Using Escribo Play Video Games to Improve Phonological Awareness, Early Reading and Writing in Preschool

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Escribo Inovação para o Aprendizado

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DISCLOSURE: In some situations, the results of this study may lead to a financial gain for the first author. This financial interest has been reviewed in keeping with Johns Hopkins' policies. It has been approved with certain conditions, which are intended to guard against bias and to protect participants. No other coauthors had any conflicts of interest.

Abstract

The increased use of smartphones and tablets sets the stage for new mobile-based educational programs that seek to increase student learning and engagement, in the school and at home. This study examines the effectiveness of Escribo Play, a game-enhanced educational program, on preschool students' phonological awareness, word reading, and writing skills. The randomized controlled trial was conducted with 749 students from 62 classrooms from 17 schools located in five cities. Quantitative pre- and post-testing procedures using standardized instruments were employed. The results indicate that the experimental classrooms which used the 20 games for three months gained 68% in their reading scores than control classrooms (d = .40). They also gained 48% more in the writing scores (d = .20). Multilevel analysis indicated that these findings were statistically significant.

Keywords: early literacy, reading, educational technology, phonological awareness, educational games

The low levels of literacy achievement are one of the most relevant challenges faced by low-income children in many countries. In Brazil, 50% of the third-grade public school students do not meet the national reading and writing standards (Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira, 2017). Prior research established that language and reading skills in preschool and kindergarten are strongly correlated to reading achievement in the first and second grades (Catts, Fey, Zhang, & Tomblin, 2001; Duncan et al., 2007; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). For example, verbal skills in kindergarten are also significant predictors of reading achievement in fourth-grade (Kurdek & Sinclair, 2001). These results indicate that improving literacy skills in preschool and kindergarten may contribute to students' later reading achievement.

An essential component of effective preschool and kindergarten programs is the instruction of phonological awareness - PA (Chambers, Cheung, & Slavin, 2016). Unfortunately, most of Brazilian schools do not yet provide PA instruction (Morais, 2012). Nevertheless, the first Brazilian common core, which will be in effect in 2020, requires PA instruction (Ministério da Educação, 2018).

Complementary evidence has suggested that PA programs applied in early childhood education have lasting effects on word recognition skills as well as reading comprehension skills, even in the final years of elementary (Kjeldsen, Kärnä, Niemi, Olofsson, & Witting, 2014). Previous studies have found that small-group PA instruction generated higher gains in reading skills than whole-class and individual instruction (Cheung & Slavin, 2013; Ehri et al., 2001). Unfortunately, differentiating instruction and conducting small-group activities becomes extremely difficult in early childhood centers with child-staff ratios that can be as high as 1 to 14.5 (Perlman et al., 2017). Given such context, developers of technology-enhanced programs

have been trying to provide means to facilitate differential and individualized instruction (Pokorni, Worthington, & Jamison, 2004).

The first era of technology-enhanced PA programs sought to assist students in building their PA, reading and writing skills (Cheung & Slavin, 2013). Although many endeavors were developed from the mid-1990 decade until 2010 employing computer-based multimedia applications, many early grade students in this period coming from low-income families were not familiar with computers. These children first had to master basic technological skills, such as how to control the mouse, so that later they could try to benefit from computer-assisted instruction.

Today we are living in a new technological scenario. Mobile devices such as smartphones and tablets are more intuitive and easy to use with their touchscreen interfaces. Children are using mobile devices early in their development, spending an average of 58 minutes per day when they are between two and four-years old (Common Sense Media, 2017). As of 2018, inexpensive mobile devices and quality tablets can be found for as low as USD 50. Smartphone penetration in low-income families is growing in developing countries like Brazil, where 77% of the inhabitants over 10 years old have a smartphone (Instituto Brasileiro de Geografia e Estatística, 2018). The widespread dissemination of mobile technology sets the stage for new mobile-based instructional programs that seek to increase student learning and engagement, at home and in the school.

The present study is part of a larger project which included the conceptualization, design, and development of a game-enhanced instructional program. The program was created to be used by preschool and kindergarten teachers and students to foster the development of their PA, reading and writing skills. The program was developed using research-based evidence from the fields of language development, instructional design, and video game design. This study examines the effectiveness of this newly developed game-enhanced program on preschool students' PA,

word reading, and writing skills using a randomized controlled trial. We employed inexpensive tablets that ran offline to maximize the number of schools which could afford to receive the intervention.

Literature Review

This work was built on the evidence that PA is a key component of reading development, and that PA instruction can benefit four and five-year-old students to build their word-reading and word-writing skills (Bus & van IJzendoorn, 1999; Chambers et al., 2016; Ehri et al., 2001). We examined previous PA intervention research to identify the instructional programs which generated the higher effect sizes in PA, word reading and writing skills. Our focus was to identify the key components of the most effective programs such as the specific PA activities, the weekly and total hours of instruction seeking to build an instructional program which could assist teachers to conduct small-group instruction capable of building student's PA, word reading and word writing skills.

Ball and Blachman (1991) found that phoneme awareness training that included letter-sound correspondences significantly enhanced early reading and spelling. A meta-analysis of 52 studies also indicated that phonemic awareness instruction had a moderate impact on reading (d = 0.53) and spelling (d = 0.59) for students from kindergarten to sixth grade (Ehri et al., 2001). Phonemic awareness was found to be the strongest predictor of reading achievement (Høien, Lundberg, Stanovich, & Bjaalid, 1995), but PA also includes syllabic and rhyming skills.

Bus and van Ijzendoorn (1999) developed a meta-analysis of 32 PA training studies and identified that the impact of PA on reading achievement was substantial (d = 0.70, r = .33, N = 745). The authors also argued that preschoolers benefit more from PA programs than kindergarten or primary school students. The results of this body of research point to the importance of PA and

the effectiveness of instructional programs that foster its development in the early grades.

A computer-based intervention can be used to address the various components of PA (Piquette, Savage, & Abrami, 2014; Segers & Verhoeven, 2005). Applications can develop syllabic, rhyming and phonemic awareness (Dias, 2006). Interventions that combine PA with letter-sound correspondence instruction were found to be more effective than interventions that only delivered PA without printed letters and texts (Bus & van IJzendoorn, 1999).

