The Trends in Paediatric Speech Audiometry: A Scoping Review

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Abstract:

Speech tests are essential assessment tools of auditory abilities for both adults and children. A scoping review was conducted with the aim to explore possible changes in materials and methods of paediatric speech tests between 1980 and 2019. Thirty-eight articles were selected, and the extractions of information were made related to the name of the paediatric speech test, country of origin, year of publication, language used in the speech test, the target age range for the speech test, and the procedural parameters. Exploration of the articles provided insights into current trends of paediatric speech test applications that should be taken into careful consideration when developing a new speech test for children.

Keywords: *paediatric, speech test, scoping review, speech test design, material, method*

Introduction:

Speech audiometry is used to assess and diagnose peripheral and central hearing impairments, verify, and monitor the rehabilitation outcomes of amplification and for research applications. Earlier speech tests focused on adults and later, tests for children were developed. Paediatric speech audiometry is important as it predicts the effect of hearing impairments on the child's speech, language, and cognitive abilities. According to Theunissen et al. (2009), the development of a speech test requires consideration on various aspects as it will influence the accuracy of the tests results by variables other than the hearing impairment. These variables include both internal and external factors such as the child's age and cognitive skills and the test's type of response format, material and method of testing (Kirk et al., 1997). Moreover, it is impossible to make a valid comparison between these tests because the differences are attributed by many factors such as the types of material, procedure, or the participants of the study. Thus, the aim of this scoping review was to explore the material and methods of paediatric speech tests between 1980 and 2019.

Materials and Methods:

To ensure a broad range of results were obtained, relevant studies on the paediatric speech tests were systematically searched through four online databases namely the Cumulated Index to Nursing and Allied Health Literature (CINAHL), Medical Literature Analysis and Retrieval System Online (Medline), PubMed, and Scopus. A research string of keywords with Boolean operator, truncation, and wildcards where applicable was used to yield desired results. The precise keywords were *speech test*, *speech recognition test*, *speech perception test*, *speech audiometry*, *speech intelligibility test*, *paediatric*, *paediatrics*, *child*, and *children*. The search was limited to relevant studies between 1980 and 2019. Additional potential articles were also searched through the reference lists of the screened articles.

In the screening phase, duplicate articles were excluded after reviewing the title of all articles retrieved in the identification phase. The articles were omitted if they were related to speech tests exclusively developed for adults, an unpublished article or published in languages other than English, a screening test, developed for a specific population (e.g., central auditory processing disorder (CAPD) or specific language impairment (SLI)) or a non-speech test. An independent review of the title, abstract and full texts were conducted by two reviewers that extracted the data from the final full-text manuscripts into a spreadsheet for further analysis. Any discrepancies on the data extracted were clarified through discussion. The extractions were made based on key information which included the name of the paediatric speech test, country of origin, year of publication, language used in these speech test, the target age range for the speech test and procedural parameters (e.g., test format, method of response, type of speech stimuli, type of masker). The data was analyses using pivot tables to identify any trends and were summarized descriptively.

Results:

A total of 6293 articles were retrieved from the online databases search. After reviewing the title, 3594 articles were excluded. Searches through reference lists within the selected articles added 33 more articles. They were then reviewed together with the remaining 2699 articles. 50 articles were left for full-text analysis after reading the abstract. Based on the exclusion criteria, in the end, 38 articles were finally selected for further review. Figure 1 below shows a flow chart of the articles' review process.

