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Research Article

Comparing Traditional and Tablet-Based Intervention for Children With Speech Sound Disorders: A Randomized Controlled Trial

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Purpose: This article reports on the effectiveness of a novel tablet-based approach to phonological intervention and compares it to a traditional tabletop approach, targeting children with phonologically based speech sound disorders (SSD).
Method: Twenty-two Portuguese children with phonologically based SSD were randomly assigned to 1 of 2 interventions, tabletop or tablet (11 children in each group), and received intervention based on the same activities, with the only difference being the delivery. All children were treated by the same speech-language pathologist over 2 blocks of 6 weekly sessions, for 12 sessions of intervention. Participants were assessed at 3 time points: baseline; pre-intervention, after a 3-month waiting period; and post-intervention. Outcome measures included percentage of consonants correct, percentage of vowels correct, and percentage of phonemes correct. A generalization of target sounds was also explored.
Results: Both tabletop and tablet-based interventions were effective in improving percentage of consonants correct and percentage of phonemes correct scores, with an intervention effect only evident for percentage of vowels correct in the tablet group. Change scores across both interventions were significantly greater after the intervention, compared to baseline, indicating that the change was due to the intervention. High levels of generalization (60% and above for the majority of participants) were obtained across both tabletop and tablet groups.
Conclusions: The software proved to be as effective as a traditional tabletop approach in treating children with phonologically based SSD. These findings provide new evidence regarding the use of digital materials in improving speech in children with SSD.
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Speech sound disorders (SSD) of unknown origin are one of the most common developmental disorders in childhood (Law, Boyle, Harris, Harkness, & Nye, 2000). Children with SSD represent 40%–90% of speech-language pathologists' (SLPs') pediatric caseloads (Joffe & Pring, 2008; Mcleod & Baker, 2014; Oliveira, Lousada, & Jesus, 2015). They have delayed speech sound acquisition (Shriberg, 2003) and limited speech intelligibility (Bowen, 2015; Raitano, Pennington, Tunick, Boada, & Shriberg, 2004). Children with SSD may attempt to accommodate their difficulties by using speech patterns and structures or phonological processes (Ingram, 1989) that simplify speech and are not present in the utterances of typically developing children of the same age. They can present substitutions, omissions, distortions, additions, and atypical prosody (Bowen, 2015; Orsolini, Sechi, Maronato, Bonvino, & Corcelli, 2001).

Advantages of Using Digital Technology as a Tool for Intervention

Over the last few years, there has been an increase in the number of interventions available for children with SSD (Dodd, Reilly, Ttofari Eecen, & Morgan, 2018). Most of the evidence-based interventions to date use the traditional medium of tabletop materials (e.g., board games,

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physical objects, and/or pictures). However, there is an increasing interest in and use of digital media (McCormack et al., 2017; Popovici & Buica-Belciu, 2012; Ramdoss et al., 2011; Saz et al., 2009). This is in response to the heightened exposure that most children have to electronic devices, computers, smartphones, and other technologies that shape their interactions and learning preferences (Furió, González-Gancedo, Juan, Seguí, & Rando, 2013). Despite research using digital technology with children with speech, language, and communication difficulties being in its infancy, initial results are promising. Digital technology can be motivating and fun for children (Ploog, Scharf, Nelson, & Brooks, 2013) and can make therapy more engaging and interesting (Chen et al., 2016). For example, Moore and Calvert (2000) found that a computerized task was more effective and motivating for children with autism than the smiles and positive reinforcement given by teachers. Similarly, Murphy, Faulkner, and Reynolds (2014) reported high levels of enjoyment experienced by children with social communication difficulties when involved in a computerized intervention program. They also found that the children usually wanted to continue with the task once the session had ended (Murphy et al., 2014). A computer game–based approach can be an effective tool not only in increasing motivation but also in promoting and enhancing children's learning experiences (Kebritchi & Hirumi, 2008). Furthermore, learning with the aid of a computer can be disguised as "gaming time," presenting additional opportunities for learning (Pennala, Richardson, Ylinen, Lyytinen, & Martin, 2014; Virvou & Alepis, 2005). The interactive, multisensory learning experiences, integral to computer-based interventions (Shi & Müller, 2013), fit well within a psycholinguistic processing model of speech, by providing multiple opportunities for multisensory learning at the input, lexical representational (semantic, phonological, motor, grammatical, and orthographic), and output levels (Popple & Wellington, 2001). To capitalize on the advantages of technology and to better suit the interests and experiences of today's children, SLPs need to innovate and expand their repertoire of strategies and activities. The use of software is one common solution.

The Use of Digital Technology in Speech-Language Pathology

Various electronic tools have been shown to have the potential to aid and enhance speech and language therapy, in both assessment and intervention, in populations as diverse as those with aphasia (Abad et al., 2013; Marshall et al., 2016), autism (Khowaja & Salim, 2013; Ramdoss et al., 2011), cerebral palsy (Hawley et al., 2013; Kanitkar et al., 2017), Down syndrome (Augusto, Kramer, Alegre, Covaci, & Santokhee, 2018; Feng, Lazar, Kumin, & Ozok, 2010), dysarthria (Saz et al., 2009), hearing impairment (Nanjundaswamy, Prabhu, Rajanna, Ningegowda, & Sharma, 2018; Stacey et al., 2010), Parkinson's disease (Theodoros, Aldridge, Hill, & Russell, 2019), and SSD (McLeod et al., 2017; Wren & Roulstone, 2008). In a recent systematic review of computer-based interventions for children and adults with articulation and phonological disorders, Chen et al. (2016) reported this mode of delivery to be effective, although the majority of these studies compared performance with a no-therapy control group rather than a traditional speech-language pathology approach. They also noted the heterogeneity in the studies using computer-based technology. Some studies used animated heads as the therapy delivery method, whereas others drew on computer-based games to deliver the therapy. All of the studies used variations of computerized visual and auditory cues to provide feedback.

This variability in what comprises computer-based speech therapy (CBST) interventions was also noted by Furlong, Erickson, and Morris (2017) in their systematic review of the efficacy of CBST programs for children with SSD. These authors defined CBST programs as software with predefined therapy tasks, including instructional, motivational, and quantitative (tracking performance) features (Furlong et al., 2017, p. 51). They differentiated this from visual feedback technologies, for example, ultrasound, which provide a computerized display of physiological variables, such as tongue position (Furlong et al., 2017, p. 51). The computer-based intervention described in this article fits well with Furlong et al.'s definition of CBST programs and is the focus of discussion.

CBST Programs With Children With SSD

Furlong et al. (2017) showed emerging evidence for the effectiveness of CBST for children with SSD, with the level of evidence reported as "moderately strong" (Furlong et al., 2017, p. 62). In their review, only six of the 14 studies included were randomized controlled trials, with two being nonrandomized or pseudorandomized and only three studies including a follow-up. Whereas treatment gains were reported in all of the studies, only four of them (two of which were randomized controlled trials) reported statistically significant differences compared to a treatment control group (Furlong et al., 2017).

Some studies (Pereira, Brancalioni, & Keske-Soares, 2013; Shriberg & Kwiatkowski, 1989; Wren & Roulstone, 2008) have specifically compared the use of software and tabletop activities in children with SSD, with results being mixed. Shriberg and colleagues (Shriberg & Kwiatkowski, 1989; Shriberg, Kwiatkowski, & Snyder, 1990), for example, found that digital and tabletop activities were equally effective and engaging for children with SSD, although anecdotal reports from the SLPs suggested that the computerized tasks were more popular with the children, and the majority of participants chose the computer-based therapy as their preferred option. In a pseudorandomized controlled trial comparing the effectiveness of the tabletop, digital, and no-intervention control groups, Wren and Roulstone (2008) reported significant improvements in speech production in all three groups, after 4 hr of intervention over 8 weeks, with the digital group making the most improvement, although this difference was not significant. Only the digital group made further progress at the 3-month follow-up.

These results make it impossible to differentiate between intervention and maturational effects as improvements were noted across all three groups. However, this study did show that a computer-based intervention could be used effectively with children with SSD. In a more recent randomized controlled trial, McLeod et al. (2017) explored the effectiveness of a computer-based intervention, delivered by early childhood educators, using an adapted version for Australia of the software originally used in the United Kingdom by Wren and Roulstone. In this study, 123 children were randomized into two groups: an intervention group receiving a total of 18 hr of computer-based intervention over 9 weeks and a no-treatment control group. There were no significant differences reported from pre- to post-intervention between the intervention and control groups, in terms of percentage of consonants correct (PCC) scores, emergent literacy, phonological processing, and measures of participation and well-being. Whereas both groups showed significant improvements from pre- to post-intervention on most outcome measures, the researchers argue that these improvements were not clinically significant (McLeod et al., 2017).

Although the use of digital technology is becoming increasingly more common in speech-language pathology service delivery, the evidence of its effectiveness remains mixed, and any added benefits using this mode of delivery versus the traditional therapy approach are unclear. There is still a gap between research and practice in the use of digital interventions, and the recent technological developments have not been associated with an increase in evidence to support their application in clinical settings (Bowen, 2015, pp. 240–244). Nevertheless, there has been an increase in the digital resources available to SLPs, and the potential benefits and attraction of technology to children are important. However, one cannot necessarily assume that children who receive digital-based intervention will respond in the same way as those who receive traditional tabletop intervention (Bowen, 2015; McLeod et al., 2017; Wren & Roulstone, 2008). There is limited research investigating the effectiveness and efficiency of digital interventions and, specifically, comparing the outcomes to traditional speech and language therapy. Thus, clinicians do not know if computer-based intervention programs can enhance the therapy process or, instead, create additional problems. It is also important to consider children's responses to digital game-based interventions and whether these differ from a traditional tabletop approach (Bowen, 2015; Wren, Roulstone, & Williams, 2010).

Aims

Most of the available evidence-based interventions for children with SSD use board games, pictures, and/or physical objects, adopting a traditional tabletop approach. However, there is an increasing interest in the use of a digital game-based approach as a tool for increasing motivation and enhancing children's learning experiences. Recent studies have shown mixed results when comparing digital and traditional intervention approaches for people with articulation and phonological disorders.

