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Lexical access in children with hearing loss or language impairments, using the cross-modal picture-word interference paradigm

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Abstract

In this study we compared the lexical access skills of 25 deaf children with cochlear implants, 13 hard-of-hearing children and 20 children with specific language impairments (SLI). Twenty-one age-matched typically developing children served as controls. The two groups of children with hearing loss in the present study had good speech perception abilities. We used a cross-modal picture-word interference paradigm to examine the lexical access skills. Results showed that children with SLI revealed overall slower reaction times and produced more errors than the implanted children, the hard-of-hearing children, and the control children. Both groups of children with hearing loss did not reveal slower reaction times than the control children. Semantic and phonological representations in long-term memory were affected more by inadequacies in linguistic processing than by a deficit in auditory perception, suggesting that a measure of lexical access could be a suitable clinical marker for SLI identification. We recommend to differentiate between the clinical groups of children regarding the focus of their language training.

Keywords

Lexical access; Picture naming; Children; Cochlear implants; Hard-of-hearing; SLI

1. Introduction

Lexical access is a crucial aspect of language acquisition in general and of word learning in particular. It is highly dependent on qualitatively good speech perception and processing skills (Hansson, Forsberg, Löfqvist, Mäki-Torkko, & Sahlén, 2004). In children with hearing loss or language impairments, lexical access may be hampered. Children with hearing loss

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often show less well-defined phonological categories in long-term memory (Jerger, Lai, & Marchman, 2002b; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000), whereas many children with language impairments show poorly defined semantic categories as well (McGregor, Newman, Reilly, & Capone, 2002; Seiger-Gardner & Schwartz, 2008). To examine the impact of such limitations on children's lexical development, this study will relate the nature of these children's semantic and phonological representations in long-term memory and the speed with which these representations are accessed during picture naming. The comparison of children with hearing loss and children with language impairment will make it possible to investigate the implications of perception and processing problems on lexical access in picture naming.

1.1. Lexical access and the cross-modal picture-word interference paradigm

The selection and retrieval of a stored word from the mental lexicon is referred to as lexical access (e.g., Bock, 1996; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Levelt, Roelofs, & Meyer, 1999). It involves the process of competition between continuous activated stored candidate words out of which the intended word is retrieved (Levelt et al., 1999; McQueen & Cutler, 2001). The underlying mechanisms involved in picture naming, relate to the retrieval of memory representations. Models of lexical access explain the activation of semantic and phonological information in time during processing. Findings from previous studies with adults have led to the proposal of three different models, focusing on language production. The serially ordered two-step model (e.g., Levelt et al., 1991; Levelt et al., 1999; Schriefers, Meyer & Levelt, 1990), the cascaded processing model (e.g., Jescheniak & Schriefers, 1998; Jescheniak, Hahne, Hoffmann & Wagner, 2006; Peterson & Savoy, 1998), and the interactive spreading activation model is the third model (e.g., Dell, 1986; Dell, Burger & Svec, 1997). These three models propose that lexical access is divided into semantic and phonological stages of processing, with varying conceptualized relations between the processing stages. In order to trace the time course of the semantic and phonological processing stages during lexical access, the cross-modal visual-auditory picture-word interference (PWI) paradigm has been adopted frequently in previous research on adult's and children's picture naming skills. This paradigm can be considered a valuable tool to assess the potential of lexical access, with or without manipulating the time course of distractor words.

In the cross-modal paradigm, participants are asked to name target pictures as quickly and accurately as possible, while ignoring related and unrelated aurally presented distractor words. The distractor words have a semantic, a phonological or no obvious relation with the target picture. A valuable dimension of the paradigm is the possibility to manipulate the appearance of the distractor words at different points in time compared to the target picture. The distractor words can appear before the picture, simultaneously with the picture or after the appearance of the picture, i.e., the stimulus asynchrony condition. To be able to determine the effect of the distractor words on picture naming, speed and accuracy for the semantically and phonologically related conditions are analyzed relative to the unrelated condition. In that way, semantic and phonological inhibition and facilitation over time can be examined in spoken word production..

Previous studies with adults on lexical access with the cross-modal PWI paradigm mainly demonstrated semantic interference effects (Jescheniak & Schriefers, 1998; Schriefers et al., 1990; Seiger-Gardner & Schwartz, 2008), followed by phonological facilitation effects (Brooks & MacWhinney, 2000; Jescheniak & Schriefers, 1998; Meyer & Schriefers, 1991; Schriefers et al., 1990; but see Seiger-Gardner & Schwartz, 2008, for contrary results). This means that adults showed slower reaction times when semantically related distractor words were presented relative to unrelated distractor words, and faster reaction times in the presence of phonologically related distractor words relative to unrelated distractor words. However, differences in the time course of the semantic and phonological effects, as evidenced by the variation in which the effects occurred during the processing stages, early or late, were found as well. Heterogeneous interference and facilitation effects have also been demonstrated in typically developing children and clinical populations of children. In some studies early phonological facilitation effects were found (Jerger, et al., 2002b; Jerger, Martin, & Damian, 2002), whereas in other studies early phonological interference effects were reported (Brooks & MacWhinney, 2000; Seiger-Gardner & Brooks, 2008; Seiger-Gardner & Schwartz, 2008). Early semantic interference effects were representative findings in many studies (Jerger et al., 2002; Jerger, Tye-Murray, Damian, & Abdi, 2013; Seiger-Gardner & Schwartz, 2008).

Table 1 provides an overview of the various semantic and phonological interference and facilitation effects in adults and children (typically developing [TD] children, children with SLI, and hard-of-hearing [HoH] children) as found in previous studies.