Another aspect of computer-based PA interventions regards the pitch, speed, and transitions of the speech. Segers and Verhoeven (2004) found no significant results for instruction with reduced speech rate and enhanced transitions. One implication of this research is that computer-based instruction shall employ natural oral language rather than computer synthetic voices.

Cheung and Slavin (2013) reviewed 20 randomized and quasi-experimental studies that involved 7,000 children to evaluate the impact of using technological applications and electronic tools developed to provide content and foster learning such as computer aided instruction (CAI), video, multimedia content, and integrated learning systems. Their results indicated a small beneficial effect size (d = .14) coming from the adoption of technology when compared with traditional reading interventions. Nevertheless, tutorial applications which are integrated with the curriculum and used by small-groups of students generated the strongest benefits (d = .32). The authors also found evidence that individual instructional programs were more effective for struggling students. Studies that focused on primary grade students had larger effects (d = .36) than those targeted to upper elementary grades (d = .07), which reinforces the focus on providing PA activities to younger students in preschool and kindergarten.

Cheung and Slavin's (2013) meta-analysis found that high-intensity programs that

included more than 75 minutes of instruction per week (d = .19) yielded larger benefits than low-intensity programs (d =.08). This finding was not statistically significant due to low statistical power ($Q_B = 1.20$, $p < .27$), but suggests that computer-based interventions shall provide an intense dosage of instructional activities. Based on the parameters identified in previous research that generated larger gains in PA, reading, and writing, an intervention was designed to provide two sessions of 45-minutes of instruction per week employing digital games, during 10 weeks.

Other kinds of technology-enhanced interventions were found to be beneficial for early literacy development. A meta-analysis of 43 papers involving 2,147 students identified that technology-enhanced stories were beneficial for story comprehension (g+ = 0.17) and expressive vocabulary (g+ = 0.20) (Takacs, Swart, & Bus, 2015). Another meta-analysis of 122 studies assessed the influence of technology applications on elementary students learning and identified significant gains in language (ES = 0.44) and other subjects (Chauhan, 2017). Digital games were found to improve reading for second grade poor readers (Gorp, Segers, & Verhoeven, 2017) and for children with Down syndrome (Felix, Mena, Ostos, & Maestre, 2017). Moreover, evidence suggests that digital games can be beneficial for second language learners (Zhang, 2018) and that pre-service teachers see game-based learning as a positive approach for reading and writing instruction (Karadag, 2015).

While there is evidence about the effectiveness educational technologies for PA, reading and writing instruction, an effective program which employs mobile games to increase learning in early childhood education is yet to be developed and studied. To address such gap we created Escribo Play, an evidence-based gamified early literacy program, compatible with inexpensive mobile devices, which has the potential to improve teaching and learning. This study seeks to explore the following hypothesis:

Hypothesis 1: Children studying with Escribo Play will display improved PA skills when compared to the students which were only exposed to the regular instructional strategies employed by the schools.

Hypothesis 2: Children studying with Escribo Play will display improved word reading ability when compared to the students only exposed to the regular instructional strategies employed by the schools.

Hypothesis 3: Children studying with Escribo Play will display improved word writing ability when compared to the students only exposed to the regular instructional strategies employed by the schools.

Method

A cluster randomized controlled trial was conducted to evaluate how the effects of program manifested in students PA, word reading and word writing skills (Shadish, Cook, & Campbell, 2002). The project employed a design with experimental and control groups with pre- and post-tests. We randomized at the classroom-level, not at the student-level, to reduce the risk of contamination between students within the same classroom (Pierre, 2004; Shadish et al., 2002; Torgerson, Torgerson, & Taylor, 2015). Figure 1 displays the design of the study.

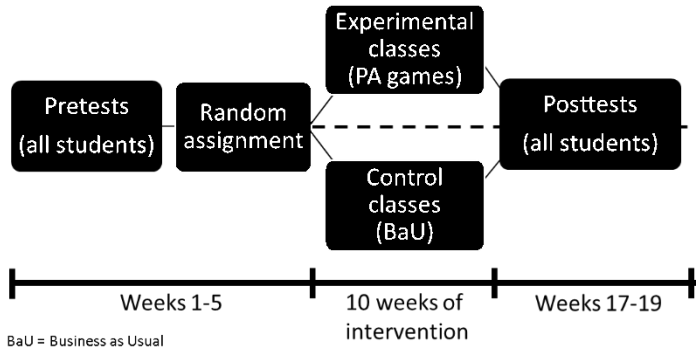

Figure 1. *Study design.*

Participants

We conducted the study in the metropolitan area of Fumaça (pseudonym). The city, located in the northeast region of Brazil, has 30,591 four- and five-year-old children in 678 schools (Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira, 2016). All students in Brazil speak Portuguese and the games were developed in Portuguese. Within this population, 448 private schools had decision autonomy to participate in research.

We sent invitation letters to 25 private schools which would probably have the proper technological resources and autonomy to fit the intervention into their academic plan. The list of schools was provided by a local company that had visited 365 institutions in 2016 and assessed their resources. The first author met each school principal to explain the research goals and procedures.

A total of 17 schools agreed to participate in the study. Together, they had 1,089 students in the four-year-old grade. The research team delivered study packets to each school that included an invitation letter and a consent form for each student/parent. Beyond the contact information, the consent form asked parents' educational attainment. The packets were delivered to the schools in the first days of August of 2017 when the second semester of the Brazilian academic year starts. Two weeks after we delivered the letters, we asked the schools to send a friendly reminder about the deadline and we received a total of 749 signed consent forms from the families. While in Brazil only 15% of the citizens attended higher education (OECD, 2015), our sample had 93.9% of the parents in this category, suggesting that the families were high-achievers. The supplementary Table S2 presents the sample composition details.