This study, therefore, aims to fill this gap by assessing the effectiveness of phonological therapy for children with SSD, using two modes of delivery: a traditional tabletop approach and a digital tablet approach.

Method

This study is a randomized controlled trial. The flowchart in Figure 1 summarizes the steps taken to conduct the study. The first step was the creation of partnerships between the University of Aveiro and schools in the Aveiro region in Portugal (Jesus, Martinez, Valente, & Costa, 2017). Teachers were asked to identify children that they thought had immature or poor speech. All identified children were then assessed (T1). Since the project was only selecting children with SSD, the other children (with different diagnoses) were referred to external (to the project) SLPs. The children who fitted the inclusion criteria were then randomly allocated to one of two groups (tabletop or tablet) and were assessed again after a waiting period of 3 months (T2). After this second assessment, the children had the intervention and were assessed at post-intervention (T3).

Thirty-three children were diagnosed with SSD, with 30 parents providing consent. Eight of these 30 children, when assessed at T2, presented with less than the minimum of two phonological processes required at pre-intervention time for them to enter the study and were therefore omitted from further involvement. A total of 22 children were assessed at T3.

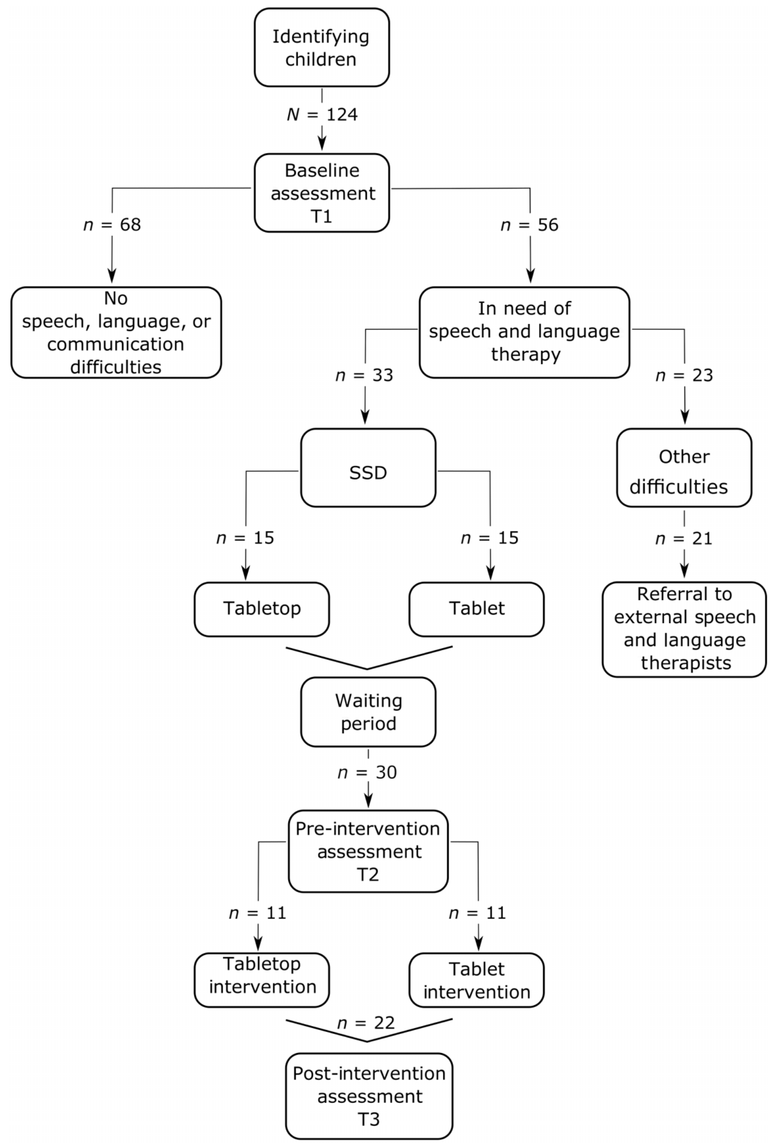
Participants

Twenty-two Portuguese children (four girls and 18 boys) with phonologically based SSD, with a mean age of 57 months, were selected. This disproportionate number of males to females is a typical distribution (70%–80% boys) in the Portuguese population and has been frequently reported in previous studies (Jesus, Lousada, Domingues, Hall, & Tomé, 2015; McLeod et al., 2017; Wren & Roulstone, 2008) and in clinical caseloads (Broomfield & Dodd, 2004). Participants had no history of prior speech and language therapy. Children were assessed and diagnosed as having phonologically based SSD after an extensive assessment by an SLP, an audiologist, and a psychologist.

Participant inclusion criteria were as follows:

- Age range from 3;6 to 6;6 (years;months).
- European Portuguese as the first and only language.
- No impairments on oro-motor structure and function, assessed with the Protocolo de Avaliação Orofacial (PAOF; Guimarães, 1995). PAOF is a standardized oro-motor abilities test that is widely used in clinical practice in Portugal.
- No symptoms of "childhood apraxia of speech" as defined by Bowen (2015), and assessed with the case history form, the PAOF, the 67-word naming task from the

Figure 1. Study scheme. SSD = speech sound disorders.



Teste Fonético-Fonológico – Avaliação da Linguagem Pré-Escolar (TFF-ALPE; Mendes, Afonso, Lousada, & Andrade, 2013), and spontaneous speech sample.

- Age-appropriate receptive language, assessed with the Teste de Linguagem – Avaliação da Linguagem Pré-Escolar (TL-ALPE; Mendes, Afonso, Lousada, & Andrade, 2014). TL-ALPE is a standardized, valid, and reliable language test that assesses Portuguese children's receptive and expressive language abilities.
- Audition of 20 dB or lower in the frequencies of 500, 1000, 2000, and 4000 Hz.
- Age-appropriate nonverbal IQ assessed with the Wechsler Preschool and Primary Scale of Intelligence–Revised (Wechsler, 2003).
- Presenting at least two phonological processes at pre-intervention time (Crosbie, Holm, & Dodd, 2005; Dodd, Zhu, Crosbie, Holm, & Ozanne, 2002).

The children's phonological abilities were assessed by an SLP with a single-word naming (67 words) task from the TFF-ALPE (Mendes et al., 2013). All the children were also assessed for consistency of production. Participants scored below the set criteria of 40%, as recommended by Dodd et al. (2002), on the Inconsistency Assessment of the TFF-ALPE (Mendes et al., 2013), showing consistent speech production, according to Dodd et al.'s criteria for consistency.

Ethical permission was obtained from an independent ethics committee (*Comissão de Ética da Unidade Investigação em Ciências da Saúde – Enfermagem da Escola Superior de*

Enfermagem de Coimbra, Coimbra, Portugal), and informed consent was collected from all carers prior to data collection. The study was also registered at ClinicalTrials.gov. For more details regarding the characteristics of the participants, see Table 1 and Supplemental Material S1.

Intervention

In order to build an intervention that mirrored existing evidence-based and well-defined speech-language pathology practice for children with SSD (Lousada et al., 2013; Lousada, Jesus, Hall, & Joffe, 2014), tabletop and digital SSD intervention programs were developed, which incorporated key target areas that have been shown to be effective. These included (a) auditory bombardment (focusing on the target phoneme or phoneme combination; Hodson & Paden, 1991), (b) hearing and discriminating (to incorporate sounds into the phonological system; Lancaster, 2008), (c) grapheme–phoneme correspondence (knowledge of phoneme–grapheme and grapheme–phoneme relationships; Gillon & McNeill, 2007), (d) phoneme identity (to identify phonemes in words; Gillon & McNeill, 2007), (e) segmentation (to analyze words at the phonemic level; Gillon & McNeill, 2007), (f) blending (to blend isolated sounds together to form words; Gillon & McNeill, 2007), (g) rhyme (to identify phonological similarities in spoken word pairs; Gillon & McNeill, 2007), and (h) phoneme manipulation (to analyze and manipulate sounds; Gillon & McNeill, 2007).

The phonologically based intervention consisted of a combination of phonological awareness activities (Lousada et al., 2013) adapted from Gillon and McNeill's (2007) phonological awareness program, Hodson and Paden's (1991) auditory bombardment, and discrimination and listening tasks from Lancaster (2008). There were 18 different activities grouped by target area (mean number of activities per area of two). Each session had a total of three activities, one from each of the eight target areas with the exception of the first two sessions, where the focus was on auditory bombardment, listening and discrimination (Gillon & McNeill, 2007), and some advice on tongue placement, using the materials developed by Pedro, Lousada, Hall, and Jesus (2018), to help elicit the target sound. The organization of the activities per session was based on Lousada et al. (2013), with sessions divided into two blocks. See Supplemental Material S2 for examples of activities making up the intervention.

One group was treated with the tabletop materials, and the other group was treated with an app running on a tablet, as shown in Figure 2. The intervention approach was identical across both groups, the only difference being the method of presenting the materials (tabletop vs. tablet-based). The tabletop materials consisted of printed cards, board games, stuffed animals, cardboard boxes, a large dice, fishing rods, and other similar materials used in traditional therapy. In the tablet group, all the activities were run on an 8-in. screen ASUS MeMO Pad 8, with 1 GB of RAM and Android 4.4.2 KitKat (Jesus, Santos, & Martinez, 2019).

The intervention for both groups consisted of 12 weekly individual sessions of 45 min, across a 3-month duration. The intervention was divided into two 6-session blocks

Table 1. Age (months), gender, intervention group allocation of participants, percentage of consonants correct (PCC), percentage of vowels correct (PVC), and percentage of phonemes correct (PPC) at baseline (prerandomization).