1.2. Lexical access in children with hearing loss and in children with language impairments

Lexical problems have been identified in many children with hearing loss and in children with language impairments (e.g., Gray, Reiser, & Brinkley, 2012; Sarant, Holt, Dowell, Rickards, & Blamey, 2009; Schwartz, Steinman, Ying, Mystal, & Houston, 2013). For children with hearing loss, these problems can at least partly be explained by their reduced exposure to new words and their slower rate of word learning processes (Houston, Carter, Pisoni, Kirk, & Ying, 2005; Pittman & Schuett, 2013; Spencer, Barker, & Tomblin, 2003). Previous studies have shown that the lexical problems of children with hearing impairments correspond to the degree of hearing loss (Kiese-Himmel 2008; Sarant et al., 2009) and the age of cochlear implantation (Nicholas & Geers, 2007; Schorr, Roth, & Fox, 2008). It can be assumed that cochlear implantation may help profoundly deaf children in achieving increased access to spoken language, with higher levels of speech perception, improved speech intelligibility and better vocabulary skills (e.g., Houston & Miyamoto, 2010; Svirsky et al., 2000). Indeed, an unilateral implant has shown to be successful in improving the auditory perception and as a result spoken language proficiency of these children, but not to a level comparable to that of hearing children (Knoors & Marschark, 2014). Previous studies suggest that children with cochlear implants (CIs) can develop (nearly) age-equivalent lexical skills, but they have more substantial difficulties in developing aspects of grammar and higher-order cognitive language functions (Boons et al., 2013; Spencer, 2004; Svirsky, Teoh, & Neuburger, 2004; Szagun, 2000). Lexical access is rarely studied in deaf children with CIs. Wass et al. (2008) reported that children with CIs can access their semantic and

phonological representations of words in long-term memory at a high speed, however, only when the words are highly familiar to them.

Children with SLI have major problems in developing language skills, despite showing normal development in nonverbal IQ and nonlinguistic aspects of development. Language difficulties cannot be accounted for by hearing loss or brain damage (Bishop, 2006). Researchers have argued that deficits in phonological working memory, particularly non-word repetition (e.g., Bishop, North, & Donlan, 1996; Conti-Ramsden & Hesketh, 2003; de Vasconcellos Hage, Nicolielo, & Guerreiro, 2014), sentence repetition (e.g., Conti-Ramsden, Botting, & Faragher, 2001; Leclercq, Quémart, Magis, & Maillart, 2014), and verb morphology (e.g., Rice, Hoffman, & Wexler, 2009; Verhoeven, Steenge, & van Balkom, 2011) serve as typical clinical markers of SLI. Furthermore, it is assumed that children with SLI have poorly specified semantic and phonological representations of words (Gray, 2005; Gray et al., 2012; Mainela-Arnold, Evans, & Coady, 2010; McGregor et al., 2002) and phonological encoding deficits (Edwards & Lahey, 1998). Word finding difficulties observed in children with SLI can be caused by breakdowns in the semantic or phonological processing levels of lexical access (Seiger-Gardner & Schwartz, 2008).

Only very few studies previously investigated lexical access skills of children with hearing impairments and children with language impairments by use of the cross-modal PWI paradigm. Table 1 presents previous results from children with hearing and language impairments concerning their semantic and phonological interference and facilitation effects.

With respect to children with CIs, Schwartz et al. (2013) were the first authors who used the PWI paradigm to examine lexical access. In their preliminary report (Schwartz et al., 2013) they thus far included 16 English-speaking children, with a mean age of 9;5 years and who have had their implants for at least 3 years. The preliminary results revealed that accuracy was at ceiling for the children, but they showed slower reaction times and greater interference and facilitation effects than their hearing peers and these effects remained present for longer periods of time. This made the authors suggest that the implanted children have different underlying lexical representations and processing skills than hearing peers. Schwartz et al. (2013) suggest delays in implanted children's auditory processing, but the authors will further analyze and interpret the preliminary data once additional participants are added.

In summary, the results from the children with CIs are not specified well enough in the preliminary report by Schwartz et al. (2013) to draw clear conclusions about their lexical access skills.

To our knowledge, there are only two studies that have examined lexical access in HoH children, with the use of the cross-modal PWI paradigm. Table 1 provides results of these studies. As for the first study, Jerger, Lai, and Marchman (2002a, 2002b) examined picture naming in 30 English-speaking children with moderate hearing loss and with a mean age of 10;6 years. Results showed early and late semantic interference effects, meaning that the HoH children showed slower reaction times when semantically related distractor words

compared to an unrelated distractor word were presented, independently whether it was before, simultaneously with, or after the appearance of the target picture. Furthermore, HoH children with good phoneme discrimination showed early and late phonological facilitation effects, indicating faster reaction times when phonologically related distractor words compared to an unrelated distractor word were presented. As for phonological access, the HoH children represented a very heterogeneous group. HoH children with good phoneme discrimination, indicated by accurately discriminating all contrasts on a same-different task, developed fine-grained phonological representations. However, the HoH children with poor phoneme discrimination developed less well specified and structured phonological representations in terms of auditory based linguistic information (Jerger et al., 2002b). In a follow-up study, Jerger et al. (2013) examined whether auditory semantically related distractor words influence semantic access in 31 English-speaking HoH children with moderate hearing loss and with a mean age of 8;0 years, by use of the picture word task. This picture word task is the same as the cross-modal PWI paradigm, with the modification that the distractor words were presented either auditorily or audiovisually. Results showed that, in the auditory mode, the HoH children revealed a late semantic facilitation effect, indicating faster reaction times when semantically related distractor words compared to an unrelated distractor word were presented after the appearance of the target picture.

In conclusion, HoH children with good phoneme discrimination showed early and late phonological facilitation effects (Jerger et al., 2002b). Conflicting results were found concerning the early semantic effect. Jerger et al. (2002a) found early and late semantic interference effects for the HoH children, whereas in the study of Jerger et al. (2013), no early semantic effects were found. Moreover, a late semantic facilitation effect was found for the HoH children in the study by Jerger et al. (2013). To resolve this difference, the authors state that further research is needed.

With reference to children with SLI, two studies were conducted using a cross-modal PWI paradigm to examine their lexical access. The first study was carried out by Seiger-Gardner and Schwartz (2008) with 20 English-speaking children with SLI with a mean age of 9;1 years. The children with SLI showed an early semantic interference effect, an early phonological interference effect, and a late phonological facilitation effect, as shown in Table 1. Although the children with SLI produced more errors than their typically developing peers, both groups exhibited a similar pattern of semantic and phonological effects, which made the authors suggest that children with SLI have similar lexical access architectures as typically developing peers. The second study with children with SLI was conducted by Seiger-Gardner and Brooks (2008). Phonological effects of lexical access in 18 children with SLI, mean age 8;7 years, were examined with the cross-modal PWI paradigm. Results of the children with SLI were comparable with the results found in the preceding study (Seiger-Gardner & Schwartz, 2008), revealing an early phonological interference effect and a late phonological facilitation effect. The authors state that further research is needed to clarify the novel finding of early phonological interference by Seiger-Gardner and Schwartz (2008) and Seiger-Gardner and Brooks (2008).

