Many interventions have been developed to address reading difficulties in clinical (e.g., Specific Learning Disabilities) and the general population of struggling readers and these have shown promise in research. However, these interventions have had a very limited impact on psychological practice as most psychologists do not implement psychoeducational interventions, but just provide recommendations for teachers, who become solely responsible for addressing the struggling reader’s needs. These gaps between research and practice may be due to psychologists limited access to these resources and by the barriers encountered by the general population when requesting psychological services. When the literature on the efficacy of these interventions is examined closely many limitations to their viability are easily identified. For example, most interventions require specialized training (e.g., doctoral, postdoctoral studies), and are expensive and difficult to implement. Furthermore, their efficacy is usually demonstrated under very rigorous implementation conditions such as long sessions and very frequent weekly sessions (e.g., four –five times) that span a few months.

When the conditions described by these studies are compared to real-world scenarios, it seems evident why these interventions have failed to impact psychological practice. For example, in the context of Puerto Rico, health insurance usually does not cover the expenses of psychological services, particularly in the educational fields. It should not be surprising then, that most struggling readers will not be able to receive psychological services four to five times a week and in most cases the frequency and consistency of these interventions are important in order to achieve improvements.

The limited access to psychological and educational services in Puerto Rico highlights the importance of developing more flexible and viable alternatives to address the difficulties of struggling readers. The integration of technology to psychological and educational practice has been a venue by which to address these limitations, as evidenced by the increasing number of studies addressing the efficacy of technology-based learning interventions. It is important, however, to investigate if technology-based interventions are effective and if these address the limitations that traditional interventions have encountered when considered in real-world scenarios. The present systematic review of the literature analyzes studies that test the effects of technology-based interventions on reading skills to address the following specific aims: (a) identify which cognitive processes mediate the impact these interventions have on reading skills, (b) identify common research methods and instruments employed in these studies (e.g., design, sampling procedures), (c) identify common analytical methods employed in these studies (e.g., inferential statistics, effect sizes).

# Methods

A detailed description of the criteria used to determine the eligibility of the studies and the protocol implemented to select these is presented below in order to guarantee the replicability of the findings. These were established *a priori,* as is customary when conducting systematic literature reviews.

## Selection criteria

The following criteria must have been met by the articles in order to be selected: (a) published between 2009 – 2019 (i.e., last ten years), (b) published in a peer-reviewed journal, (c) empirical and quantitative study (e.g., journal article, thesis, or dissertation), (d) the intervention must have been administered through a computer, tablet or other technological device, (e) the intervention must have addressed one or more basic reading skills (e.g., decoding, word recognition, word reading, phonological awareness, phonemic awareness, phonics, spelling), and (f) the participants intervention must have assisted elementary school while the intervention was administered.

## Search protocol

The consulted database providers and databases are presented in table 1. These were selected because these commonly publish studies relevant to the field of psychology and education. The keywords used during the search are presented in table 2 and were selected in order to identify studies relevant to the population of interest, that used technology-based interventions, and that focused on basic reading skills. Whenever available, the delimiters for using *related keywords*, *equivalent subjects*, and *scholarly/peer reviewed articles* were selected.

Table 1

Database providers and databases

| Database provider | Databases |
| --- | --- |
| Academic Search Ultimate | Academic Search Ultimate, E-Journals, ERIC, Fuente Académica Plus, MEDLINE with Full Text, Psychology and Behavioral Sciences Collection, PsycINFO, Teacher Reference Center |
|  |  |
| ScienceDirect | Across all databases (general search) |

Table 2

Keywords used during the search process

| Keyword combinations | | | |
| --- | --- | --- | --- |
| Elementary | Computer\* | Reading | Intervention |
| Elementary | Computer\* | Reading | Remediation program |
| Elementary | Computer\* | Reading | Phonics |
| Elementary | Computer\* | Reading | Phonological awareness |
| Elementary | Computer\* | Reading | Decoding |
| Elementary | Computer\* | Reading | Word Recognition |
| Elementary | Computer\* | Reading | Phonemic Awareness |

Note: \*refers to the wild card character used to match any keyword starting with the string  
computer (e.g., computerized, computer).

## Study Selection

The following procedure was followed in order to identify the studies: (a) searches were conducted on the relevant databases; (b) the study’s title and abstract was reviewed to determine its eligibility; (c) eligible articles were downloaded; (d) duplicates were removed; (e) the study’s full text, with a particular emphasis on its title, abstract and methods section was reviewed in order to determine its eligibility. During the last step of the process, four judges reviewed each article to determine its eligibility. The majority of the authors had to agree in order for an article to be deemed eligible. Whenever there was disagreement between the judges, it was discussed and resolved. Table 3 presents the screening process and table 4 presents the general characteristics of the studies.

