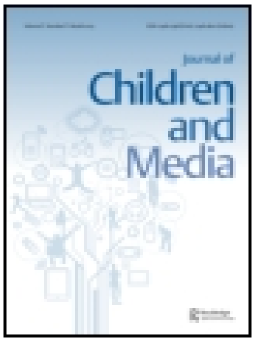

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Education in the app store: using a mobile game to support U.S. preschoolers' vocabulary learning

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ABSTRACT

Despite the prevalence of educational apps for children, there is little evidence of their effectiveness for learning. Here, children were asked to learn ten new words in a narrative mobile game that requires children use knowledge of word meanings to advance the game. Study 1 used a lab-based between-subjects design with middle-SES 4-year-olds and used a receptive vocabulary test to examine whether children learned the game's words. Children who played the game answered more questions correctly than children who did not play the game. Study 2 used a within-subjects design with low-SES preschoolers who played the game four times as part of a larger classroom intervention. Children showed evidence of learning on both a receptive and an expressive vocabulary measure. The difference between pre- and post-test scores was significantly larger for target words than for five non-exposure control words. Results show that both middle-SES children in the lab and low-SES children in the classroom learned new vocabulary from an interactive mobile game, suggesting that developmentally-appropriate mobile games show promise for vocabulary learning.

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Technology pervades childhood. A recent survey using a representative sample of more than 1,400 U.S. parents found that 98% of children under 8 years old have access to a mobile device at home, and that the time children spend on mobile gaming tripled between 2013 and 2017 (Common Sense Media, 2017). Apps marketed as "educational" are abundant: More than 80% of top-selling apps in iTunes' Education category target children, and more than half of those are in the toddler/preschool category (Shuler, Levine, & Ree, 2012). However, very few of these apps were developed with benchmarks of educational quality in mind (Hirsh-Pasek et al., 2015; Vaala, Ly, & Levine, 2015) or provide developmentally appropriate guidance (Callaghan & Reich, 2018).

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One domain that could benefit from high quality educational apps is language. Early language is an important predictor of later reading ability (NICHD ECCRN, 2005; Storch & Whitehurst, 2002). For example, preschool vocabulary skills predict reading comprehension in 4th grade (Dickinson & Porche, 2011). Similarly, vocabulary knowledge predicts average literacy scores and gains in literacy from 1st to 3rd and from 3rd to 5th grade (Pace, Alper, Burchinal, Golinkoff, & Hirsh-Pasek, 2019). Research shows that children from under-resourced communities are likely to have slower language development than their middle- and upper-SES peers (Durham, Farkas, Hammer, Tomblin, & Catts, 2007; Golinkoff et al., 2019; Hart & Risley, 1995; Reardon, 2013; von Hippel & Hamrock, 2016). These early delays may contribute to disparities in other literacy skills (Beck & McKeown, 2007; Hoff, 2013; Muter, Hulme, Snowling, & Stevenson, 2004). Children from disadvantaged backgrounds are also likely to spend more time with screen media: Lower-SES children use screen media almost 3.5 hours a day compared to less than 2.5 hours for middle-SES children (Common Sense Media, 2017). Taken together, these facts highlight a potential role for mobile games in supporting early language skills.

Notably, research suggests that vocabulary instruction occurs infrequently in preschool classrooms (Dickinson, Pierre, & Pettengill, 2004). Furthermore, studies suggest that many children from low-SES backgrounds do not experience the same rich vocabulary in the home environment that is experienced by their middle-SES peers (Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010). Thus, mobile games could supplement adult-child interactions that support children's early vocabulary, such as storybook reading. Research-based games could become a staple during the over 2 hours a day that children under the age of 8 are already spending with screen media (Common Sense Media, 2017). Although they lack a strong evidence base, many apps do focus on vocabulary: vocabulary skills are the second most common language and literacy skill targeted in apps behind only alphabet knowledge (Vaala et al., 2015).

Research suggests that children can learn new words from e-books read with an adult (e.g., Strouse & Ganea, 2017), but less research focuses on independent use of digital games. A few studies hint that digital games played on traditional computers may be effective for promoting vocabulary learning. In one study, 2nd and 3rd graders played a PBS game called *Mission to Planet 429* over a two-week period and showed gains on the vocabulary words the game taught compared to a group who played science games (Michael Cohen Group, 2010). Similarly, a recent study found that preschoolers and kindergartners who played PBS literacy-focused games for 8 weeks at home improved on the vocabulary presented in the games relative to children who received puzzle- and arts-themed games (Schmitt, Hurwitz, Duel, & Linebarger, 2018).

These studies were among the earliest in the field and they used computer delivery rather than mobile devices. A small amount of preliminary evidence suggests that mobile games also support vocabulary learning: Michael Cohen Group (2013) found that Spanish-speaking preschoolers who played PBS's *Pocoyo* app in their classrooms over a 3-week period gained more vocabulary than a control group who played two different games designed for bilingual vocabulary learning. In Chiong & Shuler (2010), 3- to 7-year-olds played two PBS app-based games at home over a two-week period, including a *Martha Speaks* app that specifically focused on introducing new vocabulary. Children appeared to learn new vocabulary from the app, with older children gaining more than 20% on vocabulary words taught in the app from pre- to posttest. However, the study did not include any controls against which to compare children's gains.

Some lab-based studies may also speak to the potential of mobile games for children's word learning. For example, Kirkorian, Choi, and Pempek (2016) found that toddlers could learn novel object labels from a researcher-designed app in an immediate test. Similarly, Russo-Johnson, Troseth, Duncan, and Mesghina (2017) found that 2- to 4-year-olds learned novel object labels from a simple researcher-designed app in an immediate test but that only 4-year-olds transferred their learning to 3D objects.

Although these findings demonstrate the potential of apps for improving vocabulary, there are several important limitations. First, few studies have investigated the use of mobile games to support word learning. Although mobile devices are more accessible to children because they can be used in many locations, we know little about how their smaller screens and touch capabilities may affect learning. Additionally, the two peer-reviewed studies assessing word learning from mobile devices only tested immediate learning on object recognition measures after a single session of game play. The current studies are the first to conduct a rigorous investigation of mobile game use to support preschoolers' vocabulary learning over multiple sessions using multiple stringent measures of learning.

