). By contrast, a transfer effect was seen on word spelling.

Thirdly and contrary to our expectations, no significant differences were observed between low and high performers within the MOVE group. That is, the beneficial effect of the embodied learning intervention that was found on measures of letter knowledge and spelling was not determined by different baseline levels in word reading performance. Several reasons might explain this finding.

As mentioned, most children had no prior knowledge of conditional letter-sounds at T1, indicating that this type of extended letter knowledge had not been directly addressed in the literacy instruction the children had received prior to the intervention. Consequently, all children could be expected to make substantial gains during the intervention where conditional letter sounds were directly and systematically taught. What might seem surprising, though, is that children with weaker literacy skills made gains as large as children with stronger literacy skills in only 4 weeks. Whether this should be ascribed to the benefits of embodied cognition, the close support provided during teaching or a combination of the two factors remains an open question. From observations from the research team, some children in MOVE used movement as a strategy to recall letter-sounds post intervention. This potential change in strategy might be an effect of the meaningfully integration of movement to the learning content but should investigated further in other studies.

We did not measure the long-lasting effects (for example, a retention test) of the intervention. Therefore, we might fail to observe differences in transfer effects over time. Immediately after the intervention, significant progress was seen in spelling performance in the intervention group among both high and low performers. It is quite possible that high performers in the control group would catch up with the high performers in the intervention group at a faster pace compared to low performers since they are better equipped to learn independently during literacy activities (Share, 2008).

In 2021, we conducted a three-armed randomized controlled trial including two intervention groups and one control group. The intervention groups engaged in embodied learning activities for 8 weeks, 3 times a week for 30 min (Damsgaard et al., 2022). In the present study, we wanted to create a condensed intervention with

the same exercises, focusing on children at risk for reading difficulties, but for only 4 weeks instead of 8 weeks, which could be more implementable for a school setting. Children who show reading delays often benefit from teaching in small groups outside the classroom (Foorman & Torgesen, 2001; Hatcher et al., 2006). A teacher fraction of 1:2 was selected for the present intervention study to make the learning environment supportive for children who have difficulties with reading. Our findings show a significant effect of embodied learning activities for both low and high performers. This is not in line with a study from 2016 by Beck et al., (2016) which reported significantly more beneficial effects of motor-enriched learning activities on math performance for average performing children in math compared to low performers. However, in Beck et al.'s study, only one teacher delivered motor enriched learning tasks to a whole class setting. This could be the reason why their findings differ from those presented in the current study. Since the teacher works with only two children, they are closely supported in their learning and the use of movements. This supports children to ensure that they properly engage with the tasks to maximize how much they learn. However, a 1:2 fraction may not be an easily applicable model for teachers in a school setting. Teachers might prefer to introduce embodied learning activities to the whole class as it may not be feasible to deliver activities in a 1:2 setting. It could therefore be interesting to investigate our embodied learning approach effects on whole classes.

Perspectives

Based on the present study results, it suggests that children who learn to combine movement to the respectively sounds become particularly adept to conditional sounds, for those who already master standard sounds. As mentioned, these literacy competencies might be the reason the children increase their spelling performance. We therefore recommend teachers to specifically work in the combination of movement and conditional sounds, as we observe the greatest effect on that specific parameter. Furthermore, the embodied learning intervention focusing on the letter-sounds seemed to benefit both children categorized as low performers in word reading and children with normal word reading performance, which emphasize that the embodied learning intervention is suitable for all children. We did not find that embodied learning was especially beneficial for children categorized as low performers based on their word reading performance at baseline. Before the randomization, we asked the teachers to rank children's reading performance to ensure an equal distribution of reading performance in MOVE and CON. Of interest, we investigated how well the teachers' subjective ranking correlated with the standardized objective measure of reading performance at baseline. Thereby, we performed an explorative analysis to examine the teacher's abilities to assess children's reading skills from the beginning of first grade. We found a positive association (data not shown) between teachers ranking and children's baseline performance. This could indicate that a subjective ranking of children's reading skills is durable in a school setting, if the focus is to divide children into high and low performers for a teaching situation.

Strengths and Limitations

One particular strength of the study is that the activities are based on previous used protocols for training children's letter-sound knowledge, and they are already well described with positive effects on children's literacy performance (Damsgaard et al., 2020, 2022; Gejl et al., 2021). In the previous study, we have not observed a transfer effect to reading and did not investigate spelling performance. However, in this study, we illustrate that the methods do have a transfer effect to spelling performance. No long-term effects of the intervention were measured, which could reveal a transfer effect to reading.

To ensure high quality of the conducted movements and learning activities in the intervention, a teacher–student factor of 1:2 was chosen. This allowed us to control the learning environment for both high and low performers in MOVE. However, this, of course, makes it more difficult to compare MOVE and CON, since CON followed their regular classroom teaching without any influence from the research team (beside testing). The comparisons between the two groups make it therefore more difficult to interpret the results; however, they are in line with our expectations based on previous studies where all groups get equal amount of teaching in phoneme knowledge. Since one of the aims for the study was to investigate whether embodied learning was particularly beneficial for low performers, we found it necessary to conduct the study with a controlled environment in MOVE.

An ideal setup with unlimited resources would consist of a matched control group. On the other hand, this study should be seen as a subsequent of studies where we earlier have shown that embodiment has a greater effect on phoneme learning compared to phoneme learning without embodiment (Damsgaard et al., 2022). Secondly, we know from the previous study (with a matched control group) that phoneme training provides improvement of 12.5% (for no-movement group, CON) vs 28% (for movement groups) progression pr. 8 weeks on conditional sound knowledge (Damsgaard et al., 2022). This means that the additional improvement is twice as big in movement groups compared to matched control group without movement. In the present study, the additional improvement is above the expected from time-corrected previous data, and here, we demonstrate that the method does indeed have a transfer effect to spelling. The purpose of this study was to obtain similar effects from 8 weeks intervention to a shorter intervention and whether there would be a difference between high and low performing children in reading, which this design set out to investigate from the beginning. We can, however, not fully conclude that the effects are caused by embodied learning, but should be seen as an effect of embodied learning and a systematic training of letter-sounds.

Nevertheless, we still find it interesting that movement can enhance the transfer effect of children's spelling performance within a short time period. In fact, it is only 5 h of modified teaching distributed over 4 weeks and this nicely demonstrates the power of embodied learning for children at this age.

Conclusion

Based on the findings of the present study, it seems that an embodied learning intervention could be helpful in improving pre-reading and spelling skills in children. However, it should be noted that there was no significant effect on whole word reading, and the results do not provide strong evidence that incorporating embodied learning in early literacy instruction would be especially advantageous for children who are at risk of experiencing reading difficulties.

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Data Availability Data sets generated during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval The study was approved by the local Ethical Committee at University of Copenhagen (protocol: 504-0032/18-5000) and was carried out in accordance with the Helsinki Declaration II. Written consent was obtained from the parents.

Conflict of Interest The authors declare no competing interests.

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