Table 3

Screening process for articles

| Phase | Results | Reasons for discarding articles |
| --- | --- | --- |
| Initial search | 451 | - |
| Initial screening | 29 | Older children, reading skills were not measured, non-empirical articles, severe neurodevelopmental disorders (e.g., autism spectrum disorder), non-technological-based intervention, not focused on basic reading skills, qualitative studies, focused on academic skills other than reading |
| Duplicate removal | 25 |  |
| Final article selection by judges | 21 | Did not address basic reading skills, the same study was published with different titles and variations of their analytical approacha |

Note. aOnly one study was included in this review.

Table 4

Characteristics of the studies

| Author | Purpose | Intervention name | Targeted reading skills |
| --- | --- | --- | --- |
| Cazzell et al. (2016) | Evaluate the effects of a Computer-based flashcard reading program with self-determined response intervals on sight-word acquisition in elementary-school children with intellectual disabilities. | Researcher-developed: Computer-based flashcard reading program | Word reading |
| Chai (2017) | Evaluate the effectiveness of using an iPad intervention to improve phonological awareness skills of young children with mild developmental delays in a rural elementary school. | Touch Sound | Phonological skills |
| Comaskey, Savage, & Abrami (2009) | Explore the effectiveness of a web-based literacy programme that delivered two distinct phonics’ programmes. | A Balanced Reading Approach for Canadians Designed to Achieve Best Results for All | Phonological skills, reading skills (not specified) |
| Ecalle, Magnan, & Calmus (2009) | Examine the effects of a computer-assisted learning program in which syllabic units were highlighted inside words in comparison with a program in which the words were not segmented. | Researcher-developed (name not provided) | Phonological skills, word reading |
| Ecalle, Kleinsz, & Magnan (2013)a | Compare the effectiveness of Grapho-syllabic training, Grapho-phonemic training, and a control group in French second-grade poor readers. | Grapho-syllabic training, Grapho-phonemic training | Word reading |
| Ecalle et al. (2013)a | Examine the long-term effects of Grapho-syllabic training with first grade French children. | Grapho-syllabic training, Grapho-phonemic training | Word reading, reading comprehension |
| Fan, Antle, Hoskyn, & Neustaedter (2018) | Determine the efficacy of Phonoblocks for improving word reading skills and spelling accuracy among Mandarin-speaking English language learners. | Phonoblocks | Reading skills (not specified), spelling |
| Gustafson, Fälth, Svensson, Tjus, & Heimann (2011) | Compare the efficacy of interventions focused on bottom-up processing, focused on top-down processing, and a traditional comprehension training on  phonological abilities and word decoding skills. | COMPHOT, Omega-Interactive Sentences | Reading comprehension, word reading, phonological skills |
| Karemaker, Pitchford, & O’Malley (2010) | Investigate if the whole-word multimedia software ‘ORT for Clicker’ facilitates developing literacy skills of first grade struggling readers. | Oxford Reading Tree for Clicker | Phonological skills |
| Kleinsz, Potocki, Ecalle, & Magnan (2017) | Investigate the effects of two types of reading training administered in parallel to different subgroups of poor readers. | Grapho-syllabic training, Comprehension training | Word reading, reading comprehension, phonological skills, vocabulary |
| Kyle, Kujala, Richardson, Lyytinen, & Goswami (2013) | Assess the efficacy of Graphogame as a supplementary Computer-Assisted Reading Instruction for students learning to read in English. | Graphogame | Vocabulary, word reading, spelling, phonological skills |
| Messer & Nash (2018) | Determine whether the use of a computer-assisted intervention that uses visual mnemonics as part of the tutorial process helps the development of reading abilities. | Trainertext | Phonological skills, rapid automatized naming, spelling |
| Moser, Morrison, & Wilcox (2017) | Examine the effectiveness of word structure practice using application software with fourth grade readers. | 8 great word patters | Reading fluency, vocabulary, reading comprehension, word reading |
| O’Callaghan, McIvor, McVeigh, & Rushe (2016) | Evaluate the effectiveness of the Lexia Reading Core 5 intervention with four- to six-year-old children in Northern Ireland. | Lexia Reading Core 5 | Phonological skills |
| Pindiprolu & Forbush (2009) | Evaluate the effects of parent implemented Funnix and Headsprout reading programs on the acquisition of basic early literacy skills of students with reading difficulties. | Funnix, Headsprout | Word reading, reading fluency, reading comprehension, phonological skills, phonics, vocabulary |
| Potocki, Magnan, & Ecalle (2015) | Determine the effects of a computerized training program on the reading skills of normal readers, poor decoders, poor comprehenders, and general poor readers. | Chassymo, Locotex | Word reading, reading fluency, reading comprehension |
| Rosas, Escobar, Ramírez, Meneses, & Guajardo (2017) | Evaluate the impact of an explicit, sustained, and direct intervention of the phonic aspects of reading in Chilean children enrolled in their first year of primary education from a low socioeconomic status and at risk of manifesting reading difficulties. | Graphogame | Word reading, phonological skills, phonics, rapid automatized naming |
| Saine, Lerkkanen, Ahonen, Tolvanen, & Lyytinen (2010) | Compare the effectiveness of a remedial reading intervention, computer assisted remedial reading intervention, and mainstream instruction in children with different profiles of compromised pre-reading skills before school age. | Graphogame | Word reading |
| Schmitt, Hurwitz, Sheridan Duel, & Nichols Linebarger (2018) | Determine the effectiveness of a web-based game played at home on literacy development among low- and middle-socioeconomic status preschool and kindergarten students. | PBS KIDS Island | Phonics, phonological skills, word reading, vocabulary |
| Solheim, Frijters, Lundetræ, & Uppstad (2018) | Investigate the efficacy of an early reading intervention delivered alongside formal reading instruction to Norwegian 6-year old children at risk for reading difficulties with a two-year follow-up. | Graphogame, On track ABC | Phonics, phonological skills, word reading, rapid automatized naming, vocabulary |
| Wood, Mustian, & Lo (2013) | Evaluate the effects of a supplemental phonemic instruction program using computer-assisted reciprocal peer tutoring with embedded audio prompting. | Researcher-developed (name not provided) | Phonological skills |