We created a mobile game to support vocabulary learning based on four principles from the science of learning that speak to how to maximize children's learning from apps (Hirsh-Pasek et al., 2015). First, children should be actively involved in a "minds-on" way with the material and second, they should be engaged and not distracted. While flashy, distracting apps can captivate children they do not necessarily lead to learning (Parish-Morris, Mahajan, Hirsh-Pasek, Golinkoff, & Collins, 2013). Third, learning is optimized when content is embedded in a meaningful context and finally, learning increases during social interactions in which a partner responds contingently to the children's actions. Specific examples of how these four principles are incorporated in the game designed for this study can be found in the Methods.

Despite children's increasing exposure to mobile media and the prevalence of apps that claim to be educational, little research has addressed whether preschool children can increase their vocabulary through exposure to a mobile game based on principles from the science of learning. To address this question, Study 1 used a between-subjects design to investigate whether children could learn new vocabulary from the game. The goal of Study 1 was to assess proof-of-concept and obtain evidence that would allow for causal attributions indicating that children learned the words as a result of playing the game. Study 2 used a within-subjects design to extend the research into a more naturalistic environment with a specific population of interest, examining learning in a classroom setting with children from low-SES backgrounds.

Study 1

Method

Participants

Participants were recruited by telephone and email from a database of families willing to participate in research at a mid-Atlantic university. Participants were predominately white, monolingual, and from middle SES backgrounds. Fifty-seven four-year-old children (31 girls) participated (M_{age} = 53.0 months, SD_{age} = 3.8). Five additional participants were tested but excluded due to experimenter error (n = 1), refusal to cooperate (n = 1), scheduling error (n = 2), and having less than 70% English spoken at home as indicated by parent report (n = 1).

Both Study 1 and Study 2 were approved by the Institutional Review Board of the university and parents provided written informed consent before children entered the testing room. All children in Study 1 received a certificate of appreciation and a sticker.

Procedure

Children in the game group (n = 34) played the game individually, sitting at a child-sized table in a quiet room. The game took 10 to 12 minutes to play through. There was little adult guidance or interaction during game play and no training prior to game play; children were only told that they would be playing a game. Immediately following the game, children completed a receptive vocabulary test. A control group (n = 23) completed the receptive vocabulary test after participating in an unrelated study that involved no exposure to the words taught in the game. Children were recruited for multiple studies in the lab and their group assignment in this study was based on the participant needs across all studies (e.g., age, gender, scheduling). Both groups were recruited using the method described above and the groups did not differ in gender (p = .88), age (p = .22), mean level of primary caregiver's highest level of education (p = .64), or on the percentage of White children (p = .53).

Target word selection. Words were selected to be difficult and uncommon for this age group to ensure that children would be unlikely to know them prior to the study. We consulted lists of words categorized based on the grade at which children should know or be taught the word (Biemiller, 2010; Chall & Dale, 1995), as well as data from a corpus of early childhood naturalistic language on the frequency of word use by children in our age range (Bååth, 2010). If two of the three sources indicated the word would be too easy, it was not included. The ten words in the game included four verbs, four concrete nouns, and two abstract nouns. See Table 1.

Game design. We created the mobile game in collaboration with SmartyPal, a Philadelphia-based educational development company; SmartyPal created static cartoon-style images for

Table 1. Words taught in game with included definitions.

Form class	Word	Definition Used in Game
Concrete noun	Spade	A type of shovel
	Knoll	A small hill
	Hammock*	A bed made of cloth or rope that you can hang between two trees
	Scroll*	A long, rolled up piece of paper with writing on it
Abstract noun	Misfortune	Bad luck
	Nutrition*	Food that is healthy for you and helps you grow
Verb	Weep	To cry for a while
	Devour	To eat food very fast
	Assemble*	To put together
	Demolish*	To destroy something

Words marked with an * were included in the analyses for both Study 1 and Study 2; all other words were only used in the analyses for Study 1.

the game and researchers wrote the game script and logic of gameplay to align with the four principles from the science of learning (Hirsh-Pasek et al., 2015). To align with the *actively involved* principle, the game used second-person narration (e.g., "You are going on a space adventure") and a gender-neutral duck as a protagonist to encourage children to be part of the action. To align with the *engaged* principle, our game used attractive, colorful images but did not include extraneous hot spots or sound effects unrelated to the vocabulary. These can be entertaining but also distracting.

In the game, the child goes on a space mission to help aliens stuck in quicksand. Aligning with the *meaningful* principle, new vocabulary words were presented as meaningful parts of the narrative rather than being presented on a flashcard isolated from any context. For example, the protagonist is seen lying in a "hammock" and an alien who broke his leg is described as experiencing a "misfortune." Each word was presented at three separate times throughout the game. See Table 2 for examples for the word "hammock."

The first time the words were introduced, children heard the definition and were asked to repeat the word out loud (a pause in the narration allowed time for the child's response). After all words were introduced, there was a prompt for children to engage with the game contingently (i.e., "Tap the rocket ship when you're ready for blast off!"). Each word was then presented in a forced choice task, aligning with the *active involvement* principle by requiring the child to recall the definition, apply it to a new situation, and make a meaningful choice in the story context to answer correctly. For example, children had to find the image of a "coop" on a sign that indicated which road to take. The game did not advance until children provided a response. For each question, three images were presented, and children selected a response by tapping an image. Children were given three chances to provide a response and the game provided feedback contingent to their response (Kirkorian et al., 2016; Lauricella, Pempek, Barr, & Calvert,

Table 2. Description of game with examples of images and audio for the target word "hammock".

Exposure	Description	Example audio	Example image
Exposure 1	Word used in context of narrative, definition given, children asked to repeat word out loud	One afternoon, you were relaxing in your backyard on a hammock. A hammock is a bed made of cloth or rope that you can hang between two trees. Can you say hammock?	
Exposure 2	Question requires children to use knowledge of word meaning to move game forward	Find the woman laying on her hammock. She'll have a fuel nozzle for you!	
Exposure 3	Word is reviewed in context of reporting back to mission control	First, we found an old lady lying in a hammock who gave us a fuel nozzle.	

