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Review Article

A Systematic Review and Meta-Analysis of Vocabulary Interventions for Deaf/Hard of Hearing Children and Adolescents

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ABSTRACT

Purpose: The development of vocabulary size in deaf/hard of hearing (DHH) children and adolescents can be delayed compared to their peers due to lack of access to early language input. Complementary vocabulary interventions are reported in the literature. Our aim is to evaluate the effectiveness of intervention methods for their vocabulary improvement.
Method: Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, we searched five databases for peer-reviewed journal articles in English, published between 2000 and 2022 (inclusive), reporting vocabulary interventions for 2- to 18-year-old DHH children and adolescents without comorbidities. We conducted separate meta-analyses using a random-effects model on receptive oral vocabulary, expressive oral vocabulary, and signed vocabulary. We assessed the methodological quality of each paper. This review is preregistered in PROSPERO (International Prospective Register of Systematic Reviews) with ID CRD42021243479.
Results: We included 25 group studies in this review out of 1,724 identified records. The quality assessment of the studies revealed risk of bias ranging from some concerns to high risk. Experimental vocabulary instruction produced improvement in receptive oral vocabulary (Hedges's g = 1.08, 95% CI [0.25, 1.90], I^2 = 93.46, p = .01), expressive oral vocabulary (Hedges's g = 1.00, 95% CI [0.18, 1.83], I^2 = 96.37, p = .02), and signed vocabulary (Hedges's g = 1.88, 95% CI [1.09, 2.66], I^2 = 96.01, p < .001) in the experimental groups. Written vocabulary and general vocabulary skills are also reported as a synthesis of results.
Conclusions: Multisensory and multimodal explicit vocabulary instruction for DHH children and adolescents is helpful in improving vocabulary acquisition with respect to baseline levels. However, its effectiveness must be carefully interpreted due to the lack of proper control groups and details on *treatment as usual* reported in the studies.
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Acquisition of vocabulary skills in the early stages of development is instrumental in language comprehension and production for typically developing children. However, some might fall behind their peers in these skills, for example, deaf/hard of hearing (DHH) children. To help with access to early language input, early interventions for DHH children can include hearing technology such as hearing aids (HAs) or cochlear implants (CIs). In a series of studies with deaf children, Yoshinaga-Itano (2003) showed the importance of hearing technology for early language development. These studies demonstrate that deaf children who received early identification of diagnosis (up to 6 months of age) and, therefore, had access to an early intervention showed better spoken language skills in standardized measures than deaf children who were identified later than 6 months of age. While early access to auditory input can significantly improve their global language development, DHH children and adolescents still suffer from delays, especially in vocabulary size, compared to their peers with typical hearing (Yoshinaga-Itano, 1999).

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Vocabulary Instruction Strategies

An often-used technique in vocabulary interventions is direct instruction, where an instructor (teacher, parent, therapist) explicitly and repetitively teaches vocabulary (Beck et al., 2013). This type of instruction is often used in preschool- or primary school–level children for early vocabulary development, and previous research used the method for at-risk populations that might not have the same vocabulary levels as their typically developing peers (Beck & McKeown, 2007). Direct instruction requires explicit vocabulary instruction through presentations of the exact meanings of the target word in stories, synonyms, and activities including using the word in different contexts. It is reported to be effective in vocabulary improvement of typical hearing kindergarten children experiencing difficulties in language development (Coyne et al., 2007). After revising the most efficient vocabulary teaching strategies for typical hearing children, Lund and Douglas (2016) compared three strategies—direct instruction, incidental learning, and follow-in labeling (when an object that is being attended to by the child is explicitly named)—for teaching new vocabulary to nine DHH children between 53 and 68 months of age in an intervention with an adapted alternating treatments design. The teachers delivered the three types of instruction in the classroom context. Their results showed that all children learned the target words better in the direct instruction condition, where the teacher explicitly taught the name of the object and provided more information about it (such as the meaning or some features of the object). The authors also state that except for one child who did not benefit from any conditions, follow-in labeling was more beneficial than the incidental learning condition (Lund & Douglas, 2016). These results provide additional evidence that direct instruction could outperform the other strategies for vocabulary teaching to DHH children, given that incidental exposure might not be as sufficient as it would be for a group of typical hearing children.

Storybooks can also be tools for explicit vocabulary instruction for DHH preschool children (Bobzien et al., 2015). Storybook reading is another method that benefits from contextual information that can simulate an incidental word learning experience (Coyne et al., 2007). Similar methodologies, such as embedding target vocabulary in passages and putting emphasis on their meanings, are used (Trussell et al., 2017; Trussell & Easterbrooks, 2014). A single-subject study by Antia et al. (2021) that included four deaf children compared two direct instruction strategies: one with storybooks and one with explicit vocabulary instruction with the storybooks. In the second condition, all the children learned and recalled more words in a retention phase. Then, they followed the same procedure with five other deaf children to see whether this instruction would result in them using the newly acquired words in a natural context. All the children learned, maintained, and used some words during a book activity after the intervention. These two studies of Antia et al. indicate that direct instruction may still be needed even when there is the chance of inferring the meaning of the word from the storybook as in their first condition with the storybooks but with no explicit vocabulary instruction. These results also show that explicit vocabulary instruction is more beneficial for DHH children than incidental learning. Other direct instruction methods can include teaching vocabulary through images; sign language; or, in the case of use of a hearing device, auditory input. Some studies also use interactive vocabulary games to combine these stimuli and modalities (oral or sign language or a multimodal approach that combines both; Massaro & Light, 2004). They can also be used differently depending on the aspect of vocabulary that is being targeted: receptive oral vocabulary, expressive oral vocabulary, or signed vocabulary. However, contrary to the thought that DHH children benefit more from visual complementary stimuli, a single-subject study by McDaniel et al. (2018) comparing audiovisual stimuli as an aid to vocabulary learning in contrast to only audios for three deaf preschool children did not find a difference between learning rates across conditions. However, Hettiarachchi et al. (2021) found that a multisensory approach with sign language during the vocabulary intervention was effective for DHH children between 5 and 7 years of age in another single-subject study. The contradictory results between two different visual modalities (audiovisual and signed) are intriguing (Hettiarachchi et al., 2021; McDaniel et al., 2018).

Vocabulary Instruction and Individual Characteristics of DHH Children and Adolescents

Strategies used during vocabulary instruction could change depending on the needs of DHH children and adolescents. Aside from the differences in methodologies, the individual and hearing characteristics of the participants and the duration of interventions might be the causes of contradictory results. Although participants with comorbidities are rarely included in research with DHH populations, some studies report cases where a participant had attentional problems during the intervention (Coleman et al., 2015), learning difficulties that were unknown before the intervention (Scott et al., 2019), or lower vocabulary and language skills compared to the other participants at pretest or baseline (Davenport et al., 2019; Lund et al., 2015). One study to point out the effects of individual language skills was conducted by Lew et al. (2014). While all three deaf children in their study were able to improve vocabulary skills in an intervention with an auditory–verbal approach, two of them demonstrated significant improvement in their receptive vocabulary scores as measured with the Peabody Picture Vocabulary Test–Fourth Edition (PPVT-4; Dunn & Dunn, 2007), as well as improving their speech perception skills with the intervention. While the third participant did not have a significant improvement in her PPVT-4 scores at posttest, her speech perception skills still improved (although less than the other two participants). Although this nonsignificant improvement in her vocabulary scores was not reported as the main cause of her less improved speech perception skills, as in this case, in DHH populations, the main confounding individual variables in vocabulary learning can be a certain level of already acquired spoken and sign language skills, the age of hearing loss, early/late cochlear implantation, residual hearing, and receiving early language intervention (Moeller, 2000; Yoshinaga-Itano et al., 2020). However, Convertino et al. (2014) argue that the use of CIs does not result in itself in a significant improvement in vocabulary knowledge over time, and the same can be said for the duration of CI use or age of CI activation (but see Majorano et al., 2017, and Robertson et al., 2017, for an alternative view). They found that the scores on standardized receptive vocabulary and content-related vocabulary measures were not significantly different between the deaf groups with and without CIs. Regardless of CI use, deaf groups still had lower scores than their hearing peers. This study also showed that age and duration of CI use did not influence the outcomes. Convertino et al. do not deny that hearing devices are effective for spoken language input, and they stress the fact that the advantages they bring should be complemented by appropriate instruction for language development, namely, in this case, vocabulary instruction.

Consistent with this principle, many vocabulary teaching strategies and interventions for DHH children and adolescents have been designed. These interventions have been conducted separately for DHH groups using CIs and HAs or without the use of hearing devices. These individual differences also align with the ideas in the literature we aforementioned; using hearing technology is not enough for enhancing the vocabulary outcomes by itself but still relates to the vocabulary outcomes of an intervention.

Previous Reviews and Meta-Analyses

To our knowledge, there are currently no systematic reviews or meta-analyses investigating the effects of vocabulary interventions on different types of vocabulary outcomes for DHH children and adolescents. A meta-analysis by Lund (2016) included studies with children using only CIs. A recent review focuses on the literacy skills of DHH children who use CIs (Bell et al., 2022). An earlier review by Moeller et al. (2007) compiled research on overall language skills of DHH children, presenting existing receptive and expressive language and literacy research and their correlations with hearing loss severity. A global vocabulary research review is by Luckner and Cooke (2010) with earlier research (1967–2008) on deaf students aged 3–21 years and did not follow a systematic review protocol. To overcome the scarcity of systematic reviews and meta-analyses on this topic, in this review article, we report a systematic review and three meta-analyses of previous research to investigate the effects of vocabulary interventions on DHH children and adolescents' vocabulary outcomes.

Aims

The current systematic review is tailored to answer this question: What are the effects of vocabulary training/interventions using different strategies and methodologies aimed at improving DHH children and adolescents on their vocabulary learning? We aim to understand whether different types of vocabulary training/interventions are effective for expressive and receptive oral vocabulary, signed vocabulary, and written vocabulary based on extant studies.

Method

Protocol

We followed the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist items and the flow diagram (Page et al., 2021). The PRISMA checklist can be found in Supplemental Material S1. The complete protocol of this systematic review was registered in PROSPERO (International Prospective Register of Systematic Reviews) and can be accessed at https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=243479.

Study Selection Criteria

The inclusion criteria for the studies were as follows: empirical studies published as journal articles in English between 2000 and 2022 (inclusive) with designs of randomized controlled trials, quasi-experimental, single-subject (multiple baseline or multiple probe), cohort analytic, cohort, and experimental time series that were carried out with DHH children and adolescents from 2 to 18 years of age. Interventions not related to vocabulary or studies that involved participants with comorbidities were excluded. Single-subject studies were later excluded from this report to allow consistent analyses of group studies.

Main and Additional Outcomes of Interest

The main outcomes involved in the analyses were standardized as well as experimental and nonexperimental ad hoc measures of oral vocabulary (receptive or expressive), written vocabulary, and vocabulary (receptive and/or expressive) in sign language. Standardized measures include vocabulary tests that went through the process of reliability and validity checks. Experimental ad hoc measures are researcher-designed testing procedures and protocols administered to measure the effectiveness of the vocabulary training and interventions in a study, and nonexperimental ad hoc measures are researcher-designed surveys, interviews, or questionnaires to gather opinions of participants or parents about the vocabulary interventions or observation notes of the researcher about the participant during an intervention. Reading skills related to vocabulary were mentioned in the protocol but ultimately excluded since this overlapped with another planned systematic review protocol (Gómez et al., 2019, with PROSPERO ID CRD42019140577). Details of the protocol for this planned systematic review were registered in PROSPERO and can be accessed at https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=140577. The additional outcomes were standardized and experimental or ad hoc measures of spoken narrative development, global standardized receptive and/or expressive language measures, academic measures and/or school grades, and observational measures of participation in conversation.

Screening Procedure

We searched the following databases in March 2021 and September 2022: Education Resources Information Center (ERIC; access through Ovid), Web of Science, Scopus, APA PsycINFO (access through ProQuest), and PubMed. The search terms were as follows: for intervention: "(instruction OR train* OR intervention OR teach* OR treat*)," for population: "(deaf* OR hard-of-hearing OR "hearing impair* OR "hearing disab*")," and for training: "(vocabulary OR word learn*)." We wrote each of the search syntaxes according to the requirements of each database to ensure the correct retrieval of studies, such as the use of different synonyms for retrieval of variations of the root keyword (*, &, $, etc.) or Booleans (OR, AND, etc.). We applied the inclusion criteria for the papers (publication type, language, and year range) in this step in each database. The search strings are available online in the PROSPERO record (https://www.crd.york.ac.uk/PROSPEROFILES/243479_STRATEGY_20210318.pdf).