In summary, lexical access in children with SLI appears to be intact at the semantic level, revealing an early semantic interference effect. Furthermore, the children with SLI showed an early phonological interference effect.

It should be noted that drawing overall conclusions is difficult, based on only four studies. The current evidence varies with regard to the availability and time course of semantic and phonological information in the lexical access process of picture naming in children with hearing loss and children with language impairments. The conflicting results could relate to the fact that the experimental design of the previous studies differs systematically. Jerger et al. (2002b) selected nonsense syllables as distractor words in picture-word pairs, whereas in the other PWI studies, described in Table 1, real words were used as distractor words. Another distinction between the PWI designs of previous studies is the measurement of the time between the distractor word and the target picture at the early stimulus asynchrony condition (when the distractor word was offered before the appearance of the target picture). Seiger-Gardner and Brooks (2008) and Seiger-Gardner and Schwartz (2008) measured the early stimulus asynchrony condition as the time between the offset of the distractor word and the onset of the target picture, i.e., the distractor word offset preceded the picture onset by 150 ms, whereas in the other PWI studies described in Table 1, the early stimulus asynchrony condition was measured as the time between the onset of the distractor word and the onset of the target picture, i.e., the distractor word onset preceded the picture onset by 150 ms. One severe limitation in all previous studies is that the researchers did not familiarize participants with the related and unrelated aurally presented distractor words. In fact, participants were familiarized only with the target pictures, assuming that the distractor words were familiar to them, based on age of acquisition. Since children with hearing loss or language impairments often lag behind in their lexical development, it may not be assumed that these children know as many lexical items as their normally developing peers (e.g., Knoors & Marschark, 2014; Watkins, Kelly, Harbers, & Hollis, 1995). Given the discrepancies between previous experimental designs of the cross-modal PWI paradigm, it is not possible to compare the results of the children from the previous studies. Furthermore, performance of children with hearing loss and children with language impairments on the PWI paradigm has never been compared within any previous study. In order to gain better insight into the nature of these children's semantic and phonological representations in long-term memory and the speed with which these representations are accessed during picture naming, we used one design to compare lexical access performance of the children with hearing loss and children with language impairments on that design.

1.3. The present study

In the first place, the cross-modal PWI paradigm was used in this study to assess whether children with hearing loss or language impairments were able to access semantic and phonological information, setting aside the temporal component of the paradigm. Second, possible semantic and phonological effects were explored by the differential influence of the time course. Therefore, in the present study we addressed the following research questions:

- (1) To what extent do speed and accuracy of lexical access in picture naming differ between deaf children with CIs, HoH children and children with SLI, compared to age-matched control children?

- (2) Do the children with hearing loss or language impairments show any facilitation or interference effects when temporal information about the availability of semantic and phonological information is taken into account?

With respect to the first question, we were interested in group differences in lexical access. By comparing the three different clinical groups of children, it is possible to investigate how variation in perception and processing affects semantic and phonological representations in long-term memory. We expected that children with hearing loss reveal faster reaction times than their peers with language impairments. This expectation was consistent with the performance-based account of a generalized processing capacity limitation in children with SLI, such as slow speed of processing (e.g., Miller, Kail, Leonard, & Tomblin, 2001; Montgomery, 2002). Also, on a test of Rapid Automatized Naming (RAN; Olofsson 2000), children with mild-to-moderate hearing loss named object pictures significantly faster than children with SLI (Hansson, Sahlén, & Mäki-Torkko, 2007). Note that the RAN is a simple naming task, without the interference of distractor words. Moreover, children with SLI supposedly produce more errors than the children with hearing loss. Since children with SLI have word finding difficulties (Faust, Dimitrovsky, & Davidi, 1997; Seiger-Gardner & Schwartz, 2008), we expected to find difficulties in retrieving the target picture's name in a real-time language processing task with limited answering time.

Concerning the second question, we were interested in whether mean reaction times changed depending on three stimulus asynchrony conditions, i.e., the appearance of the distractor words before the picture, simultaneously with the picture, or after the picture. We expected differential interference and facilitation effects for the three clinical groups in the present study as a consequence of the presumed lexical access availability difficulties and the heterogeneous results regarding the semantic and phonological effects in previous studies.

2. Method

2.1. Participants

Two groups of children with hearing loss; 25 deaf children with CIs and 13 children with hearing loss, and one group of 20 children with SLI participated in the study. A group of 21 TD children served as controls. Table 2 provides an overview of the characteristics of the four participating groups. Of the children with hearing loss and the children with language impairments, 57% followed mainstream education and 43% followed education for children with special needs in the Netherlands at the time of testing. All children were selected by speech-language pathologists and psychologists working at the schools of the children, meeting the following criteria; being between 7;0 and 12;0 years old at the time of testing, having spoken Dutch as their first language, having nonverbal intelligence within normal limits and no developmental disorders (e.g., autism or attention deficit hyperactivity disorder) or neurological problems. In addition, all children were required to have a linguistic competence score of at least a six-year-old child on the Dutch *Reynell Test voor Taalbegrip* [Reynell Test for Language Comprehension] by Van Eldik, Schlichting, Lutje Spelberg, Van der Meulen and Van der Meulen (1995) or the Dutch *Taaltest voor Kinderen* [Language Test for Children] by Van Bon (1982) and be able to speak in such an audible way that picture names could be understood well by the experimenter. The children with CIs

had a mean unaided pure tone-average hearing loss of 85 dB hearing level (HL). Eight of the 25 children were implanted bilateral and seven children had bimodal hearing. Four of the children with CIs had progressive hearing loss. All children had their implant(s) for at least two years. Nineteen children received their implant(s) before the age of 2;6 and mean age of first implantation was 35 months. In Table 2, a detailed background information of the children with CIs is described. For the HoH children, the mean unaided pure tone-average hearing loss was 59 dB HL. According to the World Health Organization's criteria for degree of hearing loss, four children had a slight hearing impairment (26-40 dB HL), two children had moderate hearing loss (41-60 dB HL), six children had a severe impairment (61-80 dB HL) and one child had profound hearing loss (>81 dB HL) (Mathers, Smith, & Concha, 2000). Both groups of children with hearing impairments obtained a minimum phoneme perception score of 80% on the Dutch *NVA Woordlijsten* [NVA word lists] (Bosman & Smoorenburg, 1995). All children were tested while wearing their CI(s) and hearing aid(s). The group of children with SLI and the TD children were selected to have normal hearing. Furthermore, the diagnosis of SLI in these children was established by a speech-language pathologist and a psychologist. The criteria for diagnosis of SLI in the Netherlands is stated in accordance with Dutch law.¹