2010), aligning with the *contingent interactions* principle. If children were right on the first attempt, they heard an affirmation along with the definition of the word (e.g., "That's right! You found the coop, which is a house where chickens live"). After an initial incorrect answer, children heard the definition and were given another chance to respond (e.g., "Uh oh, that's not right. You need to find a coop, which is a house where chickens live. Try again!"). This type of scaffolded feedback is rare in commercially-available mobile games (Callaghan & Reich, 2018) and may support children's learning. After a second incorrect attempt, children were told to try again, and after a third incorrect attempt, children were provided with the correct answer before moving on to the next question. Finally, at the end of the game each word was reviewed as part of reporting back to mission control.

Receptive vocabulary measure. A receptive vocabulary measure targeting the 10 words taught in the game was designed for the study. A receptive measure was chosen over an expressive measure because it was quick, easy to administer, and enjoyable for children and because we thought that children might be hesitant to verbally define words they had only heard in one session of game play. The measure was administered on a tablet using an app created for this purpose. Children were first given the opportunity to respond to practice items. The words for these items were selected based on several data sources indicating that they are quite likely to be known by children in this age range (i.e., data from prior studies [Toub et al., 2018], word lists used to identify target words [Biemiller, 2010; Chall & Dale, 1995], data on infants' first words [Tardif et al., 2008], and piloting with children in this age range). On both the practice items and the test items, children had to select the target from four response images. Children heard each word twice – once prior to seeing the response images and then again immediately after the response images appeared. For the practice items, children were given generic feedback if they responded incorrectly (i.e., "Try again!"). To progress onto the test items, children had to respond to two practice items correctly on the first attempt. Most children (89%) responded to the first two practice items correctly; three children missed one practice item (two in the control condition and one in the game condition), two children missed two practice items (both in the game condition), and one child (in the control condition) missed three practice items. All children eventually answered two items correctly on the first attempt and continued on to the test. In the test items, children similarly heard each word once prior to seeing the response images and then again immediately after the response images appeared (See Figure 1). The app randomized the order of items for each child and randomized the placement of the target and foil images on the screen for each item. Two easy filler items were spaced evenly throughout the test to help maintain children's attention and motivation. Most children (82%) answered both filler items correctly; eight children missed one filler item (four in the control condition and four in the game condition) and one child (in the game condition) missed both filler items. No feedback was given for the test or filler items. Excluding children who missed more than two practice items or both filler items did not change the pattern of results.

Foil selection was guided by research on lexical development (e.g., Golinkoff et al., 1995) and included three meaningfully-related foils: thematic (frequently found in same event or situation, e.g., a window for the target word *awning*); conceptual (shares a common category, e.g., a beach umbrella for *awning*); and phonological (shares a similar sound or rhymes, e.g., yawning for *awning*). This measure was a stringent test of word learning, requiring children to 1) generalize beyond the game context as the picture used for test was not the same as the picture from the game; and 2) choose between meaningfully-related options, such that an incomplete understanding of the word's meaning would be revealed through the use of these purposefully close choices (Shirilla, et al., in preparation).

Results

Children who played the game answered a significantly higher proportion of test questions correctly (M = .54, SD = .22) than control group children who did not play the game (M = .25, SD = .16), t (54) = 6.1, p < .0001, d = 1.6 (see Figure 2). Children who played the game also answered a significantly higher proportion of questions correctly than would be expected by chance, t (33), p < .0001 d = 1.3, whereas children in the control group did not, p = 1.

Figure 1. Sample item for the receptive measure. Children could receive a maximum of 10 points.

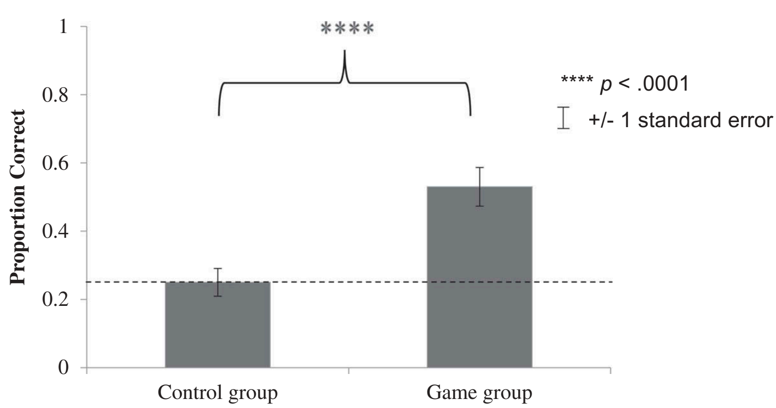

Figure 2. Proportion of words correct on receptive measure for control group compared to game group in Study 1. Note: the dashed line represents chance performance.

Additional exploratory analyses showed that the number of words for which children responded correctly on the first try in the game was correlated at trend level with the proportion of receptive questions they answered correctly (r = .47, p = .053), suggesting that children who performed better during the game also showed more evidence of learning afterwards.

Discussion

These results suggest that children can learn new vocabulary from a single bout of playing a mobile game. Further, the stringent nature of our learning measure suggests that children were able to generalize beyond the game context. This finding is important because children are spending increasingly large amounts of time with digital media, and many games marketed as educational have little or no research supporting their effectiveness. The current findings suggest that mobile games designed based on principles from the science of learning could play a role in supporting early vocabulary development.

However, because the test was immediately following the game, it is not clear whether learning would be retained over a longer period of time. Furthermore, children were from middle-SES backgrounds and may have more advanced language skills and more experience playing educational games and learning new vocabulary than children from under-resourced communities. Finally, the game was played in a quiet and minimally distracting environment, providing optimal learning circumstances, whereas children's everyday environments include many potential distractions from learning. Study 2 addresses these limitations by testing the game's effectiveness over a 4-week-long intervention with low-SES children in a preschool setting.

Study 2

Early childhood education settings have traditionally been slow to incorporate technology (Zevenbergen, 2007). Classrooms present unique challenges for learning from mobile games such as increased distraction from peers and having enough devices for all children. However, more recent data shows that over half of early childhood teachers use tablets in their classrooms at least once a week, but only one third know where to find developmentally appropriate content (Center on Media and Human Development, 2015). Research is needed to examine how high-quality mobile games can become more accessible to classroom teachers and how those apps might be incorporated into preschool classrooms in a way that can support teachers' curricular goals.

