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Embodied reading in a transparent orthography

Ashley Marie Adams, Arthur M. Glenberg*, M. Adelaida Restrepo

Arizona State University, USA

A B S T R A C T

The embodiment framework posits that reading comprehension requires simulation. That is, the reader must use perceptual, action, and emotional systems to create an analogical representation of the situation described in the text. *Moved by Reading* teaches children to simulate by having them a) move images on a computer screen to correspond to sentences (externalizing the simulation), and then b) imagine moving the images (internal simulation). Although *Moved by Reading* greatly enhances comprehension, it does not always produce transfer when children read new texts without manipulation. The decoding hypothesis provides an explanation: Before children can simulate the sentences, they must be able to decode the words. In orthographically opaque languages such as English, decoding skill greatly varies across children, hence limiting transfer when reading unfamiliar texts. If true, *Moved by Reading* should produce successful transfer in Spanish, an orthographically transparent language in which decoding is more transparent. As predicted, monolingual Spanish-speaking children taught simulation performed better than children in a control condition on comprehension tests a) for texts in which they moved images, b) for texts in which they imagined moving images, and c) most importantly, in an untrained transfer text. Thus, the data demonstrate the effectiveness of *Moved by Reading* in Spanish in line with predictions from the decoding hypothesis, and the results highlight a need for studies that directly compare the effects of this training across readers with different decoding skills and languages.

The embodied cognition framework (e.g., Glenberg, Witt, & Metcalfe, 2013) proposes that all cognitive processes are based on bodily and neural systems of perception, action, and emotion. This framework applies to language comprehension through a process of simulation (Fischer & Zwaan, 2008; Glenberg, 2011; Kiefer & Pulvermüller, 2012; Sadoski, 2017), that is, using these systems to create an analogical representation of the situation described by the language. For example, consider understanding a sentence such as "While walking on the trail, the hiker was awed by the red cliffs of the Grand Canyon." Simulation requires the reader to use her motor system to simulate walking, her perceptual system to simulate seeing red cliffs, and her emotional system to simulate awe. Although the simulation may sometimes result in conscious imagery, the conscious experience is not a necessary requirement for simulation.

In the current research, we demonstrate the effectiveness of an embodied reading comprehension intervention, Moved by Reading (*MbR*), in teaching children how to use simulation. Furthermore, we test for transfer of *MbR* training to new texts in an orthographically transparent language. That is, we test the hypothesis that *MbR* should be particularly effective in orthographies that allow for easy decoding because, according to theory, reading comprehension builds on decoding. If a child is having difficulty in decoding new words in a transfer text, then the simulation process cannot get started. Because decoding is difficult in an orthographically opaque language such as written English, transfer may be poor. In contrast, in an orthographically transparent language where decoding is less problematic, such as Spanish, transfer to new texts should be greater. To test this hypothesis, in the current study we used *MbR* with monolingual, Spanish-speaking children. We examined whether the intervention was effective for texts the children read using explicit *MbR* strategies, and whether the effectiveness of those strategies transferred to a new text. In addition, we review data from a previous publication that allows a rather direct comparison of the effects of *MbR* in an orthographically opaque language (the previous data) and an orthographically transparent language (the current data). Of course, since the data come from a different experiment, the comparison is not as strong as it could be.

In the remainder of this introduction, we briefly review data supporting simulation theory and the effectiveness of *MbR* for English-speaking children. However, some of those data (e.g., Adams, Restrepo, & Glenberg, 2018) indicate little transfer. We then describe the current study using monolingual, Spanish-speaking children, to test whether children can transfer the simulation strategy taught by *MbR* to new texts in an orthographically transparent language.

1. Simulation theory, language, and reading

Many theories of language comprehension (e.g., Kintsch, 1998) propose that understanding depends on forming relations among a) abstract symbols that represent words, or b) abstract symbols such as propositions, that represent ideas. In contrast, simulation theory proposes that language is understood by creating a representation of what the language is about (a mental model) using activity in perception,

* Corresponding author. Department of Psychology, Arizona State University, Mail Code 1104, Tempe, AZ, 85283-1104, USA.
E-mail address: glenberg@asu.edu (A.M. Glenberg).

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action, and emotional systems (Glenberg & Robertson, 2000; Glenberg & Gallese, 2012; Kaschak & Glenberg, 2000; Pulvermüller, 2012; Zwaan, Stanfield, & Yaxley, 2002). Thus, understanding language uses systems comparable to understanding events directly experienced.

Research strongly supports at least some components of simulation theory. For example, using fMRI, Hauk, Johnsrude, and Pulvermüller (2004) found activity in somatotopic areas of motor cortex when people listened to action verbs. Thus, listening to "kick" generated neural activity in motor cortex that controls the legs, and listening to "pick" generated neural activity in motor cortex that controls the hand. Pulvermüller, Hauk, Nikulin, and Ilmoniemi (2005) further determined that this activity is causally connected to language processing. To do so, they used transcranial magnetic stimulation to directly affect neuronal firing in the motor cortex, and they found faster lexical decisions to action verbs after stimulation. Behavioral data are also consistent with simulation theory. For example, Glenberg and Kaschak (2002) had participants read sentences such as "Art gave you the pen" (implying movement toward the participant) and "You gave Art the pen" (implying movement away from the participant) and judged whether or not the sentence was sensible by moving to a response button either toward the body or away from the body. When the response direction matched the direction of implied movement in the sentence, responses were faster than in a mismatch condition. That is, understanding the sentence generated a motor simulation that affected responding. Simulation using other neural systems has also been documented. For example, Stanfield and Zwaan (2001) produced strong evidence that perceptual systems play a role in language comprehension by demonstrating that people mentally represent the implied spatial orientation of objects mentioned in sentences they read. Havas, Glenberg, Gutowski, Lucarelli, and Davidson (2010) demonstrated a causal role of emotional systems in comprehending language about emotional events by using Botox to paralyze the frown muscles which slowed comprehension of sentences with negative connotations, but not those with positive connotations.