2.2. Materials and instrumentation

The cross-modal PWI paradigm was adapted from Seiger-Gardner and Schwartz (2008). In this paradigm, children were asked to name pictures as quickly and accurately as possible, while ignoring related and unrelated aurally presented distractor words that were offered at different stimulus asynchronies. For this visual-auditory picture-word experiment, twenty black-and-white line drawings pictures of common objects were selected as target items, five pictures were selected as practice items and eight pictures as filler items. All black-and-white line drawings were selected from Snodgrass and Vanderwart (1980) and the Dutch list of pictures *Woordbenoemtest* (Picture Naming Test, Verhoeven, Keuning, Horsels, & Van Boxtel, 2013). Each of the target items was paired with three different aural distractor word conditions; (1) a semantic distractor condition in which the distractor word and the picture name were related in their word meaning (e.g., *wolk* [cloud] – *zon* [sun]), (2) a phonological distractor condition in which the distractor word and the picture name were either related in their word forms by onset consonant and vocal (e.g., *boom* [tree] – *boot* [boat]), or in their word forms by final vocal and consonant (e.g., *vuur* [fire] – *muur* [wall]), and (3) an unrelated distractor condition in which the distractor word and the picture name were not related in either form or meaning (e.g., *bank* [couch] – *fles* [bottle]). There was also (4) a silent condition, i.e., the baseline condition, in which no distractor words were presented. All aurally presented items were selected from two Dutch word lists with words well known by six-year old Dutch TD children (Kienstra, 2003; Schaerlaekens, Kohnstamm, & Lejaegere, 1999). The Appendix includes all target items and distractor words. The twenty target items were connected to 60 distractor words. Each of the three distractor word conditions

¹According to Dutch law, art. 17 § 1 “Law on centers of expertise” (2003), SLI is diagnosed when on the base of logopaedic and psychodiagnostic examination addressing communicative and cognitive functioning, and if needed supplemented with audiological examination, is determined that the speech and language problems are not attributed to a cognitive constraint, and the scores on at least two out of four separate language tests (speech, auditive processing, grammar and semantics-lexicon) are lower than 1.5 standard deviations or when the total score on a general SLI test is lower than 2 standard deviations.

(semantically related, phonologically related and unrelated) consisted of 20 words. Furthermore, 10 practice items (five pictures and five distractor words) and 16 filler items (eight pictures and eight distractor words) were used. These were different from the experimental items. All words in the experiment were of the type CVC, CVCC, or CCVC, with high familiarity.

All distractor words were digitally recorded by the same female speaker. The sampling rate was 44 kHz with 16-bit mono amplitude resolution. All target items were presented on a 15,4 inch HP EliteBook Laptop monitor. Distractor words were offered to the TD children and the children with SLI via Monacor MD-2000 headphones, or via the Solaris Transmitter induction loop system in case of the deaf children with CI and the HoH children. *Delphi 6* was used to present all target items and distractor words. Reaction times were recorded using a Philips desk microphone connected to a voice key and the HP EliteBook Laptop. A Monacor MMX-24 mixer generated a pure tone that remained on until the target item disappeared. Each session was taped using a Philips FC 153 tape recorder. The pure tone was recorded at the left channel of the tape recorder and children's responses were recorded on the right channel. The loudness was chosen to be optimal and comfortable for the children, by asking each individual child whether the loudness was comfortable for him/her. All children were tested in a quiet room without any noise.

2.3. Design

The stimulus asynchronies were measured in terms of onset (Stimulus Onset Asynchronies: SOAs). The distractor words were presented in three different SOAs; early, synchronous, and late. In the early SOA, the onset of the distractor word was presented 150 milliseconds prior to the onset of the target item (SOA -150). In the synchronous SOA, the onset of the distractor word and the onset of the target item were presented simultaneously (SOA 0). In the late SOA, the onset of the distractor word began 150 milliseconds after the onset of the target item, relative to the individual child's mean reaction time (RT) performance in the mean RT determination phase. In this phase, prior to testing the children, a baseline RT for the late SOA was calculated based on results of 42 adults, ranging from 17;8 to 30;9 years old ($M = 20;5$ years, $SD = 32.3$ months), naming 10 of the experimental target items as quickly and accurately as possible in a mean RT determination phase. These target items were presented without distractor words. RTs were measured from the onset of the target item to the voice key trigger. The target item disappeared when the voice key was triggered. If there was no response, the target item disappeared automatically after four seconds. The mean RT from the adults in the determination phase was 638 milliseconds, to which the children's mean RTs were calibrated. For example, when the mean RT in the determination phase from any individual child was 892 milliseconds, then $892 - 638$ (mean RT adults) = 254 milliseconds were added up to 150 milliseconds. In this example, the onset of the distractor word began $(150 + 254 =) 404$ milliseconds after the onset of the target item. In that way, we accounted for the proportional slowing effect, i.e., age differences in processing speed during childhood and adulthood (Kail, 1991) and processing speed differences between language impaired children and chronological-age peers (Miller et al., 2001; Windsor & Hwang, 1999). For terms of ease, throughout the remaining of this article, the late SOA condition will be referred to as SOA +150, but it is a relative +150.