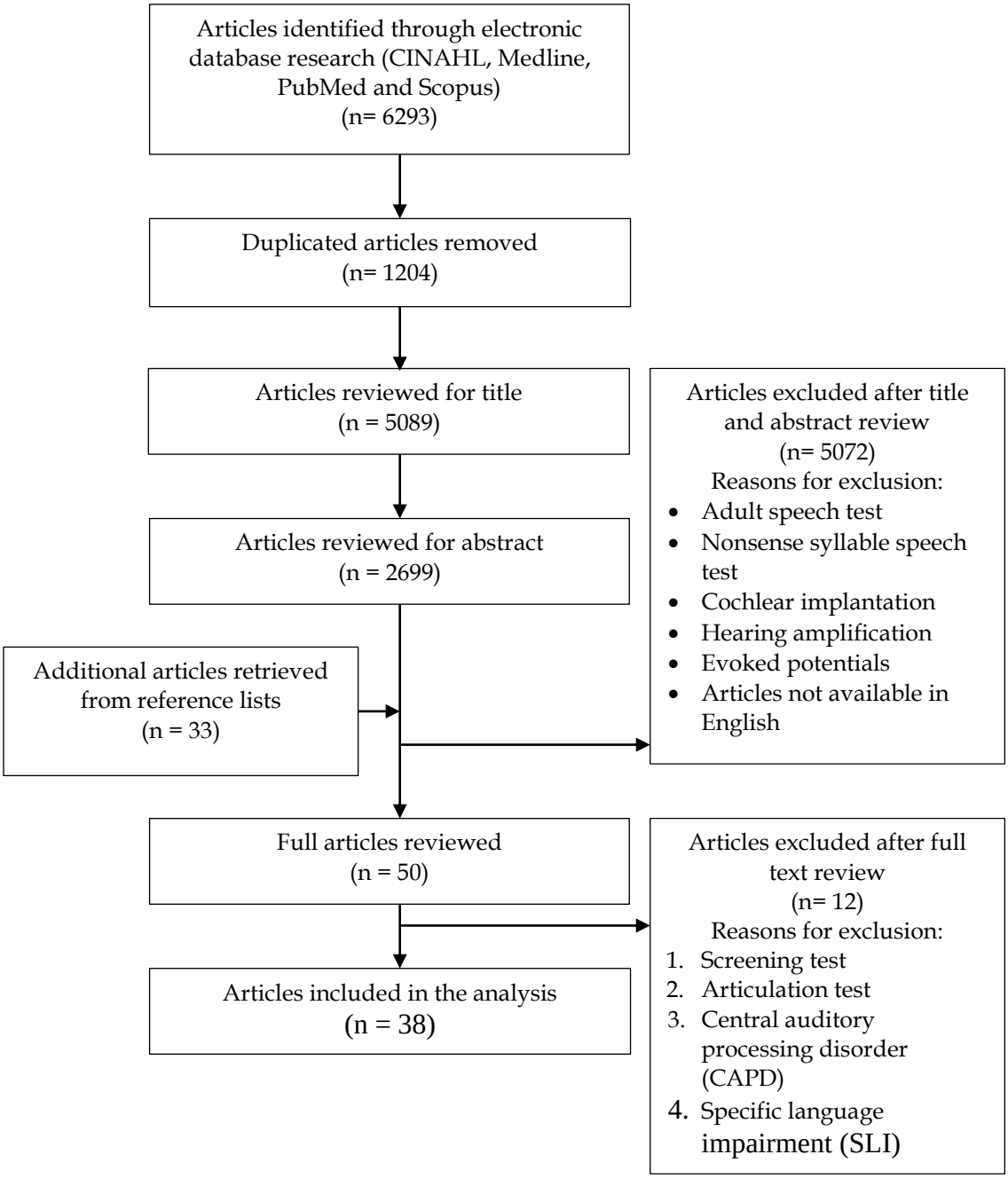

Figure 1 Flow chart of the review process

Paediatric speech tests articles identified within the four decades showed that 74% of the studies were published in the last decade (2010 to 2019) followed by 18% in the 1980s, 5% in the 1990s, and 3% in the 2000s. Even though there were 38 articles included in this scoping study, the total number of paediatric speech tests accounted for were 34. Four articles (the Mandarin Tone Identification Test (MTIT) (1), The Galker test (1) and the Pediatric Speech Intelligibility (PSI) test (2)) were studies on the same paediatric speech tests with different objectives. There were four speech tests that were not named. A list of all the included Paediatric Speech tests as well as its key characteristics is summarized in Appendix 1.

Countries of origin and the languages used in the speech tests

Altogether the paediatric speech tests originated from 18 countries. 38% were from Europe which included Sweden, the United Kingdom, Denmark, Greece (at 6% respectively), Germany, Romania, Belgium, Poland, and Norway (at 3% respectively). As for the language of the speech tests included in this review, the highest percentage was in English

at 32.4% followed by Mandarin and Cantonese at 8.8% respectively. Other languages recorded in the findings were Arabic, Greek, Swedish, Danish which accounted for 5.9% respectively, and German, Norwegian, Thai, Portuguese, Romanian, Spanish, Urdu, Polish, and Estonian languages that were 2.9% respectively.