Note. aBoth are reported in the same article but as different studies.

## Coding

Some information about the studies was coded in order to analyze the information. Table 5 shows the categories and their definitions. Only categories that were coded and whose definition could not be directly derived from its name are presented for brevity and simplification.

Table 5

Definitions for categories

| Dimension | Category | Sub-category | Definition |
| --- | --- | --- | --- |
| Methods | Design | Single Subject Design (SSD) | Any variant of SSD were coded as SSD |
| Pretest-posttest design with comparison groups | Designs that included a pretest, posttest, and one comparison group |
| Pretest-posttest design with multiple comparison groups | Designs that included a pretest, posttest, and multiple comparison groups (e.g., multiple baseline profiles) |
| Pretest-posttest design with multiple experimental groups | Designs that included a pretest, posttest, and multiple experimental groups (e.g., various technology-based interventions were compared) |
|  |  | Randomized control trial with pretest-posttest | Studies that explicitly stated being a randomized control trial |
| Methods and findings | Reading skills | Phonological skills | Skills that required phonological processing (e.g., phonemic awareness, phonological awareness) |
| Word reading | Skills that required reading or recognizing words |
| Phonics | Skills that required the integration of or knowledge about the relationship between graphemes and phonemes |
| Reading: Otherwise not specified | No specific skill was identified |

## Cognitive component

Cognition comprises the underlying mental processes by which we learn, and research has established an intricate and direct and indirect relationship between cognitive processes and reading skills. The original plan for this review was to identify the cognitive processes that reading interventions addressed or considered because from a neuropsychological perspective, this provides the best rationale for designing academic interventions (Feifer, Kaufman, & Kaufman, 2011). However, only one study was identified that addressed the impact of the reading intervention on cognitive processing For this reason, the results of this study will be complemented by a discussion of how cognitive processes are related to reading skills with the aim of providing information that will aid in the development of reading interventions or that take into consideration the cognitive mechanisms that underlie these.

The study by Messer & Nash (2018) tested the effects of the Trainertext intervention on working memory and phonological short-term memory and basic reading skills. The findings show a medium effect (d = .65 - .69) on these cognitive processes and a small to large effect (d = .27 - .97) on reading fluency and spelling. The findings suggest that the intervention was efficacious for improving working memory functioning, phonological short-term memory, reading fluency, and spelling skills. This suggests that interventions that address reading difficulties may impact the cognitive processes that support these.

Research on cognition and reading has identified several cognitive processes that are vital to the development of reading skills. Basic reading skills (e.g., phonological skills, spelling) are associated with various cognitive processes. For example, phonological mechanisms of working memory (WM) are associated with dyslexia (Beneventi, Tønnessen, Ersland, & Hugdahl, 2010; Cruz-Rodrigues, Barbosa, Toledo-Piza, Miranda, & Bueno, 2014; Pinto & Peixoto, 2011). These mechanisms support the reading process by providing the ability to manipulate the phonological elements of language (e.g., producing the sounds associated with particular letters and integrating these sounds into words). This relationship has proven particularly useful at understanding reading difficulties because it provides a parsimonious explanation of the difficulties presented by these children. Visual mechanisms of working memory have also been associated with these skills (Pinto & Peixoto, 2011) because the inefficient processing of visual representations of sounds (i.e., graphemes) could disrupt the integration of visual and auditory components of written text, resulting in poor basic reading skills.