2.4. Procedure

All children were tested individually by the same experimenter. The experiment was performed in one session of approximately one hour and was administered in a fixed order of four parts. In the first part the children were familiarized with all items, including the target items, the semantic, phonological and unrelated distractor words and the filler and practice items. We chose to familiarize all experimental items since the clinical populations are known for their deviant vocabulary acquisition. The pictures or words that were unknown or not correctly named by the children were corrected immediately by the experimenter. After this familiarizing session, the experimenter showed flashcards of the unknown or incorrectly named pictures to the children to make sure they knew the pictures and words after the familiarization stage. The children were not allowed to use articles (e.g., 'the' boat or 'a' bottle). In the second part of the experiment, the children practiced the naming of pictures into the microphone, while they used headphones or the Solaris Transmitter induction loop system. In this part, the voice key was set correctly to the loudness of each child's voice. The third part was the mean RT determination phase, in which the children were asked to name 10 fixed pictures as quickly as possible. These pictures were target items which were presented throughout the experiment, and were the same 10 pictures as the previously mentioned 42 adults were asked to name in the adult's mean RT determination phase. No distractor words were presented in this phase. After the determination phase, the experiment started. The experiment was divided into three different SOA blocks (-150, 0, and +150). These blocks were counterbalanced across all children in such a way that no item repetition effects would occur. Each block consisted of four sub-blocks in which every distractor word condition and silent condition occurred once. The order of distractor word condition and silent condition was latin-squared counterbalanced across the SOA conditions. Each sub-block began with two filler items to attain the focus of the children. The filler items were paired with unrelated distractor words. Since the voice key was very sensitive to any sound or movement, the children were asked to sit as quiet as possible and to avoid coughing or doing anything else (except for naming the pictures) until a smiley appeared. The smiley emerged after each sub-block, which meant that the children could ask questions, cough or move. The experimenter kept a record of errors and lost trials. When the voice key was triggered by children's non speech sounds, stuttering or mouth or tongue clicks before they answered, reaction times were recalculated from the audiotapes. This was done by a certified linguist, using RecordPad Sound Recording Software from NCH Software and the phonetics program Praat, which is a system for doing phonetics by computer (Boersma, 2001).

3. Results

Missing trials were excluded before the RT data was analyzed. The missing trials were considered to be responses after four seconds, missed responses, voice key malfunction, and the impossibility to recalculate RTs due to technical problems with recordings. For each group of children, missing trials accounted for less than 2% of all trials. An one-way ANOVA demonstrated no significant group differences with respect to missing trials, $F(3, 75) = 0.487$, $p = .692$, $\omega = .14$.

3.1. Speed and accuracy

To be able to answer the first research question, an one-way ANOVA was conducted. Tukey Honestly Significant Difference (HSD) post hoc tests or Games-Howell post hoc tests (when Levene's test for homogeneity of variances was significant) were conducted to analyze for RT and accuracy differences between the groups of children (i.e., children with CIs, HoH children, children with SLI, and TD children). In the analyses, participants were used as the random factor (F_1). An F_2 analysis was also conducted with target items as the random factor. One ANOVA treating subjects as random variable, and one ANOVA treating items as random variable, allows generalizations over both subject and item populations. An alpha level of .05 was used for all statistical tests. Effect sizes are given to estimate the comparing size of sources of variation (Field, 2009).

Mean RTs for correct responses to the experimental trials in each distractor word condition for each group of participants were computed and are presented in Table 3. Note that the mean RTs in Table 3 were calculated across the three different SOAs, meaning that the temporal component was left aside. Significant differences between the four groups of children were found with regard to mean RTs in the semantic distractor word condition, $F_1(3, 75) = 3.348, p = .023, \omega = .29$; $F_2(3, 76) = 11.640, p < .001, \omega = .13$, in the phonological distractor word condition, $F_1(3, 75) = 8.572, p < .001, \omega = .47$; $F_2(3, 76) = 28.367, p < .001, \omega = .71$ and in the unrelated distractor word condition, $F_1(3, 75) = 3.906, p = .012, \omega = .32$; $F_2(3, 76) = 13.170, p < .001, \omega = .56$. Tukey HSD post hoc tests revealed that mean RTs in the semantic condition were significantly slower for children with SLI than for the group of children with CIs, $t_1(19) = 2.99, p = .019$; $t_2(19) = 5.54, p < .001$, the HoH children, $t_2(19) = 3.48, p = .005$, and the TD group, $t_2(19) = 4.54, p < .001$. Also in the phonological condition, Tukey HSD post hoc tests showed that mean RTs were significantly slower for the children with SLI than for the children with CIs, $t_1(19) = 4.91, p < .001$; $t_2(19) = 8.82, p < .001$, the HoH group, $t_1(19) = 3.11, p = .014$; $t_2(19) = 6.37, p < .001$, and the TD children, $t_2(19) = 3.85, p = .001$. The children with CIs revealed faster mean RTs in the phonological condition than their TD peers, $t_1(24) = 2.74, p = .038$; $t_2(19) = 4.97, p < .001$. In the unrelated condition, the children with SLI showed significant slower mean RTs than the children with CIs, $t_1(19) = 3.36, p = .007$; $t_2(19) = 6.09, p < .001$, the HoH group, $t_2(19) = 4.19, p < .001$, and their TD peers, $t_2(19) = 2.79, p = .033$. Furthermore, Tukey HSD post hoc tests revealed faster mean RTs in the unrelated condition for the children with CIs than for the TD children, $t_2(19) = 3.30, p = .008$.

In summary, the children with SLI revealed slower RTs than the two groups of children with hearing loss and the TD controls in all conditions. Furthermore, the children with CIs produced faster RTs than the TD controls in the phonological and the unrelated conditions.

Mean number of errors were calculated in each distractor word condition for each group of participants. Table 4 presents the group's accuracy data. Significant differences were found between accuracy data of the four groups of children in the semantic condition, $F_1(3, 75) = 4.949, p = .003, \omega = .36$; $F_2(3, 76) = 8.777, p < .001, \omega = .48$, in the phonological condition, $F_1(3, 75) = 5.617, p = .002, \omega = .39$; $F_2(3, 76) = 8.071, p < .001, \omega = .46$, and in the unrelated condition, $F_1(3, 75) = 4.626, p = .005, \omega = .35$; $F_2(3, 76) = 6.023, p = .001, \omega = .$

40. Games-Howell post hoc tests revealed that the mean number of errors were significantly higher for children with SLI than for their TD peers, $t_1(19) = 4.03$, $p = .002$; $t_2(19) = 4.46$, $p = .001$, and their HoH peers, $t_2(19) = 3.51$, $p = .008$, in the semantic condition. The HoH children, $t_1(12) = 2.94$, $p = .035$ and the children with CIs, $t_2(19) = 3.55$, $p = .009$, produced significantly more errors in the semantic condition than the TD children. In the phonological condition, Games-Howell post hoc tests showed that the children with SLI produced significantly more errors than the children with CIs, $t_1(19) = 2.81$, $p = .038$, the HoH children, $t_2(19) = 3.93$, $p = .003$, and the TD group, $t_1(19) = 3.47$, $p = .010$; $t_2(19) = 3.16$, $p = .018$. In the unrelated condition, the children with SLI produced significantly more errors than their TD peers, $t_1(19) = 2.91$, $p = .035$, and their HoH peers, $t_2(19) = 3.55$, $p = .008$. Finally, the group with CIs produced significantly more errors than their HoH peers in the unrelated condition, $t_2(19) = 2.85$, $p = .036$.