We completed the second step, title and abstract screening, in Rayyan software (Ouzzani et al., 2016). Systematic reviews, meta-analyses, or commentaries were excluded before applying the population and intervention criteria. We excluded the papers reporting the age range out of our protocol in the abstracts. If the abstracts did not report age, we checked them in full-text screening. Finally, we excluded interventions without focus on vocabulary (only surveys or receptive and/or expressive language assessments without preceding interventions or experiments). Once the papers were uploaded to Rayyan, a second reviewer (the second author) was invited to the review page. The second author screened 20% of the studies blind to the first reviewer. The interrater agreement was calculated using Cohen's kappa coefficient, and there was strong agreement between reviewers (κ = .83).

The third step of the identification of studies was full-text screening. The same inclusion and exclusion criteria used in the title and abstract screening were applied. This time, both the first and second authors screened 100% of the papers that passed the second step. The interrater agreement was calculated using Cohen's kappa coefficient, and there was strong agreement between the reviewers (κ = .79) prior to consensus. All disagreements were resolved upon discussion.

Data Extraction and Description of the Variables

Extracted data were compiled in an Excel spreadsheet by the first author. The data were collected for the following.

(1) ***Study:*** authors, place and year of study, inclusion and exclusion criteria for the study, total number of participants, participating groups, study design, and experimental and standardized measurements for pre- and posttests.

(2) ***Participants:*** age, gender, socioeconomic status (SES) and ethnicity of the sample, primary spoken and sign language at home, diagnosis, age onset and degree of hearing loss, use of sign language, duration since and age of HA use, and duration since and age of CI activation.

(3) ***Intervention:*** name of the intervention program, setting and context, practitioners, components, weekly frequency, duration and length, planned level of application, software or other assisting tools used, and language of interventions and outcomes.

Methodological Quality

The methodological quality of the studies was analyzed in terms of risk of bias (RoB). To determine the risk levels (high, some concerns, or low), we used the Cochrane RoB tool, RoB 2 (Sterne et al., 2019). This tool has five domains to analyze the RoB: randomization, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of reported results. The field of *intention to treat* (assignment to interventions) was used during the analyses since we focus on interventions. Methodological quality analyses were completed by two reviewers (first and second authors) with a blind assessment. The discrepancy check was completed with the tool. Disagreements were resolved upon discussion until 100% agreement was reached in each domain.

Meta-Analyses, Publication Bias, and Sensitivity Analyses

We conducted three separate meta-analyses on the outcomes of expressive oral, receptive oral, and signed vocabulary with group studies that report sufficient data. Groups that received experimental vocabulary instruction were defined as the experimental groups, whereas control groups received business-as-usual instruction. Typical hearing groups were ignored, and the different interventions within a study were analyzed between groups to see the variance of the effect sizes depending on the type of intervention. Since not every paper reported enough pre–post test data (and we were not successful in locating the required data), this resulted in the inclusion of four papers in receptive oral vocabulary, three papers in expressive oral vocabulary, and six papers in signed vocabulary meta-analyses. We also report the study characteristics of the studies we could not include in meta-analyses in the results in Tables 1 and 2. We calculated Hedges's g for the pre–post intervention scores within each group by comparing the standardized mean differences. Hedges's g allows correction for biases related to sample sizes and is preferred in reporting meta-analyses where studies with different sample sizes are compiled (Lakens, 2013). When the correlations between pre–post test scores were not reported or were not possible to calculate, we used Rosenthal's conservative correlation estimate of $r = .7$ (Rosenthal, 1991). Positive Hedges's g values indicated improved scores at posttest. We investigated comparisons between effect sizes by separating experimental and control groups as subgroups and analyzing overlap of confidence intervals for effect sizes. Due to differences often arising from different pretest scores, we preferred this approach to comparison of posttest scores between experimental and control groups.

We performed the meta-analyses with the software Comprehensive Meta-Analysis (CMA), Version 3 (Borenstein et al., 2009). We report data from random-effects model analyses for each outcome because interventions across studies differed (Borenstein et al., 2010). Heterogeneity was thus assumed and reported with the Q statistic and I^2. We analyzed the publication bias using the trim-and-fill method (Duval & Tweedie, 2000). We conducted sensitivity analyses with the one-study-removed method for each subgroup of interest (control and experimental). This analysis recalculates the point estimates by removing each inserted study and recalculating the cumulative effect size in each study row. The aim of these analyses was to see whether any study within any group (experimental and control) was overly influencing the pooled effect size.

Results

Results of Study Screening and Selection

We retrieved 1,724 papers in total. After duplication removal with Rayyan and manual checking by the reviewers, we then removed 445 papers. A total of 1,279 papers were eligible for title and abstract screening. One paper was excluded due to language criteria (in French; Daigle et al., 2010). After 1,184 papers were excluded in this step, 95 were sought for full-text screening. One paper could not be retrieved (Loeterman et al., 2002). Additionally, 12 papers were identified from the reference lists of the included papers. From this list, one paper could not be retrieved (Lederberg & Spencer, 2001). In total, our systematic review reports 25 group studies from 26 papers on vocabulary interventions for DHH children and adolescents (see the extended PRISMA 2020 flow diagram in Figure 1).

Characteristics of the Studies

There were 13 studies that took place in the United States of America. The others were conducted in Australia (Paatsch et al., 2006; Salins et al., 2021), Hong Kong (Fung et al., 2005), India (Joy et al., 2019), Iran (Zamani et al., 2016), Italy (Majorano et al., 2017), the Netherlands (van Berkel-van Hoof et al., 2020; Wauters et al., 2001), South Africa (van Staden, 2013), Thailand (Plaewfueang & Suksakulchai, 2020; Wicha, Chakpitak, & Adipattaranan, 2012), and Turkey (Birinci & Sarıçoban, 2021).

The age of the 857 DHH participants ranged from 1;10 (years;months) to 18 years of age, although the inclusion criterion was set at 2 years of age. This change was due to the inclusion of Majorano et al.'s (2017) study, with participants' age ranging from 22 to 62 months, and the mean was reported as 38.87 months. Wicha, Chakpitak, and Adipattaranan (2012) did not report age but indicated that participants were primary school students. Joy et al. (2019) recruited participants from an oral school for the deaf but did not report age or school level.

Initially, there were 299 boys and 277 girls reported as participants. Two participants were excluded from the analyses in Wauters et al. (2001), but the gender of these excluded participants was not reported. Fung et al. (2005);

Table 1. The measurement features of each of the studies included in the review.

Author(s)	*N* and age	Experimental measures	Standardized measures	Outcomes of interest
Anderson-Inman et al., 2009	*N* = 9 (DHH) 12–17 years	Multiple-choice questions		Written vocabulary
Barcroft et al., 2021	*N* = 16 (DHH) 5;8 (years;months) to 10 years	Accuracy in picture naming	(Preassessments) PPVT-4, EVT-2	Expressive oral vocabulary
Birinci & Sarıçoban, 2021	*N* = 80 (DHH) 15–18 years	Multiple-choice questions		Written vocabulary
Blaiser et al., 2015	*n* = 19 (DHH) and *n* = 17 (typical hearing) 3;8–5;6	Accuracy in picture naming (saying the name of the picture and finding the named item)	(Preassessments) PPVT-III, EOWPVT-R, PLS-4	Receptive and expressive oral vocabulary
Falk et al., 2020	*N* = 30 6–12 years	Cumulative Bedrock Literacy Sight Word Assessment	TOSWRF-2	Signed vocabulary
Fung et al., 2005	*N* = 28 5;2–9;1		RCPM, PPVT-III	Receptive oral vocabulary
Haptonstall-Nykaza & Schick, 2007	*N* = 21 4–14 years	Accuracy in picture naming (finger spelling, choosing, and writing)		Written vocabulary
Houston et al., 2005	*n* = 24 (DHH) and *n* = 24 (typical hearing) 3;1–4;9	Accuracy in object labeling		Receptive and expressive oral vocabulary
Joy et al., 2019	*N* = 28 Age not reported	Accuracy in picture naming (choosing the matching picture)		Signed vocabulary
Lederberg et al., 2000	*N* = 19 2;2–6;8		CDI and GAEL-P	Vocabulary learning skills
Lederberg & Spencer, 2009	*N* = 98 3;2–6;1		CDI, GAEL-P, CPVT	Vocabulary learning skills
Majorano et al., 2017	*n* = 15 (DHH) and *n* = 30 (typical hearing) 1;8–5;2	Accuracy in object labeling		Receptive and expressive oral vocabulary
Meinzen-Derr et al., 2021	*N* = 41 3–12	Recorded and transcribed language samples (mean length of utterance, mean turn length, and number of different words spoken)	(Preassessments) CELF-5 or the preschool edition	Expressive oral vocabulary
Paatsch et al., 2006	*N* = 21 5;9–12;2	Speech perception test (repeating the word) and accuracy in word identification (saying the meaning of the word)	108 Single-Word Articulation Test	Receptive and expressive oral vocabulary
Parton et al., 2009	*N* = 7 3–4 years	Accuracy in picture naming (sign)		Signed vocabulary
Plaewfueang & Suksakulchai, 2020	*N* = 16 10–14 years	Multiple-choice vocabulary test (choosing the correct answer for the picture)		Signed vocabulary
Robertson et al., 2017	*n* = 16 (DHH) and *n* = 16 (typical hearing) 1;9–3;5	Accuracy and reaction times in eye-tracking	MCDI Words and Sentences	Receptive oral vocabulary

(*table continues*)

Table 1. *(Continued).*

Author(s)	*N* and age	Experimental measures	Standardized measures	Outcomes of interest
Salins et al., 2021	*n* = 23 (DHH) and *n* = 23 (typical hearing) 6–12 years	Accuracy in picture naming and picture word matching, response times, and fixation latency	(Preassessments) PPVT-4, Castles and Coltheart Test 2 (Castles et al., 2009)	Receptive and expressive oral vocabulary
Stiles et al., 2013	*n* = 16 (DHH) and *n* = 24 (typical hearing) 6–9 years	Accuracy in word identification (choosing the correct word [nonwords])	PPVT-III-Form A	Receptive oral vocabulary
van Berkel-van Hoof et al., 2020	*n* = 19 (DHH) and *n* = 38 (typical hearing) 9–11 years	Accuracy in word identification and reaction times in picture naming (choosing the matching picture and verbal short-term memory)		Signed vocabulary
van Staden, 2013	*N* = 64 6;03–11;08	(Researcher-developed) diagnostic sight word, receptive and expressive vocabulary, and reading comprehension tests	RCPM, reading tests	Signed vocabulary
Walker & McGregor, 2013	*n* = 24 (DHH) and *n* = 47 (typical hearing) 3;6–6;9	Accuracy in object labeling	(Preassessments) KBIT-2, MCDI, PPVT-III	Receptive and expressive oral vocabulary
Wauters et al., 2001	*N* = 14 6–10 years	Accuracy and reaction times in picture naming (choosing the correct word)		Written vocabulary
Wicha, Chakpitak, & Adipattaranan, 2012	*N* = 141 Age not reported	Multiple-choice vocabulary test		Signed vocabulary
Zamani et al., 2016	*N* = 66 2–3 years		(Preassessment) Vineland test, Newsha test	Receptive and expressive oral vocabulary

Note. DHH = deaf/hard of hearing; PPVT-4 = Peabody Picture Vocabulary Test–Fourth Edition (Dunn & Dunn, 2007); EVT-2 = Expressive Vocabulary Test–Second Edition (Williams, 2007); PPVT-III = Peabody Picture Vocabulary Test–Third Edition (Dunn & Dunn, 1997); EOWPVT-R = Expressive One-Word Picture Vocabulary Test–Revised (Gardner, 2000); PLS-4 = Preschool Language Scale–Fourth Edition (Zimmerman et al., 2002); TOSWRF-2 = Test of Silent Word Reading Fluency–Second Edition (Mather et al., 2004); RCPM = Raven's Coloured Progressive Matrices (Raven et al., 1995); CDI = Communicative Development Inventories (Fenson et al., 1993); GAEL-P = Grammatical Analysis of Elicited Language–Pre-sentence Level (Moog et al., 1983); CPVT = Carolina Picture Vocabulary Test (Layton & Holmes, 1985); CELF-5 = Clinical Evaluation of Language Fundamentals–Fifth Edition (Wiig et al., 2013); MCDI Words and Sentences = MacArthur–Bates Communicative Development Inventories Words and Sentences (Fenson et al., 2006); KBIT-2 = Kaufman Brief Intelligence Test–Second Edition (Kaufman & Kaufman, 2004); MCDI = Minnesota Child Development Inventory (Ireton & Thwing, 1974).