Higher order memory processes also support reading skills. Cruz-Rodrigues et al. (2014) have found semantic memory deficits in children who experience reading difficulties. Semantic memory is involved in the coding of general knowledge, which refers to information that lacks a temporal context with regards to the subject (Groome, 2014) and could be associated with difficulties in retrieving information about a specific sound (i.e., phoneme) that corresponds to a specific letter (i.e., grapheme). It could also explain the difficulties struggling readers usually experience producing the sound that corresponds to a specific word and the retrieval of the meaning of words. Furthermore, deficits in successive processing of information has also been linked to reading difficulties (Keat & Hj. Ismail, 2011). Successive processing of information involves the sequential processing of information (i.e., ordered) and could help explain the reason why many struggling readers have severe difficulties in pronouncing words correctly (Das, Naglieri, & Kirby, 1994).

Attention is another cognitive process that has been associated with reading skills. Studies have shown a relationship between phonological awareness and divided attention and alertness (Lewandowska, Milner, Ganc, Wlodarczyk, & Skarzynski, 2014). These difficulties could be related to a reduced ability to focus on the phonological components of letters and words, which would lead to errors in the retrieval of the sounds and their integration. These phonological processing problems have also been related to deficits in processing speed and verbal fluency (Moura, Simões, & Pereira, 2015). In these cases, the loss of speed in the decision-making process of selecting the appropriate sound for a given grapheme may result in difficulties integrating sounds into words and could lead to a slow and fragmented reading process. This would in turn result in limited verbal fluency because the speed with which words are retrieved based on their meaning or phonological characteristics is limited.

Another area of interest are complex reading skills. Similar to basic reading skills, complex reading skills have been associated with various cognitive processes. For example, simultaneous processing of information (i.e., integration of information into a whole) deficits have been found in struggling readers (Keat & Hj. Ismail, 2011) and these deficits could explain their difficulties in deriving meaning from words and sentences (Das et al., 1994).

Attention has also been associated with reading comprehension, although its relationship to basic reading skills is stronger (Keat & Hj. Ismail, 2011). With regards to reading comprehension, deficits in attention are believed to be associated with the loss of information, which is detrimental to comprehending the narrative that is being read. Complex reading skills have also been associated with deficits in executive functions (FE). Children with Dyslexia have been found to present deficits in efficiently regulating their focus of attention (Krause, 2015; Lewandowska et al., 2014; Moura et al., 2015; Pinto & Peixoto, 2011) and response inhibition (Pinto & Peixoto, 2011). These deficits are believed to limit children’s ability to change their attention between the different parts of the text (i.e., ideas) in order to achieve an integrated picture of the narrative (i.e., derive a central idea). Finally, deficits in cognitive flexibility (Lewandowska et al., 2014) and planning (Keat & Hj. Ismail, 2011) have been found in children with dyslexia. Deficits in these areas could explain the reason why struggling readers do not benefit as expected from reading comprehension strategies or make the necessary adjustments to the information that has just been read in order to integrate the information that will be read.

It is important to note that although the same cognitive processes are often associated with different reading skills (e.g., attention is associated with basic and complex reading skills), there are differences in how these support reading skills. This fact should not be surprising because cognition, as well as the brain, works as an integrated system by which we perceive the world and process information. For most behaviors, we use an intricate array of cognitive processes and brain circuits, but certain processes and circuits are more involved than others for any given behavior. This same concept applies to reading skills. Some of the processes involved may change during different phases of the reading process (e.g., cognitive planning) and other may always be involved to the same extent (e.g., attention). This evidences the complexity of designing interventions for improving reading skills derived from the cognitive processes that are associated with them as these intricate relationships must be considered.

## Methodological component

The studies reviewed primarily used pretest-posttest design with multiple experimental groups (33.33%), pretest-posttest design with comparison group (23.81%), and randomized control trials (RCT) with pretest-posttest (19.05%). The term *multiple experimental groups* is used in this context to identify studies which compared different groups that were exposed to different technology-based interventions. The study design had to be inferred for 19.05% of the articles discussed because these did not state an explicit study design. In these cases, the study design was inferred from more general descriptions in the methods section (e.g., random assignment, administration of pretest and posttest). Most studies used random assignment (66.67%) to allocate participants to each group in the study, yet not many were considered by their authors to meet the standards to be considered RCTs. About half the studies (46.67%) balanced the different study’s groups based on important characteristics, but only a few studies counterbalanced the order of test administration (16.67). Furthermore, only a small number of studies used a probabilistic sampling scheme (9.52%). The median number of participants across studies was 31, but it varied greatly across studies (minimum = 2, maximum = 744). Most studies worked with four- to eight- year-old children (66.67%) from Kindergarten to fourth grade (66.67%), whose main language was English. Please refer to the supplemental materials for more details (S1).