After finishing the pretests, we conducted a cluster randomization procedure to assign its units, the classrooms, to the control and experimental groups (Torgerson et al., 2015). The goal

was to allocate half of the 62 classrooms to each group. During the randomization, four classrooms which were assigned to experimental group had to be converted to control group because the classrooms had their schedule already established and the limited number of research staff could not adjust the schedule. These four classrooms did not receive instructional sessions neither their teachers were subject of the professional development sessions. The final experimental sample included 27 classrooms.

The teachers of the experimental classrooms had an average of 14 years of teaching experience. All teachers had obtained their undergraduate degrees, and on average, they graduated 4.6 years before the intervention. About 71% of the teachers finished *lato sensu* specialization programs beyond their undergraduate degree, and 5% obtained a master's degree. Regarding professional development experiences, 47% of the teachers reported that they participated in courses that covered reading and writing instruction.

The 35 control classrooms had 418 (55.8%) students and the 27 experimental classrooms had 331 children (44.2%). The mean age for the participants was 56 months (standard deviation [SD] = 3.8) during the pretests, equivalent for both groups. In the experimental group, 48.6% were boys, and 51.4% were girls. In the control group, 51.3% were boys, and 48.7% were girls. The average teacher to student ratios were 1:11.6 in the control classrooms (SD = 4.5) and 1:12.1 in the experimental classrooms (SD = 3.3).

In Brazil, schools usually function in the morning and afternoon, each shift with a different set of students. In our sample, 68.1% of the students attended the school in the morning, while 31.9% attended in the afternoon. This distribution reflected an overall trend observed in the cities of Fumaça, where most families prefer that their children attend in the morning.

All four-year-old students of the participating schools were eligible to participate in the

study. After finishing the intervention and the posttests, we found that 12 (1.6%) out of 749 students had some level of learning disability, according to the schools' documents and teachers reports. Although those students participated in all research activities because we wanted to give the opportunity for all children which wanted to participate in doing so, we excluded their data from the statistical procedures.

Study Measures

We employed the Phonological Awareness Test by Oral Production (PAT-OP) assessment in pre and post-tests (Seabra, Dias, & Capovilla, 2013). It includes ten subtests to assess awareness of syllables, rhymes, alliterations, and phonemes in Portuguese. The PAT-OP scores were positively and significantly correlated with the student age, grade level and with other tests such as the word and pseudoword repetition test and the phonological discrimination test (Dias, Duarte, Macedo, & Seabra, 2013). Psychometric data of the PAT-OP test revealed a Cronbach's alpha of 0.91, and Spearman-Brown's coefficient of 0.86, with normative data are available for Brazilian children (Dias et al., 2013). In this study, the PAT-OP had adequate Cronbach's alphas of .86 in the pretest and .91 in the posttest.

The Word Reading and Writing Test (RWT) was employed in pre and post-tests to determine students' word reading and writing skills in Portuguese (Pazeto, Seabra, & Dias, 2014; Pazeto, Leon, & Seabra, 2017). The first part of this assessment consists of eight words and two pseudowords that shall be read by the student. In the second part, the researcher dictates eight words and two pseudowords for the student to write. Each word is more complex than previous ones. Words are classified by their regularity and frequency of usage. The test score is calculated by the percentage of the letters that were correctly answered by the student so that the performance ranges from zero to 100% for each skill.

The same group of researchers who created the PAT-OP started to develop the RWT instrument in 2012 (Pazeto, 2012) and released its normative data in 2019 (León et al., 2019). Pazeto et al. (2014) identified robust and significant correlations between the RWT and the PAT-OP scores (r = .76 and .80, p < .01), letter-sound knowledge (r = .73 and .87, p < .01), letter-name knowledge (r = .49 and .57, p < .01), and between its own reading and writing measures (r = .81, p < .01). In this study, the reading scores displayed a Cronbach's α of .94 in pretests and .95 in post-tests. The writing scores had a Cronbach's α of .94 in pretests and .92 in posttests, excellent consistency levels.

To assess inter-rater reliability between coders, we calculated the intraclass correlation coefficients (ICC) using a one-way random effects model in SPSS 25. For the reading pretest, the ICC was 0.95 (p = 0.00), with 20.7% of the subjects being rated by a second rater. The ICC for the writing pretest was 0.97 (p = 0.00) and for the PAT-OP was 0.90 (p = 0.00). The three ICCs were high, indicating that the PAT-OP, reading and writing pretests ratings were reliable across the raters (Graham, Milanowski, & Miller, 2012).

For the posttests, the reading assessment ICC was 0.97 (p = 0.00), calculated with 20.6% of the subjects being rated by a second rater. The ICC for the writing posttest was 0.94 (p = 0.00) and for the PAT-OP posttest was 0.85 (p = 0.00). The ICCs for the reading and writing posttests were high. The PAT-OP posttest was above the minimum desired level of 0.75, indicating that ratings were reliable (Graham et al., 2012).

The Instructional Program

The goal of the intervention was to develop the students' PA, word reading and writing in Brazilian Portuguese. The intervention was designed to provide two instructional sessions of 45 minutes per week, during the period of 10 weeks, a total of 20 sessions for each classroom (a total

of 900 minutes). All classrooms completed 20 sessions. We conducted four syllable awareness sessions so that the learners could master syllable segmentation, blending, as well as adding, removing and inverting syllables to create new words (Mesmer & Williams, 2015). Then, four sessions were conducted to enhance rhyming and alliteration awareness. The phoneme awareness activities started in session 9 with the identification of the first and last phonemes in given words. In sessions 10 and 11, phonemic blending tasks stimulated students to build words from phonemes. We developed letter-sound activities in sessions 12 to 14.

Word reading and writing activities were developed from sessions 15 to 20 so that students could exercise their grapheme-phoneme correspondence skills. Such practice is essential to consolidate the ability to write any word spoken in Portuguese and to read any word written in a given text. Words which employed irregular orthographic structures were not included in the instruction since they can be learned at later ages according to the Brazilian common core (Ministério da Educação, 2018). Before the intervention, the content and designs of the 20 mobile games were improved based on feedback from field tests and doctoral-level experts from the fields of education, cognitive psychology, and speech therapy. More information about the design, development, and implementation of the games is presented in the supplementary online material.