Table 2. The intervention features of the studies with deaf/hard of hearing (DHH) children and adolescents included in the review but not in the meta-analyses.

Author(s)	Study design	Experimental group	Control group	Duration	Results
Anderson-Inman et al., 2009	Randomized controlled trial	Learning content words included in documentaries by expanded captions (including definitions, illustrations, and conceptual information) while watching videos with subtitles	Control condition and group: One group watched two documentaries with expanded and standard captions, and the other group watched the documentaries in the reverse order of the captions.	20 min	Nonsignificant increases in posttest scores for the experimental group, though outperforming the control group
Birinci & Sarıçoban, 2021	Randomized controlled trial	Use of visual materials and real objects with participants' sign language (Turkish) for foreign target vocabulary (English)	Use of participants' sign language but no visual materials for foreign target vocabulary	5 weeks	Visual materials enhanced vocabulary learning in the experimental group, as shown in the multiple-choice test scores.
Blaiser et al., 2015	Nonrandomized controlled study	Word learning with images in quiet and noise conditions with either a single exposure or 3 times exposure to the target vocabulary	Typical hearing children receiving the same training	Less than 5 min	The repetition of the target vocabulary is better for deaf children regardless of the absence/existence of noise, and there were no significant differences in post-test performances for spoken responses between the deaf and hearing peers for the repeated-exposure condition.
Haptonstall-Nykaza & Schick, 2007	Controlled before-and-after study	Learning new words by the use of finger spelling or sign language that are accompanied by corresponding images of the written target words	No control group, but data were presented divided by two: deaf children of deaf parents and hearing parents	20 min	Higher posttest scores in the finger-spelling condition compared to the sign condition, except receptive posttest scores. Deaf children of deaf parents obtained significantly higher scores compared to deaf children of hearing parents.
Houston et al., 2005	Nonrandomized controlled study	Deaf children with CIs learning word–object associations with stuffed animal toys with different attributes in a play scenario with the experimenter	Typical hearing age-matched children receiving the same training		Deaf children with CIs scored better when they had to associate labels with words they already know with toys, instead of the novel labels. They showed lower performance in the receptive vocabulary task compared to their typical hearing peers.
Lederberg et al., 2000	Controlled before-and-after study	Learning novel vocabulary with novel objects and signs by the instruction of the experimenter also with oral language		20 min, 2 days each	In signed and spoken novel word learning tasks that differed in the number of exposures to the novel words, deaf children exhibited three different levels of word learning abilities as "novel mappers," "rapid word learners," and "slow word learners." These levels were highly correlated with the raw expressive and receptive vocabulary scores of the participants.

(*table continues*)

Table 2. *(Continued).*

Author(s)	Study design	Experimental group	Control group	Duration	Results
Lederberg & Spencer, 2009	Controlled before-and-after study	Learning novel vocabulary with novel objects and signs by the instruction of the experimenter also with oral language			The novel mappers outperformed the rapid and slow word learners in direct, repeated exposure. The extensive investigation of the correlations between the individual characteristics (parents' hearing status, use of CI, whether they sign or not) and word learning performance showed that there was no difference across the three levels of groups. Fast word learning occurred when direct instruction was presented for participants with lower raw vocabulary scores; direct instruction was overall more effective.
Majorano et al., 2017	Nonrandomized controlled trial	Deaf children with CIs learning new words with puppets and toys in a play scenario with the experimenter	Typical hearing peers (one chronological age–matched group and one of the same hearing age) receiving the same training		Deaf children with CIs and their chronological age– and hearing age–matched peers did not show a significant difference in receptive oral vocabulary tasks. Deaf children with CIs can learn new vocabulary, as well as younger hearing age–matched children, with a lower but nonsignificant difference in the expressive vocabulary test in both groups compared to the chronological age–matched group.
Meinzen-Derr et al., 2021	Randomized clinical trial	Use of an augmentative and alternative communication (AAC) app for language learning with speech-language therapy	Treatment as usual: therapy that the participants were receiving at the time of the study, no addition of AAC app use	60 min once a week for 24 weeks (6 weeks in therapy, 6 weeks at home, 6 weeks in therapy, 6 weeks at home)	The number of different words spoken by the deaf children who received the intervention with the app embedded in their speech-language therapy sessions increased significantly compared to the control group that was under usual speech-language therapy instruction.
Parton et al., 2009	Controlled before-and-after study	Word learning with the Language Acquisition Manipulatives Blending Early-Childhood Research and Technology system that connects a real object to a multimedia system for showing corresponding signs, images, and audios of written word of the name of the object	No control group. A set of control words that have not been thought with the multimedia system	20 min for 4 weeks	Increased accuracy in signing newly learned words with multimedia system compared to the control set

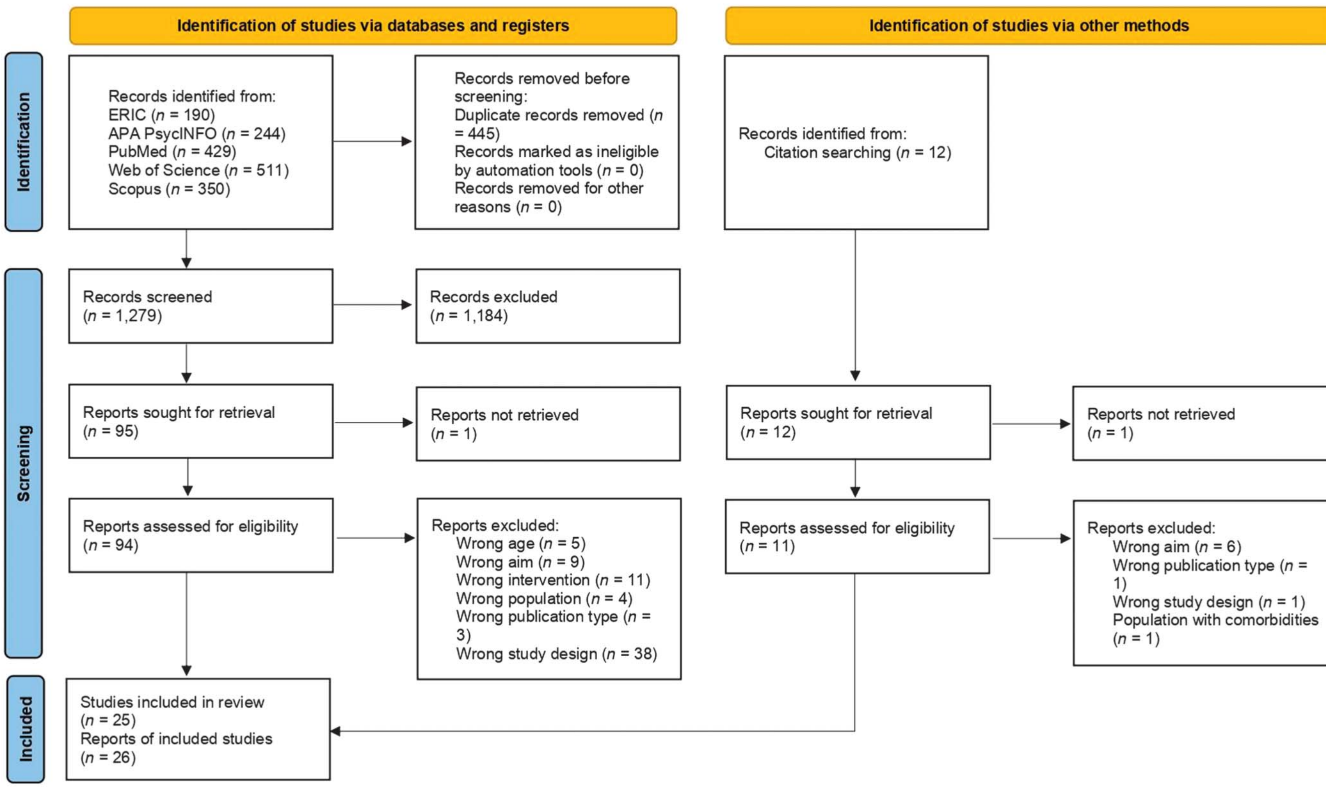
(*table continues*)

Table 2. *(Continued).*

Author(s)	Study design	Experimental group	Control group	Duration	Results
Salins et al., 2021	Nonrandomized controlled trial	Learning novel words with images presented with either present or absent orthography conditions	Typical hearing age-matched children receiving the same training	45 min	Orthographic training effect: Deaf children had a higher performance when they were trained with consistent spelling of a word in a picture–word matching task.
Stiles et al., 2013	Nonrandomized controlled trial	Learning novel words with audio matched with images of real objects of different semantic categories shown with differentiating wordlikeness	Typical hearing children receiving the same training		Wordlikeness of novel words influences learning, and similarity is used as a cue by DHH children. The performance of deaf children on the receptive vocabulary task depended on their raw vocabulary skills.
Wauters et al., 2001	Randomized controlled trial	Learning new words with written and spoken modality or with the addition of sign language accompanied by corresponding images of the target words on computer screen	Four groups were randomly assigned to four different balanced-order target word lists.	15 min	When deaf children learned unfamiliar words delivered with speech and sign, they were able to recognize more words than those who were trained only with speech.

Note. CI(s) = cochlear implant(s).

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 flow diagram indicating the results of the screening procedure.



Parton et al. (2009); Plaewfueang and Suksakulchai (2020); Salins et al. (2021); Wicha, Chakpitak, and Adipattaranan (2012); and Zamani et al. (2016) did not report gender information. Only van Staden (2013) mentioned the SES of the participants (low SES), whereas Meinzen-Derr et al. (2021) reported household income.

Intervention Components

There were 12 studies using digital devices for vocabulary training such as mobile applications and computer-based experiments or games. All studies adopted direct, explicit vocabulary instruction strategies for experimental groups regardless of presentation modality (audiovisual, oral, or signed). The durations of the interventions ranged from less than 5 min to 36 weeks. Information about the number and age of participants, experimental and standardized measures, and outcomes of interest is presented in Table 1 for all studies' features that are subject to this review. Table 2 shows study designs, experimental and control groups, intervention duration, and summary of results for studies that were not included in the meta-analyses but were kept in the review, and Table 3 shows this information for studies that were included in the meta-analyses.

Hearing Loss and Sign Language Variables of Participants

In 11 studies, participants had prelingual hearing loss or hearing loss at early ages (at birth or during infancy, early childhood). Nine papers reported use of both CIs and HAs, whereas only two papers reported all participants as using HAs (Stiles et al., 2013; Zamani et al., 2016). Five studies reported only CI use. Reports of all participants using sign language were as follows: American Sign Language (Falk et al., 2020; Haptonstall-Nykaza & Schick, 2007; Lederberg et al., 2000; Parton et al., 2009), Dutch Sign Language (Wauters et al., 2001), South African Sign Language (van Staden, 2013), Thai Sign Language (Plaewfueang & Suksakulchai, 2020), and Turkish Sign Language (Birinci & Sarıçoban, 2021). Lederberg and Spencer (2009) reported that 61 out of 98 participants used sign language.

Five studies do not report any information regarding the hearing loss severity of participants (Birinci & Sarıçoban, 2021; Houston et al., 2005; Joy et al., 2019; Parton et al., 2009; Wicha, Chakpitak, & Adipattaranan, 2012). In 11 studies, severity levels are reported with direct classification (such as mild, moderate, and severe)

Table 3. The intervention features of the studies with deaf/hard of hearing (DHH) children and adolescents included in the meta-analyses.