The described studies present various strengths and limitations. These implemented strong designs with pretest-posttest and comparison groups and used random assignment to balanced participant characteristics across the groups. However, must studies did not counterbalanced testing procedures, which may have resulted in patterns of participant performance related to the order of administration and not to differences between groups. Additionally, studies did not use probabilistic sampling schemes, and this makes it difficult to determine the generalizability of the findings to the population. The sample size varied greatly across studies but in general, these consisted of small to medium studies. The sample characteristics are important as these helps to understand the population to which these results may generalize and this are discussed next. In general, the fact that most interventions were tested on younger children in elementary grades (i.e., Kindergarten to fourth grade) is important because it means the interventions are suitable to be used as early intervention programs. Another important characteristic is the native language in which the intervention was administered. Most studies focused on reading skills of English and French languages which are considered as having an opaque orthography because the same sound (i.e., phoneme) can be associated with different visual representations (i.e., graphemes; Aro, 2013).

Intervention implementation details are also important to determine how viable are these interventions in real-word scenarios. A great number of interventions were tested in the different studies, but GraphoGame, in its different variants, is the most used technology-based intervention (33%). Many studies did not report the number of sessions provided to the participants (38.10%), but there was great variability among those that provided the information (i.e., from less than 20 to more than 40 sessions). In some cases, the total amount of time dedicated at working with the interventions was provided. Interventions were administered most commonly four times a week (50%), individually or in groups in 10- to 30-minute sessions (76.19%). There was a general tendency across studies to not report the size of the groups (45.45%), but small groups were preferred (2 – 3 participants; 36.36%). Note that in this review, interventions were considered *group-administered* if more than one participant received the intervention in the same space and time as another participant, even if they worked completely independently. Finally, most interventions were administered in controlled settings (e.g., schools) under supervision (90.48%) but many authors reported only providing support with technical difficulties. Please refer to the supplemental materials for more details (S2).

Implementation details provide information about under which circumstances were the interventions tested. This information is very valuable in determining the viability of the interventions in real-word scenarios. It seems there are many alternatives in technology-based interventions, as evidenced by the great number of interventions used. In most cases, the number of sessions were not provided, which imposes great limitations to determining how many sessions are necessary to improve academic skills. The fact the interventions were implemented 4 times a week is less than ideal, as it imposes a challenge to expose children that many times a week to a supervised intervention, even if it is computerized and mobile. Another important finding is that interventions were implemented in short sessions and these can be administered in small groups, which contributes to their viability because many students can work during a single session and they only require technical assistance.

## Statistical component

In this section, the statistical components of these studies are explored. A detailed description of the analytical methods used in studies is extremely important as these helps to determine the validity of the findings in any study. Most of the studies reported descriptive results of the main outcomes (90.48%). Descriptive statistics are important because these describe the variables of interest and allow to determine if any strange patters exist in the data. For example, mean scores that are too low suggest problems with sampling (e.g., the control group may not be a *typically developing group)*. The mean or median and standard deviation were frequently reported (90% and 75%, respectively), but only a few studies did report confidence intervals for the means (11.76%). Mean confidence intervals are extremely important for estimating the true mean of the population, but are usually not emphasized in favor of the predominant p-value and point-estimate approach. This omission of confidence intervals comes at the expense of losing confidence in the certainty of the estimated true value of the population mean, as a point-estimate (i.e., estimate made from a single value) is usually not very reliable across studies. Other reported descriptive statistics are total score (33.33%) and accuracy (50%). Please refer to the supplemental materials for more details (S3).

With regards to inferential statistics, ANCOVA (38.89%) and ANOVA (33.33%) were the two most popular choices among studies. Baseline reading skills were the most commonly controlled variable across studies that controlled any variables (38.89%), but most studies did not control any variables (44.44%). Only one study controlled for variables other than cognitive ability or academic skills (e.g., age, income, parent’s education level). Another important detail to note is that most studies did provide specific p-values for the analysis conducted (77.78%), particularly when statistical significance was not reached. The actual *p-value* is important, contrary to popular believe, as this value should not be interpreted as a binary outcome (i.e., statistically significant or nonsignificant), but as the probability of finding results as extreme as the ones found in the current study, if it is assumed that there are no real difference. This means that p-values can suggest whether a *nonsignificant* result is still worth pursuing in further research or if it is unlikely there is a true relationship among the variables studied.