The target age range for the speech tests

These speech tests were developed for children ranging from two to 17 years old. Age three is the minimum age of speech testing accounted for 28.9% of the total selected articles while the maximum age of six years old at 15.8%. However, three articles did not mention the intended age of the developed speech tests. Interestingly, two of these articles recruited adults as participants (Munthuli et al., 2015; Xi et al., 2012) even though the test was intended for the use for the paediatric population. While one article (Elberling et al., 1989) reported only about the development of new Danish speech material known as DANTALE with no participant recruited.

Test format and method of response

Three test formats were identified from the reviewed articles which were open-set (where the participants responded subjectively), closed-set (responded objectively) and multi response mode (both open and closed-tests format). Both closed-set and open-set each accounted for 41%, while 15% used the multi response mode. However, one article (3 %) did not specify the type of test format used in the procedure (named as THAI in this article) (Munthuli et al., 2015).

There were different methods of responses used across the selected articles. Verbal repetition and pointing to pictures or toys were reported at 41% each. Six of the 15% of the articles that applied the multi response mode, used verbal repetition, pointing to words or pressing button followed by 6% that used raise hand or pointing to pictures or words. An example of a speech test that allowed verbal repetition or verbal description, gesture, drawing, or writing was the Cantonese Spoken Word Recognition Test (CanSWORT) (Ng et al., 2016). While the raised hand and picture point was the procedure of the Urdu speech perception test (USPT) (Noor & Arif, 2018). The remaining 3% utilized a combination of verbal repetition, gesture, drawing or writing while another 3% did not specify the method of responses. Figure 2 illustrates the types of test format in relation to the method of responses in the selected articles.

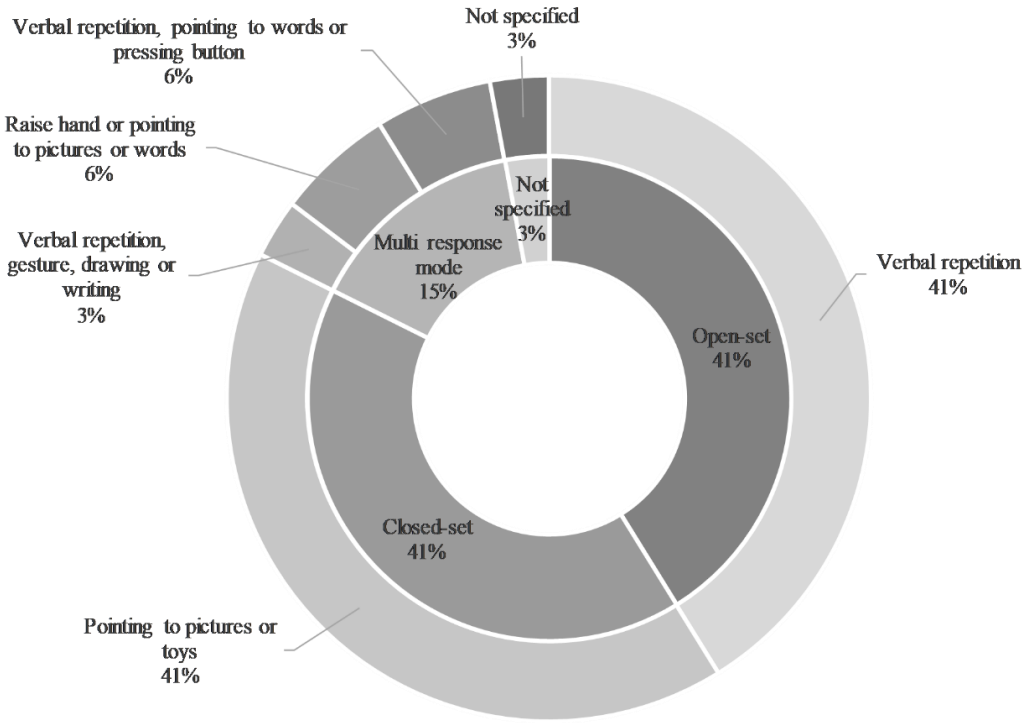

Figure 2 The percentage of method of response and test format used in the selected articles

Types and selection of the test stimuli

The types of speech stimuli in this review were divided into three different categories; words, sentences and a mixture of both words and sentences. The words were either mono-, bi- or tri-syllables and a few tests used word pairs with minimal difference in phonemes as stimuli. As for sentences, the sentence can vary from three-word utterances or have a length between three to 12 words or between five to eight syllables per sentence. However, many of those articles, especially for tests that selected the sentences from adult tests materials, did not specify the length of the sentences. Our findings revealed that 59% of the articles used words as the test stimuli followed by sentences at 35% and both words and sentences at 6%.