One might wonder why it is important to teach a simulation strategy (e.g., using *MbR)* for reading comprehension, but explicit teaching of simulation is not necessary for oral language comprehension. In learning a spoken language, there is ample opportunity to link words to sensorimotor and emotional representations. For example, a mother might say to her infant, "Here is your bottle," while handing the bottle to the baby. In this case, the word "bottle" is presented in close contiguity to the baby seeing, feeling, and drinking from the bottle, and thus the process of language comprehension is supported by sensorimotor activity (Masur, 1997). Oral language also allows for the use of gestures to aid in the construction of meaning (Beilock & Goldin-Meadow, 2010; Goldin-Meadow & Beilock, 2010; Hostetter & Alibali, 2008). The child can use gesture cues to scaffold the perception of the auditory signal and to aid in linking words to sensorimotor activity (Ping, Goldin-Meadow, & Beilock, 2014; Wakefield, Hall, James, & Goldin-Meadow, 2018). Relatedly, such cues as tone, prosody and body language can all be used to aid the child in deriving meaning from speech.

In contrast, when learning to read, the sensorimotor and emotional contexts are usually unrelated to the text. For example, when a child in a classroom confronts the written word "dog," generally there is no dog there, no petting, and no happiness. Even when pictures are present as in a child's storybook, there is no guarantee that the child is accurately indexing the words to the pictures. In fact, Dekker, Mareschal, Johnson, and Sereno (2014) used fMRI to demonstrate that children were less likely to spontaneously map written words to sensorimotor representations compared to adults. Moreover, even when a child becomes a highly proficient decoder, it is unlikely that the language produced when reading aloud will contain the cues of prosody and tone to the same extent as fluent speech (see, Elbro, de Jong, Houter, & Nielsen, 2011). However, De Koning et al. (2017) demonstrated that an intervention supporting children in linking their own sensorimotor experiences to stories they read improved reading comprehension and motivation for children in third grade. Similarly, Berenhaus, Oakhill, and Rusted (2015) found that poor comprehenders between the ages of seven and eleven benefitted from embodied reading strategies in terms of their recall of descriptive idea units. These studies suggest the value in explicitly teaching embodied strategies for improving reading comprehension.

In summary, sensorimotor simulation is the natural outcome of learning an oral language in the course of everyday activity. Learning to comprehend written text, however, may require more explicit instruction in simulation, at least for some children. This may be especially true for children who are learning to read in a language with an opaque orthography (so that effort is devoted to decoding rather than simulation) and when reading in a language they do not speak, or they speak with less fluency than their native language (Adams et al., 2018).

2. Moved by reading

MbR is an internet-based system designed to teach young children how to simulate while reading. (For a tablet-based system, see Walker, Adams, Restrepo, Fialko, & Glenberg, 2017). In the first phase of the intervention, called Physical Manipulation (PM), children are taught to create an externalized simulation. Texts are presented on the computer screen along with images of objects referred to in the text (see Fig. 1). After reading a sentence, the child uses the computer mouse to move the images to reflect the content of the sentence. For example, after the child reads "Rosa y Sara van a la cocina" ["Rosa and Sara go to the kitchen"], the child uses the mouse to move Rosa to Sara, the two are automatically conjoined, and the child moves the two to the kitchen. Thus, the child is taught to link the word "kitchen" to the perceptual representation of the picture of the kitchen, and the child is taught to link the syntax of the sentence, the who does what to whom, to her own actions.

The second phase of the *MbR* intervention is called Imagined Manipulation (IM). IM is meant to teach the child how to create internal simulations and to scaffold the child toward independent reading. In this stage, children are taught to *imagine* manipulating the images. It is well-known that visual imagery can enhance comprehension (Bell, 1986; Paivio, 1991; Sadoski & Paivio, 2001). IM may be particularly beneficial in the context of the *MbR* intervention because having just completed PM, the children have a good idea of what to imagine and how to create the simulation.

Whereas many interventions have focused on algorithmic component skills of reading (i.e. phonological awareness, alphabetic knowledge, etc.), *MbR* targets the comprehension of the text. Harris and Pressley (1991) note that children who are low-performing readers tend to perceive decoding or simply finishing the task as the ultimate goal of reading. For these children, explicit instruction in reading strategies is an effective method of improving reading comprehension. By teaching children the strategies of PM and IM, *MbR* shifts the focus away from simply decoding and explicitly emphasizes the importance of understanding through action.

MbR has been shown to be an effective reading comprehension intervention (for a review, see Glenberg, 2011), although most of the work has been conducted with monolingual English-speaking children in the early elementary years with slight variations in the method of delivery of the intervention. Often, children who use *MbR* answer comprehension questions one to two standard deviations better than children who simply read the same texts (i.e., Cohen's *d* is often 1.0 or greater).

Three studies, Marley, Levin, and Glenberg (2010), Adams et al. (2018), and Walker et al. (2017) are particularly relevant to the current research because they imply a decoding constraint on the use of simulation. Marley et al. tested an all-English version of *MbR* with Native American children in 2nd and 3rd grade, some of whom spoke English as a second language. For these children, PM (moving physical toys to

Fig. 1. An example text and pictures from the House scenario.

demonstrate understanding of sentences) was effective when compared to a control group in which children read each sentence twice. However, IM (imagining moving the toys) was only effective for the older (third grade) children, perhaps because the younger children were not skilled decoders and the cognitive effort of decoding precluded IM. There was not, however, a test of strategy transfer to a novel text in this experiment.