Child	Age (months)	Gender	Intervention group	PCC (%)	PVC (%)	PPC (%)
1—DC	64	F	Tabletop	59.79	94.84	75.98
2—DR	43	M	Tabletop	51.06	96.13	72.35
3—FC	51	M	Tabletop	69.07	96.13	81.84
4—GP	67	M	Tabletop	42.27	84.52	61.45
5—SC	49	M	Tabletop	59.28	94.84	75.70
6—DB	49	M	Tabletop	53.61	96.77	73.46
7—JR	48	F	Tabletop	48.97	87.10	66.20
8—BF	67	M	Tabletop	75.26	96.77	85.20
9—NM	61	M	Tabletop	64.43	94.06	78.21
10—FM	55	M	Tabletop	48.45	92.13	70.11
11—LS	42	F	Tabletop	43.81	92.77	67.88
M (*SD*)	54.18 (8.78)					
12—SI	51	M	Tablet	47.94	90.97	67.88
13—SF	72	M	Tablet	61.31	95.48	77.09
14—DU	54	M	Tablet	54.06	95.48	69.55
15—GO	61	M	Tablet	69.59	96.77	82.12
16—RA	46	M	Tablet	51.03	94.84	71.23
17—TS	53	M	Tablet	71.23	96.77	82.96
18—RD	75	M	Tablet	45.98	91.61	66.48
19—RP	67	M	Tablet	64.07	97.42	82.12
20—DV	60	M	Tablet	60.82	95.13	77.09
21—GM	59	F	Tablet	65.98	97.42	80.45
22—JS	57	M	Tablet	64.43	94.19	78.49
M (*SD*)	59.55 (8.47)					
M_{total} (*SD*)	56.86 (9.24)					

Figure 2. Comparison between a tabletop (left) and a tablet (right) activity.

with no breaks (there was an assessment between them and a change of focus—a different phonological process). A duration of six sessions is enough to significantly impact phonological skills, but a greater total intervention duration is needed to demonstrate an intensity effect (Allen, 2013).

For each child, one phonological rule was chosen as an intervention target for each block. The criteria taken into account to choose the target phonological processes for intervention were frequency—occurring at least at a 40% rate in the child's speech (Hodson & Paden, 1991), intelligibility (Dodd & Bradford, 2000; Lousada et al., 2014)—less than two thirds (66%) of the utterances of a child can be understood by unfamiliar listeners (Gordon-Brannan & Hodson, 2000, p. 146), stimulability—including stimulable sounds (Dodd & Bradford, 2000), and developmental—earlier acquiring sounds (Dodd & Bradford, 2000; Jesus et al., 2015). A maximum of three speech sounds, produced in 24 different words, were targeted per block, for all participants across the two interventions. The number of attempts a child was given to identify and produce the target picture depended on the accuracy of their production, with a minimum of one and a maximum of five attempts. There was an average of two attempts per child for both modes of delivery. Both groups were treated by the same SLP trained in both methods.

Parents or caregivers were invited to be present in therapy sessions, either at their child's school or at the clinic, and short homework tasks (approximately 15 min in duration) were given at the end of each session to complete for the following session. The homework took the form of a set of games and worksheets specifically developed for the project. Regular homework is recommended for maximizing progress (Gunther & Hautvast, 2010).

In the tabletop group, the homework activities were worksheets focusing on the targeted phonological processes, and in the tablet group, homework was based on four different computerized games (see Figure 3). Parents or caregivers returned a form at each session reporting on the adherence to and completion of the homework.

Each child allocated to the tablet group received a tablet with the games installed at the beginning of the intervention. At the end of each session, an information sheet explaining the worksheets (tabletop) and games (tablet) for homework that week was given to the parent or caregiver, together with a form where they could note their adherence to the homework.

The allocation to one of the interventions (with the same content but different delivery method—tabletop or tablet) took place during the waiting period, after the selection process and before the pre-intervention assessment. Each child was given a number from 1 to 22 and randomly allocated to one of the two groups. The numbers were randomized using an online tool (RANDOM.ORG [Randomness and Integrity Services Ltd.], a true random integer sequence generator based on atmospheric noise data, available at https://www.random.org/sequences/).

Fidelity of Intervention

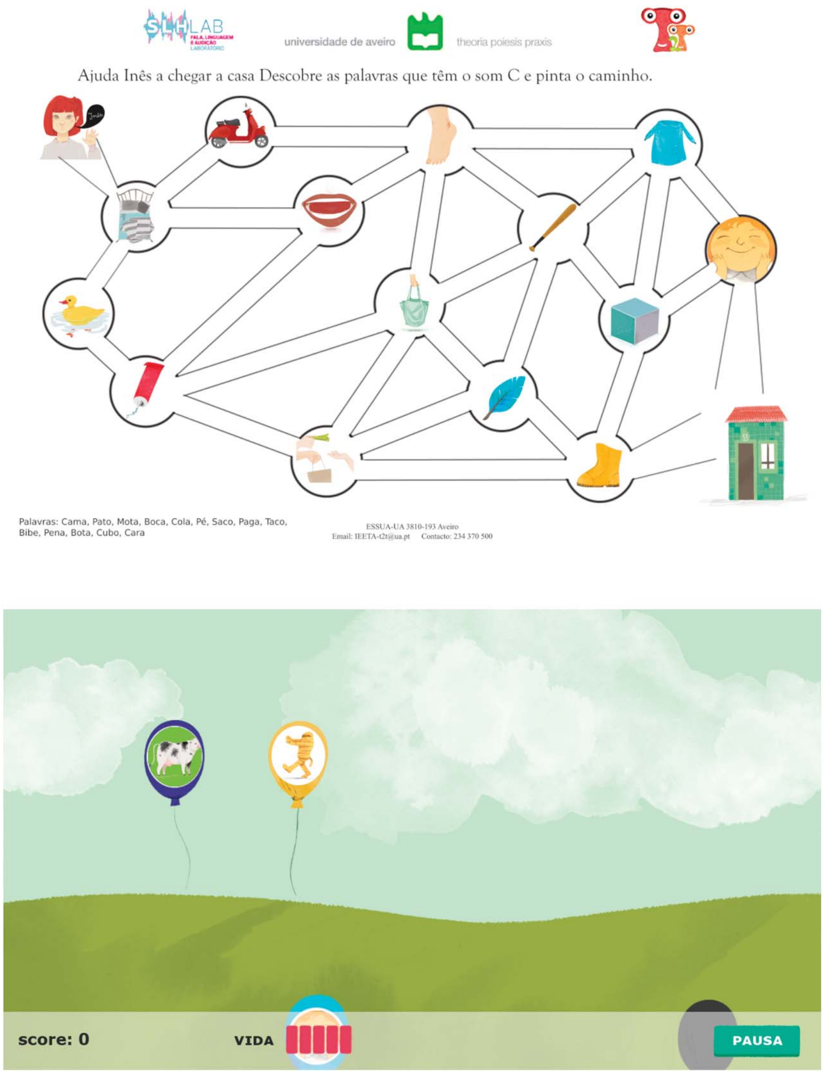
Two SLPs, blind to the therapy content, each observed six treatment sessions (three tabletop and three tablet-based) and completed an observational rating scale, recording key elements of the intervention: duration of session, target sound(s), type of reinforcement, type of intervention, and main activities used, mirroring the procedure used from a previous study to assess treatment fidelity (Lousada et al., 2013, p. 177). A list of activities was provided to the SLPs, who were then required to select what they had observed. They were instructed to observe the session and complete the questionnaire about the session (e.g., activities and duration).

Intervention Targets

The activities included were based on a phonological therapy approach. The selection of words used in therapy was based on syllabic structure (consonant–vowel, consonant–vowel–consonant, or consonant–consonant–vowel; Brooks & Kempe, 2014), number of syllables (one or two; Flipsen, 2006), being age appropriate (Fenson et al., 1993), being easily illustrated, and being different from words used for assessment (Lousada et al., 2013; Mendes et al., 2013). Words used in therapy were those with which children had difficulty, a criterion used in previous research (Gillon, 2008), and included initial, medial, and final word (where applicable) positions of the target sound. A list of minimal pair words was selected for "hearing and discriminating" and "phoneme manipulation." For the "rhyme" activity, a list of monosyllabic rhyming words was identified. The criteria used to select these words were that they are all phonologically simple and of high frequency, well known by most Portuguese children, and two-syllable ("hearing and discriminating" and "phoneme manipulation") or one-syllable ("rhyme") words that would rhyme and could be represented by an illustration. Nineteen short stories (one for each phonological process) that included at least 20 words with the target sound were also created, as used by Bowen (2015).

Each target word was illustrated by a professional designer, resulting in more than 350 illustrations. A set of three background images was also created (by the same designer) for each short story.

Figure 3. Examples of tabletop (top) and tablet-based (bottom) homework activities.



Testing

Assessments of the children with SSD took place at three time points:

- T1—baseline and prerandomization,
- T2—pre-intervention and after a waiting period of 3 months, and
- T3—post-intervention.

The baseline assessments (T1) and the pre- and post-intervention assessments (T2 and T3) were carried out by the same SLP, blind to the study's aims and group allocation.

In all the assessments (T1, T2, and T3), children's productions were recorded to allow a careful off-line analysis (Lancaster, Keusch, Levin, Pring, & Martin, 2010). The recordings were made with a Behringer ECM8000 electret microphone, held by a table support at approximately 1 m and aligned with the mouth of the children. The microphone was connected to an Olympus LS-100 multitrack linear PCM recorder. The data were recorded in mono format .wav (Windows PCM) without compression at a sample rate of 48000 Hz, with 16 bits per sample. The assessments were conducted in one of two places: University of Aveiro's Speech, Language, and Hearing Laboratory clinic or the child's school in a quiet room. Table 2 shows the assessment probes used at the three time points.

To ensure the accuracy of the annotation of the children's phonological abilities, their productions were transcribed phonetically based on perceptual and acoustic analysis using Praat (Version 6.0.17). These transcriptions were annotated on two levels: the child's actual production, transcribed phonetically using the Speech Assessment Methods Phonetic Alphabet (Wells, 1997), a machine-readable phonetic alphabet, and the child's syllabic structure,

Table 2. Assessments used and timing.