Surprisingly, most studies did provide effect sizes (88.89%) and the most commonly reported was Cohen’s d (56.25%). Effect sizes are an indicator of the magnitude of the relationship (i.e., in this case, the magnitude of the intervention effect) and should be reported independently of statistical significance (Durlak, 2009). Consistent with the reporting of confidence intervals for the mean, only a few studies (14.29%) reported the confidence interval for the mean difference (i.e., differences between the means). Please refer to the supplemental materials for more details (S3).

The studies reported followed some of the best practices in the report of results. These used sound analytical methods (e.g., ANOVA, ANCOVA), provided descriptive statistics, and provided the specific p-values and effect sizes. Additionally, the studies controlled for variables that are known to influence improvements after the implementation of an intervention (e.g., baseline reading skills). However, the studies could have presented Hedges’ G as the effect size index, which is described as an unbiased estimator of the true effect (Hedges, 1981). Furthermore, corrections for small sample sizes could have been used to avoid overestimating the intervention’s effect (Durlak, 2009). Confidence intervals were another very important statistic that is missing in most of the reviewed studies. As stated previously, mean confidence intervals allow better estimation of the population means and mean difference confidence intervals allow to estimate the true difference between the groups as an interval that is more reliable across studies than a point-estimate.

## Study findings component

The most commonly addressed reading skills were phonological skills (e.g., phonological awareness, phonemic awareness; 26.79%) and word reading (25%). Across the studies, word reading and phonological skills were the ones that showed the greatest improvement (29.73%) and (16.22%), respectively. The effect sizes evidenced medium (68.75%) and large (81.25%) intervention effects across all reading skills that showed improvements across all studies. The classifications of the effect sizes were interpreted following the general guidelines provided by Cohen, 1988). Many studies reported interventions having an effect on all targeted skills (33.33%), but most reported not being able to improve at least one reading skill. Phonological skills were also the reading skill that most interventions failed to show improvements on (16.67%). This apparent contradiction is due to how the original reported reading skills were coded. Most studies targeted one or more components of phonological skills and some of these components showed improvements while others did not. Please refer to the supplemental materials for more details (S4).

The effect of these interventions on basic reading skills such as phonological skills and word reading is apparent. It is also important to note that these effects were medium and large in most studies, which is particularly encouraging. The particular skills that participants showed improvements on are consistent with their developmental level, given they were mostly young children in primary grades. The fact that most interventions failed to have an effect on some of the targeted skills demonstrates inconsistencies in the intervention’s efficacy. It seems these are better at improving some basic reading skills that others, particularly within the domain of phonological skills.

## Conclusion

Technology-based reading interventions are being developed as a complementary tool to traditional *paper-and-pencil* interventions in order to address these important skills. The findings of this systematic review suggest there are many different options when it comes to technology-based interventions and these have great potential for improving reading skills. Studies that test these interventions implement strong designs, conduct strong statistical analyses and comply with good statistics reporting standards. Furthermore, these interventions have been tested with short sessions and in groups, which suggest these may be viable in real-world scenarios. In the context of Puerto Rico, viability is very important as the limited access to resources and the high prevalence of Specific Learning Disabilities (Disdier‐Flores & Jara Castro, 2017), for which reading difficulties are the most common, requires cost-effective tools to address this population’s needs.

The findings also suggest that many studies do not use sampling schemes that allow generalizations to the population level. Confidence intervals are also missing, and this is a very important statistic because it would allow to better estimate the improvements caused by the interventions. In this line, the use of Hedges’ G as an index of the size of the intervention’s effect would result in better estimates, as has been previously stated. Future studies should make efforts to include these statistics to strengthen confidence in their results. Additionally, the impact of technology-based interventions on more transparent orthographies (e.g., Spanish and Italian) should be explored. It would also be interesting to compare the specific teaching methodologies the interventions implement and determine which are more effective.

Another aspect that is particularly important but missing from the reviewed studies is knowledge of the relationship between cognition and reading to derive interventions that address the development of reading skills through their cognitive correlates. How cognition and brain circuits are used during the reading process should play a central role in intervention design, planning, and monitoring. One reason why consideration about cognition may be absent from the reviewed interventions is that a deep understanding of how cognition supports reading is required in order to design these interventions because the mechanisms by which cognition support reading are intricate. Nonetheless, future studies should address the cognitive mechanisms by which these interventions impact reading skills.

Despite the limitations discussed, most of the studies reviewed had strong methodological and statistical characteristics and the findings of this review suggest that technology-based interventions have high potential for improving reading skills. More research should be conducted to continuously refine these interventions in order to improve their efficacy and cost-effectiveness. Technology is flexible, powerful, and highly engaging for children which makes it an ideal venue to explore.