Instructional sessions. We conducted the intervention with four research assistants from September to November of 2017. To compensate for the holidays and school events, some classrooms had to implement three sessions per week and others had to extend the last sessions into the first two weeks of December.

Each session followed Gagné's instructional events (1965), lasting 45 minutes and was divided into three components. In the first component, lasting from 10 to 15 minutes, the attention of the student was gained when the teacher explained the target skill on the whiteboard (ex:

cutting words into small parts - syllable segmentation) to the whole-group and developed three exercises using the whiteboard or the movable alphabet. The second part, lasting around 5 minutes, started when the teacher explained how to develop the target operation in the game, playing the first three levels together with the whole group.

The third component started when the research assistant randomly assigned the students to their pairs so that two students would work cooperatively with one tablet. The Amazon Fire 8" tablet (2017 edition) with an EVA protective case designed for children was used to deliver the intervention. Amazon Fire tablets are inexpensive devices which cost as low as USD 50 each, but offer superior performance and battery duration than the requirements of the Escribo Play app.

As the students played in pairs, ten tablets were enough as the classrooms had up to 20 students and the tablets were rotated from classroom to classroom. This strategy was employed because previous studies found that small-group instruction generated higher PA gains than large-group and individual instruction (Cheung & Slavin, 2013; Ehri et al., 2001). The goal was that each student would play cooperatively with a different peer in each of the 20 sessions of the intervention. The researcher assistants paired the children in each session to accomplish this goal. Random allocation was used to minimize the eventual effect that specific students might have in inhibiting or supporting another peer. Having different pairs of students playing in one tablet was facilitated because the Escribo Play mobile application provided the names of students so that the RA could easily call them to sit and work together.

The teacher and the research assistant were instructed to act as facilitators while the students were playing. They should rotate, from pair to pair, observing how the children were using the game. When the students were having difficulty in a task, the teacher or the research assistant would remind them about the clues which were provided by the games. If students were

still unable to advance, the facilitators would perform the same activity with the students orally, or with printed support, using a word different than the one provided by the game.

As students finished the game, they received a virtual medal and were congratulated by the teacher or the research assistant. When students finished the game before the time was up, the teacher suggested them to play again to make more points or to win a virtual gold medal, when they had gotten silver or bronze. After 20 sessions, the students received the established dosage for each ingredient of the treatment (e.g., rhyming, phoneme awareness). The supplementary online material presents more details about the sessions, content and dosage. During the 10 weeks of the treatment, control classes kept doing their regular activities.

Data Collection

Pretests. After we received the signed consent forms, trained research assistants conducted the pretests. Because the randomization was completed after the pretests, the research assistants conducted the pretests without bias to allocation of classrooms to control or experimental groups (Torgerson et al., 2015). One of the authors of the assessments trained the assistants. Each assessment started with the PAT-OP test which was followed by the reading and the writing tests. All tests were audio-recorded so that we could calculate inter-rater reliability later. In average, pretests lasted a total of 20-30 minutes. The goal was to finish the assessments with one seating, but when students lost their focus the assistants stoped the procedure and continued later.

Professional development. We conducted one professional development session in each school. During these one hour meetings with the experimental group teachers, the first author followed a strict instructional protocol so that all teachers received the same content before starting the instructional sessions with their students. The content included some background

about the importance of PA instruction and an explanation of how the experiment would be developed, including how each instructional session would be implemented. In the end, the teachers defined the days and times for the instruction to be delivered to each classroom.

Posttests. Posttests using the same instruments (PAT-OP and the reading and writing assessment) started in the last week of November 2017 for the control classrooms. As the experimental classrooms finished the instructional sessions on different days, when a classroom finished the 20th session, we conducted the posttests in the following days.

We hired two additional research assistants at this stage due to the urgent timeline (the winter vacation began on December 15 for most of the schools), and a total of six research assistants conducted the posttests. We sent the research assistants to different schools than the ones in which they had implemented the intervention. This was done to reduce bias, as they could not know which students were from the experimental and control groups. Students were assessed individually, with the same instruments used in the pretests.

Findings

Pretest Findings

Pretests revealed that students in the control group had a similar mean score in the PAT-OP test 9.3 (SD = 5.2) compared to the experimental group, which had a mean of 9.4 (SD = 5.1). The reading mean score for the control group was 10.66 (SD = 20.84) while the experimental group had 9.41 (SD = 19.59). Finally, the writing mean score for the control group was 15.06 (SD = 20.36) while the experimental group had 14.95 (SD = 19.76). Independent samples t-tests did not show significant differences between the control and experimental groups for the PAT-OP, reading and writing scores. As noted in Table 1, when controlling for the student shift, the results indicated that students in the morning had better scores in the three tests, but a significant

difference was only found in the writing score ($p = 0.044$).

Intervention Effects

The posttests revealed that students in the control group had a mean score in the PAT-OP test of 11.5 (SD = 6.2), lower than the experimental group, which had a mean of 12.4 (SD = 6.6), but this difference was not significant according to the independent samples t-test ($p = 0.08$). The reading mean score for the control group was 19.84 (SD = 27.88), significantly different ($p = 0.02$) than the experimental group which had 24.86 (SD = 30.94). The writing mean score for the control group was 23.57 (SD = 26.47) and the experimental group was 27.55 (SD = 26.63). The test of writing approached to statistical significance ($p = 0.05$).

A correlational analysis with the posttest data indicated that the correlations between the tests for the experimental group were stronger than the control group, with the higher difference between the reading and writing assessments, as can be seen in Table 2. Regarding the student shift, the significant difference that was found in the writing pretests ($p = 0.04$) was not observed in the posttests ($p = 0.58$). The lack of difference in posttests can indicate that the intervention contributed to equalizing the writing levels of the morning and afternoon students.

To compare the growth patterns between the experimental and control groups, we calculated the differences between each students' pretest and posttest mean scores. On average, control classes gained 9.18 points in reading between pretest and posttest. Experimental classes gained 15.45 points between pretest and posttest. We subtracted the experimental gain from the control gain (15.45 - 9.18 = 6.27) to find the difference in gain. By dividing the difference in gain by the control gain (6.27/9.18), the relative gain was obtained. Experimental classes gained 68% more in the reading score when compared to the gains of control classrooms. The same procedure was done with the writing score, which revealed that experimental classrooms gained 48% more

in the writing assessments when comparing to the control classes gains.