In summary, the children with SLI produced more errors than the two groups of children with hearing loss and the TD controls in all conditions. In the semantic condition, the children with hearing loss produced more errors than the TD controls

3.2. Semantic and phonological effects

The second research question was addressed by analyzing participant's mean RTs in a 3 (SOA) $\times$ 3 (distractor word; i.e., DW) $\times$ 4 (Group) Repeated Measures ANOVA. The between-subject variable consisted of four groups of participants; 25 children with CIs, 13 HoH children, 20 children with SLI, and 21 TD children. SOA (-150 , 0 , and $+150$) and DW (semantic, phonological, and unrelated) were the within-subject variables. Table 5 presents the mean RTs for each group of participants in each distractor word condition at each SOA.

Significant main effects were found for SOA, $F_1(1.467, 109.989) = 56.570$, $p < .001$, $\eta_p^2 = .43$; $F_2(2, 152) = 211.865$, $p < .001$, $\eta_p^2 = .74$. The two-way interaction SOA $\times$ DW was significant, $F_1(4, 300) = 2.495$, $p = .043$, $\eta_p^2 = .03$; $F_2(3.470, 263.750) = 2.709$, $p = .038$, $\eta_p^2 = .03$. The two-way interaction SOA $\times$ Group was significant in the item analysis, $F_2(6, 152) = 5.288$, $p < .001$, $\eta_p^2 = .17$. A significant two-way interaction DW $\times$ Group was found, $F_1(6, 150) = 5.787$, $p < .001$, $\eta_p^2 = .19$; $F_2(6, 152) = 3.729$, $p = .002$, $\eta_p^2 = .13$. Planned comparisons between the unrelated distractor word and the semantically and phonologically related distractor words were conducted at each SOA to test for semantic and phonological effects. Table 6 provides an overview of the facilitation and interference effects for each group of participants at each SOA condition and distractor word. At SOA -150 , both the TD group, $F_1(1, 20) = 4.819$, $p = .040$, $\eta_p^2 = .19$, and the children with SLI, $F_1(1, 19) = 16.136$, $p = .001$, $\eta_p^2 = .46$; $F_2(1, 19) = 11.992$, $p = .003$, $\eta_p^2 = .39$, revealed a significant early phonological effect, demonstrating slower RTs in the presence of phonologically related distractor words compared to unrelated distractor words. At SOA $+150$, the HoH children showed a significant late phonological facilitation effect, $F_2(1, 19) = 7.240$, $p = .014$, $\eta_p^2 = .28$, demonstrating faster RTs in the presence of phonologically related distractor words compared to unrelated distractor words.

In summary, the children with language impairments and the TD controls demonstrated an early phonological interference effect. A late phonological facilitation effect was found for the HoH children. No other significant (semantic) effects were observed.

4. Conclusions and discussion

The purpose of the present study was to examine the availability and time course of semantic and phonological information in the lexical access process for picture naming in children with hearing loss or language impairments by means of the cross-modal PWI paradigm. By comparing these clinical groups, it was possible to assess whether differences might be attributed to auditory perception deficits, or processing difficulties, or both. Two research questions were addressed. The first question focused on the extent to which speed and accuracy of lexical access in picture naming is different for children with CIs, HoH children and children with SLI, compared to age-matched TD control children. As previously hypothesized, the children with SLI revealed slower RTs and produced more errors in the semantic, the phonological and the unrelated conditions than the deaf children with CIs, the HoH children, and the TD controls, independent of the time course in which the distractor word was presented. The two groups of children with hearing loss in the present study did not reveal slower RTs than the TD control children. In the phonological and the unrelated conditions, we found that the deaf children with CIs produced even faster RTs than the TD controls. In the semantic condition, both groups of children with hearing loss produced more errors than the TD controls.

The second research question addressed whether the children with hearing loss or language impairments show any facilitation or interference effects when temporal information about the availability of semantic and phonological information is taken into account. Results revealed an early phonological interference effect for the children with SLI, indicated by slower RTs when phonologically related distractor words were presented before the appearance of the target picture compared to unrelated distractor words. Furthermore, a late phonological facilitation effect was found for the HoH children, evidenced by faster RTs when phonologically related distractor words compared to unrelated distractor words were presented after the appearance of the target picture. No significant semantic effects were found in the present study, but there seems to be a tendency towards faster mean RTs over time. Mean RTs decreased as the SOA varied from -150 to +150. This is a returning pattern for every group of children and corresponds to results of previous PWI studies with children (Jerger et al., 2002a, 2002b; Jerger et al., 2002). Only a few significant effects were found related to the time course of lexical access, and the variation of effects within this study and between studies is high. This may be due to the huge variation in study designs. Alternatively, the time course of lexical access and thus the moment semantic and phonological information becomes available might be subject to considerable individual variation. This makes interpretation of the results, and verification of lexical access models very hard, if not impossible.