Adams et al. (2018) used *MbR* with Latino dual language learners (DLLs) in 2nd and 3rd grade reading in English. These participants ranged in age from seven to ten years old and, on average, were highly proficient in English according to the Spanish-English Language Proficiency Scale (*SELPS,* Smyk, Restrepo, Gorin, & Gray, 2013). Children were randomly assigned to read texts using *MbR*, or, in the control condition, to read identical texts (with pictures) and think carefully about target sentences but without any mention of manipulation. The method of delivery of the intervention was identical to that in the present study except for two differences. First, in Adams et al. (2018), the texts were in English. Second, the first of the 3 p.m. stories and the first of the three IM stories were read out loud to the children (whereas in the present study the children themselves read aloud all of the stories). When using PM and IM, children in the *MbR* condition outperformed children in the control condition (for PM, d as large as 1.2; for IM, d as large as 0.89). Following the IM stories, children read a transfer text that included non-manipulatable pictures, and the children were not given any instruction on use of strategies (as in the current research). For this text, there was no difference between the conditions (i.e. no evidence of successful transfer of the intervention strategies). To ease comparison with the present study, data from Adams et al. (2018) is presented in Table 4.

Walker et al. (2017) used an updated version of *MbR* implemented on iPads. Spanish-English DLLs in early elementary school read narrative and expository texts in English while using PM throughout the intervention. Walker et al. (2017) found that decoding appeared to be an important determiner of benefit from the intervention. Children who were low decoders requested more help in completing the manipulations than children who were better decoders. Secondly, when reading the more difficult expository text the simulation strategy was effective for good decoders, but not poor decoders. Finally, children who were poor decoders, but had strong English oral language skills (as judged by performance on a story retell task) benefitted from a dual language version of the intervention. However, Walker et al. (2017) did not include a transfer stage, so there was no data concerning how decoding affected performance on a transfer story.

Results from Marley et al. (2010), Adams et al. (2018), and Walker et al. (2017) led us to the decoding hypothesis. That is, before children can successfully simulate in untrained transfer texts, they must be able to decode the words in the text. Consequently, simulation taught by *MbR* may be more successful when reading in an orthographically transparent language (such as Spanish) than an orthographically opaque language (such as English). It is well-documented that learning to decode in orthographically opaque languages is more difficult than in orthographically transparent languages (Goswami, Gombert, & de Barrera, 1998; Ziegler & Goswami, 2005; Öney & Durgunoğlu, 1997), and that decoding skills are acquired earlier in children learning to read in transparent orthographies (Seymour, Aro, & Erskine, 2003). In addition, when children make decoding errors in transparent orthographies such as Spanish, they tend to produce a nonword instead of the target word (e.g. error: "tola" [Spanish nonword]; target: "toalla" [towel]), whereas in opaque orthographies like English, children tend to mistakenly produce another real word that is similar visually to the target word (error: "cat" vs. target: "cart") (Ellis & Hooper, 2001). This difference in error patterns may be particularly relevant to the simulation process. If a child reading in English mistakenly produces "cat" when the target is "cart", there is likely more interference in the mapping of words to sensorimotor simulations than for the child reading in Spanish who mistakenly produces a nonword that has no real-world correlate.

The cognitive load associated with decoding difficulties likely also plays a role in how well children are able to implement the intervention strategies, especially when reading unfamiliar transfer texts. According to the verbal-efficiency theory (Perfetti, 1985), decoding accuracy and fluency facilitates reading comprehension because cognitive resources normally employed in decoding can be reallocated to meaning-making. When reading a transfer text (with new vocabulary) in English, children may have significant problems with decoding that preclude this meaning-making process (i.e., simulation). However, if children are reading in an orthographically transparent language, such as Spanish, decoding should be successful leading to successful transfer of simulation (and hence comprehension) to new texts and contexts. This hypothesis is also consistent with Levin (1973) in that he reported that an imagery strategy was effective for good decoders, but not for poor decoders. Much like IM, imagery requires significant cognitive resources. Also, explicit imagery is consistent with embodied processing in that it uses the visual perceptual system–one component of embodied processing–although as we noted above, embodied accounts do not require that the simulation be explicit or conscious.

We do not intend to suggest that decoding performance has no effect on the PM and IM stages of the intervention. A vast body of literature confirms that decoding is an integral predictor of reading comprehension. However, there are two reasons to predict stronger effects of decoding on the performance in the transfer stage. 1) In the PM and IM stages, children receive a preview of the important vocabulary. That is, using an introduction narrative, the experimenter points to images while saying the words out loud, thereby priming the decoding of these words during the subsequent PM and IM texts. 2) Using PM and IM helps compensate for some level of decoding difficulty by prompting children to choose an image that they believe corresponds to the words they have just read. For example, if the child is having difficulty decoding "pumpkins" in a sentence such as "The farmer put the pumpkins in the cart," the child can look at the screen, see the position of the farmer, and see objects on the screen that could possibly fit into the cart – one of these being pumpkins – and use this information to assist in decoding "pumpkins." However, in the transfer stage, there is no vocabulary introduction and no movement of images, so we would expect decoding difficulties to have a more salient impact on comprehension of the transfer story.

To test for transfer of Moved by Reading training to new texts in an orthographically transparent language, we used a Spanish version of *MbR* with monolingual Spanish-speaking children in the Canary Islands, Spain. The texts used were direct translations (appropriate for the Canary Islands dialect of Spanish) of the English-only texts used in Adams et al. (2018). In that research, children in the ***MbR*** condition outperformed children in the control condition after reading using PM and IM, but not on a transfer text (see data in Table 4). If the decoding hypothesis is correct, then when using an orthographically transparent language, we should find a significant effect of the *MbR* condition over the control condition in all three stages of the experiment: PM, IM, and Transfer.