The test stimuli were selected from a variety of sources. 20% of the tests selected their stimuli by adapting the adult speech tests while 17% were obtained from spoken corpus and 15% selected theirs through adaptation of other paediatric speech tests. Meanwhile, test stimuli chosen from textbooks or stories recorded 12% and another 12% of the paediatric speech tests did not specify the sources of the test stimuli. The remaining speech tests obtained the test stimuli from written corpus (9%), frequency dictionary (6%), modification of adult test (6%) and dictionaries (3%) (Figure 3). The majority of the speech tests selected the stimuli from one of these sources, however, an exception were made for six tests: the Norwegian Hearing in Noise Test (NHINT-C) (Myhrum et al., 2016), the MTIT (Zhu et al., 2014, 2016), the Galker Test (Lauritsen et al., 2015, 2016), the CanSWORT (Ng et al., 2016), the Pediatric Spanish–English Speech Perception Task (Calandruccio et al., 2014) and the THAI (Munthuli et al., 2015) which selected stimuli from two different sources.

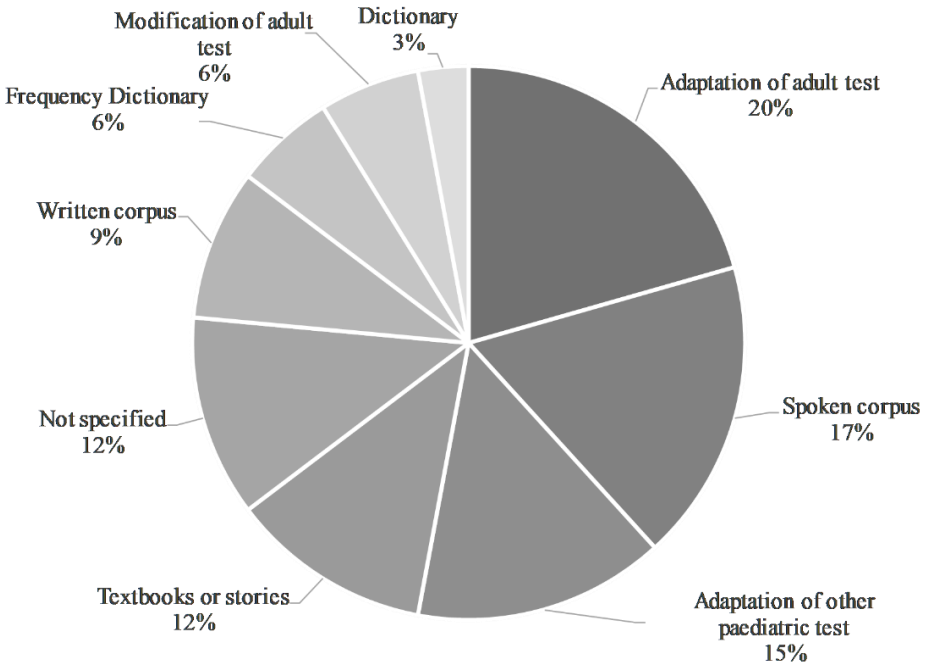

Figure 3 The percentage of sources for selection of test stimuli used in the reviewed paediatric speech tests

Masker

This review also looks at the masker used in these paediatric speech tests. The paediatric speech tests included were either conducted in quiet conditions or in noise conditions or in both test conditions (Figure 4). 41% of the tests were conducted with background noise, 32% were conducted in quiet conditions and 24% of the tests were conducted in both conditions. In the noise conditions, there were different types of masking noise applied namely; single talker sentence, two-talker babble, four-talker babble, multi-talker babble, amplitude modulated noise, broadband noise, steady state speech shaped noise, white noise, pink noise and cafeteria noise. The majority tests had only one masker except for two tests; the Paediatric Spanish–English Speech Perception Task (two-talker babble and steady state speech shaped noise) (Calandruccio et al., 2014) and the Toy Discrimination Test (two-talker babble and pink noise) (Lovett et al., 2013). Eight reviewed paediatric speech tests applied both quiet and noise procedural parameters; the Cantonese Hearing in Noise Test (CHINT-C) (Wong