# References

Aro, M. (2013). Literacy acquisition from cross-linguistic perspectives. En R. Malatesha Joshi & P. G. Aaron (Eds.), *Handbook of Orthography and Literacy* (pp. 531–550). New York city: Routledge. https://doi.org/10.4324/9780203824719

Beneventi, H., Tønnessen, f. e., Ersland, L., & Hugdahl, K. (2010). Executive working memory processes in dyslexia: Behavioral and fMRI evidence. *Scandinavian Journal of Psychology*, *51*(3), 192–202. https://doi.org/10.1111/j.1467-9450.2010.00808.x

Cazzell, S., Skinner, C. H., Ciancio, D., Aspiranti, K., Watson, T., Taylor, K., … Skinner, A. (2016). Evaluating a computer flash-card sight-word recognition intervention with self-determined response intervals in elementary students with intellectual disability. *School Psychology Quarterly*, *32*(3), 367–378. https://doi.org/10.1037/spq0000172

Chai, Z. (2017). Improving Early Reading Skills in Young Children Through an iPad App. *Rural Special Education Quarterly*, *36*(2), 101–111. https://doi.org/10.1177/8756870517712491

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2a ed.). Lawrence Erlbaum Associates.

Comaskey, E. M., Savage, R. S., & Abrami, P. (2009). A randomised efficacy study of Web-based synthetic and analytic programmes among disadvantaged urban Kindergarten children. *Journal of Research in Reading*, *32*(1), 92–108. https://doi.org/10.1111/j.1467-9817.2008.01383.x

Cruz-Rodrigues, C., Barbosa, T., Toledo-Piza, C. M., Miranda, M. C., & Bueno, O. F. A. (2014). Neuropsychological characteristics of dyslexic children. *Psicologia: Reflexao e Critica*, *27*(3), 539–546. https://doi.org/10.1590/1678-7153.201427315

Das, J. P., Naglieri, J. A., & Kirby, J. (1994). *Assessment of Cognitive Processess: The PASS theory of intelligence*. Massachusetts: Allyn & Bacon.

Disdier‐Flores, O. M., & Jara Castro, A. G. (2017). *Anuario Estadístico del Sistema Educativo*. Recuperado de https://estadisticas.pr/files/Publicaciones/Anuario\_Estadistico\_Educativo\_2014-2015.pdf

Durlak, J. A. (2009). How to Select, Calculate, and Interpret Effect Sizes. *Journal of Pediatric Psychology*, *34*(9), 917–928. https://doi.org/10.1093/jpepsy/jsp004

Ecalle, J., Kleinsz, N., & Magnan, A. (2013). Computer-assisted learning in young poor readers: The effect of grapho-syllabic training on the development of word reading and reading comprehension. *Computers in Human Behavior*, *29*(4), 1368–1376. https://doi.org/10.1016/j.chb.2013.01.041

Ecalle, J., Magnan, A., & Calmus, C. (2009). Lasting effects on literacy skills with a computer-assisted learning using syllabic units in low-progress readers. *Computers and Education*, *52*(3), 554–561. https://doi.org/10.1016/j.compedu.2008.10.010

Fan, M., Antle, A. N., Hoskyn, M., & Neustaedter, C. (2018). A design case study of a tangible system supporting young English language learners. *International Journal of Child-Computer Interaction*, *18*, 67–78. https://doi.org/10.1016/j.ijcci.2018.08.001

Feifer, S., Kaufman, A. S., & Kaufman, N. L. (2011). How SLD manifiest in reading. En D. P. Flanagan & V. C. Alfonso (Eds.) (pp. 21–42). New Jersey: John Wiley & Sons.

Groome, D. (2014). Long-term memory. En D. Groome, N. Brace, G. Edgar, H. Edgar, M. Eysenck, T. Manly, … E. Styles (Eds.), *An Introduction to Cognitive Psychology: processes and Disorders* (3a ed.). Sussex: Psychology Press.

Gustafson, S., Fälth, L., Svensson, I., Tjus, T., & Heimann, M. (2011). Effects of Three Interventions on the Reading Skills of Children With Reading Disabilities in Grade 2. *Journal of Learning Disabilities*, *44*(2), 123–135. https://doi.org/10.1177/0022219410391187

Hedges, L. V. (1981). Distribution Theory for Glass ’ s Estimator of Effect Size and Related Estimators. *Journal of Educational Statistics*, *6*(2), 107–128.