3. Method

3.1. Participants

Using the more conservative effect size ($d = 0.89$) from Adams et al. (2018), we needed approximately 20 participants in each group to achieve a power of .80 with a non-directional alpha = .05. Consequently, parental permission to participate in the experiment was obtained for 42 children in the first, second, and third grades. Consent forms were distributed to every student from a single classroom at each grade level. A total of 19 1st graders, 18 2nd graders, and four 3rd graders returned signed consent forms and were included in the study. All children qualified for free lunch, indicating that children were from families from low SES. One child (a first grader) was eliminated due to difficulty reading the stories and poor decoding skills (i.e. < 10 correct) as measured by performance on the *Woodcock-Muñoz Pruebas de Aprovechamiento, Bateria III* [Woodcock Muñoz Tests of Achievement, 3rd edition] (Muñoz-Sandoval, Woodcock, McGrew, & Mather, 2005). As a result, there were 20 children in the control group and 21 children in the intervention group (see Table 1 for group descriptions). All participants came from homes in which Spanish was the only language and they presented no significant history of speech, language or cognitive delay (based on parent report). Age ranges per grade are reported in Table 1 and are similar to age ranges for corresponding grades in the United States.

3.2. Materials

Woodcock Muñoz Pruebas de Aprovechamiento, Bateria III [Woodcock Muñoz Tests of Achievement, 3rd edition] (Muñoz-Sandoval et al., 2005). This battery of tests includes 22 subtests that measure oral language ability, reading, mathematics, writing achievement, phonological awareness, and academic knowledge. These tests were developed to be the Spanish parallel to the well-known Woodcock-Johnson Tests of Achievement (Woodcock, McGrew, & Mather, 2001). For the purposes of the current study, only the identificación de letras y palabras [letter and word identification] and comprensión de textos [text comprehension] subtests of *Woodcock-Muñoz Pruebas de Aprovechamiento* instrument were used. The letter and word identification subtest requires children to identify individual letters, simple words, and then words of increasing difficulty. The text comprehension subtest requires children to fill in the blank to complete sentences and paragraphs of increasing complexity. These tests were normed on Spanish-speakers both inside and outside of the United States; some in the norming sample came from Spain. The reported reliability coefficients of the letter and word identification subtest ($r = 0.95$) and the text comprehension subtest ($r = 0.91$) suggest a high level of reliability of these subtests.

3.2.1. Moved by reading stories

The texts used consisted of 14 interactive stories from two scenarios presented online through a computer. Seven stories take place in a farm scenario, and seven stories take place in a house scenario. For all stories, the interactive images were based on Fisher Price toys (see Fig. 1 for an example story). According to the Fernández Huerta (1959) measure of readability in Spanish, the average readability of the Farm stories (94.6) and of the House stories (98.4) correspond to a descriptive term of "very easy." Before the stories were presented, the research assistant familiarized each child with all relevant objects and characters in the stories using an introduction screen (see Fig. 2).

Note in Fig. 1 that several of the sentences are followed by images of green traffic lights. These traffic lights cued the child as to which sentences should be simulated. A standard computer mouse was used to manipulate the images for simulation. The first story each child read was an introduction and practice story and required four manipulations. Each story the child read during the PM, IM, and Transfer stage contained an average of eight sentences and required five manipulations.

3.2.2. Open-ended cued recall outcome measure

Following completion of every story, the computer screen was turned off and the experimenter asked four to five open-ended questions assessing the children's comprehension of the story (see Table 2 for example questions). If the child answered incorrectly, the experimenter asked the child a follow-up, two-alternative, forced choice

Table 1
Participant characteristics.

Condition	*n*	Gender	Grade	Mean age in years; months (SD in months)	WM LWI (SD)	WM PC (SD)
Control	20	10 F	10 1st grade	6; 10 (3.5) range 6; 6–7; 4	54.8 (15.5)	18.3 (3.7)
			8 2nd grade	7; 10 (2.6) range 7; 8–8; 4	67.9 (7.5)	26.5 (2.7)
			2 3rd grade	8; 8 (9.9) range 8; 3–9; 3	70.0 (4.2)	28.5 (0.7)
Intervention	21	12 F	9 1st grade	6; 11 (4.5) range 6; 5–7; 5	61.2 (8.2)	19.4 (3.9)
			10 2nd grade	7; 10 (2.9) range 7; 6–8; 2	61.0 (11.5)	22.7 (4.1)
			2 3rd grade	8; 11 (4.9) range 8; 7–9; 2	63.0 (4.2)	22.0 (2.8)

Note: WM = *Woodcock-Muñoz Pruebas de Aprovechamiento-BateriaIII*; Numbers reported for WM scores are raw numbers correct.

Fig. 2. The pictures used to introduce the vocabulary for the House scenario.

Table 2
Example cued-recall questions and follow-up two-alternative choice questions.

P1: Al principio del cuento, ¿dónde está Sara? [At the beginning of the story, where is Sara?]
¿Al principio del cuento, Sara está en su cuna o en la cocina? [At the beginning of the story, is Sara in her crib or in the kitchen?]
P2: ¿Quién cogió a Sara? [Who picked up Sara?]
¿Quién cogió a Sara, Rosa o Martin? [Who picked up Sara: Rosa or Martin?]
P3: ¿A dónde llevó Rosa a Sara? [Where did Rosa take Sara?]
¿Rosa llevó a Sara a la cocina o a la sala de juegos? [Did Rosa take Sara to the kitchen or to the play room?]
P4: ¿En dónde puso Rosa a Sara? [Where did Rosa put Sara?]
¿Rosa puso a Sara en la cuna o en su trona? [Did Rosa put Sara in her crib or in her high chair?]
P5: ¿Qué hace Martin en la sala? [What did Martin do in the living room?]
¿Martin juega con Sara en la sala o lee en la sala? [Did Martin play with Sara or read in the living room?]

question. The experimenter recorded the child's answer by typing the answer into a prepared protocol. The experimenter initially scored all comprehension questions. However, because the experimenter was not blind to condition, a second scorer was trained on the procedures for scoring the comprehension questions. Files were renamed so that the new scorer was blind to condition. Initial inter-rater agreement was 73%. Any discrepancies were reviewed and re-scored by the initial coder and the final inter-rater agreement was 98%.

