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THE EFFECTS OF TECHNOLOGY-ASSISTED INSTRUCTION
TO IMPROVE PHONOLOGICAL-AWARENESS SKILLS IN
CHILDREN WITH READING DIFFICULTIES:
A SYSTEMATIC REVIEW

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Structured Abstract

Clinical Question: For preschool and school-age children with or at risk for reading difficulties, does technology-assisted instruction lead to better phonological-awareness (PA) skills than instruction without technology?

Method: Systematic Review

Sources: Eric, PsychInfo, CINAHL, and ASHA journal search

Search Terms: phonological awareness, phonological sensitivity, technology, computer-based instruction, computer-assisted instruction, computer software, e-book, AND reading difficulty, disorders, at-risk.

Number of Included Studies: 6

Number of Participants: Total *n* for all 6 studies = 469

Primary Results:

Children who received instruction using technology showed improved PA skills during post-test as compared to pre-test.

Children who received instruction using technology showed better PA skills than children who received instruction without technology.

Conclusions: Research evidence for the effects of technology use to improve PA skills in children with reading difficulties is still limited. However, existing studies commonly reported that PA skills in these children were improved when technology was used for instruction. PA skills in these children were better than children who received instruction without technology. Thus, clinicians may elect to incorporate technology when they implement PA training for children with reading difficulties after they fully understand limitations of current studies and characteristics of individual clients in their caseload.

The effects of technology-assisted instruction to improve phonological-awareness skills in children with reading difficulties: A systematic review

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Clinical Scenario

Jessica is a new speech-language pathologist (SLP) who is working with preschool and school-aged children in a public school. When she was a graduate student in a SLP program, Jessica learned that technology can be used effectively in SLP intervention. She personally loves to use computers, tablet PCs, and other types of technology daily. She has noticed that young children are likely to use computers and tablet PCs nowadays. Thus, Jessica is interested in using a computer program in her intervention—in particular, for improving children’s phonological-awareness (PA) skills, as many of the children on her caseload have or are at risk for reading difficulties. Jessica learned that PA skills are closely related to reading ability during graduate school. Recently, Jessica received a letter from the local district. The letter recommended that SLPs and school teachers use technology in their instruction or intervention at least once per semester. Thus, Jessica plans to use computer software when she provides intervention for children who demonstrate difficulties with PA and/or reading. Jessica has shared her plan with the school principal, who has asked her to find research evidence before she makes her decision to use a computer program in her interventions to improve PA skills in children with reading difficulties.

Background

Phonological Awareness

PA refers to “the metalinguistic skills involved in understanding that spoken words can be broken down into smaller parts” (Gillon, 2004, p.11). It comprises an individual’s precise awareness of syllable structures, onset and rime units, and the individual phonemes in syllables. Gillon proposed a hierarchical structure of PA. That is, a word can be divided into syllables if the word has two or more syllables. Each syllable can be broken down into onset, if any, and rime. The rime can be further divided into vowel nucleus and final consonant, if any. The word

“basket,” for example, can be divided into two syllables (i.e., /bæ/ & /skɪt/) and six different phonemes (i.e., /b/ /æ/ /s/ /k/ /t/ & /t/).

PA skills begin to emerge when children are in preschool and continue to develop as children progress through the primary grades. Adams (1990) outlined five developmental stages of PA skills. At the primitive stage, children are able to detect rimes. Next, they are able to determine whether a word contains a different sound as compared to the others in a group of words. Children are then able to split and blend syllables. Subsequently, children are able to segment each phoneme in a word. Finally, children are able to manipulate phonemes to generate a new word form.

Examination of PA skills in young children is of interest because PA skills are important for reading and bear a predictable relationship with later literacy development (Hogan, Catts, & Little, 2005; Lyon, Shaywitz, & Shaywitz, 2003; Meyer, Schvaneveldt, & Ruddy, 1974). Successful readers should be able to execute phonological decoding, which requires mapping printed symbols with the corresponding spoken language components (Meyer et al., 1974). In other words, children need to develop knowledge about the sounds of speech in order to learn the grapheme-to-phoneme connection. Hogan et al. (2005) conducted a longitudinal study in which PA skills were measured in kindergarteners. Their PA skills were then re-measured along with word-reading abilities in the second and fourth grades. They found that PA in kindergarten was a significant, positive predictor of second-grade reading abilities (see Lyon et al., 2003).