Method

Participants

As part of a larger study, participants were recruited from two low-SES preschool programs, one in Philadelphia and one in Nashville. Of the ten teachers recruited to participate in the larger study, one from each city was randomly assigned to use the mobile game in their classrooms. Within those two teachers' classrooms, 33 three- and four-year-old children participated (15 girls; M_{age} = 52.7 months, SD_{age} = 4.8 months). Based on parent report, the majority of the children were African-American (54.5%) and Hispanic (30.3%), with 6.0%

White, 3.0% Native American, and 6.0% other. Parents reported highest level of maternal education for all but two children: 32.2% some high school, 42.4% high school diploma or GED, 18.2% some college, 12.1% trade school or higher.

Procedure

Study design. To align with the larger study design (Hopkins et al., 2019), children played two versions of the same game: the Quicksand Rescue Mission from Study 1 and the Golden Eggs Mission, which had a different storyline about finding a chicken who lays golden eggs. Both versions included the five words that we focus on here (two verbs, two concrete nouns, and one abstract noun; see Table 1). Each version also taught five additional words that are not discussed here because they were also taught in storybook reading activities that were part of the larger study design, and thus, we cannot isolate the impact of the game on children's knowledge of those words. Otherwise, the two versions of the game were identical in design. Children saw each version of the game twice, so each of the five target words was encountered during four gaming sessions.

This study used a within-subjects design with pre- and post-testing to determine whether children could learn the words to which they were exposed. Because we did not have a control group of children who did not see the game, we included five no-exposure control words in this study. Children were tested on these words at pretest and posttest but had no exposure to them in between, so we did not expect children to learn them. Control words were drawn from the same pool of difficult words and were matched to the game words on difficulty, word type, and frequency in everyday speech using several data sources (Bååth, 2010, Biemiller, 2010; Chall & Dale, 1995). These no-exposure words provide a useful control for any natural learning gains that may occur on the target words across this period.

Classroom procedure. Teachers were asked to pull children from other classroom activities (e.g., center time and free play) to play the game individually once a week, for a total of four times across the four-week study period. Children played the game in a relatively secluded area facing away from the classroom and wore headphones. Children played the game independently; teachers were instructed to only help in the case of technical difficulties. The app was preloaded with children's names; teachers clicked on a child's name before game play and the app indicated which children had played by placing a star next to their name.

Measures. Experimenters administered both receptive and expressive vocabulary knowledge measures to each child at pre- and posttest. Notably, testing took place the week before and the week after the intervention period. Thus, in this study, the posttest was not conducted immediately after the final session of game play, representing a significant delay between game play and testing. Children were tested on twenty-five words in the testing session; we focus here on the five words that were taught in both versions of the game and the five no-exposure control words. Order of the receptive and expressive measures was randomly assigned at both pretest and posttest.

Receptive measure. Children were given the same receptive measure as in Study 1. Practice item data was missing for one site (20 children) at pre-test. Of the practice item data available, most children responded to the first two practice items correctly (62% at pretest, 81% at posttest). At pretest, three children missed one practice item and two children missed two practice items. At posttest, five children missed one practice item and one child missed seven practice items. Similarly, most children answered both of the easy filler items correctly (76% at pretest and 88% at posttest); at pretest, seven children missed one filler item and two children missed both, and at posttest, three children missed one filler item and one child missed both. Excluding children who missed more than two practice items or both filler items did not change the pattern of results.

Expressive measure. The expressive measure was adapted from Hadley et al.'s (2016) New Word Definition Test – Modified (NWDT–M) and was administered by a trained experimenter. The NWDT–M does not measure the extent to which children give adult-like definitions of words, but instead codes for the presence of various elements of semantic and contextual information that students provide for each word. The experimenter asked the child to define each word (i.e., "What does awning mean?"). Responses were then coded for the following *information unit categories*: perceptual features, superordinate/subordinate, functional information, part/whole, synonyms, antonym, gestures, meaningful context, and basic context. See Table 3 for examples and for more information see Hadley et al. (2016). The first four categories were used for concrete nouns only. The remaining categories were used for all word types. Three coders were trained to distinguish information units and allowed to code independently if they reached at least 90% reliability with a gold standard coder on a set of five tests. If a coder did not reach 90% reliability, they were given feedback and the process was repeated. Throughout coding, the gold standard coder coded every fifth test. If reliability was below 90%, all disagreements were discussed until agreement was reached and prior to the research assistant continuing independent coding. Analyses were conducted using a binary variable where a word was scored as correct if children provided at least one information unit. Two pseudo-randomly-created word orders were created; one version was used for all children at pretest and the other was used for all children at posttest.

Table 3. Examples of expressive measure coding.

Information unit category	Description	Example
Perceptual feature (concrete nouns only)	How the target looks, smells, tastes, feels, or sounds	Knoll: "It's small"
Superordinate/ subordinate (concrete nouns only)	Naming a larger category of which the target is a member or naming a memory of a category when the target word is the category	Spade: "It's a shovel."
Functional information (concrete nouns only)	Any process, purpose or use of the target	Spade: "You can shovel with it."
Part/whole (concrete nouns only)	Describes a distinct part of the target or describes the whole that the target is part of	Spade: "It has a handle."
Synonyms	Any word or phrase that is equivalent to the target	Weeping: "Crying"
Antonym	A word that is the opposite of the target, plus "not" or other negating word	Devouring: "Not eating slow"
Gesture	A gesture, action, or facial expressive that shows knowledge of word meaning	Devouring: *Child mimes quickly moving food to their mouth and chewing.*
Meaningful context	A longer phrase that uses detailed, meaningful context to explain the target	Misfortune: "It was a misfortune when my toy broke."
Basic context (.5 points)	Uses minimal context/typical association but shows little to no understanding of word meaning	Knoll: "There was a grassy knoll."

Results

Receptive test

First, we conducted a mixed effects logistic regression model predicting correct responses on the receptive measure at the trial level from session (pre/post) and word type (target/no-exposure) controlling for age at pretest and including random intercepts for subjects nested within sites (or classrooms given that one classroom at each site used the game). There was a significant interaction between session and word type showing the gain from pretest to posttest was significantly larger for target words (odd ratio post/pre = 2.56) than for the no-exposure control words (odds ratio post/pre = 1.1), $B = 0.50$, $p = .01$ (see Figure 3). To further examine the change from pre- to posttest on target words, we conducted a similar model predicting correct responses on target words only. Significant gains for target words were observed on the receptive vocabulary measure from pre-test ($M = 0.18$, $SD = 0.39$) to post-test ($M = 0.38$, $SD = 0.49$), $B = 0.53$, $p < .0001$.