Multilevel Analysis to Determine Intervention Significance

Since the randomization was conducted at the classroom-level, it is expected that students nested in the classrooms may display similar properties as they interacted and were exposed to the same instruction. To adequately account for such hierarchical data, we employed multilevel analyses (Wears, 2002). The focus of the multilevel analysis was to determine the effectiveness of the intervention on the student's PA, reading and writing skills while adjusting for the nested data structure. The multilevel parameters are presented in Table 3.

The model included the student's pretest PA, reading and writing scores, gender, shift, age at pretest and the parent educational attainment as covariates, besides the experimental condition. The model revealed a significant relationship between the experimental treatment and the reading ($p = 0.04$) and writing ($p = 0.03$) posttests. This model explained 54.15% of the variance in reading, 55.22% of the variance in writing and 62.36% of the variance in PA posttests.

The results of the multilevel analysis confirmed our hypothesis two and three. The children who studied using Escribo Play displayed improved word reading ($d = .40$) and word writing ($d = .20$) skills when compared to the students who were only exposed to the regular instructional strategies employed by the schools. Nevertheless, the multilevel analysis did not reveal a significant relationship between the treatment and the PA posttests ($p = 0.33$). This lack of significance does not allow us to confirm the hypothesis one, which was that the children studying with Escribo Play would display improved PA skills when compared to the students which were only exposed to the regular instructional strategies.

Discussion

The findings show that the intervention led to a significant gain in the experimental

classrooms reading and writing scores when compared to the gains of the control classrooms. The effect of PA instruction in reading and writing development that was detected in this research is in line with international research (Bus & van IJzendoorn, 1999; Chambers et al., 2016; Ehri et al., 2001). There is also evidence of reading gains as an effect of PA instruction for Brazilian Portuguese (Morais, 2015; Paula, Mota, & Keske-Soares, 2005; Santos & Maluf, 2010).

We consistently communicated with the teachers and their coordinators during the intervention to support their instruction. From these observations and conversations along with the previous literature review, we suspect that the learning gains might have come from three factors. The first is that most of the teachers had heard about PA activities but had never implemented them systematically. With the intervention, they received professional development support and adequate tools to develop PA activities. The second factor is that students were highly engaged with the games, which may have served to increase their desire to learn how to read and write. The third factor is the design of the program, with all games employing text together with spoken sound and some games providing visual cues. Such features probably increased student's exposure to printed words and reduced the cognitive load required to build and automatize print-to-sound relationship skills.

The lack of effect in the PA posttests can be explained by the fact that the instructional activities employed sound and print, as this is the most effective strategy to enhance reading and writing skills (Ehri et al., 2001), but the PAT-OP assesses oral skills without print support. Another possibility for such lack of significance comes from the nature of the PA activities. When we observed the PAT-OP syllabic awareness subscale, which includes syllabic segmentation, blending, addition, removal, and transposition tasks, we identified a treatment effect ($d = 0.22$) like the one we found for the writing assessment. We observed no effect among the other

subscales of the PAT-OP instrument. This finding may indicate that the reading and writing gains stemmed primarily from the increased syllabic awareness skills, as syllables are very apparent in Brazilian Portuguese. It is possible that the four-year-old students were not ready to develop more advanced phonemic awareness skills.

The innovative aspect of this research is that it employed mobile games to scaffold students' skills and to increase motivation. The quantitative data from pre and post assessments revealed that experimental classes gained 68% more in their reading scores and 48% more in their writing scores than the gains of the control classrooms. These gains suggest that the games and the instructional strategies were beneficial for students' reading development. This finding is in line with previous research which detected the beneficial effects of using technology to develop reading (Cheung & Slavin, 2013; Piquette et al., 2014).

One relevant finding for practice is that this game-enhanced intervention was delivered using the inexpensive Amazon Fire tablets which cost as low as USD 50 each. These tablets met all of our expectations in terms of performance and durability. They ran for the full day of classes and were recharged only at night. In schools that shut down the power grid at night, it would be advisable to charge the tablets during the morning, lunch and afternoon breaks.

Limitations

The main limitation of this study regards its generalizability of the sample, which included 17 schools from five cities in the metropolitan area of Fumaça. While this sample is an adequate composition when considering the private school sector that serves 30% of the students (Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira, 2016), it did not include public schools. As Brazilian public schools display reduced student achievement levels than private schools, this intervention may display different results in public schools. For example, in the RWT

normative sample with five-year-old students (one year older than our sample), private school students reading scores were 22.7 times higher than those of the public school students (León et al., 2019). Such high degree of inequality may indicate that public school preschool students may not have the prerequisite skills for the intervention to be effective, such as reduced vocabulary or print knowledge, but also suggests that this intervention may generate stronger learning gains for low-income children as students who perform below average often benefit greatly when they receive high quality instruction.

Another variable which may increase or reduce the effectiveness of the program is that in our sample the students were from families of higher educational attainment. There was probably increased access to books and incentives provided for these children to learn how to read and write when compared to low-income students.

Despite the limitations described above, it is worth noting that this is the first large-scale randomized trial conducted to evaluate an intervention which employed mobile games as an instructional tool to develop PA, word reading and word writing skills in preschool. The trial revealed significant gains in word reading and writing, early literacy skills which are very important as children progress towards entering primary schools. The adoption of gamification mechanics such as the ones that were employed in this intervention has the potential to increase student motivation and learning at scale, as mobile devices such as tablets and smartphones are significantly cheaper and easier to use and maintain when compared to the traditional computer-based laboratories.

Future Research

During the conversations with the teachers, we noticed that several teachers experienced high levels of anxiety during phoneme awareness activities. They reported that learning how to

pronounce individual phonemes was a challenge as they had never received such instruction. It would be interesting to investigate if conducting a second professional development meeting focused on letter-sound knowledge before the phoneme awareness sessions could increase the intervention effectiveness, as teachers could be more confident while delivering the instruction.