Methods of PA Intervention

There are a number of programs available to improve children’s PA. For instance, Swanson, Hodson, and Schommer-Aikins (2005) provided PA instruction to seventh-grade students with poor reading skills, most of whom had learned English as a second language. They found that the students who received the training performed better on reading, PA, and other related skills

than students who did not receive training. Although not all studies report strong effects of PA training (e.g., Nancollis, Lawrie, & Dodd, 2005), the National Reading Panel (2000) reported that, after reviewing 52 studies that examined the effects of PA training, PA training significantly impacts children's development of reading and spelling skills.

There also has been increasing interest in using computers and other technologies in delivering PA instruction. Foster, Erickson, Foster, Brinkman, and Torgesen (1994) examined the effectiveness of a computer program to increase PA in typically developing young children. They found that children who were involved in instruction using the computer program showed significantly better PA skills than those who received regular instruction without the computer program. Macaruso and Rodman (2011) also reported the efficacy of using a computer-assisted program for a phonics-based reading curriculum for preschoolers and kindergarteners. Children who were involved in computer-assisted instruction demonstrated better reading skills than children who received the same classroom instruction without technology. The better PA or reading performance found in children who received technology-assisted instruction was attributed to increasing students' motivation (Barker & Torgesen, 1995; Lundberg, 1995), providing modeling without teachers, and giving immediate feedback (Edwards, Blackhurst, & Koorland, 1995). However, there has been relatively little systematic research in order to evaluate the effects of technology use for improving PA skills in children with special needs. Thus, the purpose of this brief is to systematically consider the research evidence regarding the effects of technology use to improve phonological awareness in children with or at risk for reading difficulties by applying an evidence-based decision-making process; this may help SLPs and allied professionals learn how to make evidence-based clinical decisions.

Clinical Question

Jessica adopted the PICO framework (Richardson, Wilson, Nishikawa, & Hayward, 1995) to develop a clinical question. In the PICO format, P is defined as the patient, patient group, or problem, I as the intervention being considered, C as the comparison treatment (or no treatment), and O as the desired outcome. The clinical

question broken into the PICO format is as follows:

- P: Preschool and school-age children with or at risk for reading difficulties
- I: Technology-involved instruction
- C: Instruction without technology
- O: Improvements in PA

Thus, Jessica's clinical question was: "For preschool and school-age children with or at risk for reading difficulties, does technology-assisted instruction lead to better PA skills than instruction without technology?"

Search for Evidence

Inclusion Criteria

All articles included in Jessica's review were to meet the following criteria: First, only experimental and quasi-experimental, either randomized or nonrandomized, designs were included. Single-subject, multiple-baseline designs, or case studies were excluded. Second, studies that examined preschool and school-age children classified as at-risk for or exhibiting reading difficulties were included. Articles including children with low socioeconomic status (SES) or who were bilingual were not considered for this review. Third, studies that compared technology-assisted instruction to instruction without technology were included. Finally, studies that examined at least one measure of PA as a post-treatment outcome were included.

Search Strategy

Jessica searched the three major electronic databases (Eric, PsychInfo, and CINAHL), as well as the journals of the American Speech-Language-Hearing Association (ASHA), to locate research articles. She used combinations of the following keywords to identify possible studies: *phonological awareness*, *phonological sensitivity*, *technology*, *computer-based instruction*, *computer-assisted instruction*, *computer software*, *e-book*, along with *reading difficulties*, *disorder*, and *at-risk*. The search was limited to studies published in the English language in the year 2000 or later. The initial search process resulted in 102 articles, 28 of which were duplicates. After reviewing the abstracts of the 74 articles in the corpus, 37 articles were excluded because they did not include children with reading difficulties. Twenty-four studies were further

excluded because they did not employ an experimental or quasi-experimental design. Five studies were eliminated because they did not measure at least one element of PA. Finally, two studies were excluded because they did not include a control group that received instruction without technology. Thus, six articles were included in Jessica's systematic review. Figure 1 shows the process by which the six articles included in the review were selected.

Evaluating the Evidence

Description of Included Studies

Table 1 provides a summary of each study, describing research design, participants, nature of the experimental and control groups, outcome measurements, findings, effect size, and appraisal decisions. Jessica and another SLP in her school conferred on the appraisal decisions to arrive at the final agreement. Out of 48 items (six studies with eight summary elements per study), only one item was not consistent between the two. The summary was re-evaluated by both SLPs until 100% agreement was achieved.