Expressive test

We could not examine the interaction between session and word type on the expressive test because no children answered any control words correctly at pre-test. Instead, we examined the simple gains for each word type separately. We conducted a mixed effects logistic regression model predicting correct responses on target words from session (pre/post) controlling for age at pretest and including random intercepts for subjects nested within sites. Significant gains were observed from pre-test ($M = 0.02$, $SD = 0.15$) to post-test ($M = 0.16$, $SD = 0.36$), $B = 1.26$, $p < .001$. The parallel analysis for control words showed that children did not show substantial improvement for control words from pre-test ($M = 0$) to post-test ($M = 0.006$, $SD = 0.08$), (see Figure 4).

Discussion

These findings suggest that learning from a mobile game is not limited to exposure in a controlled lab environment but can occur in the potentially distracting setting of

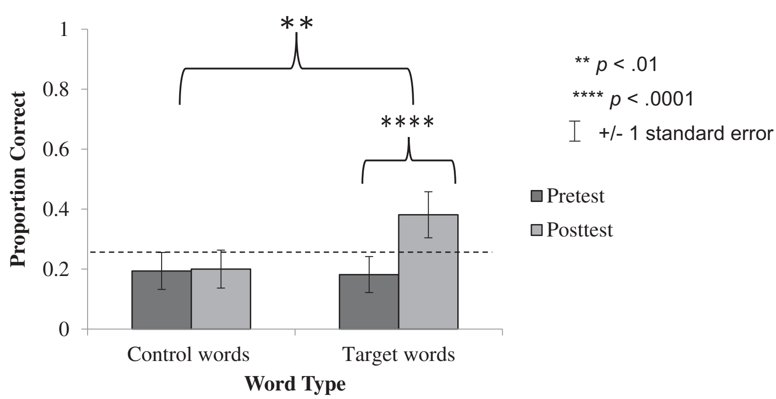

Figure 3. Proportion of control and target words correct on receptive test at pre-test and post-test in Study 2. Note: the dashed line represents chance performance (25%).

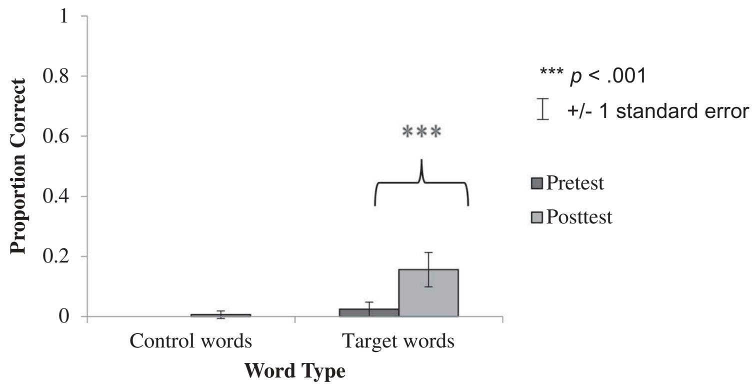

Figure 4. Proportion of control and play-only words correct on expressive test at pre-test and post-test in Study 2.

a preschool classroom. Strikingly, these differences emerged despite the week-long delay between game play and posttests. Furthermore, these findings extended beyond receptive knowledge to children's expressive knowledge of the words' meanings.

General discussion

Can preschool-age children learn new vocabulary from mobile games? Despite the prevalence of these games in the marketplace and in children's lives (Common Sense Media, 2017), there is remarkably little research to inform our understanding of how children may learn new word meanings through game play on mobile devices. The current data suggest that mobile games can be used to support preschoolers' vocabulary. This finding could have important implications, especially for children from low-SES populations who are likely to have slower language development than their middle- and upper-SES peers (Hart & Risley, 1995; Golinkoff et al., 2018). Because children from lower-SES homes are likely to spend more time with media than children from middle-SES households (Common Sense Media, 2017), using mobile games to support vocabulary development during their screen time represents an exciting educational opportunity and a chance to reduce the gap in early literacy and school readiness.

Primary findings

The mobile game created here was designed according to the principles of learning science (Hirsh-Pasek et al., 2015). Many mobile games for preschoolers purport to be educational (Shuler et al., 2012; Vaala et al., 2015), but research on their effectiveness lags behind their rapid adoption. Although this study is an early step in investigating the role of mobile games in vocabulary instruction, the current results demonstrate that mobile games have the potential to effectively promote vocabulary learning when they are designed based on principles from the science of learning.

These findings provide causal evidence that children can learn vocabulary from a mobile game. In Study 1, middle-SES children showed evidence of learning after a single session of game play, compared to children in a control group with no exposure to the game. In both studies, preschoolers played the game without adult support and never heard the words outside of the game, indicating that word learning occurred in response to the game itself. These findings are novel because even the limited previous research in this domain often focused on traditional computer games rather than games played on mobile devices (Michael Cohen Group, 2010; Schmitt et al., 2018), which are now much more prevalent in children's lives (Common Sense Media, 2017). Furthermore, some previous studies demonstrating word learning from mobile devices have used simple apps and novel object labels (Kirkorian et al., 2016; Russo-Johnson et al., 2017), whereas the current study shows that children can learn a wider variety of words from a narrative-based mobile game that is more representative of games likely to be played in children's everyday lives.

Study 2 found evidence of learning even in the naturalistic environment of a preschool classroom and at a week delay. There are many challenges to incorporating educational digital media into school contexts. Teachers may not have access to technology and also have many different priorities competing for their attention. Although mobile games can be played independently, teachers are responsible for overseeing children's time on the device and ensuring that each child gets an opportunity to play. In our study, participation data was captured for one classroom, and all students played the game four times as instructed by the intervention protocol, suggesting that teachers seemed to effectively incorporate mobile game play into their classroom, at least when provided with the technology in the context of a structured intervention.

Additionally, compared to studies conducted in the lab, schools have the potential for more distraction from peers and other activities in the classroom. When children are exposed to a mobile game in this environment, there might be reduced attention, leading to lower levels of learning. The current results go beyond prior research focused on home settings, suggesting that children can learn from mobile games in the classroom, despite these challenges. Note that having children wear headphones may be an important factor in mitigating distractions.