et al., 2019), the Listen-Say test (Mentzer et al., 2018), the Hearing in Noise Test (HINT-Brazil) (Novelli et al., 2018), the Estonian words-in-noise (EWIN) test (Veispak et al., 2016), the NHINT-C (Myhrum et al., 2016), the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test (MDDB CSPT) (Mealings et al., 2015), the Mandarin Pediatric Speech Intelligibility (MPSI) (Meng et al., 2013), and the IHR-McCornick Automated Toy Discrimination Test (ATT) (Palmer et al., 1994).

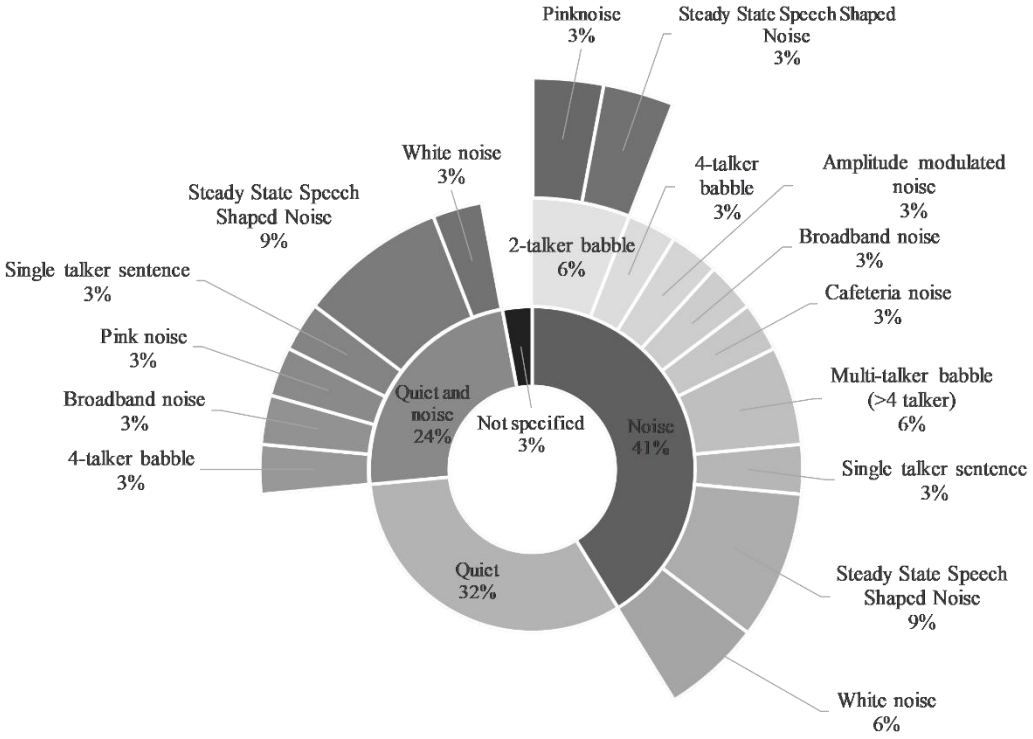

Figure 4 The proportion of maskers based on the test conditions of the paediatric speech tests

Discussion:

The 38 articles identified through this scoping review gave insights into the country of origin, language used, target age ranges, test formats, method of responses, types and selection of speech stimuli and masker of paediatric speech tests, between 1980 to 2019.

An increased trend in the development of paediatric speech tests in the year between 2010 to 2019 from various countries was observed. In the early decades, the speech tests were developed in Europe and the United States of America (USA). However, in the 2010s, other countries were found to have also developed speech tests in their own native language. This trend is in line with findings by Warzybok et al. (2015) and van Wijngaarden et al. (2002) that acknowledged that normal non-native listeners tend to have higher speech thresholds than the normal native listeners especially with background noise. Thus, speech recognition conducted in one's native language is recommended to prevent inaccurate diagnosis. Furthermore, the differences in the sound system across languages might also motivate the development of multilingual speech tests. One major limitation of "an unpublished article or published in other languages than English" as one of the exclusion criteria in this review was English might be overestimated as the major language used in the speech tests.