Author(s)	Study design	Experimental group	Control group	Duration	Results
Barcroft et al., 2021	Controlled before-and-after study	Speech recognition training program including listening games as a part of a larger study by Tye-Murray et al. (2022), with meaning-based training		45–60 min of lessons, four per week, 4–6 weeks	Increased word gains after the auditory training with the focus on the meaning of the vocabulary
Falk et al., 2020	Controlled before-and-after study	Bedrock Literacy intervention program by Di Perri (2013) presented sight words with conceptually corresponding visual materials and sign language, including writing practices by the participants.		32 weeks	Higher increase in sight word reading scores for younger participants compared to older participants; increased scores on the TOSWRF-2 regardless of age
Fung et al., 2005	Randomized controlled trial	Dialogic storybook reading practices with parents, including prompts, questions, and picture cards	Typical reading groups: No prompts or picture cards were used with the same storybooks. Control group: received the same storybooks 8 weeks after the dialogic and typical reading groups	15–30 min, 2 times a week for 8 weeks	Higher vocabulary scores for the dialogic reading group in posttest compared to typical reading and control groups. Two intervention groups performed better than the control group.
Joy et al., 2019	Randomized controlled trial	Learning new sign vocabulary with a mobile application (SiLearn) providing visual support with signs when scanned a text	Treatment as usual: classroom instruction		The SiLearn group had higher scores in receptive vocabulary posttest compared to the control group.
Paatsch et al., 2006	Controlled before-and-after study	Speech production training with phonemes (not detailed) and vocabulary training (meaning and image based) embedded into school curriculum activities that were also supported to practice at home	Two groups were only used due to the time tables of school and balanced experimental design, but no control group exists.	20 min each school day for 30 weeks	Speech production training increased the number of words identified correctly; vocabulary training was more effective.
Plaewfueang & Suksakulchai, 2020	Nonrandomized controlled trial	Learning new words with an interactive multimedia program including sign language support with avatar illustrations	Treatment as usual: classroom instruction	60 min for 20 weeks	Increase in vocabulary scores in the interactive multimedia group and sentence scores in the control group in posttests; effective for vocabulary learning with sign language support
Robertson et al., 2017	Nonrandomized controlled trial	Learning novel words with infant- or adult-directed speech with novel corresponding images presented on computer screen	Age-, gender-, and maternal education–matched typical hearing children receiving the same training	5–6 min	DHH participants learned novel words in both infant- and adult-directed speech conditions. Control group showed significantly better performance.

(*table continues*)

Table 3. *(Continued).*

Author(s)	Study design	Experimental group	Control group	Duration	Results
van Berkel-van Hoof et al., 2020	Nonrandomized controlled trial	Learning pseudowords corresponding to novel images and pseudosigns with short videos and audios that include sentences with the target words	Control group: typical hearing children who received the same training with babble noise Control condition: no-sign condition, in counterba-lanced order	20 min, 4 times a week for 1 week	Use of signs increased reaction time but not accuracy. Effective for nonsigning DHH children
van Staden, 2013	Randomized controlled trial	Use of a print-language mapping strategy with images, objects, finger spelling, and sign, as well as activities with tracing games and clay corresponding to the target words and their meanings, including scaffolding	Treatment as usual: classroom instruction, no access to workbooks the experimental group worked on, no scaffolding by the teacher or any use of multimodal strategy	45 min, 3 days a week for 36 weeks	Increase in scores of sight word reading, receptive and expressive vocabulary, and reading comprehension and higher increase compared to the control group
Walker & McGregor, 2013	Nonrandomized controlled trial	Deaf children with CIs learning novel words matched with novel objects by the instruction of the experimenter with gesture and eye gaze cues	Age- and vocabulary-matched typical hearing children receiving the same training	60 min, 2 days each	No significant differences between age-matched hearing peers, vocabulary-matched hearing peers, and the deaf children with CIs in terms of vocabulary scores
Wicha, Chakpitak, & Adipattaranan, 2012	Controlled before-and-after study	Use of the Total Communication with Animation Dictionary sign integrated digital program to learn English vocabulary	A control group of nine participants was involved in the first stage of the study, who received treatment as usual: classroom instruction with sign language and finger spelling.	20 min daily for a month	Higher increase in vocabulary scores in the experimental group; higher scores on the multiple-choice vocabulary test in the larger scale study with 141 participants
Zamani et al., 2016	Randomized clinical trial	Use of gestures in auditory–verbal training during speech therapy to teach comprehension and expression of target verbs. Parents were instructed to use the method at home.	Treatment as usual: no addition of gestures in auditory–verbal training in speech therapy	60 min, 3 times a week for 5 weeks	Higher increase in expressive and receptive vocabulary scores in the experimental group compared to the control group

Note. TOSWRF-2 = Test of Silent Word Reading Fluency–Second Edition; CIs = cochlear implants.

without any additional data for each participant. In the rest of the papers that reported severities in decibels, we applied the classification provided by the American Speech-Language-Hearing Association (ASHA, n.d.; for more information, see https://www.asha.org/public/hearing/degree-of-hearing-loss/). Across all studies, the distribution of hearing loss severity is as follows: four participants with mild hearing loss, 33 participants with mild-to-moderate/severe hearing loss, 34 participants with moderate hearing loss, 48 participants with moderate-to-severe hearing loss, 126 participants with severe hearing loss, 90 participants with severe-to-profound hearing loss, and 132 participants with profound hearing loss. Falk et al. (2020) and Stiles et al. (2013) reported 30 and 16 deaf participants, respectively, having a range of mild-to-severe hearing loss. Meinzen-Derr et al. (2021) reported 41 participants having a range of mild-to-profound hearing loss. Additionally, in the work of van Berkel-van Hoof et al. (2020), two participants are reported with moderately severe hearing loss in the right ear and mild hearing loss in the left ear, and one participant is reported as having no hearing at all.

Methodological Quality

The methodological quality of the 25 studies from 26 papers was analyzed, because two papers reported the results of the same study (Wicha, Chakpitak, & Adipattaranan, 2012; Wicha, Sharp, et al., 2012). Eight group studies included typical hearing groups as controls, making randomization not feasible (Blaiser et al., 2015; Houston et al., 2005; Majorano et al., 2017; Robertson et al., 2017; Salins et al., 2021; Stiles et al., 2013; van Berkel-van Hoof et al., 2020; Walker & McGregor, 2013). The RoB results can be seen in Figure 2. The “traffic light” plot showing each study’s risk level by domain can be found in Supplemental Material S2. Both figures were generated with the “robvis” tool (https://www.riskofbias.info/welcome/robvis-visualization-tool; McGuinness & Higgins, 2021). Although the results showed high risk or some concerns of bias, this was not a determining factor to compile the outcomes of the interventions for the meta-analysis. The results by domain are as follows.

Randomization Process

There was no random allocation in eight studies with typical hearing control groups, but the RoB 2 tool allowed us to determine if there was a possibility of concealment from the interventions before assignment and whether there was a baseline problem, which concluded five studies with some concerns (Blaiser et al., 2015; Majorano et al., 2017; Robertson et al., 2017; Stiles et al., 2013; van Berkel-van Hoof et al., 2020) and three studies with high risk (Houston et al., 2005; Salins et al., 2021; Walker & McGregor, 2013). Among the remaining studies in which there were no typical hearing control groups, two papers were of high risk (Barcroft et al., 2021; Plaewfueang & Suksakulcahi, 2020), seven papers were of some concerns (Falk et al., 2020; Haptonstall-Nykaza & Schick, 2007; Lederberg et al., 2000; Lederberg & Spencer, 2009; Paatsch et al., 2006; Parton et al., 2009; Wicha, Chakpitak, & Adipattaranan, 2012), and eight papers were of low risk (Anderson-Inman et al., 2009; Birinci & Sarıçoban, 2021; Fung et al., 2005; Joy et al., 2019; Meinzen-Derr et al., 2021; van Staden, 2013; Wauters et al., 2001; Zamani et al., 2016).

Deviations From Intended Interventions

Here, most of the concerns arose due to the context of the interventions; that is, the delivery of the instruction could have been affected by the classroom context and knowledge of the peers or those who deliver the interventions. While it was clear that there were no deviations in the works of Blaiser et al. (2015), Fung et al. (2005), and Salins et al. (2021), this was not easily interpretable in other studies, hence causing some concerns for them and high risk for Barcroft et al. (2021).

Missing Outcome Data

There were only two studies with missing outcome data (Parton et al., 2009; Plaewfueang & Suksakulchai,

Figure 2. Results of the risk-of-bias assessment by each domain.

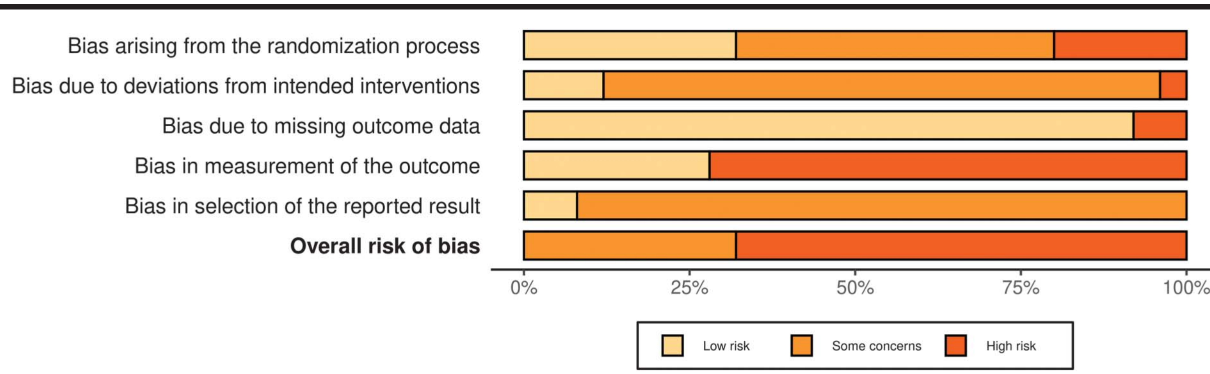
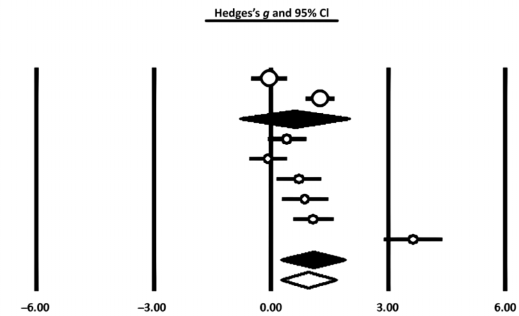


Figure 3. Forest plot showing effect size data for studies reporting receptive oral vocabulary outcomes. CI = confidence interval.

Effect sizes for studies with receptive oral vocabulary outcomes

Group by Subgroup within study	Authors	Statistics for each study						
		Hedges's *g*	Standard error	Variance	Lower limit	Upper limit	*z* value	*p* value
Control	Fung et al. (2005) Control	−0.047	0.224	0.050	−0.486	0.392	−0.210	.834
Control	Zamani et al. (2016) Control	1.255	0.178	0.032	0.907	1.604	7.055	.000
Control		0.610	0.716	0.513	−0.794	2.014	0.852	.394
Experimental	Fung et al. (2005) Experimental Group 1	0.410	0.245	0.060	−0.070	0.890	1.674	.094
Experimental	Fung et al. (2005) Experimental Group 2	−0.077	0.234	0.055	−0.535	0.380	−0.331	.740
Experimental	Robertson et al. (2017) - Experiment 1	0.715	0.277	0.077	0.173	1.258	2.584	.010
Experimental	Robertson et al. (2017) - Experiment 2	0.867	0.291	0.085	0.296	1.437	2.979	.003
Experimental	Walker & McGregor (2013)	1.077	0.251	0.063	0.585	1.570	4.287	.000
Experimental	Zamani et al. (2016) Experimental	3.640	0.371	0.138	2.912	4.367	9.806	.000
Experimental		1.076	0.421	0.177	0.251	1.902	2.556	.011
Overall		0.957	0.363	0.132	0.245	1.668	2.635	.008



2020). The compilation of results was not greatly affected by the lack of reporting of individual or group pre–post test scores.

Measurement of the Outcome

The highest risk appears to be in the measurement of the outcome in this review (with 18 studies qualifying for high risk). This is because coders of the interventions or outcome assessors were aware of the interventions and students' performance.

Selection of the Reported Data

Meinzen-Derr et al. (2021) and Salins et al. (2021) were the only studies with low risk in this domain (risk here is defined by a preplanned data analysis and reports according to this plan). These studies both had a preregistration (Clinical Trials ID NCT02998164 and https://osf.io/dq36v, respectively), but we did not find any preregistered plan for the others, which were graded as with some concerns.