Some teachers reported that they were surprised by the results of the intervention. One said that she never had “imagined that a four-year-old student could read” and that as she was delivering the intervention, she saw her students beginning to read. This increased awareness about the students' capabilities led her to set higher expectations and to enhance her reading instruction with additional PA activities. It would be worthwhile to investigate the dosage of such additional PA activities and how they affected the effectiveness of the Escribo Play intervention.

An additional avenue for future research is to replicate this intervention in public schools. A cost-effective approach might include developing a prior needs assessment to determine the level of instruction and student skills in public schools. Changes in the instructional strategies and games may be needed to maximize the effectiveness potential in public schools. For example, we suspect that students with less exposure to print text may lack prerequisite knowledge to play the games, so we may need to design new games to fullfill this gap.

Another research direction is to seek more evidence about how the process of the intervention works in different circumstances. One interesting questions is how the existing student's skills are related to the intervention effectiveness. Else, it would be helpful to understand how the technology mediation provided by the teacher, or the parents, influences the reading and writing development.

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Table 1

Descriptive Statistics for Pre and Posttests

Assessment	Mean		n		Std Dev.	
	Experimental	Control	Experimental	Control	Experimental	Control
PAT-OP Pretest	9.40	9.30	318	399	5.10	5.20
PAT-OP Posttest	12.40	11.50	306	392	6.60	6.20
Reading Pretest	9.41	10.66	331	417	19.59	20.84
Reading Posttest	24.86	19.84	331	417	30.94	27.88
Writing Pretest	14.95	15.06	331	418	19.76	20.36
Writing Posttest	27.55	23.57	331	418	26.63	26.47

Table 2

Correlations Between Posttests for Both Groups

	PAT-OP	Reading		PAT-OP	Reading
	Control classrooms			Experimental classrooms	
PAT-OP	--	.55	PAT-OP	--	.53
Reading	.55	--	Reading	.53	--
Writing	.56	.72	Writing	.58	.81

Note. All correlations were significant at the $p < 0.01$ level.

Table 3

Multilevel Analyses on Reading, Writing and Phonological Awareness Outcomes

1. Fixed effects without covariates	Reading		Writing		PA	
	B	SE	B	SE	B	SE
Intercept	19.40***	2.27	23.13***	2.04	11.64***	0.62
Experimental	4.56^{+}	2.53	3.25	2.31	0.57	0.61
Random parameters	Variance		Variance		Variance	
Classroom (Level 2)	13.72		14.47		1.96	
School (Level 3)	33.70		26.53		3.44	
Explained variance	Reading		Writing		PA	
Marginal R^2	0.00%		0.00%		0.00%	
Conditional R^2	0.06%		6.21%		13.77%	
2. Fixed effects with covariates	Reading		Writing		PA	
	B	SE	B	SE	B	SE
Intercept	-18.35	13.23	-26.40*	11.96	1.04	2.60
Experimental	3.61*	1.79	3.48*	1.63	0.45	0.46
PA at Pretest	1.01***	0.22	0.92***	0.19	0.67***	0.04
Reading at Pretest	0.60***	0.05	0.36***	0.05	0.04***	0.01
Writing at Pretest	0.36***	0.06	0.51***	0.06	0.03**	0.01
Gender	-3.27^{+}	1.77	-0.67	1.59	0.39	0.34
Shift	1.01	1.90	1.52	1.72	-0.65	0.47
Age at Pretest	0.23	0.23	0.44*	0.21	0.04	0.04
Parent Edu. Attainment	2.44	1.64	2.29	1.46	0.57^{+}	0.31
Random parameters	Variance		Variance		Variance	
Classroom (Level 2)	0.00		0.00		1.13	
School (Level 3)	4.62		10.92		2.50	
Explained variance	Reading		Writing		PA	
Marginal R^2	53.63%		53.76%		53.34%	
Conditional R^2	54.15%		55.22%		62.36%	

Note. $^{+}p < .08$; $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

Instructional Goal & Rationale

The goal of the intervention is to develop the students' phonological awareness, word reading, and word writing skills. To this end, students need to understand that the written text is a notation of the spoken language, that words are created by combining syllables and that syllables are created by joining letters. Further, learners would need to be able to execute multiple words, syllable and phoneme awareness operations so that they become proficient in analyzing and reading new words that are introduced to them. Finally, it is expected that they would be able to write new words and evaluate their productions based on their language knowledge.

Component Skills

Table S1 synthesizes the prerequisites and component skills for each learning objective.

Table S1

Program Component Skills

Objective	Prerequisites	Component Skills
1. Segment syllables	Is familiar with the words that would be used for instruction. Understands that words can be broken into smaller parts.	Splits the syllables of two, three and four-syllable words orally.
2. Synthesize syllables	Understands that words can be formed by connecting the syllables.	Orally connects the syllables of two, three and four-syllable words.
3. Add syllable to a word	Synthesizes syllables.	Connects the syllable to the end or the beginning of two, three and four-syllable words.
4. Remove a syllable	Separates syllables.	Removes a syllable from two, three and four-syllable words.
5. Invert the syllables	Separates and synthesizes syllables.	Inverts the syllables of two and three-syllable words.
6. Find words that rhyme	Has an adequate vocabulary	Identifies when the ending

	to support the development of this skill.	syllable of two words is the same.
7. Find the alliterate word	Has an adequate vocabulary to support the development of this skill.	Identifies when the starting syllable of two words is the same.
8. Identify the first phoneme	Understands that syllables are formed from individual phonemes.	Identifies when the starting phoneme of two words is the same.
9. Identify the last phoneme	Understands that syllables are formed from individual phonemes.	Identifies when the last phoneme of two words is the same.
10. Synthesize phonemes	Understands that individual phonemes can be connected to create words.	Connects the phonemes of two, three and four phoneme words orally.
11. Segment phonemes	Understands that words can be broken into their constituent phonemes.	Splits the phonemes of two, three and four phoneme words orally.
12. Add a phoneme	Synthesize phonemes.	Adds one phoneme to an existing word.
13. Transpose phonemes	Segments and synthesizes phonemes.	Inverts the phonemes of three-phoneme words.
14. Link letters to sounds	Knows the sounds of the letters and how they are written.	Identifies the sound of a letter and recalls how it is written.
15. Reading	Links letters to sounds.	Can produce the phonemes of the written word and comprehend its meaning.
16. Writing	Links letters to sounds.	Upon hearing a word can identify its phonemes and write the corresponding letters.