We used the proportion of correct answers to the open-ended question as the dependent variable and we did not focus on performance on forced choice questions for two reasons. First, performance on the two-alternative questions can be strongly influenced by guessing. Second, Keenan, Betjemann, and Olson (2008) found that, when compared to three other standardized tests of reading comprehension, the open-ended questions accounted for the most variance in listening comprehension and the least variance in decoding. (Nonetheless, the forced choice data are presented in Table 5.) Using the open-ended questions resulted in a maximum possible score of 15 for the PM and IM stages, and a maximum possible score of 5 for the transfer stage. [Note that in the Adams et al. (2018) study, the only difference in procedure (besides the stories being in English) was that the first story in the PM and IM stages was read aloud to the child. Therefore, the performance on the comprehension questions related to these stories was not included in the analysis. This resulted in a maximum possible score of 10 for the PM and IM stages, and a maximum possible score of 5 for the transfer stage.]

3.2.3. Parent consent and questionnaire

A parental consent form and brief questionnaire was collected for each child. Information about language use and reading practices in the home, history of any language or speech disorders, and parental education levels were included in the questionnaire. This information was used to ensure that all participants were typically developing Spanish monolinguals.

3.3. Procedure

Random combinations of the two conditions (Control and Intervention) were generated, such that for every two children, one would be assigned to each condition. Separate assignment sheets were made for each grade to ensure an equal number of children per grade participated in each experimental condition. Stories were counterbalanced so that half the children saw Farm stories (ten children from the control group and 11 from the experimental group) during the PM and IM intervention, and a House story for the test of transfer. The other half of the children saw House stories (nine from the control group and 11 from the experimental group) during the intervention and a Farm story for the test of transfer. Furthermore, each story appeared in every order an approximately equal number of times, with the exception that story one from each scenario was always presented first.

3.4. Pre-intervention procedure

On Day one, each child came from his/her after school class or activity to a quiet testing room. Children assented to participate in the project and were administered the *Woodcock-Muñoz* subtests of letter and word identification and text comprehension. The administration of consent and *Woodcock-Muñoz* materials were identical for every child in the study and took place in a single session lasting between 20 and 40 min.

4. Intervention procedure (Days two and three)

On Day two, the first day of the intervention, children randomly assigned to the *MbR* group were first familiarized with the objects and characters from the scenario in which the stories were going to take place. For example, from the House scenario, the crib, high chair, living room and people living in the house were identified (see Fig. 2 for an example of the introduction screen). The experimenter read (in Spanish) the narrative that introduced the characters to the child, and the experimenter asked the child to point with the mouse to each item on the screen as the experimenter said the words and pointed with her finger to each item. This assured that the child was able to use the mouse and was attending to each item as it was introduced.

After the scenario was introduced, the experimenter instructed the child how to use the physical manipulation (PM) strategy; that is, how to use the mouse to move the images to simulate what was happening in the story. Next, the experimenter instructed the child to read three

Table 3
Correlations between pretest scores and session performance.

	Woodcock-Muñoz Letter-Word ID	Woodcock-Muñoz Text Comprehension	PM Performance	IM Performance	Transfer Performance	Grade
Woodcock-Muñoz Letter-Word ID	1	.644**	.388	.369	.076	.032
Woodcock-Muñoz Text Comprehension	.627**	1	.549**	.644**	.174	.329
PM Performance	.279	.572**	1	.756**	.477**	.037
IM Performance	.587**	.750**	.645**	1	.421	.279
Transfer Performance	.283	.586**	.309	.496*	1	.219
Grade	.481*	.789**	.429	.533*	.370	1

Note. Correlations for the experimental condition are reported above the diagonal and correlations for the control condition are reported below the diagonal. ** = p < .01, * = p < .05.

stories in Spanish using the PM procedure.

On Day three, children began to use the imagined manipulation (IM) procedure. The experimenter instructed the children in Spanish that, at each green light, they would need to imagine that they were moving the toys on the screen. To practice IM, the children listened to a three-sentence Spanish practice story. Next, the child read aloud three stories in Spanish while using IM. The stories read using IM were always from the same scenario (e.g., House or Farm) as the stories read using PM on the previous day.

The last story the child read was the transfer story, which was from a new scenario, and it was accompanied by (non-moveable) images. For example, if the child had practiced PM and IM while reading stories from the Farm scenario, then the transfer story came from the House scenario. This story was read on the same day as the IM stories, immediately following the completion of the IM stage. The experimenter gave no instructions for how to read the transfer story, and no additional vocabulary support was provided for the new story scenario. Following completion of the transfer story, the experimenter turned off the computer screen and asked five open-ended recall questions assessing the children's comprehension of the story (see Table 2 for example questions).

4.1. Control procedure (Days two and three)

Children in the control group received the same pattern of language input (i.e. introduction to vocabulary and instructions for how to read the stories) as the *MbR* condition. All procedures were identical to the *MbR* condition, except that the experimenter instructed the children that when they saw the green lights, they should stop and think about the sentence they had just read, and, once they had finished thinking carefully about the sentence, to move on to read the next sentence. Importantly, the children in the control group could see the same images as the children in the intervention group, but they did not manipulate any objects on the screen, nor did they receive any explicit instruction to imagine the objects moving on the screen.

4.2. Error and scoring procedure

Errors in decoding were few, but when they occurred they were not corrected. If the child made an error in manipulation, the images would snap back to their original position and the child would be prompted to try again until the manipulation was completed correctly. If a child responded “I don't know” to a comprehension question, this response was recorded, and they were asked the follow-up, forced choice question. There were pre-set answers determined to be acceptable and only slight variations were accepted (e.g., for the question “Who went to pick up the baby from her crib?” acceptable answers were “Rosa” or “the mom”). The experimenter followed a script when administering the questions to avoid influencing the children's responses.

5. Results

Three different analyses were performed. The first was a set of ANOVAs to ensure the groups did not differ on baseline (Day one) decoding or text comprehension skills as measured by their performance on the decoding and text comprehension subtests of the *Woodcock-Muñoz Pruebas de Aprovechamiento*. Secondly, we ran a MANCOVA to examine the effectiveness of the intervention among Spanish children while controlling for their baseline comprehension and decoding skill. Finally, a MANOVA compared the performance of the Spanish children reading in Spanish with that of children from Adams et al. (2018) who read in English.