Assessment probes	T1	T2	T3
University of Aveiro's Case History Form for Child Language	✓		
TFF-ALPE phonetic and phonological test	✓	✓	✓
TL-ALPE language test	✓		
PAOF oro-motor structure and function test	✓		
TOCS images	✓	✓	✓
SPAA-C Portuguese version	✓	✓	✓
Nonverbal IQ with WPPSI-R	✓		
Hearing assessment	✓		

Note. T1 = baseline and prerandomization; T2 = pre-intervention and after a waiting period of 3 months; T3 = post-intervention; TFF-ALPE = Teste Fonético-Fonológico – Avaliação da Linguagem Pré-Escolar; TL-ALPE = Teste de Linguagem – Avaliação da Linguagem Pré-Escolar; PAOF = Protocolo de Avaliação Orofacial; TOCS = Test of Childhood Stuttering; SPAA-C = Speech Participation and Activity Assessment of Children; WPPSI-R = Wechsler Preschool and Primary Scale of Intelligence–Revised. ✓Assessment carried out at this time point.

using the code C for consonants, V for vowels, and G for glides.

The speech-language pathology assessments used were University of Aveiro's Case History Form for Child Language (Jesus & Lousada, 2010), the TFF-ALPE phonetic–phonological test (Mendes et al., 2013), the TL-ALPE language test (Mendes et al., 2014), and the PAOF oro-motor abilities test (Guimarães, 1995). The TFF-ALPE test provides the context to test and analyze all sounds in different word positions across 67 target words and includes the following phonological processes for analysis: final consonant deletion, weak syllable deletion, cluster reduction, gliding of liquids, stopping, fronting, depalatalization, backing, palatalization, and devoicing. None of the assessment words was targeted in therapy. Images from the Test of Childhood Stuttering (Gillam, Loga, & Pearson, 2009) were used to engage the children in conversation and generate spontaneous speech (Limbrick, McCormack, & McLeod, 2013).

Children's transcribed productions were entered into the Automatic Phonological Analysis Tools (APAT), and all PCC, percentage of vowels correct (PVC), and percentage of phonemes correct (PPC) analyses were conducted, following the procedures described by Saraiva, Lousada, Hall, and Jesus (2017), and carried out by an SLP blind to the study's aims and group allocation using the Speech Assessment Methods Phonetic Alphabet (Wells, 1997). The APAT is a valid and reliable tool (Saraiva et al., 2017) to analyze phonological parameters in an automatic way.

The baseline period occurred between the first assessment at baseline (T1) and the pre-intervention assessment (T2). This period was used to organize all the logistics, schedules, and places to deliver therapy (clinic and schools). It was also used to assess the children's nonverbal IQ and hearing. The children did not receive any intervention in this time period. All the children waited 3 months (the same duration as the intervention) before treatment and, therefore, acted as their own control (Sadlier, Stephens, & Kennedy, 2008). This period allowed us to see the impact of natural maturation on the children's speech and to compare it to performance after intervention.

The mean PCC (Shriberg & Kwiatkowski, 1982), PVC, and PPC scores were used to compare the performance of the two groups. The PCC index is one of the most commonly used indexes to quantify the severity of speech impairment in children with SSD during both evaluation and intervention (Wren, McLeod, White, Miller, & Roulstone, 2013). This quantitative measure is highly sensitive to differences in phonological deficits because it provides information pertaining to the two main error types: omissions and substitutions (Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997).

Although there is evidence that only a small number of children have difficulties producing vowels, Watts (2004) recommends doing a more detailed analysis at this level using PVC in addition to PCC and PPC.

Generalization

After each block of intervention, a total of five nonintervention words, which included the process targeted in intervention, were given as generalization words, in order to assess generalization to nontargeted words (Palle, Berntsson, Miniscalco, & Persson, 2012). These tasks are included to allow SLPs to test if changes in a child's phonological system went beyond the treatment words and targets (Bowen, 2015). The words were selected based on the phonological process trained and controlled for phonetic context. They were different from those used during assessment and intervention but targeted the same phonological processes and were a close match in terms of production difficulty, frequency in the Portuguese language, and syllable structure. Each child had five opportunities to produce the correct target and was deemed to have generalized the target sound if they produced the word correctly on at least one occasion. Generalization scores were calculated by taking the percentage of nontreated words that the child produced correctly out of the total number of nontreated words produced by the child. These words were used to determine if the child generalized the targeted speech sound to nonintervention words and provide important insight into the impact of intervention on a child's phonological system (Baker & McLeod, 2004).

Reliability

The production of all words of two randomly selected children from the three assessment periods (baseline, pretreatment, and posttreatment) was annotated and transcribed, using the APAT by a trained SLP not involved in the study and blind to its aims. Point-to-point reliability was 95.52% (baseline assessment: T1), 94.74% (pretreatment assessment: T2), and 96.46% (posttreatment assessment: T3). These values are comparable with those reported in other studies in disordered child phonology (Shriberg & Lof, 1991; Shriberg, Tomblin, & McSweeny, 1999) and were considered adequate for the objective of this study. Two children (for each assessment point) represent 9% of speech samples, and this percentage is equivalent to what is reported when checking reliability in other effectiveness studies (Crosbie et al., 2005; Dodd & Bradford, 2000; Lousada et al., 2013, 2014).

Data Analysis

Nonparametric Wilcoxon and Mann–Whitney U tests were used to compare data between groups and time periods, and multicomparison corrections for Type I errors were made using Bonferroni correction for every pair of comparisons involving both tabletop and tablet groups. Effect sizes were calculated using Cohen's d, with the bias correction given by Hedges's g for the independent-samples case (Lakens, 2013). For the purpose of interpreting the effect sizes, the following commonly used benchmarks were used (Field, 2017): small (d = 0.2), medium (d = 0.5), and large (d = 0.8). The statistical analysis was undertaken using IBM SPSS Statistics (Version 22). The level of significance used was .05.

Results

The PCC, PVC, and PPC scores were calculated at the three time points: baseline (T1), pre-intervention (T2), and post-intervention (T3). Figure 4 contains boxplots of all scores at the three time points. Independent-samples Mann–Whitney U tests were used to determine any differences between the groups prior to intervention (at T2).

Baseline (T1) PCC, PVC, and PPC Scores

The PCC scores at T1 ranged from 42.27% to 75.26% (M = 56.00%, SD = 10.54) for children in the tabletop group and from 45.98% to 71.23% (M = 59.68%, SD = 8.65) for children in the tablet group. The PVC scores at T1 ranged from 84.52% to 96.77% (M = 93.28%, SD = 4.03) for children in the tabletop group and from 90.97% to 97.42% (M = 95.10%, SD = 2.16) for children in the tablet group. The range for PPC scores spanned from 61.45% to 85.20% (M = 73.49%, SD = 6.95) for children in the tabletop group and from 66.48% to 82.96% (M = 75.95%, SD = 6.10) for children in the tablet group.

Pre-intervention (T2) PCC, PVC, and PPC Scores

At T2, PCC scores ranged from 45.36% to 84.54% (M = 59.59%, SD = 11.35), PVC scores ranged from 91.61% to 98.06% (M = 94.95%, SD = 2.46), and PPC scores ranged from 67.32% to 90.92% (M = 75.70%, SD = 6.96) for children in the tabletop group. PCC, PVC, and PPC scores for children in the tablet group ranged from 48.97% to 84.57% (M = 63.68%, SD = 9.67), from 90.97% to 98.71% (M = 95.49%, SD = 2.27), and from 67.60% to 90.78% (M = 77.95%, SD = 6.59), respectively. Independent-samples Mann–Whitney U tests showed no significant differences between the tabletop and tablet groups at pre-intervention (T2) in PCC (p = −.277, U = 43.5), PVC (p = .507, U = 60.5), and PPC (p = .308, U = 44.5), thereby indicating the groups were evenly matched at this time point.

Post-intervention (T3) PCC, PVC, and PPC Scores

At T3, PCC scores varied between 68.56% and 96.39% (M = 78.12%, SD = 9.28) for children in the tabletop group and between 65.46% and 97.94% (M = 79.85%, SD = 10.99) for children in the tablet group. For PVC and PPC, scores ranged from 95.48% to 100.00% (M = 97.71%, SD = 1.30) and from 80.73% to 97.21% (M = 87.13%, SD = 5.44) for children in the tabletop group as well as from 94.19% to 100.00% (M = 97.42%, SD = 1.58) and from 79.89% to 98.88% (M = 87.94%, SD = 6.51) for children in the tablet group.

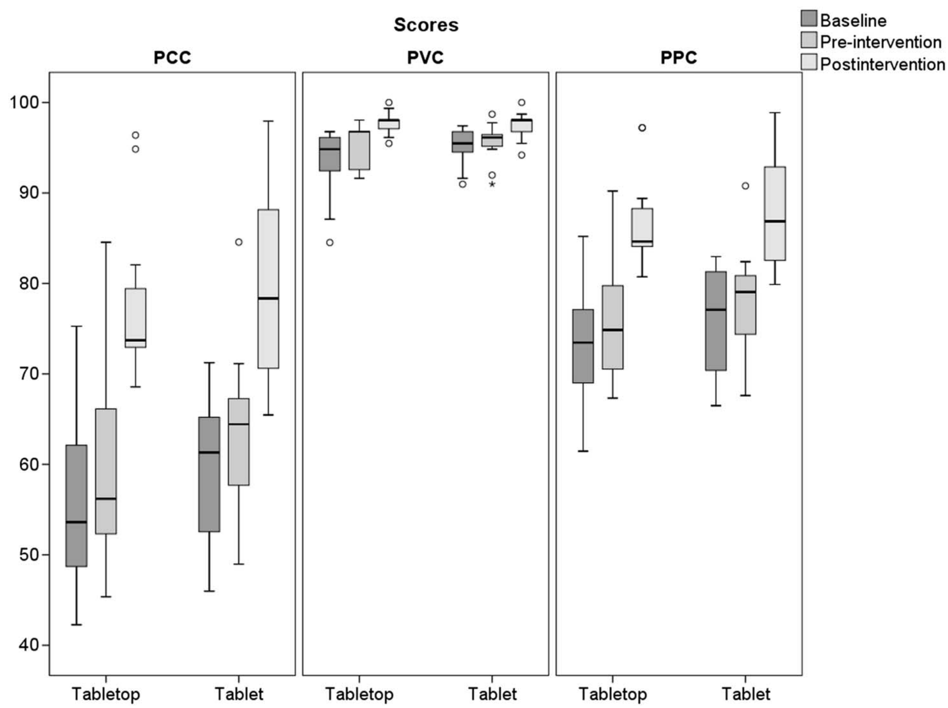
Comparison of PCC, PVC, and PPC Scores From T1 to T2

The PCC, PVC, and PPC scores were then compared from T1 to T2 (prior to intervention) and from T2 to T3 (intervention period).