Another novel aspect of the current studies is that unlike prior studies using simple recognition measures of vocabulary (Kirkorian et al., 2016; Michael Cohen Group, 2013; Russo-Johnson et al., 2017), we found gains on a stringent measure of receptive vocabulary designed to require children to have deeper understanding of the word meaning (Shirilla, et al., in preparation) and on an expressive measure of vocabulary requiring children to produce, rather than simply recognize, information about the word. By using these rigorous measures, we demonstrate that children's knowledge gains are more meaningful than superficially associating a word with a specific object or a general context, suggesting that mobile games can engender deeper knowledge of word meanings.

Implications

That children demonstrated vocabulary learning from a mobile game in both studies suggests that parents and educators could capitalize on children's attraction to digital media devices for positive effects. In addition to the rapid integration of these devices into children's lives (Common Sense Media, 2017) and recent data suggesting that children are more engaged with digital than traditional media (Lauricella, Barr, & Calvert, 2014; Richter & Courage, 2017), we saw that, anecdotally, children liked the game used in the current studies, appeared highly engaged during game play, and often asked to play it again. Given that engagement and interest are necessary for learning, children's interest in digital devices might be effectively harnessed to support learning.

Vocabulary, in particular, is an important domain that could benefit from effective mobile games, given the disparities between low-SES and middle-SES children's language skills and home language environments (Durham et al., 2007; Huttenlocher et al., 2010) and the importance of vocabulary knowledge to children's later literacy and reading skills (Dickinson & Porche, 2011; Golinkoff, Hoff, Rowe, Tamis-LeMonda, & Hirsh-Pasek, 2019; Pace et al., 2019). Although screen media should not replace book reading with caring adults (Dore, Hassinger-Das, et al., 2018), children can benefit if we capitalize on the time they are already spending with these devices to support important skills.

Mobile games in which children make responses have several advantages over passive consumption of media like television. Although the current studies did not compare learning from the game to passive exposure, principles from the science of learning suggest that children learn best when they are active rather than passive and when they have to mentally manipulate ideas (Hirsh-Pasek et al., 2015). Further, because mobile games require children to respond to questions or activities, the games also have the potential to give adults feedback about children's progress. For example, teachers could receive an email with performance information, indicating which children need more support and which words children are struggling to learn.

Limitations and future directions

The current studies have several limitations. First, a relatively small number of words were taught. Future research should examine the potential of mobile games to support learning larger numbers of words. Second, Study 2 used a within-subjects design and could not assess how well children would have learned the words from other types of instruction. Furthermore, although in Study 2 children retained their knowledge of word meanings after a week delay, future research should determine whether gains remain over a longer time period. Additionally, because the experimenter or teacher asked children to play the game, children may have experienced some extrinisic motivation that would not be present in a more naturalistic context. Current research in our lab is investigating whether children will also learn from the game in the home environment, where it may compete for time and attention with other enticing game options.

Although we show significant gains on both measures of word learning used in Study 2, children did not reach ceiling levels of word knowledge on the receptive test and expressive scores were fairly low. However, children played the game only four times across the four-week intervention; larger effects may have been observed with a higher dosage. Future research should investigate how different levels of dosage, as well as different spacing schedules, would influence children's word learning. Regardless, the effect sizes we obtained (posttest target vs. control words: d = 1.37), are consistent with book reading interventions (Mol, Bus, & de Jong, 2009).

Relatedly, although this game was designed based on principles from learning science, these principles could translate into mobile games in a variety of ways and we did not test different game features individually. For example, we chose to use a fantastical context because children find fantasy engaging and motivating (Parker &

Lepper, 1992) and some evidence suggests that fantasy contexts may promote vocabulary learning relative tp realistic contexts (Weisberg et al., 2015). However, other research suggests that fantastical contexts might limit children's transfer of information from fiction to reality (Richert & Smith, 2011; Walker, Gopnik, & Ganea, 2015). Similarly, games might be more effective if the words being taught were more thematically-related and game creators could create a more coherent and meaningful relationship between to-be-learned information and the surrounding narrative (Gunter, Kenny, & Vick, 2008). Indeed, interventions using thematically-related words have been effective in prior research (e.g., Neuman & Dwyer, 2011). Future research might compare children's learning from games with different features such as fantasy content, thematically-related words, narrative structure, second-person narration, and anthropomorphized animal characters.

The current studies tested children's learning from playing a mobile game independently, but children may learn better during joint media engagement with an adult (Dore, Hassinger-Das, et al., 2018; Takeuchi & Stevens, 2011). Similarly, children may benefit more from the game if they play in dyads, as recent research shows that even infants learn language better in the presence of a peer (Lytle, Garcia-Sierra, & Kuhl, 2018). Studies should investigate whether children would show even stronger learning after engaging with a social partner during gameplay.

Further, these studies investigated children's learning of vocabulary that they only heard in the game. However, mobile games could also be used as a supplement to other classroom learning activities (Brittain et al., 2019; Piotrowski, Jennings, & Linebarger, 2012). For example, a teacher could play a board game supporting vocabulary learning with a small group of children while one or more children play the mobile game independently to prepare for small group instruction or to review their learning. Similarly, mobile games could promote engagement with educational materials outside of school. Such a practice could be especially valuable for low-SES families who are less likely to have a rich home language environment (Huttenlocher et al., 2010). Future research should test the effectiveness of using mobile games in the classroom and at home to supplement teacher-led instruction.

Conclusions

The current findings suggest that despite concerns about screen time, digital media can be used effectively to promote educational aims in young children, especially if media are constructed according to science of learning principles (Hirsh-Pasek et al., 2015). Given children's increasing access and exposure to these devices, an indication of their potential for learning is promising, especially for children from low-SES families. However, the effectiveness of one game does not indicate that all educational games are beneficial. The current studies demonstrate that apps can be designed to promote learning but, as very few apps labeled as "educational" are supported by research (Vaala et al., 2015), we do not know how far an app can deviate from learning principles and still be effective.