As mentioned earlier, only experimental and quasi-experimental studies were included in this systematic review. Four of the six studies included were randomized controlled trials (Lonigan et al., 2003; Mioduser, Tur-Kaspa, & Leitner, 2000; Shamir & Shlafer, 2011; Shamir, Korat, & Fellah, 2012), and two studies were quasi-experimental studies (Jimenez et al., 2003; Mathes, Torgesen, & Allor, 2001).

A total of 469 children with or at risk for reading difficulties were participants, as well as 65 children who demonstrated an above-average level of reading performance in Mathes et al. (2001) and 60 typically developing children in Shamir and Shlafer (2011). The children were in preschool or the primary grades, and their ages ranged from 3:6 to 10:6. Five studies (Lonigan et al., 2003; Mathes et al., 2001; Mioduser et al., 2000; Shamir & Shlafer, 2011; Shamir et al., 2012) included children at risk for learning disabilities or reading failure. One study (Jimenez et al., 2003) involved children with dyslexia and those described as garden-variety poor readers in addition to children with poor reading performance.

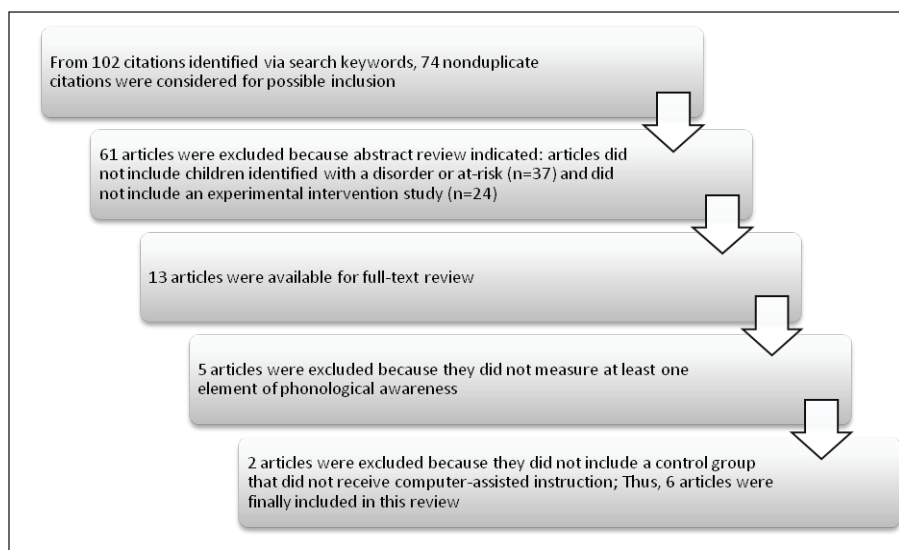


Figure 1.
Study search and selection process

Table 1. Description of Studies Included for the Review

Reference	Design	Population	Experimental Group	Control Group	PA Outcomes	Results	Effect Size	Appraisal
Mioduser, Tur-Kaspa, & Leitner (2000)	Randomized Controlled Trial	46 children (ages 5 to 6) at risk for learning disabilities participated. The children were randomly assigned to one of the three study groups.	Group 1 received computer-based instruction.	Group 2 received instruction with printed materials. Group 3 received the regular special education program.	PA	Children who received instruction using computers showed better PA than the other two groups who received instruction without computers.	Group 1 and Group 3 only $d = 3.35$ (CI = 2.26–4.44)	Suggestive
Mathes, Torgesen, & Allor (2001)	Quasi-Experimental Design	183 first graders (ages 6:39 to 6:64) were divided into three groups. Low-achieving (LA) students ($n = 118$) Average-performing (AA) students ($n = 33$) High-performing (HA) students ($n = 32$). The LA students were further divided into three groups.	One group of LA students ($n = 42$) received Peer-Assisted Literacy Strategy (PALS) plus computer-assisted instruction (CAI) focusing on PA (Group 1)	One group of LA students ($n = 43$) received PALS only (Group 2). One group of LA students ($n = 33$) received regular classroom instruction (Group 3).	Elision & Segmentation subtests of Comprehensive Test of Phonological Processes (CTOPP)	Group 1 and Group 2 showed better segmentation skills than Group 3, but no difference between Group 1 and Group 2. Group 2, but not Group 1, performed better than Group 3 on the elision task.	Effect size reported. ES = .37 for segmentation and ES = .11 for elision between Group 1 and Group 3.	Equivocal
Jimenez et al. (2003)	Quasi-Experimental Design	73 Spanish children (ages 7:1 to 10:6) with poor reading performance participated. They were divided into three groups. Group 1 ($n = 14$): children with dyslexia Group 2 ($n = 31$): garden-variety poor readers Group 3 ($n = 28$): poor reading performance	Group 1 and Group 2 received instruction with computers.	Group 3 received regular classroom instruction.	1) Odd Word Out Task 2) Phoneme Segmentation Test 3) Phoneme Reverse Test	Post-test performance was significantly improved over pre-test performance for all three groups. However, only Group 2 demonstrated better PA skills than Group 1 and Group 3 during post-test.	Effect size reported. ES = .09 for significant difference between the groups.	Equivocal
Lonigan et al. (2003)	Randomized Controlled Trial	45 children at risk for reading problems (ages 3:7 to 5:3) participated. The children were randomly assigned to two groups.	Group 1 received instruction using computers.	Group 2 received traditional classroom instruction.	8 PA sensitivity tasks: rhyme oddity, rhyme matching, word blending, syllable/phoneme blending, multiple-choice blending, word elision, syllable/phoneme elision, multiple-choice elision.	Children in the CAI group evidenced significantly more growth in rhyme oddity, rhyme matching, word elision, and syllable/phoneme elision than the control group.	Effect size reported. ES = .07 for rhyme oddity, .08 for rhyme matching, .10 for word elision, and .18 for syllable/phoneme elision.	Suggestive