Paired-samples Wilcoxon tests showed that there were significant differences in PCC in the tabletop group (unilateral p = .008, Z = −2.524, d = 1.1) and in the tablet group (unilateral p = .008, Z = −2.524, d = 0.83) between baseline (T1) and pre-intervention (T2)—the baseline period. In both cases, the effect sizes were large (> 0.8). This suggests that natural maturational changes resulted in increases in the children's PCC over time.

Paired-samples Wilcoxon tests showed that the PVC scores at T2 were significantly higher than those at T1 in the tabletop group (unilateral p = .004, Z = −2.677, d = 0.72) but not in the tablet group (unilateral p = .086, Z = −1.752, d = 0.53). Although not statistically significant in the tablet group, the difference produced a medium effect size across both groups, indicating some level of natural maturation. It is important to note that PVC scores are, in general,

Figure 4. Boxplots of all scores at the three time points. PCC = percentage of consonants correct; PVC = percentage of vowels correct; PPC = percentage of phonemes correct.



at ceiling and considerably higher than PCC or PPC scores (see Figure 4); therefore, significant differences are less likely to be observed.

Similarly to PCC, PPC scores at T2 were significantly higher than those at T1 in both groups (tabletop: unilateral p = .23, Z = −2.253, d = 0.83; tablet: unilateral p = .037, Z = −2.09, d = 0.65), indicating maturational changes over this time.

Comparison of PCC, PVC, and PPC Scores From T2 to T3

Paired-samples Wilcoxon tests showed that PCC was significantly higher at T3 (after intervention) than at T2 in both groups, with large effect sizes (tabletop: unilateral p = .001, Z = −2.934, d = 2.5; tablet: unilateral p = .001; Z = −2.934, d = 2.4).

Similarly to PCC, PVC scores were significantly higher after intervention (T3) when compared to pre-intervention (T2) for both intervention groups, with large effect sizes (tabletop: unilateral p = .002, Z = −2.805, d = 1.6; tablet: unilateral p = .002, Z = −2.810, d = 1.3).

PPC scores were also significantly higher after intervention (T3) when compared to pre-intervention (T2) for both groups, with large effect sizes (tabletop: unilateral p = .001, Z = −2.936, d = 2.7; tablet: unilateral p = .001, Z = −2.936; d = 2.6).

In all scores (PCC, PVC, and PPC), significant differences were observed from T2 to T3, with large effect sizes. However, at this point, we cannot be certain these effects are due to intervention because of the strong effects seen from T1 to T2 (except for PVC).

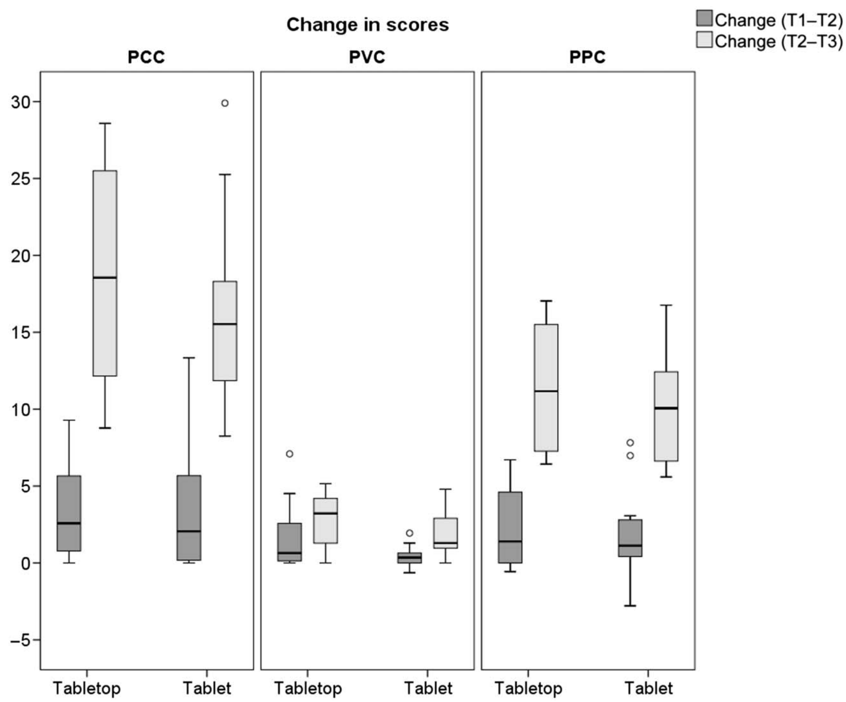
Changes in Scores Across Both Time Periods (T2–T1 and T3–T2)

Since there was a significant improvement in both periods (baseline and intervention) across almost all outcomes, comparisons between changes in scores across both time periods (T2–T1 and T3–T2) were conducted using paired-samples Wilcoxon tests in order to ascertain if the differences between T2 and T3 were only due to natural maturation or specifically to the intervention. Change scores in both periods should not be significantly different if the groups were only subject to natural maturation over the two periods. However, if change scores between T2 and T3 were significantly greater than those between T1 and T2, this would suggest an intervention effect. Figure 5 shows the change scores for all variables in both periods.

Comparison of PCC Changes

The range of PCC changes from T1 to T2 spanned from 0% to 9.28% (M = 3.59%, SD = 3.39) for the tabletop group and from 0% to 13.34% (M = 4.00%, SD = 4.85) for the tablet group. From T2 to T3, the changes spanned

Figure 5. Boxplots of change in scores for all variables in both periods. PCC = percentage of consonants correct; PVC = percentage of vowels correct; PPC = percentage of phonemes correct.



from 8.77% to 28.58% (M = 18.54%, SD = 7.38) and from 8.25% to 29.90% (M = 16.17%, SD = 6.72) for the tabletop and tablet groups, respectively.

Paired-samples Wilcoxon tests showed that the improvement observed between T2 and T3 was significantly greater than that observed between T1 and T2 for both groups, with large effect sizes (tabletop: unilateral p = .001, Z = −2.934, d = 2.0; tablet: unilateral p = .005; Z = −2.667, d = 1.2).

In order to evaluate if the intervention method produced any significant differences between the intervention groups between T2 and T3, an independent-samples Mann–Whitney U test was used. No significant differences were evident between the two groups, with a small-to-medium effect size observed (p = .508, U = 50, d = 0.32).

Comparison of PVC Changes

PVC change scores from T1 to T2 ranged from 0% to 7.09% (M = 1.67%, SD = 2.34) and from −0.64% to 1.94% (M = 0.39%, SD = 0.73) for the tabletop and tablet groups, respectively. From T2 to T3, PVC change scores ranged from 0% to 5.16% (M = 2.76%, SD = 1.73) for the tabletop group and from 0% to 4.80% (M = 1.93%, SD = 1.53) for the tablet group.

Paired-samples Wilcoxon tests showed that, for the tablet group, the T2–T3 improvements were significantly higher than those from T1 to T2, with a large effect size (unilateral p = .037, Z = −2.090, d = 0.81). In the tabletop group, this difference was not significant, but the effect size was close to medium (unilateral p = .175, Z = −1.423, d = 0.42).

An independent-samples Mann–Whitney U test showed no significant differences between the changes (T3–T2) of the two groups, but a medium effect size was observed (p = .291, U = 44.5, d = 0.49), with the tabletop group showing better performance than the tablet group.

Comparison of PPC Changes

PPC change scores from T1 to T2 ranged from −0.56% to 6.71% (M = 2.21%, SD = 2.66) and from −2.79% to 7.82% (M = 2.00%, SD = 3.08) for children in the tabletop and tablet groups, respectively. From T2 to T3, the changes in PPC scores spanned from 6.43% to 17.04% (M = 11.43%, SD = 4.18) for children in the tabletop group and from 5.59% to 16.76% (M = 9.99%, SD = 3.82) for children in the tablet group.

Paired-samples Wilcoxon tests showed that the T3–T2 changes were significantly higher than the T2–T1 changes in both groups, with large effect sizes (tabletop: unilateral p = .001, Z = −2.934, d = 2.1; tablet: unilateral p = .005, Z = −2.667, d = 1.3).

No significant differences between the changes in PPC scores (T3–T2) across the two groups were found, with a small-to-medium effect size observed (p = .374, U = 46.5, d = 0.35).

Generalization Probe

There were no apparent differences in the generalization of words between the two groups in Block 1. In the tabletop group, 10 children achieved substantial levels of generalization (60% for one child [DB], 80% for another [FC], and 100% for eight of the children), and for one child (participant DC), the generalization level was 40%. In the tablet group, all of the children presented considerable levels of generalization (60% for one child [RD], 80% for three children, and 100% for seven children).

After Block 2, generalization probe data revealed slightly lower levels of generalization across both groups. In the tabletop group, the child who scored the lowest value in Block 1 (participant DC) also presented the lowest level in Block 2 (20%). One child (FC) obtained a level of 40%, and the remaining nine children obtained high levels of generalization (60% for two children and 100% for the other seven children). Generally, children who obtained the highest scores in Block 1 also achieved the highest values after Block 2. In the tablet group, one child (SI) generalized for 40% of the words, and all the others obtained substantial levels of generalization (60% for four children, 80% for one child [DV], and 100% for the other five children).

Fidelity of Intervention

Reports provided by the two SLPs, blind to group allocation, showed close agreement across all parameters observed about the intervention, including session duration, target sounds, type of intervention, activities used in the session, and type of reinforcement given. One hundred percent agreement was obtained on all the elements observed, across the six sessions, indicating that the interventions were administered as intended and reported, and therefore, fidelity of treatment was high.