Karemaker, A., Pitchford, N. J., & O’Malley, C. (2010). Enhanced recognition of written words and enjoyment of reading in struggling beginner readers through whole-word multimedia software. *Computers and Education*, *54*(1), 199–208. https://doi.org/10.1016/j.compedu.2009.07.018

Keat, O. B., & Hj. Ismail, K. Bin. (2011). The Relationship between Cognitive Processing and Reading. *Asian Social Science*, *7*(10), 44–52. https://doi.org/10.5539/ass.v7n10p44

Kleinsz, N., Potocki, A., Ecalle, J., & Magnan, A. (2017). Profiles of French poor readers: Underlying difficulties and effects of computerized training programs. *Learning and Individual Differences*, *57*(May), 45–57. https://doi.org/10.1016/j.lindif.2017.05.009

Krause, M. B. (2015). Pay Attention!: Sluggish Multisensory Attentional Shifting as a Core Deficit in Developmental Dyslexia. *Dyslexia*, *21*(4), 285–303. https://doi.org/10.1002/dys.1505

Kyle, F., Kujala, J., Richardson, U., Lyytinen, H., & Goswami, U. (2013). Assessing the effectiveness of two theoretically motivated computerassisted reading interventions in the United Kingdom: GG Rime and GG Phoneme. *Reading Research Quarterly*, *48*(1), 61–76. https://doi.org/10.1002/rrq.038

Lewandowska, M., Milner, R., Ganc, M., Wlodarczyk, E., & Skarzynski, H. (2014). Attention Dysfunction Subtypes of Developmental Dyslexia. *Medical Science Monitor*, *20*, 2256–2268. https://doi.org/10.12659/MSM.890969

Messer, D., & Nash, G. (2018). An evaluation of the effectiveness of a computer-assisted reading intervention. *Journal of Research in Reading*, *41*(1), 140–158. https://doi.org/10.1111/1467-9817.12107

Moser, G. P., Morrison, T. G., & Wilcox, B. (2017). Supporting Fourth-Grade Students’ Word Identification Using Application Software. *Reading Psychology*, *38*(4), 349–368. https://doi.org/10.1080/02702711.2016.1278414

Moura, O., Simões, M. R., & Pereira, M. (2015). Executive Functioning in Children With Developmental Dyslexia. *The Clinical Neuropsychologist*, *28*(Supplement 1), 20–41. https://doi.org/10.1080/13854046.2014.964326

O’Callaghan, P., McIvor, A., McVeigh, C., & Rushe, T. (2016). A randomized controlled trial of an early-intervention, computer-based literacy program to boost phonological skills in 4- to 6-year-old children. *British Journal of Educational Psychology*, *86*(4), 546–558. https://doi.org/10.1111/bjep.12122

Pindiprolu, S., & Forbush, D. (2009). Evaluating the promise of computer-based reading interventions with students with reading difficulties. *Journal on School Educational Technology*, *4*(3), 41–49.

Pinto, A., & Peixoto, B. (2011). Neurocognitive profile of children with developmental dyslexia. *Journal of Health Sciences*, *1*(3), 115–125.

Potocki, A., Magnan, A., & Ecalle, J. (2015). Computerized trainings in four groups of struggling readers: Specific effects on word reading and comprehension. *Research in Developmental Disabilities*, *45*–*46*, 83–92. https://doi.org/10.1016/j.ridd.2015.07.016

Rosas, R., Escobar, J. P., Ramírez, M. P., Meneses, A., & Guajardo, A. (2017). Impact of a computer-based intervention in Chilean children at risk of manifesting reading difficulties / Impacto de una intervención basada en ordenador en niños chilenos con riesgo de manifestar dificultades lectoras. *Infancia y Aprendizaje*, *40*(1), 158–188. https://doi.org/10.1080/02103702.2016.1263451

Saine, N. L., Lerkkanen, M. K., Ahonen, T., Tolvanen, A., & Lyytinen, H. (2010). Predicting word-level reading fluency outcomes in three contrastive groups: Remedial and computer-assisted remedial reading intervention, and mainstream instruction. *Learning and Individual Differences*, *20*(5), 402–414. https://doi.org/10.1016/j.lindif.2010.06.004

Schmitt, K. L., Hurwitz, L. B., Sheridan Duel, L., & Nichols Linebarger, D. L. (2018). Learning through play: The impact of web-based games on early literacy development. *Computers in Human Behavior*, *81*, 378–389. https://doi.org/10.1016/j.chb.2017.12.036

Solheim, O. J., Frijters, J. C., Lundetræ, K., & Uppstad, P. H. (2018). Effectiveness of an early reading intervention in a semi-transparent orthography: A group randomised controlled trial. *Learning and Instruction*, *58*(July 2017), 65–79. https://doi.org/10.1016/j.learninstruc.2018.05.004

Wood, C. L., Mustian, A. L., & Lo, Y. yu. (2013). Effects of supplemental computer-assisted reciprocal peer tutoring on kindergarteners’ phoneme segmentation fluency. *Education and Treatment of Children*, *36*(1), 33–48. https://doi.org/10.1353/etc.2013.0004