Table 1. Description of Studies Included for the Review, continued

Reference	Design	Population	Experimental Group	Control Group	PA Outcomes	Results	Effect Size	Appraisal
Shamir & Shlafer (2011)	Randomized Controlled Trial	136 Israeli kindergarteners (ages 5 to 7) participated; 77 children at risk for learning disabilities and 60 typically developing children. Each group of children was randomly assigned to two groups.	Group 1 received PA instruction using e-book.	Group 2 received traditional classroom instruction.	Sub-syllabic awareness	Group 1 showed more improved sub-syllabic PA skills than Group 2. No difference on sub-syllabic awareness improvement between children at risk and the typically developing group.	Effect size reported. $\eta^2_p = .12$ for significant difference between Group 1 and Group 2.	Suggestive
Shamir, Korat, & Fellah (2012)	Randomized Controlled Trial	110 Israeli kindergarteners (ages 5 to 7) at risk for learning disabilities. The children were randomly assigned to three groups. Group 1 (n = 42) Group 2 (n = 34) Group 3 (n = 34)	Group 1 received PA instruction using e-book.	Group 2 received instruction using printed version of book. Group 3 received standard special education program.	Sub-syllabic awareness	Group 1 showed better sub-syllabic awareness skills than Group 2 and Group 3.	Effect size reported. $\eta^2_p = .12$ for significant difference among the three groups.	Suggestive

Five studies (Lonigan et al., 2003; Mathes et al., 2001; Mioduser et al., 2000; Shamir & Shlafer, 2011; Shamir et al., 2012) employed control groups, whereas one study (Jimenez et al., 2003) did not contain a true control group. Jimenez and colleagues (2003) included three groups in their study: (a) an experimental group comprising children with dyslexia (based on a large discrepancy between word reading and intellect), (b) an experimental group comprising children referred to as garden-variety poor readers (based on a smaller discrepancy between word reading and intellect), and (c) a control group of children whose word-reading skill was lower than the 25th percentile. The two experimental groups received computer-assisted instruction, whereas the control group did not. Although the intelligence quotient (IQ) of the control group was matched with that of the garden-variety poor readers group, it was not clear whether the reading level of the control group was similar to that of the garden-variety poor readers. Thus, it is difficult to consider it as a true control group.

All six studies measured the children's PA skills but assessed a variety of outcome measures (see Table 1 for details). Four randomized control design studies (Lonigan

et al., 2003; Mioduser et al., 2000; Shamir & Shlafer, 2011; Shamir et al., 2012) reported that children who received computer-assisted instruction or instruction using e-books showed better PA skills than children who received instruction with either printed materials or traditional instruction. Mathes et al.'s (2001) finding was slightly different from those reported in the randomized controlled trials. Mathes et al. examined three groups: one group received Peer-Assisted Literacy Strategy (PALS) and computer-assisted instruction, one group received only PALS, and one group received regular classroom reading instruction. They found that children who received PALS, regardless of computer-assisted instruction, showed better segmentation skills than children who received regular instruction. In Jimenez et al.'s (2003) study, the garden-variety poor readers, but not the children with dyslexia, demonstrated better PA skills using computer-assisted instruction than children with poor reading performance who received only traditional instruction.