Meta-Analyses, Publication Bias, and Sensitivity Analyses for Each Outcome

Receptive Oral Vocabulary

Two control groups qualified for inclusion, since participants of the other two control groups were hearing peers (Robertson et al., 2017; Walker & McGregor, 2013). The pooled effect size for the control groups was not significant (Hedges's g = 0.61, 95% CI [−0.79, 2.01], p = .39). The pooled effect size for the six experimental groups was significant (Hedges's g = 1.08, 95% CI [0.25, 1.90], p = .01) The largest effect sizes belonged to Zamani et al.'s (2016) experimental and control groups (Hedges's g = 3.64, 95% CI [2.91, 4.37], and Hedges's g = 1.25, 95% CI [0.91, 1.60], $p < .001$, respectively; see Figure 3). A high overlap between the mean effects of the control and experimental groups was observed.

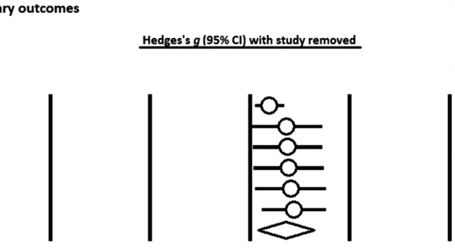
One-study-removed analysis did not change the significance of the effect size for the experimental groups only (Hedges's g = 1.08, 95% CI [0.29, 1.93], p = .01; see Figure 4); however, the point estimate decreased to Hedges's g = 0.59, 95% CI [0.17, 1.00], p = .01, if Zamani et al. (2016) was removed. The pooled effect size for the control groups was still nonsignificant, and the point estimate for each study did not change (Hedges's g = 0.61, 95% CI [−0.66, 1.89], p = .35). The overlap between the main effects was still observed. A high level of significant heterogeneity was observed within the control and experimental groups (Q = 20.17, I^2 = 95.17, p = .00, and Q = 76.48, I^2 = 93.46, $p < .001$, respectively).

Publication bias analyses require at least three rows of values entered to the CMA; therefore, we performed

Figure 4. Forest plot showing effect size data for experimental groups with receptive oral vocabulary outcomes when sensitivity analysis (one-study-removed analysis) is conducted. CI = confidence interval.

One-study-removed analysis for experimental groups with receptive oral vocabulary outcomes

Authors	Subgroup within study	Statistics with study removed						
		Point	Standard error	Variance	Lower limit	Upper limit	*z* value	*p* value
Zamani et al. (2016) Experimental	Experimental	0.586	0.212	0.045	0.170	1.002	2.764	.006
Walker & McGregor (2013)	Experimental	1.085	0.536	0.287	0.034	2.136	2.024	.043
Robertson et al. (2017) - Experiment 2	Experimental	1.126	0.524	0.275	0.098	2.154	2.147	.032
Robertson et al. (2017) - Experiment 1	Experimental	1.157	0.529	0.280	0.120	2.194	2.187	.029
Fung et al. (2005) Experimental Group 1	Experimental	1.220	0.531	0.282	0.180	2.260	2.299	.022
Fung et al. (2005) Experimental Group 2	Experimental	1.315	0.476	0.226	0.382	2.248	2.763	.006
		1.078	0.434	0.188	0.228	1.928	2.487	.013



the analyses with the experimental groups only, as well as the overall publication bias. The trim-and-fill report did not indicate any change in the effect sizes in either of the conditions, as there were no studies missing according to the analyses (see Figures 5 and 6).

Expressive Oral Vocabulary

There were three papers reporting sufficient data for expressive oral vocabulary outcomes. Subgroup analyses revealed that the effect size for the control group of Zamani et al. (2016) was significant (Hedges's g = 1.16, 95% CI [0.83, 1.50], p < .001), as well as the experimental group (who received audiovisual therapy with additional gesture instruction; Hedges's g = 2.28, 95% CI [1.78, 2.78], p < .001). It was also the case in the work of Barcroft et al. (2021), where they introduced an auditory instruction again based on meanings (Hedges's g = 0.67, 95% CI [0.51, 0.84], p < .001). Phoneme training combined with the meaning-based vocabulary instruction of Paatsch et al. (2006) showed a nonsignificant effect (Hedges's g = 0.16, 95% CI [−0.09, 0.42], p = .21). The pooled effect size for the three experimental groups was significant (Hedges's g = 1.00, 95% CI [0.18, 1.83], p = .02; see Figure 7). One-study-removed analysis showed a decrease in the point estimate when the study of Zamani et al. was removed (Hedges's g = 0.43, 95% CI [−0.07, 0.93], p = .09) but an increase when the studies of Barcroft et al. or Paatsch et al. were removed (Hedges's g = 1.21, 95% CI [−0.86, 3.29], p = .25, and Hedges's g = 1.46, 95% CI [−0.11, 3.04], p = .07, respectively; see Figure 8). A high level of significant heterogeneity was observed in the experimental groups (Q = 55.14, I^2 = 96.37, p < .001). Since there was no other control group than that of Zamani et al., no overlap in confidence intervals could be observed.

Publication bias analyses require at least three rows of values entered to the CMA; therefore, we performed the analyses with the experimental groups only, as well as the overall publication bias (see Figures 9 and 10). The trim-and-fill report indicated one study missing from the analysis with experimental groups. Under the random-effects model, the pooled effect size became nonsignificant when this is included in the calculation (Hedges's g = 0.47, 95% CI [−0.43, 1.37]). It decreased also when the control group was involved; two studies were detected as missing (Hedges's g = 0.49, 95% CI [−0.15, 1.13]).

Signed Vocabulary

There were three control groups we could include: van Berkel-van Hoof et al.'s (2020) control group was typical hearing peers, and Wicha, Chakpitak, and Adipattaranan

Figure 5. Funnel plot indicating no publication bias for experimental groups with receptive oral vocabulary outcomes.

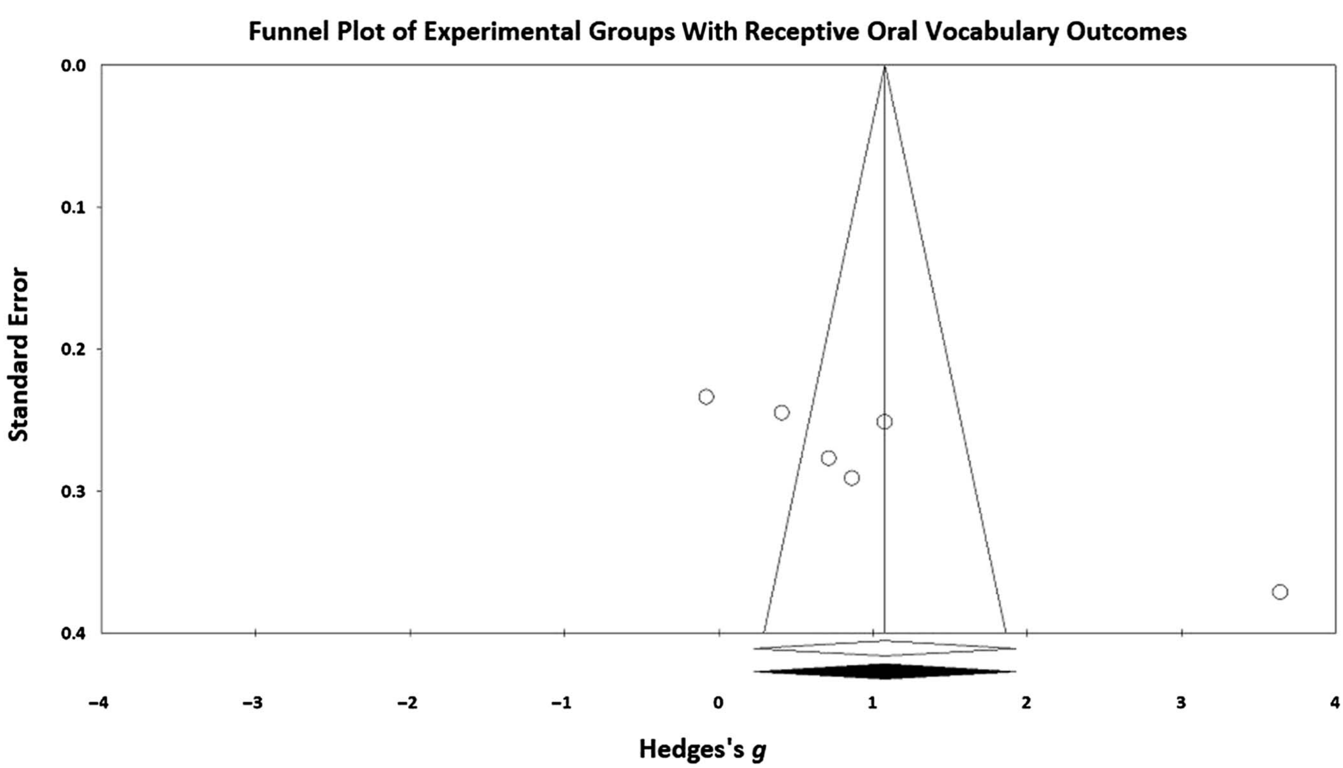
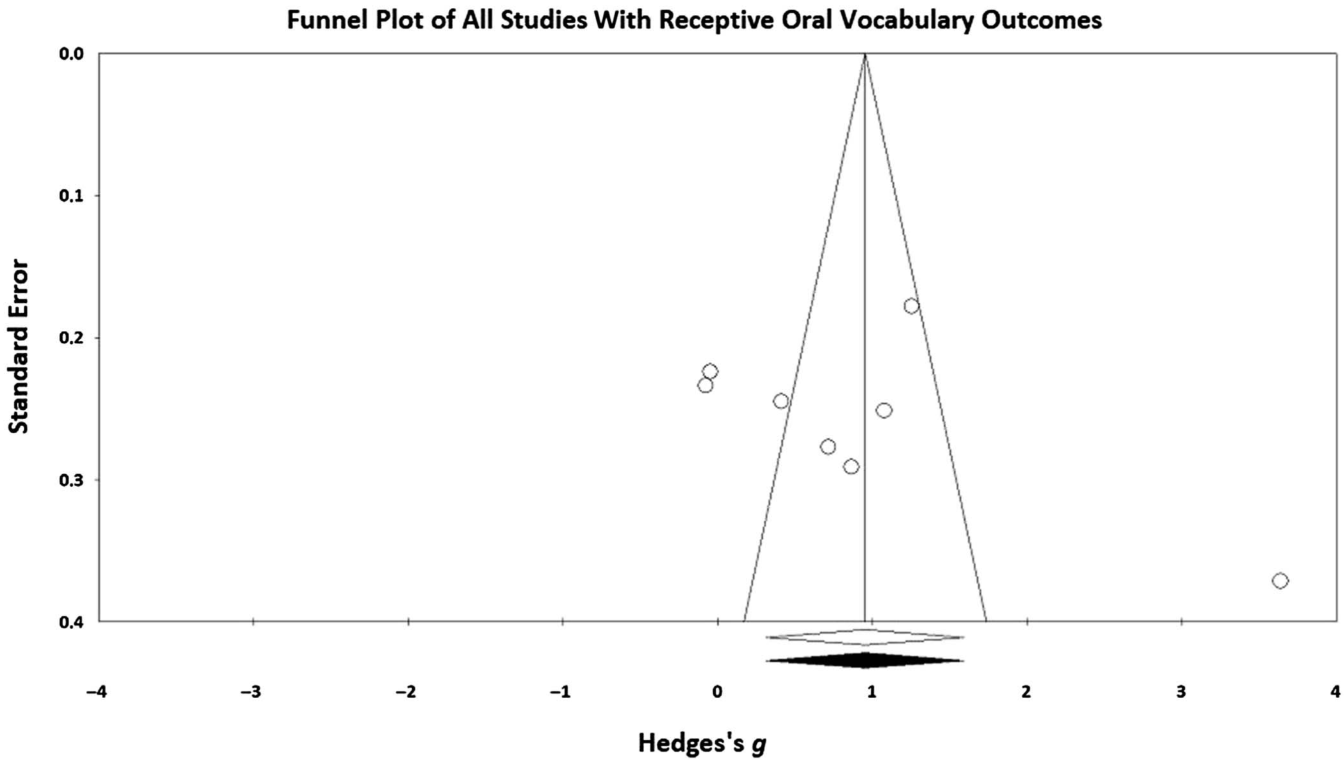


Figure 6. Funnel plot indicating no publication bias for all studies with receptive oral vocabulary outcomes.