Discussion

This study investigated the effectiveness of a phonological treatment delivered through two mediums, tabletop and tablet, for remediating phonologically based SSD in 22 children.

Comparisons of PCC Scores Across Time Points

Results suggest greater improvement in PCC scores after intervention than during the waiting period, despite there being some maturational improvement during baseline, indicating that both types of intervention were effective in improving children's speech. There were no significant differences between the tabletop and tablet interventions.

The use of the baseline period and the three time points for assessment is important and allowed us to better understand the role of maturation and how children with phonologically based SSD improve without additional support. Significant improvements were noted in PCC between baseline (T1) and pre-intervention (T2) for both groups, a period where no speech-language pathology support was provided, reflecting the important role of natural maturation. Although a significant change in speech was observed, between T1 and T2, the improvements by both intervention groups were significantly greater during the intervention period (between T2 and T3), suggesting that children improved significantly more as a result of both interventions and that this change reflected an intervention rather than a maturational effect. This is an important finding, giving further weight to the evidence supporting the effectiveness of phonological therapy with children with phonologically based SSD (Allen, 2013; Crosbie et al., 2005; Lancaster et al., 2010; Lousada et al., 2013; Wren & Roulstone, 2008).

The therapy content of both interventions was kept as similar as possible in order to allow a comparison across the different delivery modes. Considering that we have shown previously that this phonological approach is effective (Lousada et al., 2013), we predicted similar positive outcomes for the traditional tabletop intervention group. However, there is less evidence (Furlong et al., 2017) about the effectiveness of using digital intervention for SSD, and the limited evidence that is available is mixed (McLeod et al., 2017; Wren & Roulstone, 2008). Therefore, it is pleasing to note, notwithstanding the maturational effects observed, that with a computer-based delivery, using the same type of phonological-based therapy, the same level of effectiveness was achieved. The PCC scores of both groups at post-intervention showed that both methods of delivering therapy were equally effective in improving children's speech. This result confirms previous findings that have shown no difference in effectiveness between tabletop and digital approaches (Shriberg & Kwiatkowski, 1989; Shriberg et al., 1990). These results add to the emerging evidence for the effectiveness of digital technology for children with SSD (Furlong et al., 2017).

Wren and Roulstone (2008) reported similar results, with no differences between digital-based and tabletop therapy in their study. However, in contrast to this study, the activities used in their computer- and tabletop-based methods were different, and therefore, comparisons between the two were not possible. A more recent randomized controlled trial (McLeod et al., 2017), using the computer-based intervention, originally proposed by Wren and Roulstone, involved listening and responding to visual and auditory stimuli and was delivered by educators. This study reported no significant differences in speech outcomes between intervention and control groups, with low adherence to implementation protocols (Crowe et al., 2017; McCormack et al., 2017). The lack of coupled speech production and perception practice (i.e., combining input and output intervention procedures) was given as a possible reason for this finding.

In contrast, in the current study, a computer-based intervention designed to be delivered by specialists (i.e., SLPs), with no problems in adherence to implementation protocols, was shown to be effective in improving PCC over a relatively short intervention period (12 weeks) and with low dosage (12 weekly 45-min sessions). Interestingly, in this study, the intervention did combine perception and production practice.

Comparisons of PVC Scores Across Time Points

Children with moderate–severe phonological disorders frequently experience difficulties producing vowels (Ball & Gibbon, 2013). The PVC scores in this study showed similar results to the PCC scores, with improvements in PVC noted at both baseline and intervention, but with the increase after intervention being significantly greater only in the tablet group. In the tabletop group, although some improvement was observed in PVC, the difference between baseline (T1–T2) and intervention (T2–T3) was smaller and not significant. This could be because the children were at ceiling for PVC (all greater than 93%) and, therefore, had less room to improve. Although the intervention primarily targeted consonants, most of the children from both groups (10/11) improved their PVC scores, illustrating a potentially indirect and beneficial impact of consonant work on vowel production. Although therapy did not focus specifically on vowel accuracy, it is possible that the activities undertaken in therapy facilitated improvements in both consonant and vowel productions (Robb, Bleile, & Yee, 1999).

Comparisons of PPC Scores Across Time Points

The PPC is obtained by scoring every phoneme produced by the children, combining the percentage of vowels and consonants produced correctly. The performance of PPC is similar to that of PCC and PVC, with PPC scores significantly higher at T2, after baseline, than at T1, indicating that there was a significant improvement in the nonintervention period. Similarly, the mean PPC scores were significantly greater after intervention (T3), than at T2, preintervention, for both groups, with change scores significantly greater after the intervention than baseline period. These results suggest that the improvements made in the children's PPC scores were because of the treatment.

Generalization

The generalization probe to nonintervention words, used after each block of intervention, showed that children from both groups made substantial and potentially longstanding changes as they generalized to untreated words. Generalization after Block 2 was slightly lower than after Block 1, but still substantial, and it is noteworthy that generalization to untreated words was evident across both intervention groups after a relatively short intervention period. Differential rates of progress were evident across participants, all of whom received the same intervention, albeit via a different modality, with the same SLP, a phenomenon reported in other studies (Baker & McLeod, 2004; Lousada et al., 2013). Children may differ in the amount of therapy they require to achieve maximum progress and generalization, and some differences among children (e.g., motivation and expressive language skills) might influence response to intervention (Baker & McLeod, 2004). Although the generalization to untreated words is a pleasing result, it is important to note that this occurred at the word level, and generalization to conversational speech was not explored in this study.

Concluding Remarks

This study provides evidence for a computer-based intervention and shows that phonological therapy is effective in treating children with phonologically based SSD, when delivered by a computer-based intervention, as well as the traditional tabletop approach. The unique collaboration between software developers, designers, and SLPs, developed during the current project (Jesus et al., 2019) and recently recognized by Furlong et al. (2017), may constitute a new framework for software development and contribute toward overcoming the limited number of studies in the field of computer-based intervention in children with SSD over the past 10 years.

Since both methods were shown to be equally effective, it is important to consider the economic viability of each one. Many countries are facing challenging economic times, and a very important goal for them is to provide the best possible care with fewer resources (American Speech-Language-Hearing Association, 2018; Harulow, 2013; Meline et al., 2010). This also affects SLPs in terms of the amount of money that they can invest in off-the-shelf materials for interventions. Digital materials, although seemingly more expensive in the initial stage, become increasingly cheaper in terms of replication and distribution. This can potentially dilute the costs of the digital materials when compared to the tabletop ones and allows the developer to place in market a product with a far more competitive and compelling price. However, the cost of maintenance and upkeep of the technology in clinics and schools is another factor that needs to be taken into account. Considering the effectiveness of both types of intervention, further investigation into their relative cost effectiveness is warranted.

Furthermore, buying the digital package brings with it some advantages for the SLP, including materials that are more easily transportable, more durable, and potentially cheaper over time and have reduced preparation time. Use of digital technology also brings with it numerous reported advantages, including increased motivation, fun factor, enhanced engagement, and repeated and multiple opportunities for multisensory learning (Chen et al., 2016; Kebritchi & Hirumi, 2008; Ploog et al., 2013; Shi & Müller, 2013). However, clinicians might need some persuasion to shift to digital technology, particularly considering the existing barriers they may face, such as the potential for breakdown and, often, the limited technological support available in health care and education settings.

Limitations

The results of this study are promising; however, the sample size is small, and replication of the study with a larger sample is needed. It is also important to note that changes were evident, not only after treatment but also during the no-treatment baseline period, which indicates maturational development, although the change was significantly greater after intervention than baseline. Another limitation of the study is the large age range of the participants, which may have resulted in age-related differences in responses to treatment. Replication of this study should attempt to target a more homogenous group concerning age.

Another consideration is that the digital technology for the tablet intervention was new, and further features could be added to enhance the computerized visual and auditory feedback given automatically to the participants, as this type of feedback is one of the main advantages of using technology. The technology could be further enhanced, for example, by using visual feedback technology, which could provide the child with a computerized display of certain physiological variables, such as tongue position. Furthermore, although a standardized phonetic–phonological test (Lousada, Mendes, Valente, & Hall, 2012) was used, PCC, PVC, and PPC are measures that consider "all speech sound errors as equal" (Preston & Edwards, 2010, p. 54), and it is possible that not all speech sounds were represented equally in the speech sample. Finally, although we showed generalization from treated to untreated words, which is a very positive finding, we did not include a follow-up assessment to measure the long-term effects of the intervention, and this is a vital step to incorporate in future studies.

Conclusions and Future Implications

The results obtained in this study suggest that both tabletop and tablet-based methods of delivery of a phonological intervention are effective in improving the speech of children with phonologically based SSD. Reports of the fidelity of the interventions were high, ensuring good internal and external validity of the study.

Since both methods seemed equally effective, it would be interesting to explore the effect of a combined approach where both tabletop and tablet activities were used with the same child. It would also be beneficial to replicate this finding with a larger sample, considering the relatively small number of participants. Another interesting avenue of investigation could be to compare the potential cognitive load differences between tabletop and tablet-based approaches. There is evidence to suggest that children process two- and three-dimensional images differently (Shimada & Hiraki, 2006), and if the cognitive load exceeds the processing capabilities of the child, learning will be impaired (Barr, 2010), and this may impact the overall effectiveness of the intervention. Finally, an adaptation of the tablet intervention to other languages is an exciting avenue to explore, considering the success with Portuguese children.

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References

Abad, A., Pompili, A., Costa, A., Trancoso, I., Fonseca, J., Leal, G., . . . Martins, I. P. (2013). Automatic word naming recognition for an on-line aphasia treatment system. *Computer Speech and Language, 27*(6), 1235–1248. https://doi.org/10.1016/j.csl.2012.10.003

Allen, M. M. (2013). Intervention efficacy and intensity for children with speech sound disorder. *Journal of Speech, Language, and Hearing Research, 56*(3), 865–877. https://doi.org/10.1044/1092-4388(2012/11-0076)

American Speech-Language-Hearing Association. (2018). *2018 Public policy agenda*. Retrieved from http://www.asha.org/uploadedFiles/2018-Public-Policy-Agenda.pdf

Augusto, J., Kramer, D., Alegre, U., Covaci, A., & Santokhee, A. (2018). The user-centred intelligent environments development process as a guide to co-create smart technology for people with special needs. *Universal Access in the Information Society, 17*(1), 115–130. https://doi.org/10.1007/s10209-016-0514-8

Baker, E., & McLeod, S. (2004). Evidence-based management of phonological impairment in children. *Child Language Teaching and Therapy, 20*(3), 261–285.