The Games

The following games were played by the students using the Escribo Play app.

Game 01. Connecting Parts

In this game, the students look at the image (finger), listen to its sound (dedo) and then need to throw the balls in the correct order to score points.

Figure S1. Syllable synthesis game

Game 02. Cutting Words

In this game, the students look at the word, listen to its sound and then need to touch on the correct scissors so that the bird cuts the syllables. If the user touches the letter, he listens to the corresponding syllable.

Figure S2. Syllable segmentation game

Game 03. Add Syllables

Students listen to a word, then listen to the syllables that are below. They need to drag one of the syllables so that a new word is formed (in this case, macaco – monkey)

Figure S3. Add syllable game

Game 04. Inverting Syllables

Students listen to a word then are prompted to invert its syllables and find the word that matches. In this case, CAVA is inverted to VACA, so the student must click on the cow.

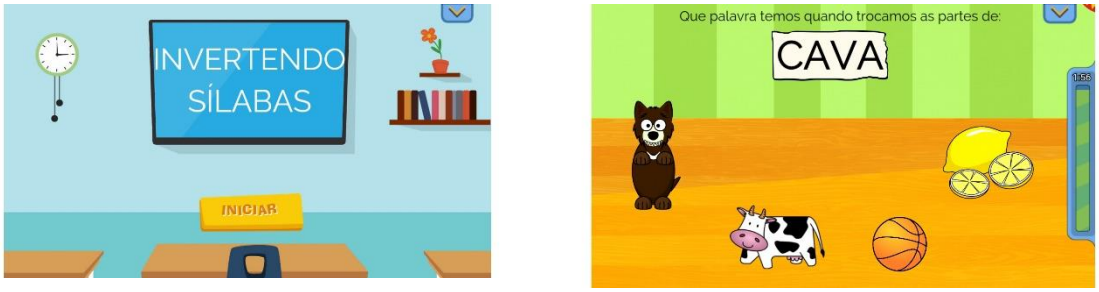

Figure S4. Inverting syllables game

Game 05. Rhyming Mine

Students listen to a word then are prompted to cut the rope that holds the gold coin which has a word that ends with the same sound (rhyme). When a student touches any word, the word is spoken. In this case, they shall touch on GELO as it rhymes with ZELO.

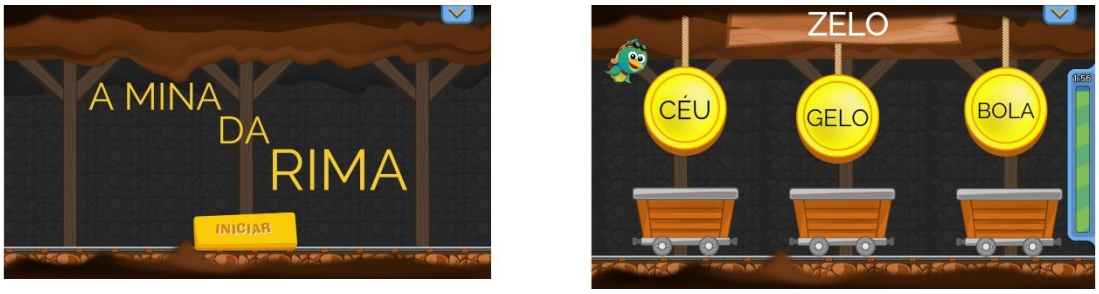

Figure S5. First rhyming game

Game 06. Alliteration Soccer

Students listen to a word and are prompted to touch on the image which represents a

word that starts with the same sound. In this case, the word PIRULITO and PIPOCA (popcorn)

Figure S6. First alliteration game

Game 07. Little Farm

Students listen to a word and are prompted to drag the sheep of the other words which rhyme to the safe area. In this case, SACOLA rhymes with ACEROLA and GRANOLA.

Figure S7. Second rhyming game

Game 08. Alliteration Lake

Students listen to a word and are prompted to drag the duck of the other words which start with the same sound to the lake. In this case, TAMANHO starts with the same sound of TAMBOR and TAMARINDO.

Figure S8. Second alliteration game

Game 09. Phoneme Basketball

Students listen to a word and are prompted to throw the ball that corresponds to the first phoneme of the word. The game also plays the sound of each phoneme.

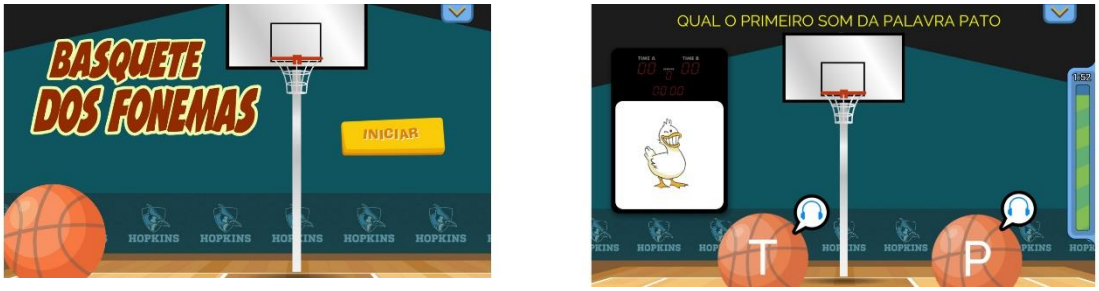

Figure S9. First phoneme identification game

Game 10. Blending Phonemes

Students listen to the individual sounds of the phonemes and then shall click on the boat with the corresponding word.

Figure S10. Phoneme blending game

Game 11. Guess the Sound

Students listen to the individual sounds of the phonemes and then shall click on the phoneme which corresponds to the first phoneme of the word written on the boat.