(2012) and Falk et al. (2020) only reported the experimental group results. The pooled effect size for the control groups was not significant (Hedges's g = 1.04, 95% CI [−0.02, 2.10], p = .054). The pooled effect size for the six experimental groups was significant (Hedges's g = 1.88, 95% CI [1.09, 2.66], p < .001; see Figure 11). A high overlap between the mean effects of the control and experimental groups was observed.

We detected two outlier effect sizes in Plaewfueang and Suksakulchai's (2020) and van Staden's (2013) experimental groups (Hedges's g = 4.25, 95% CI [2.57, 5.93], and Hedges's g = 4.50, 95% CI [3.61, 5.39], p < .001, respectively). One-study-removed analysis revealed that the pooled effect size of the experimental groups did not change (Hedges's g = 1.91, 95% CI [1.05, 2.77], p < .001). However, the point estimates decreased if the study of van Staden was removed (Hedges's g = 1.30, 95% CI [0.63, 1.98], p < .001) and if the study of Plaewfueang and Suksakulchai was removed (Hedges's g = 1.61, 95% CI [0.75, 2.49], p < .001). In control groups, one-study-removed analysis revealed a difference in pooled effect sizes (Hedges's g = 1.06, 95% CI [0.52, 1.59], p < .001), and point estimates decreased if the study of van Staden was

Figure 7. Forest plot showing effect size data for studies reporting expressive oral vocabulary outcomes. CI = confidence interval.

Effect sizes for studies with expressive oral vocabulary outcomes

Group by Subgroup within study	Authors	Hedges's *g*	Standard error	Variance	Lower limit	Upper limit	*z* value	*p* value
Control	Zamani et al. (2016) Control	1.164	0.172	0.030	0.827	1.502	6.760	.000
Control		1.164	0.730	0.533	−0.267	2.595	1.594	.111
Experimental	Paatsch et al. (2006)	0.163	0.131	0.017	−0.093	0.420	1.248	.212
Experimental	Barcroft et al. (2021)	0.675	0.084	0.007	0.510	0.839	8.035	.000
Experimental	Zamani et al. (2016) Experimental	2.283	0.254	0.065	1.784	2.781	8.974	.000
Experimental		1.002	0.421	0.177	0.177	1.828	2.380	.017
Overall		1.043	0.365	0.133	0.328	1.758	2.859	.004

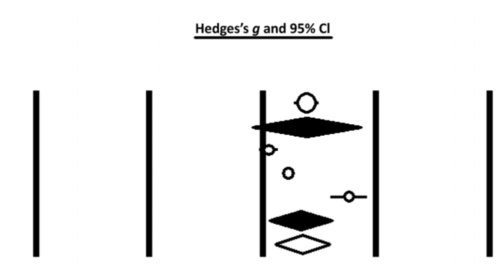
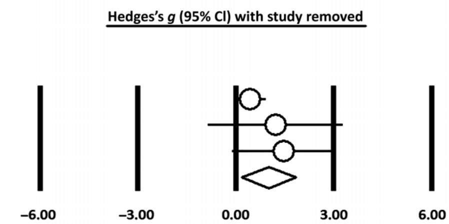


Figure 8. Forest plot showing effect size data for experimental groups with expressive oral vocabulary outcomes when sensitivity analysis (one-study-removed analysis) is conducted. CI = confidence interval.

One-study-removed analysis for experimental groups with expressive oral vocabulary outcomes

Authors	Subgroup within study	Point	Standard error	Variance	Lower limit	Upper limit	*z* value	*p* value
		Statistics with study removed						
Zamani et al. (2016) Experimental	Experimental	0.429	0.256	0.065	−0.072	0.930	1.678	.093
Barcroft et al. (2021)	Experimental	1.212	1.060	1.123	−0.865	3.289	1.144	.253
Paatsch et al. (2006)	Experimental	1.461	0.804	0.646	−0.114	3.036	1.818	.069
		1.002	0.421	0.177	0.177	1.828	2.380	.017



removed (Hedges's g = 0.78, 95% CI [0.43, 1.13], p < .001) but increased when the study of Plaewfueang and Suksakulchai was removed (Hedges's g = 1.16, 95% CI [0.40, 1.92], p = .00) or when the study of Joy et al. (2019) was removed (Hedges's g = 1.20, 95% CI [0.48, 1.92], p = .001; see Figures 12 and 13). The overlap between the main effects was still observed. A high level of significant heterogeneity was observed for both the control and experimental groups (Q = 8.12, I^2 = 75.37, p = .00, and Q = 125.23, I^2 = 96.01, p < .001, respectively).

The trim-and-fill report did not indicate any changes in the effect sizes for the control groups, as there were no studies missing according to the analyses (see Figure 14). However, the report stated that three studies were missing from the experimental groups, and with these imputed studies, under the random-effects model, the pooled effect size for the experimental groups decreased to Hedges's g = 0.66, 95% CI [0.21, 1.52] (see Figure 15).

Written Vocabulary and General Vocabulary Skills

There were four papers reporting written vocabulary outcomes (Anderson-Inman et al., 2009; Birinci & Sarıçoban, 2021; Haptonstall-Nykaza & Schick, 2007; Wauters et al., 2001). Two studies that we were unable to include in the meta-analyses due to lack of enough data on general

Figure 9. Funnel plot indicating publication bias for experimental groups with expressive oral vocabulary outcomes.

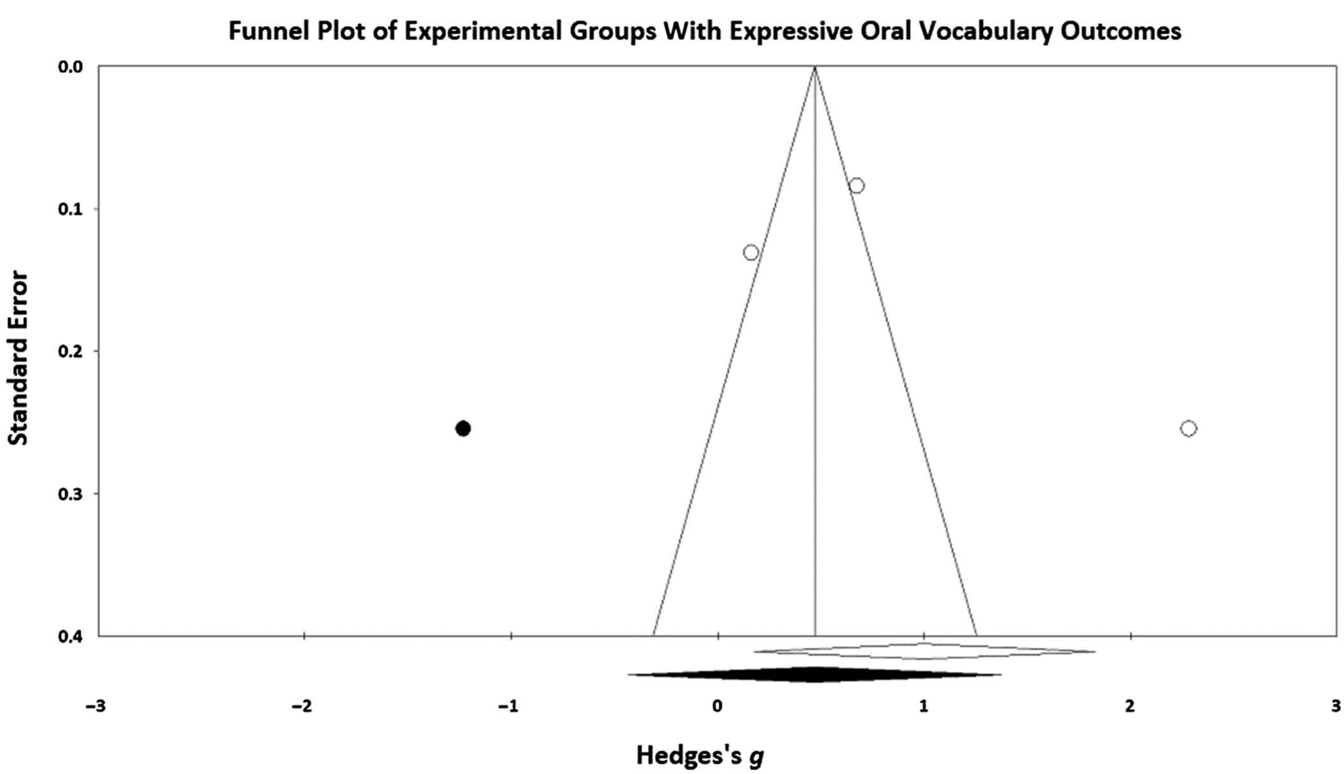
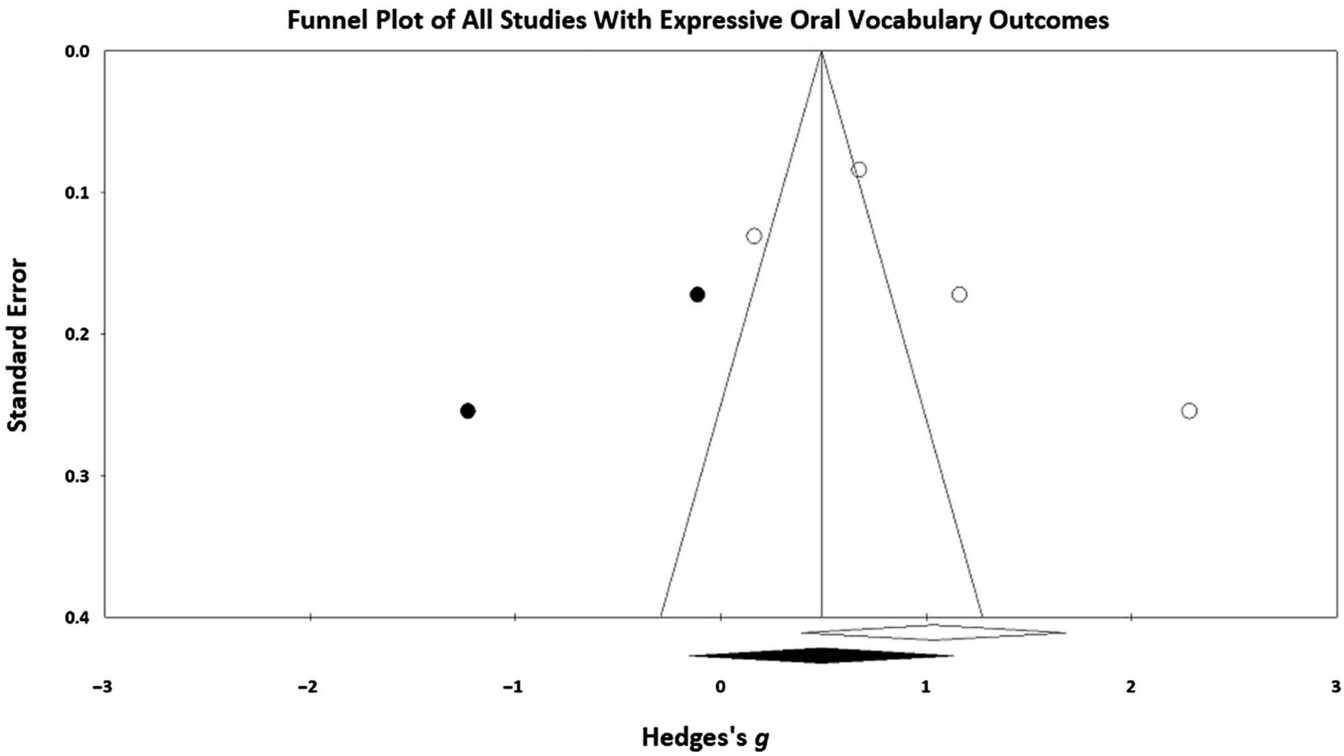


Figure 10. Funnel plot indicating publication bias for all studies with expressive oral vocabulary outcomes.



vocabulary skills were of Lederberg et al. (2000) and Lederberg and Spencer (2009). Both explored whether deaf children's new word-learning skills depend on contextual factors. The extensive investigation of the correlations between the individual characteristics (parents' hearing status, use of CI, whether they sign or not) and word-learning performance showed that there was no difference between the three levels of groups. However, the slow word learners were more likely to experience attention and motor problems, late cochlear implantation, or decreased bimodal language input, compared to the other two levels. Although we were unable to conduct a meta-analysis due to lack of enough pre–post data to calculate gains from the training in these studies, Table 2 reports the training received by the participants and the control groups, as well as the results obtained in these studies.