Ball, M., & Gibbon, F. (Eds.). (2013). *Handbook of vowels and vowel disorders*. Hove, United Kingdom: Psychology Press.

Barr, R. (2010). Transfer of learning between 2D and 3D sources during infancy: Informing theory and practice. *Developmental Review, 30*(2), 128–154. https://doi.org/10.1016/j.dr.2010.03.001

Bowen, C. (2015). *Children's speech sound disorders* (2nd ed.). Oxford, United Kingdom: Wiley.

Brooks, P., & Kempe, V. (Eds.). (2014). *Encyclopedia of language development*. New York, NY: SAGE.

Broomfield, J., & Dodd, B. (2004). Children with speech and language disability: Caseload characteristics. *International Journal of Language & Communication Disorders, 39,* 303–324.

Chen, Y.-P. P., Johnson, C., Lalbakhsh, P., Caelli, T., Deng, G., Tay, D., . . . Morris, M. E. (2016). Systematic review of virtual speech therapists for speech disorders. *Computer Speech and Language, 37,* 98–128.

Crosbie, S., Holm, A., & Dodd, B. (2005). Intervention for children with severe speech disorder: A comparison of two approaches. *International Journal of Language & Communication Disorders, 40*(4), 467–491.

Crowe, K., Cumming, T., McCormack, J., Baker, E., McLeod, S., Wren, Y., . . . Masso, S. (2017). Educators' perspectives on facilitating computer-assisted speech intervention in early childhood settings. *Child Language Teaching and Therapy, 33*(3), 267–285.

Dodd, B., & Bradford, A. (2000). A comparison of three therapy methods for children with different types of developmental phonological disorders. *International Journal of Language & Communication Disorders, 35*(2), 189–209.

Dodd, B., Reilly, S., Ttofari Eecen, K., & Morgan, A. T. (2018). Articulation or phonology? Evidence from longitudinal error data. *Clinical Linguistics & Phonetics, 32,* 1027–1041. https://doi.org/10.1080/02699206.2018.1488994

Dodd, B., Zhu, H., Crosbie, S., Holm, A., & Ozanne, A. (2002). *Diagnostic Evaluation of Articulation and Phonology (DEAP)*. London, United Kingdom: The Psychological Corporation.

Feng, J., Lazar, J., Kumin, L., & Ozok, A. (2010). Computer usage by children with Down syndrome. *ACM Transactions on Accessible Computing, 2*(3), 1–44. https://doi.org/10.1145/1714458.1714460

Fenson, L., Dale, P., Reznick, J. S., Thal, D., Bates, E., Hartung, J., . . . Reilly, J. S. (1993). *The MacArthur communicative development inventories: User's guide and technical manual*. San Diego, CA: Singular.

Field, A. (2017). *Discovering statitics using IBM SPSS Statistics* (5th ed.). London, United Kingdom: SAGE.

Flipsen, P. (2006). Syllables per word in typical and delayed speech acquisition. *Clinical Linguistics & Phonetics, 20*(4), 293–301.

Furió, D., González-Gancedo, S., Juan, M.-C., Seguí, I., & Rando, N. (2013). Evaluation of learning outcomes using an educational iPhone game vs. traditional game. *Computers & Education, 64,* 1–23.

Furlong, L., Erickson, S., & Morris, M. (2017). Computer-based speech therapy for childhood speech sound disorders. *Journal of Communication Disorders, 68,* 50–69.

Gillam, R., Loga, K., & Pearson, N. (2009). *Test of Childhood Stuttering (TOCS)*. Austin, TX: Pro-Ed.

Gillon, G. T. (2008). *The Gillon Phonological Awareness Training Programme: An intervention programme for children at risk for reading disorder—Programme handbook*. Christchurch, New Zealand: University of Canterbury.

Gillon, G. T., & McNeill, B. C. (2007). *Integrated phonological awareness: An intervention program for preschool children with speech-language impairment*. Christchurch, New Zealand: University of Canterbury.

Gordon-Brannan, M., & Hodson, B. (2000). Intelligibility/severity measurements of prekindergarten children's speech. *American Journal of Speech-Language Pathology, 9,* 141–150.

Guimarães, I. (1995). *Protocolo de Avaliação Orofacial [Oro-motor Structure and Function Test]*. Lisbon, Portugal: Fisiopraxis.

Gunther, T., & Hautvast, S. (2010). Addition of contingency management to increase home practice in young children with a speech sound disorder. *International Journal of Language & Communication Disorders, 45*(3), 345–353.

Harulow, S. (2013). Facing cuts? Keep calm and star negotiating. *Bulletin—The Official Magazine of the Royal College of Speech & Language Therapists,* (February), 12–15.

Hawley, M. S., Cunningham, S. P., Green, P. D., Enderby, P., Palmer, R., Sehgal, S., & O'Neill, P. (2013). A voice-input voice-output communication aid for people with severe speech impairment. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 21*(1), 23–31. https://doi.org/10.1109/TNSRE.2012.2209678

Hodson, B., & Paden, E. (1991). *Targeting intellligible speech: A phonological approach to remeditation* (2nd ed.). Austin, TX: Pro-Ed.

Ingram, D. (1989). *Phonological disability in children* (2nd ed.). London, United Kingdom: Whurr.

Jesus, L. M. T., & Lousada, M. (2010). Protocolo de Anamnese de Linguagem na Criança da Universidade de Aveiro [University of Aveiro's Case History Form for Child Language]. In *INPI Registration Number 465220 and IGAC Registration 2/06/2010*. Aveiro, Portugal: University of Aveiro.

Jesus, L. M. T., Lousada, M., Domingues, D., Hall, A., & Tomé, D. (2015). Phonological processes in Portuguese children with speech sound disorders. *Poznan Studies in Contemporary Linguistics, 51*(1), 75–88.

Jesus, L., Martinez, J., Valente, A., & Costa, M. (2017). Speech and language therapy service delivery: Overcoming limited provision for children. *Public Health, 151*(10), 39–50. https://doi.org/10.1016/j.puhe.2017.06.013

Jesus, L., Santos, J., & Martinez, J. (2019). The Table to Tablet (T2T) Speech and Language Therapy Software development roadmap. *JMIR Research Protocols, 8*(1), e11596. https://doi.org/10.2196/11596

Joffe, V., & Pring, T. (2008). Children with phonological problems: A survey of clinical practice. *International Journal of Language & Communication Disorders, 43*(2), 154–164.

Kanitkar, A., Szturm, T., Parmar, S., Gandhi, D. B., Rempel, G. R., Restall, G., . . . Kamate, M. A. (2017). The effectiveness of a computer game-based rehabilitation platform for children with cerebral palsy: Protocol for a randomized clinical trial. *JMIR Research Protocols, 6*(5), e93. https://doi.org/10.2196/resprot.6846

Kebritchi, M., & Hirumi, A. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education, 51*(4), 1729–1743.

Khowaja, K., & Salim, S. S. (2013). A systematic review of strategies and computer-based intervention (CBI) for reading comprehension of children with autism. *Research in Autism Spectrum Disorders, 7*(9), 1111–1121. https://doi.org/10.1016/j.rasd.2013.05.009

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for *t*-tests and ANOVAs. *Frontiers in Psychology, 4,* 863.

Lancaster, G. (2008). *Developing speech and language skills*. London, United Kingdom: Routledge.

Lancaster, G., Keusch, S., Levin, A., Pring, T., & Martin, S. (2010). Treating children with phonological problems: Does an eclectic approach to therapy work. *International Journal of Language & Communication Disorders, 45*(2), 174–181.

Law, J., Boyle, J., Harris, F., Harkness, A., & Nye, C. (2000). Prevalence and natural history of primary speech and language delay: Findings from a recent systematic review of the literature. *International Journal of Language & Communication Disorders, 35,* 165–188.

Limbrick, N., McCormack, J., & McLeod, S. (2013). Designs and decisions: The creation of informal measures for assessing speech production in children. *International Journal of Speech-Language Pathology, 15,* 296–311.

Lousada, M., Jesus, L. M. T., Capelas, S., Margaça, C., Simões, D., Valente, A. R., . . . Joffe, V. L. (2013). Phonological and articulation treatment approaches in Portuguese children with speech and language impairments: A randomized controlled intervention study. *International Journal of Language & Communication Disorders, 48*(2), 172–187. https://doi.org/10.1111/j.1460-6984.2012.00191.x

Lousada, M., Jesus, L. M. T., Hall, A., & Joffe, V. (2014). Intelligibility as a clinical outcome measure following intervention with children with phonologically based speech-sound disorders. *International Journal of Language & Communication Disorders, 49*(5), 584–601. https://doi.org/10.1111/1460-6984.12095

Lousada, M., Mendes, A., Valente, A., & Hall, A. (2012). Standardization of a phonetic–phonological test for European Portuguese children. *Folia Phoniatrica et Logopaedica, 64*(3), 151–156.