Study Appraisal

Jessica adopted the Critical Appraisal of Treatment Evidence (CATE; Dollaghan, 2007) strategy in order to make an appraisal of each study. Among the 15 appraisal points, she assessed 11 appraisal points that are relevant to the six articles selected in her review. In addition, she included initial group similarity from Gillam and Gillam (2006). Therefore, Jessica evaluated a total of 12 appraisal points for each study (see Table 2). According to Dollaghan, studies can be ranked by three descriptors: “compelling,” “suggestive,” or “equivocal.” Studies ranked as *compelling* provide incontrovertible evidence. Studies ranked as *suggestive* are considered evidence that is open to debate. Finally, studies ranked as *equivocal* are evidence in which unbiased experts make opposite conclusions.

Jessica also examined the effect sizes of the outcome measures in each study in the clinical decision-making process. All studies reported effect sizes except for Mioduser et al.’s (2000) study. For the study that did not report effect size, Cohen’s *d* and confidence interval were calculated using data provided in the article. Cohen’s *d* is a

commonly used method to measure effect size that can be obtained by dividing the difference of the mean by the average of the standard deviations between the two groups (see Robey, 2004 for more information). Cohen suggested that an effect size of 0.2 be considered small, 0.5 medium, and 0.8 large.

For the 12 appraisal points examined, Jessica observed several common limitations across studies. First, none of the studies clearly addressed whether they employed blinding to minimize subjective biases. Thus, it was unclear whether evaluators were blind to the purpose of the study and the types of participating groups when they evaluated PA skills, which may threaten internal validity of the study. Second, except for two studies (Lonigan et al., 2003; Mathes et al., 2001), the studies did not report participant attrition. It was therefore unclear whether the studies maintained the same number of children between the beginning and end of the study. Given the large number of participants in each study, it is difficult to assume that no participant attrition was observed during the experimental process. Third, three

Table 2. Appraisal of Study Quality

Appraisal Points		Mioduser et al. (2000)		Mathes et al. (2001)		Jimenez et al. (2003)		Lonigan et al. (2003)		Shamir & Schlafer (2011)		Shamir et al. (2012)	
		Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
1	Was there a plausible rationale of the study?	X		X		X		X		X		X	
2	Was the evidence from an experimental study?	X		X		X		X		X		X	
3	Was there a control group or condition?	X		X			X	X		X		X	
4	Was randomization used to create the contrasting condition?	X			X		X	X		X		X	
5	Were methods and participants specified prospectively?	X		X		X		X		X		X	
6	Were patients representative and/or recognizable at beginning and end?		X	X			X	X			X		X
7	Were the groups the same for pre-test measurements?	X			X		X		X	X		X	
8	Was treatment described clearly and implemented as intended?		X	X		X		X		X		X	
9	Was the measure valid and reliable, in principle and as employed?		X	X			X		X	X		X	
10	Was the outcome evaluated with blinding?		X		X		X		X		X		X
11	Was the finding statistically significant?	X			X	X		X		X		X	
12	Was the effect size large?	X			X		X		X		X		X
Counts		8	4	7	5	5	7	8	4	9	3	9	3

out of the six studies reported reliability for PA measurements (Mathes et al., 2001; Shamir & Shlafer, 2011; Shamir et al., 2012), whereas the remaining three studies did not (Jimenez et al., 2003; Lonigan et al., 2003; Mioduser et al., 2000). In terms of effect size, a large effect size was found in only one study (Mioduser et al., 2000), whereas the effect size was small in the other five studies (Mathes et al., 2001; Jimenez et al., 2003; Lonigan et al., 2003; Shamir & Shlafer, 2011; Shamir et al., 2012). A small effect size suggests that although there is a significant difference between groups, it may not be a “true measure of the significance of the difference” (Coe, 2002) between the two groups. Besides these common limitations, most studies met the other appraisal points.

Considering all the information Jessica obtained, she identified the two studies done by Shamir and colleagues (Shamir & Shlafer, 2011; Shamir et al., 2012) as providing suggestive evidence, as they were both well-designed experimental studies and provided significant results regarding the effectiveness of technology-assisted instruction to improve PA. However, the effect sizes for these studies were small. It should also be noted that the datasets used in the two studies overlapped. Thus, it is difficult to view them as independent studies. Similarly, Jessica ranked Mioduser et al.’s (2000) and Lonigan et al.’s (2003) studies as suggestive. Although they were well-controlled experimental design studies, they were ranked as suggestive because Mioduser et al. did not provide detailed information on experimental procedures, blinding of the study, and measurement reliability. Lonigan et al. did not satisfy requirements of blinding, measurement reliability, and initial group similarity. The effect size for the study was also small.