Discussion

To our knowledge, this study is the first to investigate the effects of different vocabulary training and interventions for DHH children and adolescents across different categories of vocabulary outcomes: expressive oral vocabulary, receptive

Figure 11. Forest plot showing effect size data for studies reporting signed vocabulary outcomes. CI = confidence interval.

Effect sizes for studies with signed vocabulary outcomes

Group by Subgroup within study	Authors	Hedges's *g*	Standard error	Variance	Lower limit	Upper limit	*z* value	*p* value
		Statistics for each study						
Control	Joy et al. (2019) Control	0.765	0.225	0.051	0.325	1.206	3.405	.001
Control	Plaewfueang & Suksakulchai (2020) Control	0.805	0.289	0.084	0.239	1.372	2.786	.005
Control	van Staden (2013) Control	1.543	0.200	0.040	1.150	1.935	7.698	.000
Control		1.043	0.540	0.292	−0.016	2.102	1.930	.054
Experimental	van Berkel-van Hoof et al. (2020)	0.182	0.172	0.029	−0.155	0.518	1.057	.290
Experimental	Wicha, Chakpitak, & Adipattaranan (2012)	0.623	0.071	0.005	0.484	0.762	8.779	.000
Experimental	Joy et al. (2019) Experimental	1.476	0.291	0.085	0.906	2.046	5.073	.000
Experimental	Falk et al. (2020)	1.771	0.224	0.050	1.331	2.210	7.893	.000
Experimental	Plaewfueang & Suksakulchai (2020) Experimental	4.252	0.859	0.737	2.569	5.935	4.952	.000
Experimental	van Staden (2013) Experimental	4.499	0.456	0.208	3.606	5.392	9.874	.000
Experimental		1.876	0.399	0.159	1.093	2.659	4.698	.000
Overall		1.539	0.409	0.167	0.737	2.340	3.763	.000

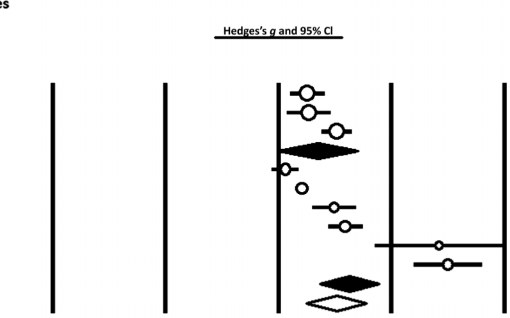
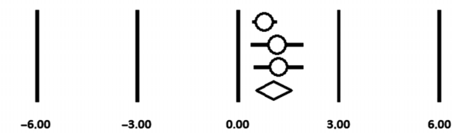


Figure 12. Forest plot showing effect size data for control groups with signed vocabulary outcomes when sensitivity analysis (one-study-removed analysis) is conducted. CI = confidence interval.

One-study-removed analysis for control groups with signed vocabulary outcomes

Authors	Subgroup within study	Point	Standard error	Variance	Lower limit	Upper limit	z value	p value
van Staden (2013) Control	Control	0.780	0.177	0.031	0.433	1.128	4.398	.000
Plaewfueang & Suksakulchai (2020) Control	Control	1.161	0.389	0.151	0.399	1.922	2.987	.003
Joy et al. (2019) Control	Control	1.204	0.367	0.135	0.483	1.924	3.275	.001
		1.057	0.274	0.075	0.520	1.594	3.856	.000



oral vocabulary, signed vocabulary, and written vocabulary, as well as general vocabulary skills. Our overall results in the systematic review show that all the studies use a multisensory approach and/or combinations of different modalities (such as written and signed and/or spoken vocabulary) to teach vocabulary for DHH children. These include combinations of using images corresponding to target words, real objects, tactile activities, picture storybooks, and signed and spoken language during training. For each of the outcomes, we discuss whether use of these approaches with additional sensory input to *treatment as usual* is effective based on the features of these studies (experimental and control groups and training/intervention received). This review also provides insights on the shortcomings of methodologies regarding vocabulary interventions, such as the lack of proper control groups to DHH participants in most cases. Following the discussion on the effectiveness of the interventions and the issues regarding methodological quality of the existing literature, we emphasize the limitations this review encountered and provide suggestions to improve protocols and methodologies of future research on vocabulary interventions for young DHH populations.

Studies on Receptive Oral Vocabulary

Interventions and training in receptive oral vocabulary were effective in improving vocabulary in the experimental groups from pre- to posttest. This was not the case for the control groups. However, the results appear to imply that, for receptive oral vocabulary, multisensory training is beneficial. In the meta-analysis results, we observed a high overlap of effect sizes between the control and experimental groups, although the main pooled effect size for experimental groups was significant, whereas for controls, it was not. This can mean that the receptive oral vocabulary training might not be more effective than what the control groups are being trained with. The issue derives from the fact that the studies do not detail what the control groups receive as their treatment as usual, such as the audiovisual therapy in the work of Zamani et al. (2016), which makes the conclusions about the training effects unclear. Also, in the case of Robertson et al.'s (2017) and Walker and McGregor's (2013) studies, the control groups consist of typical hearing children receiving the same training as the experimental groups. Although it seems that the DHH children in the experimental groups benefit from the receptive oral vocabulary training with multisensory approaches (images, eye gaze, and gesture cues), it is not clear in these two studies whether a control group of DHH children receiving treatment as usual would differ from the experimental groups, simply because such groups were not included.

However, among the studies we could not include in the analyses, Houston et al. (2005) found lower performance in the receptive vocabulary task for 2- to 5-year-old deaf children with CIs compared to their hearing peers as a result of the vocabulary training with real toys. Additionally, Majorano et al. (2017) compared deaf preschool children with CIs with their typical hearing peers in terms

Figure 13. Forest plot showing effect size data for experimental groups with signed vocabulary outcomes when sensitivity analysis (one-study-removed analysis) is conducted. CI = confidence interval.

One-study-removed analysis for experimental groups with signed vocabulary outcomes

Authors	Subgroup within study	Point	Standard error	Variance	Lower limit	Upper limit	z value	p value
van Staden (2013) Experimental	Experimental	1.304	0.343	0.118	0.631	1.977	3.799	.000
Plaewfueang & Suksakulchai (2020) Experimental	Experimental	1.613	0.441	0.195	0.748	2.478	3.656	.000
Falk et al. (2020)	Experimental	1.966	0.512	0.262	0.963	2.968	3.842	.000
Joy et al. (2019) Experimental	Experimental	2.029	0.513	0.263	1.024	3.034	3.958	.000
Wicha, Chakpitak, & Adipattaranan (2012)	Experimental	2.313	0.687	0.471	0.968	3.659	3.370	.001
van Berkel-van Hoof et al. (2020)	Experimental	2.370	0.597	0.356	1.200	3.540	3.971	.000
		1.913	0.440	0.194	1.050	2.775	4.346	.000

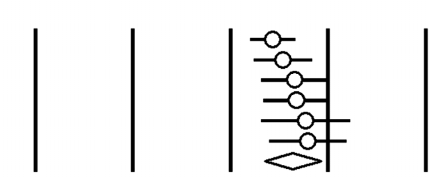
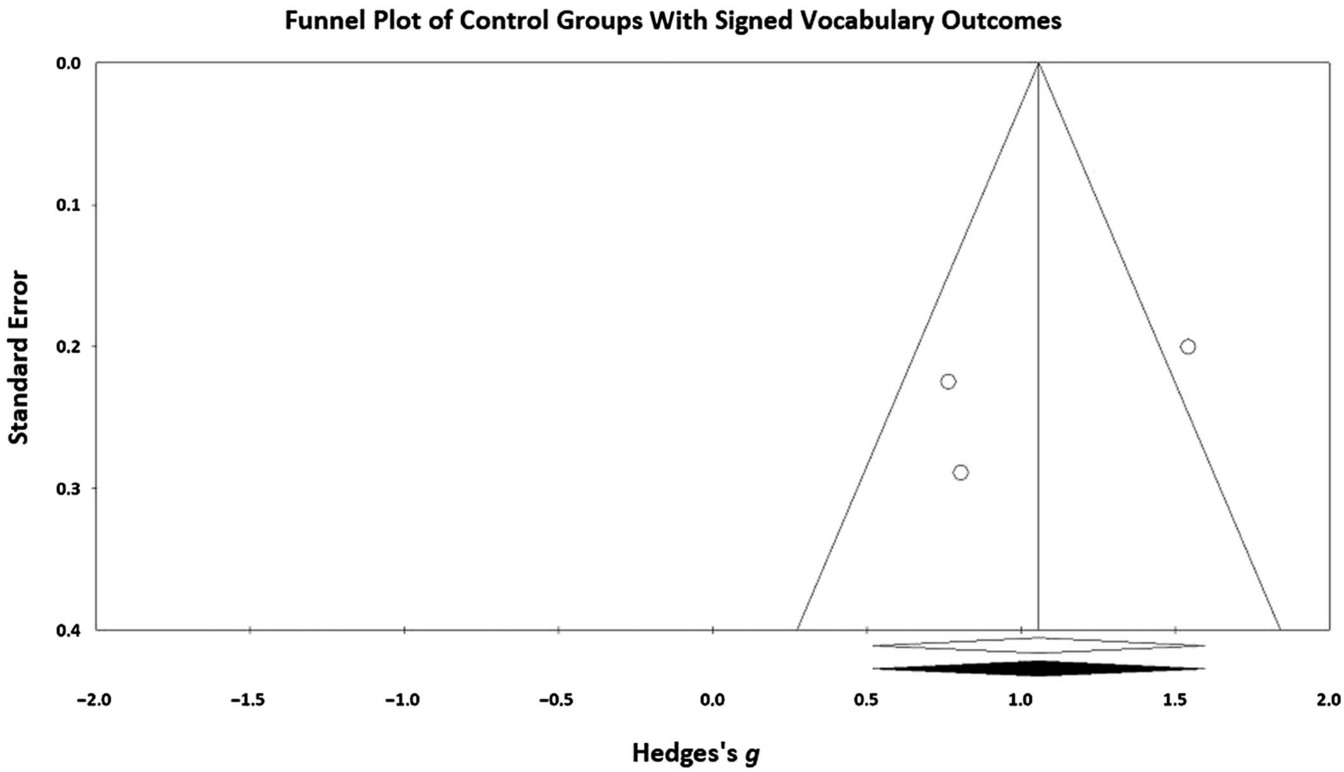


Figure 14. Funnel plot indicating no publication bias for control groups with signed vocabulary outcomes.