Marshall, J., Booth, T., Devane, N., Galliers, J., Greenwood, H., Hilari, K., . . . Woolf, C. (2016). Evaluating the benefits of aphasia intervention delivered in virtual reality: Results of a quasi-randomised study. *PLOS ONE, 11*(8), e0160381. https://doi.org/10.1371/journal.pone.0160381

McCormack, J., Baker, E., Masso, S., Crowe, K., McLeod, S., Wren, Y., & Roulstone, S. (2017). Implementation fidelity of a computer-assisted intervention for children with speech sound disorders. *International Journal of Speech-Language Pathology, 19*(3), 265–276. https://doi.org/10.1080/17549507.2017.1293160

Mcleod, S., & Baker, E. (2014). Speech-language pathologists' practices regarding assessment, analysis, target selection, intervention, and service delivery for children with speech sound disorders. *Clinical Linguistics & Phonetics, 28*(7–8), 508–531. https://doi.org/10.3109/02699206.2014.926994

McLeod, S., Baker, E., McCormack, J., Wren, Y., Roulstone, S., Crowe, K., . . . Howland, C. (2017). Cluster-randomized controlled trial evaluating the effectiveness of computer-assisted intervention delivered by educators for children with speech sound disorders. *Journal of Speech, Language, and Hearing Research, 60*(7), 1891–1910. https://doi.org/10.1044/2017_JSLHR-S-16-0385

Meline, T., Kauffman, C., Bender, F., Daly, G., Lang, C., & Mcginty, A. (2010). *A speech-language pathologist's dilemma: What is the best choice for service delivery in schools? EBP briefs* (Vol. 5). Bloomington, MN: Pearson.

Mendes, A., Afonso, E., Lousada, M., & Andrade, F. (2013). *Teste Fonético-Fonologico ALPE [Phonetic-Phonological Test]*. Aveiro, Portugal: Edubox.

Mendes, A., Afonso, E., Lousada, M., & Andrade, F. (2014). *Teste de Linguagem ALPE [Language Test]*. Aveiro, Portugal: Edubox.

Moore, M., & Calvert, S. (2000). Brief report: Vocabulary acquisition for children with autism: Teacher or computer instruction. *Journal of Autism and Developmental Disorders, 30*(4), 359–362. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11039862

Murphy, S. M., Faulkner, D. M., & Reynolds, L. R. (2014). A randomised controlled trial of a computerised intervention for children with social communication difficulties to support peer collaboration. *Research in Developmental Disabilities, 35*(11), 2821–2839. https://doi.org/10.1016/j.ridd.2014.07.026

Nanjundaswamy, M., Prabhu, P., Rajanna, R., Ningegowda, R., & Sharma, M. (2018). Computer-based auditory training programs for children with hearing impairment—A scoping review. *International Archives of Otorhinolaryngology, 22*(1), 88–93. https://doi.org/10.1055/s-0037-1602797

Oliveira, C., Lousada, M., & Jesus, L. (2015). The clinical practice of speech and language therapists with children with phonologically based speech sound disorders. *Child Language Teaching and Therapy, 31*(2), 173–194. https://doi.org/10.1177/0265659014550420

Orsolini, M., Sechi, E., Maronato, C., Bonvino, E., & Corcelli, A. (2001). Nature of phonological delay in children with specific language impairment. *International Journal of Language & Communication Disorders, 36*(1), 63–90.

Palle, N., Berntsson, A., Miniscalco, C., & Persson, C. (2012). The effectiveness of phonological intervention in preschool children: A single-subject design study. *Logopedics Phoniatrics Vocology, 39*(1), 19–29.

Pedro, C. F., Lousada, M., Hall, A., & Jesus, L. M. T. (2018). Visual stimuli in intervention approaches for pre-schoolers diagnosed with phonological delay. *Logopedics Phoniatrics Vocology, 43*(1), 20–31. https://doi.org/10.1080/14015439.2017.1307445

Pennala, R., Richardson, U., Ylinen, S., Lyytinen, H., & Martin, M. (2014). Computer game as a tool for training the identification of phonemic length. *Logopedics Phoniatrics Vocology, 39*(4), 149–158.

Pereira, L., Brancalioni, A., & Keske-Soares, M. (2013). Phonological therapy with the use of computers: Case report. *Revista CEFAC, 15*(3), 681–688.

Ploog, B. O., Scharf, A., Nelson, D., & Brooks, P. J. (2013). Use of computer-assisted technologies (CAT) to enhance social, communicative, and language development in children with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 43*(2), 301–322. https://doi.org/10.1007/s10803-012-1571-3

Popovici, D., & Buica-Belciu, C. (2012). Professional challenges in computer-assisted speech therapy. *Procedia—Social and Behavioral Sciences, 33,* 518–522.

Popple, J., & Wellington, W. (2001). Working together: The psycholinguistic approach within a school setting. In J. Stackhouse & B. Wells (Eds.), *Children's speech and literacy difficulties 2: Identification and intervention* (pp. 299–329). London, United Kingdom: Whurr.

Preston, J., & Edwards, M. L. (2010). Phonological awareness and types of sound errors in preschoolers with speech sound disorders. *Journal of Speech, Language, and Hearing Research, 53*(1), 44–60.

Raitano, N. A., Pennington, B. F., Tunick, R. A., Boada, R., & Shriberg, L. D. (2004). Pre-literacy skills of subgroups of children with speech sound disorders. *The Journal of Child Psychology and Psychiatry and Allied Disciplines, 45*(4), 821–835.

Ramdoss, S., Lang, R., Mulloy, A., Franco, J., O'Reilly, M., Didden, R., & Lancioni, G. (2011). Use of computer-based interventions to teach communication skills to children with autism spectrum disorders: A systematic review. *Journal of Behavioral Education, 20,* 55–76. https://doi.org/10.1007/s10864-010-9112-7

Robb, M., Bleile, K., & Yee, S. (1999). A phonetic analysis of vowel errors during the course of treatment. *Clinical Linguistics & Phonetics, 13*(4), 309–321.

Sadlier, M., Stephens, S. D. G., & Kennedy, V. (2008). Tinnitus rehabilitation: A mindfulness meditation cognitive behavioural therapy approach. *The Journal of Laryngology & Otology, 122,* 31–37.

Saraiva, D., Lousada, M., Hall, A., & Jesus, L. M. T. (2017). Paediatric Automatic Phonological Analysis Tools (APAT). *Logopedics Phoniatrics Vocology, 42*(4), 153–159. https://doi.org/10.1080/14015439.2016.1237544

Saz, O., Yin, S.-C., Lleida, E., Rose, R., Vaquero, C., & Rodríguez, W. R. (2009). Tools and technologies for computer-aided speech and language therapy. *Speech Communication, 51,* 948–967. https://doi.org/10.1016/j.specom.2009.04.006

Shi, Z., & Müller, H. J. (2013). Multisensory perception and action: Development, decision-making, and neural mechanisms. *Frontiers in Integrative Neuroscience, 7,* 81. https://doi.org/10.3389/fnint.2013.00081

Shimada, S., & Hiraki, K. (2006). Infant's brain responses to live and televised action. *NeuroImage, 32*(2), 930–939. https://doi.org/10.1016/j.neuroimage.2006.03.044

Shriberg, L. D. (2003). Diagnostic markers for child speech-sound disorders: Introductory comments. *Clinical Linguistics & Phonetics, 17*(7), 501–505.

Shriberg, L. D., Austin, D., Lewis, B. A., McSweeny, J. L., & Wilson, D. L. (1997). The percentage of consonants correct (PCC) metric: Extensions and reliability data. *Journal of Speech, Language, and Hearing Research, 40*(4), 708–722.

Shriberg, L. D., & Kwiatkowski, J. (1982). Phonological disorders III: A procedure for assessing severity of involvement. *Journal of Speech and Hearing Research, 47,* 256–270.

Shriberg, L. D., & Kwiatkowski, J. (1989). Tabletop versus microcomputer-assisted speech management: Stabilization phase. *Journal of Speech and Hearing Disorders, 54*(2), 233–248.

Shriberg, L. D., Kwiatkowski, J., & Snyder, T. (1990). Tabletop versus microcomputer-assisted speech management: Response evocation phase. *Journal of Speech and Hearing Disorders, 55*(4), 635–655.

Shriberg, L. D., & Lof, G. L. (1991). Reliability studies in broad and narrow phonetic transcription. *Clinical Linguistics & Phonetics, 5,* 225–279.

Shriberg, L. D., Tomblin, J. B., & McSweeny, J. L. (1999). Prevalence of speech delay in 6-year-old children and comorbidity with language impairment. *Journal of Speech, Language, and Hearing Research, 42,* 1461–1481.

Stacey, P. C., Raine, C. H., O'Donoghue, G. M., Tapper, L., Twomey, T., & Summerfield, A. Q. (2010). Effectiveness of computer-based auditory training for adult users of cochlear implants. *International Journal of Audiology, 49*(5), 347–356. https://doi.org/10.3109/14992020903397838

Theodoros, D., Aldridge, D., Hill, A. J., & Russell, T. (2019). Technology-enabled management of communication and swallowing disorders in Parkinson's disease: A systematic scoping review. *International Journal of Language & Communication Disorders, 54,* 170–188. https://doi.org/10.1111/1460-6984.12400

Virvou, M., & Alepis, E. (2005). Mobile educational features in authoring tools for personalised tutoring. *Computers & Education, 44*(1), 53–68.

Watts, N. (2004). Assessment of vowels summary. *ACQuiring Knowledge in Speech, Language and Hearing, 6*(1), 22–25.

Wechsler, D. (2003). *Escala de inteligência de Wechsler para a idade pré-escolar e escolar. Edição revista [Wechsler Preschool and Primary Scale of Intelligence–Revised] (WPPSI-R)*. Lisbon, Portugal: CEGOC.

Wells, J. (1997). SAMPA: Computer readable phonetic alphabet. In D. Gibbon, R. Moore, & R. Winski (Eds.), *Handbook of standards and resources for spoken language systems* (pp. 684–732). Berlin, Germany: De Gruyter Mouton.

Wren, Y., McLeod, S., White, P., Miller, L., & Roulstone, S. (2013). Speech characteristics of 8-year-old children: Findings from a prospective population study. *Journal of Communucation Disorders, 46*(1), 53–69.

Wren, Y., & Roulstone, S. (2008). A comparison between computer and tabletop delivery of phonology therapy. *International Journal of Speech-Language Pathology, 10*(5), 346–363.

Wren, Y., Roulstone, S., & Williams, A. (2010). Computer-based interventions. In A. Williams, S. McLeod, & R. McCauley (Eds.), *Interventions for speech sound disorders in children*. Baltimore, MD: Brookes.