The finding that children with language impairments in the present study revealed overall slower RTs and produced more errors than the two groups of children with hearing loss and the TD controls in all conditions, is consistent with results from a previous study by Hansson et al. (2007) in which children with SLI were significantly slower than a group of peers with hearing loss on a test of simple rapid naming. We can conclude that both groups of children with hearing loss in the present study, who have relatively good speech perception abilities, outperform their peers with language impairments on speed and

accuracy in lexical access, even when they are being distracted by auditory intervening words during picture naming. Furthermore, the present finding replicates previous results of slower naming times in picture naming for children with SLI, compared to age-matched peers (Coady, 2013; Mainela-Arnold et al., 2010; Seiger-Gardner & Brooks, 2008; Seiger-Gardner & Schwartz, 2008). Slow naming times may be related to less robustly specified lexical representations (McGregor et al., 2002; Sheng & McGregor, 2010) and slow speed of processing (Miller et al., 2001; Montgomery, 2002; Seiger-Gardner & Brooks, 2008). It was also reported in previous studies that children with SLI are less accurate in naming pictures than their typically developing peers (Seiger-Gardner & Brooks, 2008; Seiger-Gardner & Schwartz, 2008; Sheng & McGregor, 2010). Some researchers have concluded that this naming deficit is related to linguistic processing involving the storage or retrieval of lexical items (Kail, 1994; Sheng & McGregor, 2010). Concluding from the present findings that children with SLI revealed slower RTs and produced more errors than the TD controls in both semantic and phonological conditions, we suggest that children with language impairments have poorly specified semantic and phonological representations of words and weak access to these representations.

The fact that both groups of children with hearing loss in the present study did not reveal slower RTs than the TD controls, suggests that they are able to construct solid semantic and phonological representations of words and that they have rapid access to these representations during picture naming despite making some errors. The variation in age of first CI implantation could explain the fast RTs of the children with CIs, since four of the children with CIs had progressive hearing loss and were implanted relatively late. The finding that the hearing impaired children with good speech perception abilities achieve age-adequate lexical skills is consistent with previous studies (Boons et al., 2013; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Svirsky et al., 2004). In a recent study by Wechsler-Kashi, Schwartz, and Cleary (2014), similar results were found on a timed picture naming task by a group of children with CIs. The implanted children revealed no RT difference with hearing age-matched peers. Moreover, in the present study, the children with CIs produced significantly faster RTs than the TD controls in the phonological and the unrelated conditions. Mean RTs from the HoH children in the phonological and the unrelated conditions were also slightly faster than the mean RTs of the TD controls. This remarkable finding could be explained by the fact that both groups of children with hearing loss were somewhat older than the TD controls, since naming speed improves with age (Wiegel-Crump & Dennis, 1986). Another explanation could be the presence of a training effect. Children with hearing loss might be more familiar with rapidly naming pictures, since they are frequently trained doing so by speech-language therapists to optimize their verbal language development and maximize the benefits of their devices. Faster RTs thus could result from the fact that the children with hearing loss were more task directed than the TD controls.

Some limitations apply to the present study. First, it is difficult to make generalizations based on the reported results, since the children with hearing loss and the children with SLI were selected on the basis of strict criteria. All three groups of children were selected based on a minimum linguistic competence score, and the children with hearing loss were also selected based on a minimum phoneme perception score. This means that the children in the

present study had sufficient vocabulary skills and relatively good speech perception scores. Second, it should be noted that we did not control for executive functions in the current study. Executive functioning may influence the process of lexical access, for example, selective attention plays an important role in PWI performance; it allows participants to respond to the target picture rather than to the distractor word (Piai, Roelofs, & Schriefers, 2012). Given the fact that many children with hearing loss suffer from executive functioning deficits (e.g., Figueras, Edwards, & Langdon, 2008; Pisoni, Conway, Kronenberger, Henning, & Anaya, 2010), we advise to include measures of executive functions in future studies focusing on lexical access in hearing impaired children in order to study possible interaction effects.

In conclusion, the results of the present study demonstrated clear differences in lexical access skills between the children with hearing loss and the children with language impairments. This suggests that semantic and phonological representations in long-term memory are affected more by inadequacies in linguistic processing than by a deficit in auditory perception. Despite the fact that children with hearing loss are often delayed or restricted in their access to language due to their auditory perception deficits, they do reveal less lexical access difficulties than peers with SLI who have full access to language. These findings suggest that reduced lexical access skills could act as a clinical marker in identifying SLI. That is, an insufficient process of selection and retrieval of a stored word from the mental lexicon, while being distracted by related and unrelated aurally presented distractor words. However, additional research is needed to determine if a measure of lexical access, like the cross-modal PWI paradigm, could be a suitable clinical marker for SLI.

Considering the results of the present study, it is clinically relevant to distinguish between the groups of children with hearing loss and the children with language impairments, regarding the focus of language training. Since the children with hearing loss performed on a similar level or even better than age-matched controls on the picture naming task, their language training should not necessarily have the emphasis on vocabulary, but more focus should be on their lagging aspects of grammar and higher-order cognitive language functions (e.g., Boons et al., 2013). Intensive picture naming training may be exceedingly useful for children with language impairments though, to build stronger semantic networks. Possible evaluated intervention methods to improve retrieval and production of spoken words could be the hybrid language intervention programme (Munro, Lee & Baker, 2008), with which significant improvements in spoken language were evident for children with SLI after six weeks, and the short-term intensive-conversation pullout intervention by Ruston and Schwanenflugel (2010), which improved expressive vocabulary skills of children with low vocabulary levels. Finally, the children with SLI in the present study demonstrated slow speed of processing which can be interpreted as a characteristic finding for these children (e.g., Miller et al., 2001). When working with children with SLI, it may therefore be clinically relevant to adapt the speed of processing to the children's abilities in perspective of effective language interventions.

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Figure 1. Mean RT differences (in milliseconds) between the semantically and phonologically related distractor words and the unrelated distractor word in each SOA condition (–150ms, 0ms, +150ms) for four groups of participants (CI, HoH, SLI and TD).