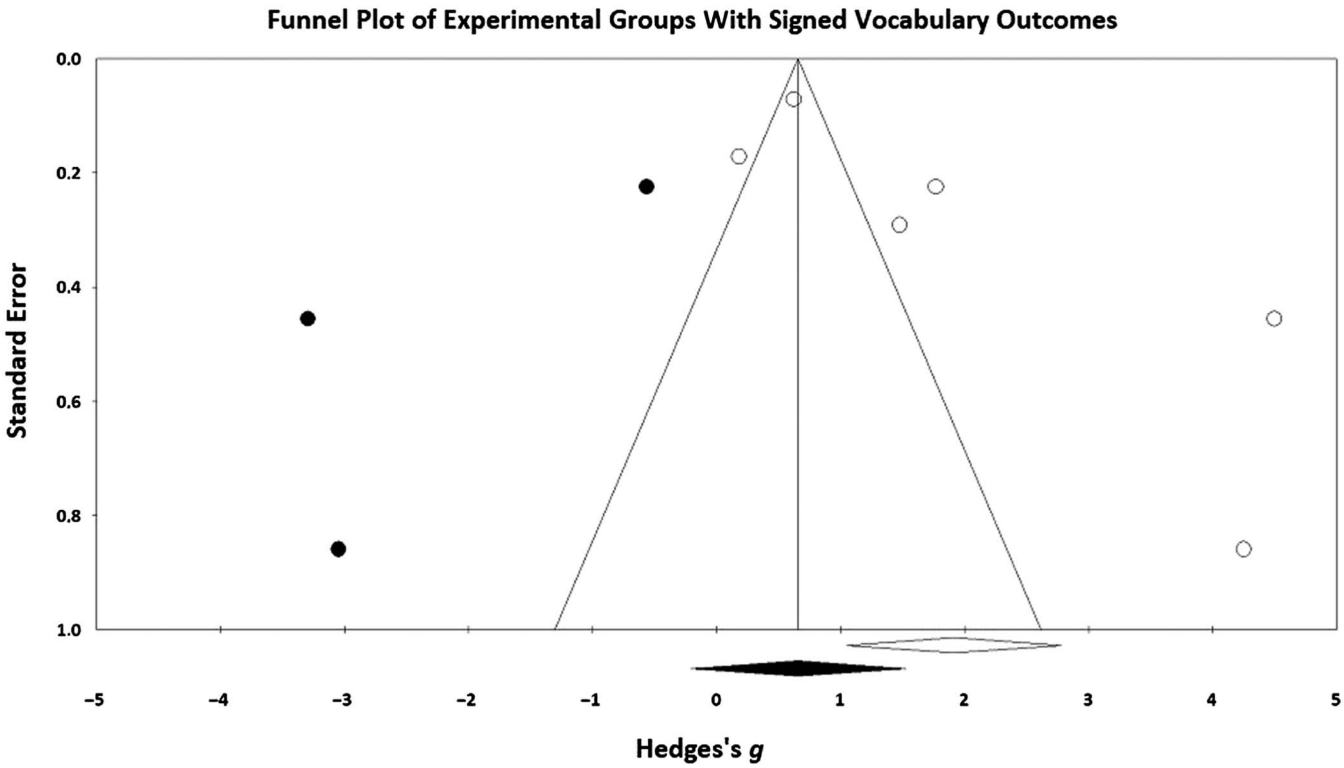
of novel vocabulary learning performance also with toys. They showed that deaf children with CIs and their chronological age– and hearing age–matched peers did not show a significant difference in receptive oral vocabulary tasks. These results showed that learning new labels/vocabulary with real objects/toys is not effective on receptive oral vocabulary; however, this could be due to participants' age and hearing loss characteristics, as well as wearing hearing technology later in age.

In the meta-analysis results, an exception to the effective trainings was the study by Fung et al. (2005), where although the experimental groups who received dialogic and typical reading instruction from their parents performed better than the control group who interacted with the storybooks after the study, the impact of the intervention was not significant as per our analysis. This might be because the parent-directed reading sessions were less controlled environments than the training and interventions in the other studies.

Studies on Expressive Oral Vocabulary

As in a previous meta-analysis (Lund, 2016), we found few studies reporting expressive vocabulary outcomes. The interventions were overall effective except for one study: Although Paatsch et al. (2006) included vocabulary training sessions with word meanings and concluded that they were helpful for vocabulary learning, our analysis did not show that this was the case for expressive oral vocabulary. The study's focus was on phoneme training, so it appears that, to be effective, direct vocabulary instruction should stand alone or be the main focus, such as in the work of Barcroft et al. (2021), where a meaning-based auditory training was used. In the case of verb teaching with gestures (Zamani et al., 2016), conveying meaning with physical movement seems to facilitate the comprehension of target vocabulary. Although we do not know the exact content of the audiovisual therapy the control group received (as in the case of receptive oral vocabulary results), the multisensory components of the intervention were effective and better than those of the control group: There was no overlap of effect sizes between the experimental and control groups of Zamani et al. (2016) as per the meta-analysis results. Unfortunately, we could not derive conclusions from the other two studies due to lack of a control group. This makes it difficult to conclude that the expressive oral vocabulary training in these studies is more effective than what a treatment as usual would provide for the DHH children. The other studies that could not be included in the meta-analyses reported similar results in terms of conclusions of the effectiveness of the interventions with toys (Houston et al., 2005; Majorano et al., 2017;

Figure 15. Funnel plot indicating publication bias for experimental groups with signed vocabulary outcomes.



Walker & McGregor, 2013) or interactive digital devices (Meinzen-Derr et al., 2021).

Studies on Signed Vocabulary

The interventions for signed vocabulary were effective. An interesting finding is that four out of seven studies included in signed vocabulary outcomes used digital devices, whereas this was the case for only one study in expressive oral vocabulary (Meinzen-Derr et al., 2021), one in receptive oral vocabulary (Robertson et al., 2017), and one in written vocabulary (Anderson-Inman et al., 2009). It is possible that the experience of these children with deaf education and the interactive nature of a sign language app might have driven positive results, such as in the works of Joy et al. (2019); Parton et al. (2009); Plaewfueang and Suksakulchai (2020); and Wicha, Chakpitak, and Adipattaranan (2012). In the case of van Staden's (2013) study, the multisensory and multimodal approach that included visual, sign, and storybook components possibly helped increase the consolidation of newly learned vocabulary. However, perhaps the addition of digital devices only brings the advantage of using varied stimuli and greater interaction. In the meta-analysis, we observed a high overlap of effect sizes between the control and experimental groups. All the control groups included in the signed vocabulary outcome analyses were reported as receiving treatment as usual, which was the classroom instruction. This instruction has not been detailed in any of the studies. Therefore, although the training on signed vocabulary seems effective with a statistically significant main effect, it does not seem to differ much from what a classroom instruction would provide for DHH children; therefore, the benefit of using various multisensory components does not show a clear additional impact on signed vocabulary outcomes as per our analyses. We were also unable to compare the results of the trainings in experimental groups and control groups in the work of Falk et al. (2020) due to lack of a control group and in the work of van Berkel-van Hoof et al. (2020) due to their control group consisting of typical hearing children.

Studies on Written and General Vocabulary Skills

Although we did not identify many studies with interventions in written vocabulary, we did find reported benefits of multisensory and multimodal approaches. One study used videos with captions (Anderson-Inman et al., 2009), and the other two used sign language with oral instruction (Haptonstall-Nykaza & Schick, 2007; Wauters et al., 2001). We see that a visual-only intervention (videos with captions) was not effective for vocabulary improvement, and the researchers attributed the null results to the demands of the additional task of reading the expanded captions, difficulty level of the content, or the lack of motivation for learning. However, the use of cospeech signs and finger spelling in the other two studies significantly improved the written vocabulary of DHH children. In the work of Birinci and Sarıçoban (2021), it was necessary to enhance the training with other visual stimuli (in addition to sign language).

Although Lederberg et al. (2000) and Lederberg and Spencer (2009) did not directly assess specific vocabulary outcomes, they found that raw vocabulary scores are important determiners of deaf children's word-learning skills and that slow vocabulary acquisition could be due to the language environment (either spoken or sign language) the deaf children have been exposed to. These participants had been HA users for approximately 3–4 months, so it could be that the auditory and sign-based explicit vocabulary instruction was beneficial. Of course, in this report, the use of sign language by the participants was rare and that of a hearing device frequent. This allows greater auditory input and increases the chances of target vocabulary learning.

Effective Intervention Components Across Vocabulary Outcomes

It is evident from this synthesis that regardless of the target vocabulary or the vocabulary outcome, the trainings/interventions need to be equipped with one additional sensory input. Furthermore, a global look at the results across outcomes shows that the most effective interventions applied direct, explicit instruction methods for vocabulary teaching as suggested by Beck et al. (2013). Just as in the single-subject study by Antia et al. (2021), the group studies in this review also show that it is a useful approach. However, the instruction still needs to be consolidated with more than one sensory input to be effective, as is evident from the single-case study by Hettiarachchi et al. (2021) and those we included (Robertson et al., 2017; Walker & McGregor, 2013; Zamani et al., 2016) where auditory and visual stimuli were combined. Our results across outcomes contrast with the single-subject study by McDaniel et al. (2018), where no significant difference was found between the vocabulary learning rates of DHH children when they received audiovisual versus audio-only instruction.

We also report that interactive vocabulary games were mainly used for signed vocabulary, such as in the work of Massaro and Light (2004). It means that the role of digital devices in the interventions is connected to the use of multisensory input and more than one modality, as well as providing a self-managed interactive environment for the participants. Still, regardless of the environment of the intervention (school, digital device, house), multisensory input (audios, pictures, signs and even gestures) is important even when DHH children and adolescents' hearing loss levels and hearing device use differ.

Methodological Quality

Our review shows that there were differences in methodologies and participants' characteristics across the studies, resulting in high levels of heterogeneity. Additionally, except for receptive oral vocabulary studies, we found that there is a publication bias toward the positive results of experimental instruction.

This review found that studies may not always include a proper control group for comparison when it comes to DHH populations, and the details of usual treatments and usual instruction the control groups receive were not clearly reported. We opted to ignore the typical hearing groups because comparing the gains DHH children and adolescents obtain from vocabulary interventions and control conditions seemed more appropriate. The comparisons with the typical hearing peers have already been investigated many times across multiple sign and spoken language outcomes. Comparisons with hearing participants (such as in Majorano et al., 2017) set the rationale for vocabulary interventions for DHH children and adolescents, but they are not useful to determine their effectiveness. A control group with DHH children and adolescents is required for this aim.

In addition, control conditions require greater specification. In many cases, the difference between the experimental and control conditions is unclear, since the treatment the participants are already receiving is unknown in the latter.

Limitations and Recommendations for Future Research

One limitation is the challenge of considering many individual differences that DHH groups have while synthesizing the results. Although it can be controlled in experimental studies, compiling research with different methodologies and participants must be done with caution. This review focused on a broader window of vocabulary interventions and outcomes across DHH groups to identify the most effective trainings, but the number of studies was too small for a meaningful analysis of potential moderating variables. Interpretation of results must be done with differences in hearing characteristics in mind. Future analyses can consider focusing on more individual differences' effects on each of the vocabulary outcomes using age, gender, SES, parental communication modality, and hearing loss severity.

We were not able to meta-analyze or have a synthesized conclusion for the additional outcomes that were in our protocol. There were not enough data reported on the outcomes of spoken narrative development, academic measures, and/or school grades or participation in conversation, except for parents' or teachers' comments. Global standardized language measurements were used only as pretest measures to determine participants' eligibility for interventions or for matched groups. Future studies should assess the implications of vocabulary improvement in the daily and educational lives of DHH children and adolescents.

In general, aligning with the literature on vocabulary teaching methods, we found that all studies inherited a direct, explicit multisensory and multimodal vocabulary instruction approach compared/additional to the usual therapy or usual instruction methods, although it is yet to explore the overall effects of indirect instruction. More research could be designed to investigate whether indirect, context-based methods could work, as well as the direct instruction approach. It is understandable that these usual settings might not always provide the required equipment, attention, time, and context to tap into specific vocabulary outcomes at the individual or even group level. Given the varying situations that can occur in a class or even in a family, the direct instruction approaches should be compiled in a way that makes them applicable in practical delivery context. The advantages of technology open a door for many new vocabulary teaching opportunities, but the role of multisensory stimuli should come first in terms of interventions' effectiveness. For example, given that interventions with audiovisual stimuli, signs, and gestures were more effective, future research might incorporate more of these inputs. However, this should be done with the proper control groups with DHH children and adolescents, but not with typical hearing peers. Only then can the positive effects of interventions on vocabulary be determined for DHH children and adolescents. Finally, researchers should opt for designs that minimize RoB, especially in randomization, and present conditions in separate groups, to minimize possible carryover effects from a previous training. We have detected only two preregistered studies. Given the many available tools to prepare research protocols and preregistrations, researchers should adopt the preplanning process before conducting their studies to reduce the reporting bias of results.

Conclusions

This systematic review and meta-analyses reveal that vocabulary interventions for DHH children and adolescents between the ages of 2 and 18 years conducted between 2000 and 2022 are effective for receptive oral vocabulary, expressive oral vocabulary, and signed vocabulary outcomes and reported as beneficial for written vocabulary and general vocabulary skills. Two of the three meta-analyses on vocabulary outcomes (expressive oral vocabulary and signed vocabulary) revealed a publication bias, which must be considered while interpreting these results. The synthesis shows that experimental vocabulary instructions with direct, explicit methodologies are more frequently used for DHH children and adolescents in vocabulary acquisition. Effective vocabulary interventions include multisensory components across each outcome. Varying individual characteristics such as demographic information and hearing variables must be considered inseparable from the outcomes of vocabulary intervention and training.

Data Availability Statement

Data for the meta-analyses, study features, and risk-of-bias assessments are available upon request from the corresponding author.

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