For the ANOVAs comparing baseline performance, neither decoding, $F(1, 39) = 0.716$, $p = .942$, partial $\eta^2 = 0.00$ nor text comprehension, $F(1, 39) = 0.841$, $p = .365$, partial $\eta^2 = 0.02$ were significantly different between the intervention and control groups. In addition, there was not a significant difference between the grades on decoding performance according to a one-way ANOVA with Woodcock-Muñoz Letter and Word identification performance as the dependent variable and grade as the independent variable, $F(2, 38) = 1.87$, $p = .17$, partial $\eta^2 = 0.09$. Bivariate correlations between baseline measures, grade, and session performance are reported in Table 3.

The proportion of cued recall questions answered correctly in each stage of the intervention are in Table 4 and Fig. 3. Also included in Table 4 are the analogous performance data from the Adams et al. (2018) study. (Although the forced choice questions were not used in this analysis, the proportion correct on these questions are reported for the reader's information in Table 5.) A multivariate ANCOVA was used with performance during the PM, IM, and Transfer stages as the dependent variables, treatment condition as the independent variable, and grade, baseline decoding performance (Woodcock-Muñoz letter and word identification subtest raw score), and baseline comprehension performance (Woodcock-Muñoz text comprehension subtest raw score) as covariates. Box's test of equality of covariances was not significant, Box's $M = 4.53$, $p = .66$, suggesting that the covariance matrices of the dependent variables did not differ between control and intervention groups. Additionally, the assumption of equality of variances was met for each intervention stage. No outliers were identified and tests of

Table 4
Proportion correct on each stage of the *MbR* intervention in Adams et al. (2018) and the present study.

	Adams et al. (2018) Mean (SD)	Present Study Mean (SD)
Control	PM = .59 (.18), $n = 15$ IM = .59 (.24), $n = 15$ Transfer = .59 (.27), $n = 15$	PM = .61 (.19), $n = 20$ IM = .62 (.19), $n = 20$ Transfer = .48 (.28), $n = 20$
Intervention	PM = .68 (.20), $n = 18$ IM = .73 (.17), $n = 18$ Transfer = .51 (.29), $n = 18$	PM = .76 (.17), $n = 21$ IM = .77 (.22), $n = 21$ Transfer = .70 (.22), $n = 21$

Note. PM = Physical manipulation; IM = Imagined Manipulation.

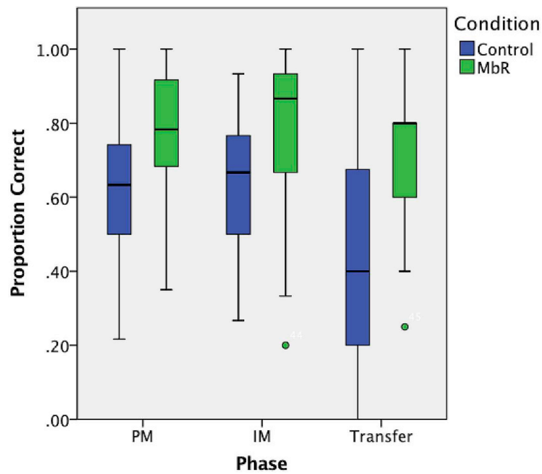

Fig. 3. Proportion correct responses to the cued-recall questions as a function of Phase of the experiment (abscissa) and Condition (color). For each box, the thick black line is at the median, the top of the box is at the 75th-percentile, the bottom of the box is at the 25th-percentile, and the error bars mark the highest and lowest scores except for outliers indicated by circles. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 5
Forced choice performance in each stage of the intervention.

	Mean (SD)
Control	PM = .84 (.17) IM = .68 (.21) Transfer = .66 (.34)
Intervention	PM = .88 (.24) IM = .77 (.23) Transfer = .78 (.38)

Note. PM = Physical manipulation; IM = Imagined Manipulation.

normality indicated normal distribution of scores for the control group in all stages and for the intervention group in the PM stage. Scores for the intervention group in the IM and Transfer stages were negatively skewed. Baseline text comprehension was the only covariate that was significant in the model in the PM stage, $F(1, 36) = 10.89$, $p = .002$, partial $\eta^2 = 0.23$ and the IM stage, $F(1, 36) = 11.98$, $p = .001$, partial $\eta^2 = 0.25$, and it was not quite significant in the transfer stage, $F(1, 36) = 3.82$, $p = .059$, partial $\eta^2 = 0.10$. Baseline decoding performance was not significant in any stage of the intervention, PM stage, $F(1, 36) = 0.19$, $p = .66$, partial $\eta^2 = 0.01$; IM stage, $F(1, 36) = 0.19$, $p = .66$, partial $\eta^2 = 0.01$; transfer stage, $F(1, 36) = 0.24$, $p = .63$, partial $\eta^2 = 0.01$. Grade was also not significant in any stage, PM stage, $F(1, 36) = 0.65$, $p = .42$, partial $\eta^2 = 0.02$; IM stage, $F(1, 36) = 0.00$, $p = .99$, partial $\eta^2 = 0.00$; transfer stage, $F(1, 36) = 0.13$, $p = .72$, partial $\eta^2 = 0.00$.

To answer the question of whether the intervention was effective at improving performance on cued recall comprehension questions during the intervention, we looked at the treatment effect in the PM and IM stages. In both cases the treatment effect was significant, PM stage, $F(1, 36) = 14.28$, $p = .001$, partial $\eta^2 = 0.28$; IM stage, $F(1, 36) = 14.76$, $p < .001$, partial $\eta^2 = 0.29$. To determine whether the effect of the intervention was still present when the child read the transfer story (with no instruction on movement, and no vocabulary support), we looked at the treatment effect in the Transfer stage. This effect was also significant, $F(1, 36) = 10.72$, $p = .002$, partial $\eta^2 = 0.23$. Thus, the data demonstrate the strong positive effects of *MbR* in an orthographically transparent language, Spanish. In addition, the data are consistent with the decoding hypothesis.