Table 1

Semantic and Phonological Interference (-) and Facilitation (+) Effects in each Distractor Word Type and Stimulus Asynchrony (SA) Condition in Previous Studies

Study		Semantically Related – Unrelated			Phonologically Related – Unrelated		
		Early SA	Simultaneous SA	Late SA	Early SA	Simultaneous SA	Late SA
Brooks & MacWhinney, 2000	TD ($n=15$, age 7;5)	X	X	X	-	+	+
	Adults ($n=15$)	X	X	X	+	+	+
Jerger, Lai, & Marchman, 2002a & 2002b	HoH ($n=30$, age 10;7)	-	-	-	+	+	+
	TD ($n=60$, age 10;4)	-	ns	ns	+	+	+
Jerger, Martin, & Damian, 2002	TD ($n=24$, age 6;0)	-	-	ns	+	+	+
	TD ($n=15$, age 13;1)	-	-	ns	+	+	+
Jerger, Tye-Murray, Damian, & Abdi, 2013	HoH ($n=31$, age 8;0)	ns	ns	+	X	X	X
	TD ($n=62$, age 7;8)	-	ns	ns	X	X	X
Seiger-Gardner & Brooks, 2008	SLI ($n=18$, age 8;7)	X	X	X	-		+
	TD ($n=18$, age 9;4)	X	X	X	ns	+	+
Seiger-Gardner & Schwartz, 2008	SLI ($n=20$, age 9;1)	-	-	ns	-	ns	+
	TD ($n=20$, age 9;4)	-	-	ns	-	ns	+
	Adults ($n=20$)	-	-	ns	-	+	+
Jescheniak & Schriefers, 1998	Adults ($n=69$)	-	X	-	ns	+	+
Meyer & Schriefers, 1991	Adults ($n=64$)	X	X	X	+	+	+
Schriefers, Meyer, & Levelt, 1990	Adults ($n=48$) <i>Exp. 2</i>	-	ns	ns	ns	+	+

Note. TD = Typically Developing children; HoH = Hard-of-Hearing children; SLI = children with Specific Language Impairment; ns = not statistically significant; X = not tested in the study.

Table 2

Characteristics of the Different Groups of Participants (CI, HoH, SLI and TD)

Characteristic	CI (<i>n</i> = 25)	HoH (<i>n</i> = 13)	SLI (<i>n</i> = 20)	TD (<i>n</i> = 21)
Mean age in months (<i>SD</i>)	120 (9.1)	117 (9.7)	112 (9.7)	111 (12.0)
Range	97-135	103-133	97-134	92-124
Gender in percentage				
Male	48	54	50	38
Female	52	46	50	62
Mean age at first CI implantation in months (<i>SD</i>)	35 (25.6)	NA	NA	NA
Range	13-111			
Average unaided hearing loss better ear in dB HT, PTA (<i>SD</i>)	85	59 (21.5)	NA	NA
Range	NA	25-90		
Mean phoneme perception score in percentage (<i>SD</i>)	92 (7.0)	88 (8.4)	NA	NA
Range	80-100	79-100		

Note. CI = Cochlear Implants; HoH = Hard-of-Hearing; SLI = Specific Language Impairment; TD = Typically Developing; SD = standard deviation; dB HT = decibel hearing threshold; PTA = Pure Tone Average; NA = not applicable.

Table 3

Mean Reaction Times (in milliseconds), Standard Deviations (SD), and Range for each Group of Participants in each Distractor Word (DW) Condition

Group	Distractor word condition		
	Semantically related DW	Phonologically related DW	Unrelated DW
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
CI	1172 (286)	1109 (261)	1134 (271)
	747-2089	664-1903	687-2041
HoH	1238 (266)	1197 (271)	1208 (231)
	948-1989	813-1812	931-1759
SLI	1384 (201)	1466 (242)	1381 (239)
	987-1700	1090-1874	919-1801
TD	1201 (174)	1305 (198)	1264 (223)
	895-1642	967-1664	881-1703

Note. CI = Cochlear Implants; HoH = Hard-of-Hearing; SLI = Specific Language Impairment; TD = Typically Developing.

Table 4

Mean Number of Errors, Standard Deviations (SD), and Range for each Group of Participants in each Distractor Word (DW) Condition

Group	Distractor word condition		
	Semantically related DW	Phonologically related DW	Unrelated DW
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
CI	3.44 (3.8) 0-15	2.28 (2.8) 0-11	2.36 (1.9) 0-6
HoH	3.23 (1.9) 1-7	2.54 (1.9) 0-6	2.08 (2.3) 0-7
SLI	5.05 (3.8) 0-14	5.00 (3.5) 1-15	4.45 (3.6) 0-14
TD	1.38 (1.6) 0-6	2.10 (1.3) 0-6	1.90 (1.6) 0-6

Note. CI = Cochlear Implants; HoH = Hard-of-Hearing; SLI = Specific Language Impairment; TD = Typically Developing.

Table 5

Mean Reaction Times (in milliseconds) and Standard Deviations (SD) for each Group of Participants in each Distractor Word (DW) Condition and Stimulus Onset Asynchrony (SOA)

Group	Semantically related DW			Phonologically related DW			Unrelated DW		
	SOA -150	SOA 0	SOA +150	SOA -150	SOA 0	SOA +150	SOA -150	SOA 0	SOA +150
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
CI	1272 (265)	1184 (340)	1061 (301)	1233 (295)	1104 (304)	989 (230)	1270 (292)	1148 (345)	986 (261)
HoH	1354 (304)	1287 (331)	1073 (260)	1339 (288)	1220 (346)	1032 (266)	1303 (250)	1192 (258)	1129 (244)
SLI	1451 (264)	1473 (236)	1228 (245)	1621 (290)	1521 (311)	1256 (253)	1475 (318)	1428 (256)	1241 (291)
TD	1274 (173)	1210 (240)	1117 (271)	1404 (262)	1286 (217)	1226 (280)	1329 (255)	1275 (280)	1189 (269)

Note. CI = Cochlear Implants; HoH = Hard-of-Hearing; SLI = Specific Language Impairment; TD = Typically Developing.

Table 6

Interference (-) and Facilitation (+) Effects for each Group of Participants under each Distractor Word Type and Stimulus Onset Asynchrony (SOA)

Group	Semantically Related - Unrelated			Phonologically Related - Unrelated		
	SOA -150 ms	SOA 0 ms	SOA +150 ms	SOA -150 ms	SOA 0 ms	SOA +150 ms
CI	ns	ns	ns	ns	ns	ns
HoH	ns	ns	ns	ns	ns	+ ($p = .014$)
SLI	ns	ns	ns	- ($p = .001$)	ns	ns
TD	ns	ns	ns	- ($p = .040$)	ns	ns

Note. CI = Cochlear Implants; HoH = Hard-of-Hearing; SLI = Specific Language Impairment; TD = Typically Developing; ns = not statistically significant.