It is challenging for researchers to keep up with the seemingly infinite number of games available and the rapid pace of development (i.e., both new games and new technology such as virtual reality). Continuing to test the effectiveness of generalizable game elements, such as the four principles from the science of learning, may help establish guideposts for developers to utilize when designing effective games. It will also be important for researchers and media creators to bridge the industry-academia gap to ensure that new technologies are developed with these principles in mind (Dore, Shirilla, et al., 2018). Furthermore, this research does not address the problem of games being deceptively marketed as "educational". Researchers should consider possible mechanisms for encouraging transparency and rigor in marketing educational apps to children and families. For the interested reader, several researchers have discussed how parents and educators could use research-based principles to evaluate educational apps (Hirsh-Pasek et al., 2015; Papadakis, Kalogiannakis, and Zaranis, 2017). Common Sense Media (www.commonsensemedia.org) also includes an evaluation of apps' educational potential in their reviews.

One thing is certain: children's use of digital technology is continuing to rise. Children from low-SES households may benefit from high-quality educational mobile games, given lower levels of home language resources (Huttenlocher et al., 2010) and higher levels of media use (Common Sense Media, 2017). Though nothing will replace human interactions, researchers may discover that mobile games could support learning across a variety of domains.

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References

Bååth, R. (2010). ChildFreq: An online tool to explore word frequencies in child language. *LUCS Minor*, *16*, 1–6.

Beck, I. L., & McKeown, M. G. (2007). Increasing young low-income children's oral vocabulary repertoires through rich and focused instruction. *Elementary School Journal*, *107*, 251–271.

Biemiller, A. (2010). *Words worth teaching: Closing the vocabulary gap*. Columbus, OH: SRA/ McGraw-Hill.

Brittain, L., Crawford, J. B., Schapiro, S., Paratore, J. R., Salinas, A., O'Brien, L., & Blodgett, S. D. (2019). Building learning pathways and community for early childhood educators. In S. Pasnik (Ed.), *Getting ready to learn: Creating effective, educational children's media* (pp. 45–60). New York: Routledge.

Callaghan, M. N., & Reich, S. M. (2018). Are educational preschool apps designed to teach? An analysis of the app market. *Learning, Media and Technology*, *43*(3), 280–293.

Center on Media and Human Development. (2015). *Technology in the lives of educators and early childhood programs: Trends in access, use, and professional development from 2012 to 2014*. http://www.fredrogerscenter.org/wp-content/uploads/2015/07/Blackwell-Wartella-Lauricella-Robb-Tech-in-the-Lives-of-Educators-and-Early-Childhood-Programs.pdf

Chall, J. S., & Dale, E. (1995). *Readability revisited: The new Dale-Chall readability formula*. Brookline: Brookline Books.

Chiong, C., & Shuler, C. (2010). Pbs kids ipod app study findings and outcomes. A report prepared for PBS KIDS. Bloomington, IN.

Common Sense Media. (2017). *The common sense census: Media use by kids age zero to eight*. Retrieved from https://www.commonsensemedia.org/sites/default/files/uploads/research/csm_zerotoeight_fullreport_release_2.pdf

Dickinson, D. K., St. Pierre, R. B., & Pettengill, J. (2004). High-quality classrooms: A key ingredient to family literacy programs' support for children's literacy. In B. Wasik (Ed.), *Handbook of family literacy* (pp. 137–154). Mahwah, NJ: Lawrence Erlbaum Associates.

Dickinson, D. K., & Porche, M. V. (2011). Relation between language experiences in preschool classrooms and children's kindergarten and fourth-grade language and reading abilities. *Child Development*, *82*, 870–886.

Dore, R. A., Hassinger-Das, B., Brezack, N., Valladares, T., Paller, A., Vu, L., … Hirsh-Pasek, K. (2018). The parent advantage in fostering children's e- book comprehension. *Early Childhood Research Quarterly*, *44*, 24–33.

Dore, R. A., Shirilla, M., Verdine, B., Zimmermann, L., Golinkoff, R. M., & Hirsh-Pasek, K. (2018). Developer meets developmentalist: Improving industry–Research partnerships in children's educational technology. *Journal of Children and Media*, *12*, 227–235.

Durham, R. E., Farkas, G., Hammer, C. S., Tomblin, J. B., & Catts, H. W. (2007). Kindergarten oral language skill: A key variable in the intergenerational transmission of socioeconomic status. *Research in Social Stratification and Mobility*, *25*(4), 294–305.

Golinkoff, R. M., Hoff, E., Rowe, M. L., Tamis-LeMonda, C. S., & Hirsh-Pasek, K. (2019). Language matters: Denying the existence of the 30-million-word gap has serious consequences. *Child Development*, *90*(3), 985–992.

Golinkoff, R. M., Shuff-Bailey, M., Olguin, R., & Ruan, W. (1995). Young children extend novel words at the basic level: Evidence for the principle of categorical scope. *Developmental Psychology*, *31* (3), 494.

Gunter, G. A., Kenny, R. F., & Vick, E. H. (2008). Taking educational games seriously: Using the RETAIN model to design endogenous fantasy into standalone educational games. *Educational Technology Research and Development*, *56*(5–6), 511–537.

Hadley, E. B., Dickinson, D. K., Hirsh-Pasek, K., Golinkoff, R. M., & Nesbitt, K. T. (2016). Examining the acquisition of vocabulary knowledge depth among preschool students. *Reading Research Quarterly*, *51*(2), 181–198.

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore, MD: Paul H Brookes Publishing.

Hirsh-Pasek, K., Zosh, J. M., Golinkoff, R. M., Gray, J. H., Robb, M. B., & Kaufman, J. (2015). Putting education in "educational" apps: Lessons form the science of learning. *Psychological Science in the Public Interest*, *16*(1), 3–34.

Hoff, E. (2013). Interpreting the early language trajectories of children from low-SES and language minority homes: Implications for closing achievement gaps. *Developmental Psychology*, *49*(1), 4–14.

Hopkins, E. J., Collins, M. F., Dore, R. A., Lawson-Adams, J. R., Scott, M. E., Shirilla, M. L., … Hirsh-Pasek, K. (2019). *Playtime is learning time: Young children learn new vocabulary through play*. Manuscript submitted for publication.

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology*, *61*, 343–365.

Kirkorian, H. L., Choi, K., & Pempek, T. A. (2016). Toddlers' word learning from contingent and noncontingent video on touch screens. *Child Development*, *87*, 405–413.