Mathes et al.’s (2001) study was considered as providing equivocal evidence, as this study had several weaknesses. In addition to failures of achieving randomization and participant attrition, children with or without computer-assisted instruction (CAI) were not truly equivalent in this study because children with CAI had significantly lower scores on several pre-test measurements. Thus, children with CAI were not comparable to those who received treatment without CAI. Finally, Jimenez et al.’s (2003) study was also considered equivocal because criteria for determining dyslexia and labeling garden-variety poor readers may not define a homogeneous subgroup of children with reading disability. Also, this study did not report whether the

three groups of children demonstrated similar pre-test performance on the PA measurements. Based on pre-test scores, it seemed that the PA of the garden-variety poor readers was better than the children with dyslexia and poor reading performance. As a result, it was difficult to argue that the PA of children labeled as garden-variety poor readers was higher than that of children with dyslexia and those with poor reading performance during post-treatment testing. Besides these issues, this study did not satisfy requirements of randomization, participant attrition, measurement reliability, and blinding.

In summary, four out of the six studies included in Jessica’s review were rated as suggestive, supporting the effectiveness of technology-assisted instruction in improving PA skills for children with reading difficulties. The two studies that did not report strong effects of technology-assisted instruction were rated as equivocal, as they had low methodological quality.

The Evidence-Based Decision

The purpose of Jessica’s systematic review was to determine whether technology-assisted instruction may be more effective than instruction without technology in improving PA skills in children with or at risk for reading difficulties. The six studies reviewed provided moderate to high quality of evidence, although there were several limitations. After reviewing the studies, Jessica decided that technology-assisted instruction may be an effective method to help children improve their PA skills, and technology-assisted instruction may be more effective than instruction without technology.

It should be noted that this clinical decision was made solely based on external evidence without considering internal evidence. According to Gillam and Gillam (2006), a number of student–parent and clinician–agency factors should be considered as internal evidence after obtaining external evidence. The student–parent factors include parents’ and students’ cultural values and beliefs, student activities and participation, families’ financial resources, levels of student–parent engagement, and parents’ or students’ beliefs on a specific activity. The clinician–agency factors consist of knowledge and skills or education, policies and financial resources of the agency or school district, data obtained from the clinician’s own practice, and the clinician’s theoretical orientation.

After Jessica makes a decision based on external evidence, her decision should be finalized after considering all of the internal evidence. Based on the short description of this clinical scenario, it seems that Jessica's students like to use technology and her school district encourages her to utilize technology in her intervention. Thus, Jessica should make her final decision after identifying parents' perspectives on her question. After implementing the technology-assisted instruction for her intervention, Jessica should also evaluate her outcome and disseminate it in order to successfully implement evidence-based practice.

Limitations and Direction for Future Research

In this brief, the authors attempted a systematic review to provide information on effects of technology-assisted instruction to improve phonological awareness skills in children with reading difficulties. Since current research evidence available to evaluate the effects of technology-assisted instruction to improve PA is limited to children with reading difficulties, we are not certain whether the same effect will be found in children with speech or language disorders. Tambyraja and McCauley (2012) reported insufficient evidence in their systematic review that PA intervention improves speech in preschool children with speech sound disorders. Thus, further studies are warranted to examine the effects of technology-assisted intervention for children with speech sound disorders in order to examine whether it improves their PA skills as well as speech production skills.

In this review, the criteria for selecting articles were somewhat broad so that some heterogeneity of study components existed across the studies. For example, Jessica included studies that measured at least one PA skill as outcome measurements. The PA skills varied across the studies. She also included studies that employed any types of technology in her review. Thus, types of technology varied among the studies. For instance, Shamir and colleagues (Shamir & Shlafer, 2011; Shamir et al., 2012) used an e-book, Mathes et al. (2001) adopted a commercially available software called DaisyQuest™ and Daisy's Castle™, and Jimenez et al. (2003) utilized a specially designed program for dyslexia. It is

recommended that a future systematic review on the effects of technology-assisted instruction to improve PA in children focus on specific PA skills (e.g., elision, segmenting, blending) and types of technology.

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