To examine differences between the present study and the Adams et al. (2018) data, we ran an additional MANOVA with the Adams et al. (2018) group of Spanish-English DLLs reading in English (15 control and 18 intervention) and the Spanish monolingual children (20 control and 21 intervention) from the present study reading in Spanish. This is not a perfect comparison because the DLLs in the United States were reading in their second language, although they all had received formal reading instruction in English for at least 1–2 years, approximately the same amount of time the Spanish monolinguals had received formal reading instruction in Spanish. Additionally, the decoding measure used in the Adams et al. (2018) study was not a standardized measure, so this covariate could not be in the analysis when looking at both groups simultaneously. Therefore, it is a-priori impossible to distinguish whether differences between the Spanish and English study were driven by language transparency, individual differences in decoding ability irrespective of language, or general differences in language expertise. Nevertheless, greater transfer effect in the Spanish than the English study would support our main hypothesis that better decoding skills can improve amenability to reading comprehension training. In Table 4, an examination of the numerical accuracy scores *in the transfer stage* shows that, among the Spanish children, the advantage of the intervention group over the control group was considerably larger than the advantage for the DLL children, whereas the intervention advantage for the Spanish children was nearly identical to the intervention advantage for the DLL children in the PM and IM stages.

Results of the MANOVA show that the main effect of Experiment was significant in the PM stage, $F(1, 69) = 4.86$, $p = .031$, partial $\eta^2 = 0.07$, not significant in the IM stage, $F(1, 69) = 2.80$, $p = .099$, partial $\eta^2 = 0.04$ and significant in the Transfer stage, $F(1, 69) = 5.24$, $p = .025$, partial $\eta^2 = 0.07$ with the children in the Canary Islands experiment numerically outperforming the DLL children in the United States in each stage. The experiment by condition interaction was not significant in any stage of the intervention, PM stage, $F(1, 69) = 0.28$, $p = .597$, partial $\eta^2 = 0.00$, IM stage, $F(1, 69) = 0.06$, $p = .81$, partial $\eta^2 = 0.00$ or Transfer stage $F(1, 69) = 2.50$, $p = .119$, partial $\eta^2 = 0.04$. Therefore, further studies with larger sample sizes are needed to compare the effectiveness of the *MbR* training across different linguistic contexts.

6. Discussion

The results demonstrate that the *MbR* intervention improved reading comprehension for young Spanish monolinguals in 1st through 3rd grade. Unlike previous studies (Adams et al., 2018, in particular), this advantage was observed across all three stages of the intervention, including the transfer test. Considering that there were no differences between groups of Spanish children on baseline decoding and text comprehension measures, the improvement in comprehension can be attributed to the efficacy of the intervention.

The decoding hypothesis (as well as much other research) suggests that decoding is an important component in reading comprehension, but our MANCOVA did not produce statistically significant effects of decoding. We believe that there are two primary reasons for this lack of significance. First, these Spanish monolingual children were quite proficient decoders as early as first grade, and although their performance improved slightly by grade, the difference between grades was not significant. This finding is consistent with research in other transparent orthographies, such as Finnish, in that early readers reach ceiling performance on reading accuracy quite soon after formal reading instruction begins (Aro & Wimmer, 2003; Seymour et al., 2003; Torppa et al., 2016). Second, the decoding demands of the intervention stories were actually quite low, especially when compared to the high decoding skills of this group. Although the Flesch-Kincaid Readability scale does not apply to Spanish texts, according to the Fernández Huerta (1959) measure of readability in Spanish, the average readability of the Farm stories (94.6) and of the House stories (98.4) correspond to a descriptive term of "very easy." Thus, we suggest that decoding was not significant in the MANCOVA, not because decoding isn't important, but because the children found the intervention stories quite easy to decode. Florit and Cain (2011) also suggested that there may be differential predictive value of decoding to reading comprehension depending on the transparency of the orthography being read. In other words, because children reach ceiling on decoding accuracy so quickly and because there is a near 1:1 correspondence between graphemes and phonemes in transparent languages, decoding becomes a less important predictor than oral language comprehension when predicting reading comprehension outcomes.

Several investigators who examined orthographic transparency and its effect on reading comprehension have hypothesized that children learning to read in very transparent orthographies are at an advantage when it comes to understanding what they read. Öney and Durgonoğlu (1997) pointed out that, for young readers of Turkish who performed near 100% accuracy in decoding words by the end of first grade, decoding skill did not hamper reading comprehension and was, in fact, not even a significant predictor of reading comprehension. Similarly, Müller and Brady (2001) pointed out that children who master decoding may be more able to focus on text meaning and that reading, for these children, may be more rewarding. Hanley, Masterson, Spencer, and Evans (2004) compared Welsh-English children learning to read in Welsh (an orthographically transparent language) and Welsh-English children learning to read in English. They found that even after six years of formal instruction, children in the lowest quartile of English readers were performing significantly lower on all measures of literacy when compared to the lowest quartile of Welsh readers. This finding suggests that there may be a long-term impact of orthographic transparency on reading comprehension, especially for children already at risk for reading difficulties. To our knowledge, there have been no experimental studies of how orthographic transparency impacts the efficacy of comprehension interventions.