It was observed that the target age range for the selected paediatric speech tests in this review was somewhat consistent throughout the decades. Previous studies reported that children age 13 years old demonstrated similar speech recognition results as adults (Myhrum et al., 2016; Wong et al., 2019). Nevertheless, a few of the included paediatric speech tests applied target age ranges of 13 years old and older in order to evaluate the effect of age on speech understanding. Even though this review focuses on paediatric speech tests, adults' participation in some of the tests were either as evaluators for the familiarity of the test materials or to evaluate the homogeneity of the speech stimulus. As these tasks took time, adults'

responses are more accurate because they are considered to be less likely to be affected by fatigue and short attention spans (Case et al., 1982). Moreover, a previous study by Wagener and Kollmeier (as cited in Puglisi et al., 2021) found similar results between adult and children when lists equivalency was evaluated. Thus, assumptions can be made that results for adults are valid with children as well, in regards to lists equivalency.

With respect to test format, there were emerging trends observed across the decades. The closed-set was prominent in the 1980s, closed-set and multi response mode in the 1990s, followed by only open-set in the 2000s and closed-set and open-set in the 2010s. Previous studies have acknowledged that performance of participants in the open-set was different from those in the closed-set format as the former is more difficult than the latter (Clopper et al., 2006). This is because in the open-set task, the listeners respond by comparing what they heard with potential words in their lexical memory. On the other hand, listeners are presented with options or alternatives to choose as a response. However, the difficulty level for the closed-set test format can be increased by adding more alternatives or creating the options that closely resemble to each other (Theunissen et al., 2009). In terms of method of response, most of the speech tests employed pointing to pictures or toys in the 1980s but in the 2010s verbal repetition is more prevalent followed by pointing to pictures or toys and multi response mode.

Regarding types of speech stimuli, from 1980 to 1983, the focus was on the combination of words and sentences in these paediatric speech tests while only words dominated between 1984 and 2010. For 2012 and onwards, words and sentences were used as the major types of stimuli. Even though, sentences were more accurate to represent everyday communication, it required more cognitive demands especially in the elderly and child population (Nittrouer & Boothroyd, 1990). While words are still relevant as speech stimuli because it minimizes the effect of working memory and fatigue on children and elderly and can be administered faster than sentences (Mendel, 2008). However, Mendel (2008) encouraged both words and sentences test material as the minimum assessment of speech recognition for children.

The selection of the speech stimuli can be from various sources depending on the objective of the speech test or the available sources. For example, there were three HINT tests for children that used the sentences from the adult HINT corpus of material: the CHINT-C (Wong et al., 2019) and the NHINT-C (Myhrum et al., 2016) objective was to develop a children's version of the HINT test while the objective of the Hearing in Noise Test (HINT-Brazil) (Novelli et al., 2018) was to evaluate the adult HINT among children. Based on the selected articles, the development of test material can be grouped into three main options: the development of own material, adaptation of available material and combination of own and available material, as suggested by Theunissen et al. (2009). Tests that were developed by selecting the stimuli through spoken corpus, written corpus, dictionary, frequency dictionary, textbook or story books fall under their own material options while adaption of adult and other paediatric tests and modification of adult tests were under the adaption of available material. However, only two tests fall under the combination of own and available material options. The Galker test (Lauritsen et al., 2015, 2016) and Paediatric Spanish–English Speech Perception Task (Calandruccio et al., 2014) are both tests where speech material was selected by adapting other available paediatric speech tests and compiling expert panel suggestions and textbook or storybook respectively.

The type of noise could be further categorized into two most used maskers that are multi-talker babble and steady-state speech-shaped noise. The former noise provides informational masking while the latter noise serves dynamic masking features. In this review, two paediatric speech tests, the Paediatric Spanish–English Speech Perception Task (Calandruccio et al., 2014) and Toy Discrimination Test (Lovett et al., 2013) applied both type of noises to take advantages of each noise. The multi-talker babble mimics everyday listening situations while steady state speech-shaped noise serves as an effective masker to give consistent speech recognition results (Wilson et al., 2007). In addition, different types of noises do influence the speech recognition results (Wilson et al., 2007). Thus, the selection of the masker depends on the aims of the paediatric speech test. Although recent speech tests centre on using maskers to represent everyday listening situations, the number of speech tests developed for testing in quiet, in noise and in both listening situations were similarly distributed during the 2010s. This showed that speech tests in quiet are still valued and relevant for testing children.