Figure S11. Letter-sound correspondence game

Game 12. Phoneme Basketball 2

Students listen to a word and are prompted to throw the ball that corresponds to the first phoneme of the word. The game also plays the sound of each phoneme.

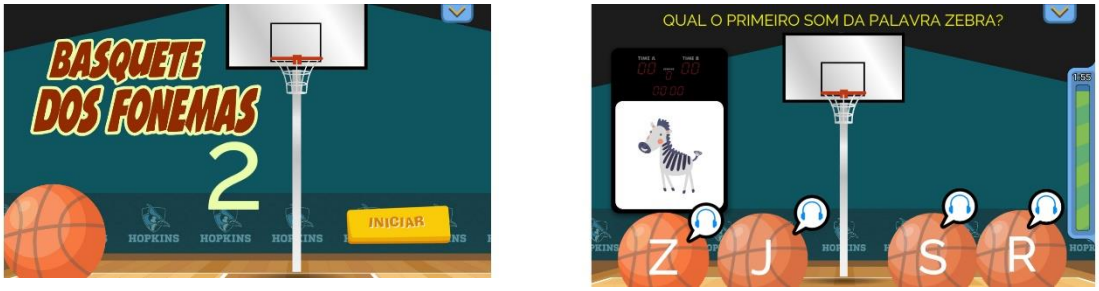

Figure S12. Letter-sound correspondence game

Game 13. Phoneme Soccer

Students listen to a word and four phonemes. They are prompted to touch on the phoneme which represents the first phoneme of the word.

Figure S13. Letter-sound correspondence game

Game 14. Sound Volley

Students listen to a word and three phonemes. They are prompted to touch on the phoneme which represents the first phoneme of the word.

Figure S14. Letter-sound correspondence game

Game 15. Correct reading

Students see a word and must read it to click on the corresponding image. The game does not speak the word.

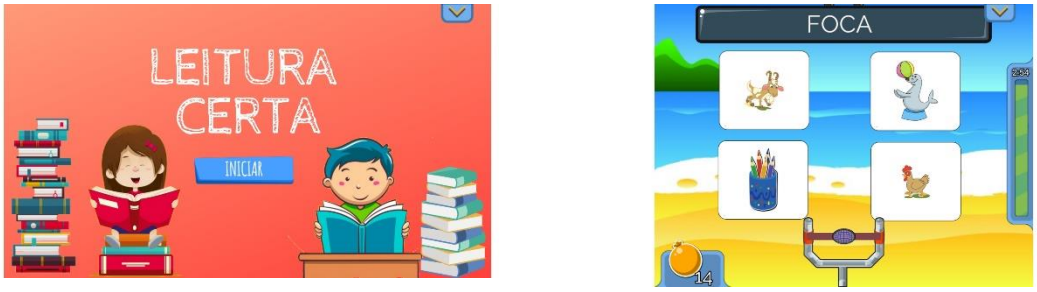

Figure S15. Word reading game

Game 16. Climbing Words

Students must look at the image and fill missing letters of the corresponding word so that the helicopter character can climb the words and get his blades.

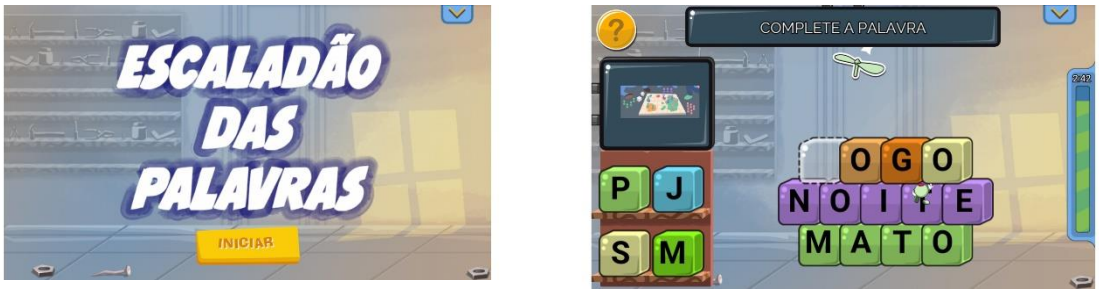

Figure S16. Word writing game

Game 17. Reading Soccer

Students must read the word and click on the corresponding image. The game does not speak the word.

Figure S17. Word reading game

Game 18. Writing Words

Students now must write more complex words by dragging the letters to the blank spaces.

Figure S18. Word writing game

Game 19. Words Volley

Students now must read and write words in different game mechanics.

Figure S19. Word reading and writing game

Game 20. Writing Words

Students now must read and write words in different game mechanics.

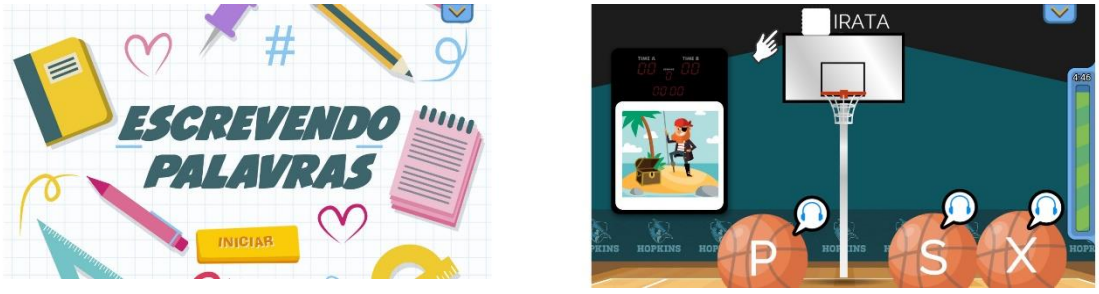

Figure S20. Word reading and writing game

Table S2

Sample Composition

	Control	Experimental
Parent educational attainment		
Primary or secondary	6%	6%
Higher education	83%	79%
Masters	8%	10%
Doctoral	3%	6%
Student gender		
Male	51%	49%
Female	49%	51%
School shift		
Morning	70%	66%
Afternoon	30%	34%
Average age		
	56.6	56.7

Note. Age presented in months.