Our preferred explanation for the difference in intervention results as compared Adams et al. (2018) is that, as hypothesized, the lower cognitive load related to decoding in an orthographically transparent language allowed for more effective use of the intervention strategies. Just and Carpenter's Capacity Theory (1992) suggests that comprehension abilities are constrained by one's cognitive capacity and Perfetti's verbal efficiency theory (1985) suggests that effortful decoding taxes this cognitive capacity to the detriment of reading comprehension. In the case of these Spanish monolinguals, the task of decoding may have required less cognitive capacity due to the near one-to-one correspondence between graphemes and phonemes in Spanish as compared to the children in Adams et al. (2018), in which children were reading in English, an opaque orthography. In addition, the Spanish children in the current research were learning to read in their native and only language rather than in their second language as in Adams et al. (2018). Thus, the children may have been better able to internalize the intervention strategies and transfer them successfully throughout the progressively more difficult stages of *MbR*. Although the decoding error patterns were not analyzed, it is also possible that the types of errors made by the Spanish-speakers (i.e. substituting nonwords for real words) produced less interference in the simulation process compared to the English-speakers who are more likely to make real-word substitution errors (Ellis & Hooper, 2001).

Dekker et al. (2014) present neurophysiological evidence consistent with the decoding hypothesis (at least for readers of English). Using fMRI, they noted which areas of the brain were especially active when viewing pictures of tools (which generally activate areas associated with manual activity) and when viewing pictures of animals (which generally activate areas associated with visual processing). For adults, these same brain areas were differentially activated when reading words describing tools and animals, respectively. For children, however, there was much less differential activation. That is, children decoding words in English did not spontaneously map words to differential sensorimotor activity, perhaps because of the decoding cognitive load.

We considered three potential explanatory factors when comparing the current results with Adams et al. (2018): SES, age, and decoding skill. SES does not appear to be a confound because children in both studies were considered low SES based on rates of qualification for free lunch programs at the respective schools. One would expect reading decoding and comprehension skills to improve with age, therefore age differences between populations were also examined. The Spanish monolingual children were nearly a year younger on average than the children in Adams et al. (2018). If the groups had been perfectly age-matched, we would expect an even larger advantage for the Spanish monolingual group over the children in Adams et al. (2018).

In terms of baseline reading ability, there was not a direct measure of comparison between the two groups because the measure administered to the DLL group in Adams et al. (2018) was not a standardized measure of decoding. However, on average, the children from the Canary Islands were decoding at an 8th-grade level, based on the grade equivalent scores from the letter and word identification subtest of the *Woodcock-Muñoz Pruebas de Aprovechamiento-Bateria III*. In contrast, the children in Adams et al. were, on average, only 85% accurate decoding 1st-grade-level words from the *Qualitative Reading Inventory-5*. Thus, we can tentatively conclude that the monolingual Spanish-speaking children were better decoders than the children in the United States sampled in Adams et al. (2018). This difference may be due to the nature of the orthography of the Spanish language, namely that almost all graphemes have only one possible pronunciation and very few irregular words exist (Cuetos, 1993). Importantly, however, although the Spanish monolinguals were excellent decoders, they were not excellent comprehenders. For the control group, the proportions correct were similar to Adams et al. (2018) (see Table 4).

Thus, the children in the current study and in Adams et al. (2018) were comparable in SES and comprehension skill. The major difference seems to be that the children in the current study were much better decoders (when reading in Spanish) than the children in Adams et al. (when reading in English). This difference in decoding could explain why children in the current research showed a large transfer effect whereas those children in Adams et al. did not. In other words, differences in decoding ability across the Spanish and US samples may (also) reflect systematic differences in baseline reading ability, independent of language transparency. Future studies are therefore needed to further disentangle contributions of language transparency and individual decoding skills to the transfer of simulation training.

Overall, the results indicate that the *Moved by Reading* intervention has potential for improving reading comprehension outcomes in several populations. The results were very clear for the monolingual Spanish-speaking children in this research. For DLL children learning to read in English (those children used in Adams et al., 2018), difficulty with decoding may play a role in the ability to use the IM strategy on new texts or in the ability to internalize the strategy. As a result, all children may need to reach a threshold of decoding skill before being able to successfully transfer the strategy to new scenarios and untrained texts. It appears that monolinguals decoding in a transparent orthography reach this threshold much earlier than DLLs reading in an opaque orthography, and thus can more readily apply the simulation strategy in untrained contexts.

7. Limitations

The practical implications of the success of this intervention should be carefully considered. There were fewer children in the 3rd grade than there were in 1st and 2nd grade, so the results should be only preliminarily generalized to children in the 3rd grade. Furthermore, the children in this sample appear to be exceptionally strong decoders which may also affect generalizability of these results. The complex nature of reading comprehension makes it unlikely that any two-day intervention would alter its long-term course. However, the large effect sizes showing an advantage for the Spanish intervention group observed in each of the stages of the intervention suggest, at the very least, a proof of concept that embodied interventions are a promising strategy for supporting reading comprehension, especially in transparent orthographies.

Our results provide preliminary support for the decoding hypothesis. Nonetheless, there are several aspects of the design, data, and analyses that warrant caution. In terms of design, better control over differences between the children in Adams et al., (2018) and the Spanish children in the current research would be beneficial. Similarly, larger sample sizes and greater statistical power would help us to determine if the apparent difference (between languages) in transfer test performance is reliable. Further research with monolinguals reading in an opaque language (such as English) should attempt to include participants with a range of decoding skill covering the spectrum from very poor to very good. This would allow for the use of decoding as a moderator for performance on each intervention stage and would further elucidate the role that decoding plays in successful implementation of the intervention strategies. Consequently, we can only provide provisional support for the decoding hypothesis.

8. Conclusion

In conclusion, *MbR* is an effective intervention for improving reading comprehension in monolingual Spanish-speaking children. We hypothesized that in a transparent orthography, the *MbR* intervention works well because the monolingual Spanish-speaking children need to dedicate less cognitive effort to decoding so that they can concentrate on simulation. Our results indicated that the simulation strategy not only improved comprehension during the intervention stories, but it also generalized to untrained stories. These results are in line with our prediction based on the decoding hypothesis, that to be most effective, children need to achieve a certain level of decoding skill to successfully transfer the simulation strategy to new, untrained texts.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.learninstruc.2019.03.003.

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