Lauricella, A. R., Barr, R., & Calvert, S. L. (2014). Parent–Child interactions during traditional and computer storybook reading for children's comprehension: Implications for electronic storybook design. *International Journal of Child-Computer Interaction*, *2*, 17–25.

Lauricella, A. R., Pempek, T. A., Barr, R., & Calvert, S. L. (2010). Contingent computer interactions for young children's object retrieval success. *Journal of Applied Developmental Psychology*, *31*, 362–369.

Lytle, S. R., Garcia-Sierra, A., & Kuhl, P. K. (2018). Two are better than one: Infant language learning from video improves in the presence of peers. *Proceedings of the National Academy of Sciences*, *115*, 9859–9866.

Michael Cohen Group. (2010). *Summative evaluation of the educational effectiveness of Mission to Planet 429*. New York, NY: Author.

Michael Cohen Group. (2013). *Effects of interaction with Pocoyo PlaySets on preschool (Spanish) ELL children's English language learning: A randomized controlled trial*. New York, NY: Author.

Mol, S. E., Bus, A. G., & de Jong, M. T. (2009). Interactive book reading in early education: A tool to stimulate print knowledge as well as oral language. *Review of Educational Research*, *79*(2), 979–1007.

Muter, V., Hulme, C., Snowling, M. J., & Stevenson, J. (2004). Phonemes, rimes, vocabulary, and grammatical skills as foundations of early reading development: Evidence from a longitudinal study. *Developmental Psychology*, *40*, 665–681.

Neuman, S. B., & Dwyer, J. (2011). Developing vocabulary and conceptual knowledge for low-income preschoolers: A design experiment. *Journal of Literacy Research*, *43*(2), 103–129.

NICHD ECCRN. (2005). Pathways to reading: The role of oral language in the transition to reading. *Developmental Psychology*, *41*(2), 428–442.
Pace, A., Alper, R., Burchinal, M. R., Golinkoff, R. M., & Hirsh-Pasek, K. (2019). Measuring success: Within and cross-domain predictors of academic and social trajectories in elementary school. *Early Childhood Research Quarterly*, *46*, 112–125.
Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2017). Designing and creating an educational app rubric for preschool teachers. *Education and Information Technologies*, *22*(6), 3147–3165.
Parish-Morris, J., Mahajan, N., Hirsh-Pasek, K., Golinkoff, R. M., & Collins, M. F. (2013). Once upon a time: Parent-child dialogue and storybook reading in the electronic era. *Mind, Brain, and Education*, *7*(3), 200–211.
Parker, L. E., & Lepper, M. R. (1992). Effects of fantasy contexts on children's learning and motivation: Making learning more fun. *Journal of Personality and Social Psychology*, *62*(4), 625–633.
Piotrowski, J. T., Jennings, N. A., & Linebarger, D. L. (2012). Extending the lessons of educational television with young American children. *Journal of Children and Media*, *7*(2), 216–234.
Reardon, S. F. (2013). The widening income achievement gap. *Educational Leadership*, *70*(8), 10–16.
Richert, R. A., & Smith, E. I. (2011). Preschoolers' quarantining of fantasy stories. *Child Development*, *82*(4), 1106–1119.
Richter, A., & Courage, M. L. (2017). Comparing electronic and paper storybooks for preschoolers: Attention, engagement, and recall. *Journal of Applied Developmental Psychology*, *48*, 92–102.
Russo-Johnson, C., Troseth, G., Duncan, C., & Mesghina, A. (2017). All tapped out: Touchscreen interactivity and young children's word learning. *Frontiers in Psychology*, *8*, 578.
Schmitt, K. L., Hurwitz, L. B., Duel, L. S., & Linebarger, D. L. (2018). Learning through play: The impact of web-based games on early literacy development. *Computers in Human Behavior*, *81*, 378–389.
Shuler, C., Levine, Z., & Ree, J. (2012). *iLearn II: An analysis of the educational category of Apple's app store*. Joan Ganz Cooney Center. Retrieved from www.joanganzcooneycenter.org
Storch, S. A., & Whitehurst, G. J. (2002). Oral language and code-related precursors to reading: Evidence from a longitudinal structural model. *Developmental Psychology*, *38*(6), 934–947.
Strouse, G. A., & Ganea, P. A. (2017). Toddlers' word learning and transfer from electronic and print books. *Journal of Experimental Child Psychology*, *156*, 129–142.
Takeuchi, L., & Stevens, R. (2011, December). *The new coviewing: Designing for learning through joint media engagement*. New York: The Joan Ganz Cooney Center at Sesame Workshop.
Tardif, T., Fletcher, P., Liang, W., Zhang, Z., Kaciroti, N., & Marchman, V. A. (2008). Baby's first 10 words. *Developmental Psychology*, *44*(4), 929–938.
Toub, T. S., Hassinger-Das, B., Turner Nesbitt, K., Ilgaz, H., Skolnick Weisberg, D., Hirsh-Pasek, K., … Dickinson, D. K. (2018). The language of play: Developing preschool vocabulary through play following shared book-reading. *Early Childhood Research Quarterly*, *45*, 1–17.
Vaala, S., Ly, A., & Levine, M. H. (2015). Getting a read on the app stores: A market scan and analysis of children's literacy apps. The Joan Ganz Cooney Center at Sesame Workshop. Retrieved from http://www.joanganzcooneycenter.org/wpcontent/uploads/2015/12/jgcc_gettingaread_exec.pdf
von Hippel, P. T., & Hamrock, C. (2016). Do test score gaps grow before, during, or between the school years? Measurement artifacts and what we can know in spite of them. *Social Science Research Network*. doi:10.2139/ssrn.2745527
Walker, C. M., Gopnik, A., & Ganea, P. A. (2015). Learning to learn from stories: Children's developing sensitivity to the causal structure of fictional worlds. *Child Development*, *86*(1), 310–318.
Weisberg, D. S., Ilgaz, H., Hirsh-Pasek, K., Golinkoff, R., Nicolopoulou, A., & Dickinson, D. K. (2015). Shovels and swords: How realistic and fantastical themes affect childrens word learning. *Cognitive Development*, *35*, 1–14.
Zevenbergen, R. (2007). Digital natives come to preschool: implications for early childhood practice. *Contemporary Issues in Early Childhood*, *8*(1), 19–29.