Conclusion:

The most significant findings to emerge from this study is that material and methods in these paediatric speech tests varies extensively with no prominent emerging patterns in recent years. This scoping review provides the summary on factors that should

be considered in developing a new speech test, particularly in terms of the materials as well as the methodology. It also highlights how the variability of these factors emphasize why speech tests cannot be standardized. Therefore, multiple assessments are needed as there is no single speech test that is adequate for all purposes. Further research is highly recommended to investigate other factors related to testing children such as cognition, language, and fatigue. The authors accept that the keywords used in this study can be limiting as this topic involves a very large body of knowledge, therefore some articles may not be represented in this article.

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Appendix 1

List of the Paediatric Speech tests included in the scoping review

No	Name of the speech test	Year	Country	Test format	Method of response	Type of speech stimuli	Selection of test stimuli	Test condition	One masker	Two masker
1	Spanish Pediatric SRT Test (SPSRT) (Mendel et al., 2019)	2019	USA (United States of America)	Closed-set	Pointing to pictures/toys	Word	Frequency Dictionary	Quiet	Not Applicable	Not Applicable
2	Cantonese Hearing in Noise Test (CHINT-C) (Wong et al., 2019)	2019	China	Open-set	Verbal repetition	Sentence	Adaptation of adult test	Quiet and noise	Steady State Speech Shaped Noise	Not Available
3	Listen-Say test (Mentzer et al., 2018)	2018	Europe	Open-set and closed-set	Multi response mode	Word	Adaptation of other paediatric test	Quiet and noise	4-talker babble	Not Available
4	Arabic Words in Noise test (Arabic WIN) (Abdel Rahman, 2018)	2018	Egypt	Open-set	Verbal repetition	Word	Adaptation of other paediatric test	Noise	Cafeteria noise	Not Available
5	Hearing in Noise Test (HINT-Brazil) (Novelli et al., 2018)	2018	Brazil	Open-set	Verbal repetition	Sentence	Adaptation of adult test	Quiet and noise	White noise	Not Available
6	Urdu speech perception test (USPT) (Noor & Arif, 2018)	2018	Pakistan	Closed-set	Multi response mode	Word and sentence	Textbook/stories	Quiet	Not Applicable	Not Applicable
7	Greek sentence-based speech audiometry test (G-SEBSAT) (Koloutsou et al., 2017)	2017	Europe	Open-set	Verbal repetition	Sentence	Spoken corpus	Quiet	Not Applicable	Not Applicable
8	Cantonese Tone Identification Test (CANTIT) (Lee et al., 2017)	2017	China	Closed-set	Pointing to pictures/toys	Word	Spoken corpus	Quiet	Not Applicable	Not Applicable
9	Estonian words-in-noise (EWIN) test (Veispak et al., 2016)	2016	Europe	Open-set	Verbal repetition	Word	Textbook/stories	Quiet and noise	Steady State Speech Shaped Noise	Not Available
10	Norwegian Hearing in Noise Test (NHINT-C) (Myhrum et al., 2016)	2016	Europe	Open-set	Verbal repetition	Sentence	Adaptation of adult test	Quiet and noise	Steady State Speech Shaped Noise	Not Available
11	Not named (Cozma et al., 2016)	2016	Europe	Open-set	Verbal repetition	Word	Written corpus	Quiet	Not Applicable	Not Applicable

12	Mandarin Tone Identification Test (MTIT) (Zhu et al., 2016) (Zhu et al., 2014)	2016 2014	China	Closed-set	Pointing to pictures/toys	Word	Dictionary	Noise	Steady State Speech Shaped Noise	Not Available
13	The Galker Test (Lauritsen et al., 2016) (Lauritsen et al., 2015)	2016 2015	Europe	Closed-set	Pointing to pictures/toys	Word	Adaptation of other paediatric test	Noise	White noise	Not Available
14	Cantonese Spoken Word Recognition Test (CanSWORT) (Ng et al., 2016)	2016	China	Open-set	Multi response mode	Word	Written corpus	Quiet	Not Applicable	Not Applicable
15	Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test (MDDB CSPT) (Mealings et al., 2015)	2015	Australia	Closed-set	Multi response mode	Sentence	Spoken corpus	Quiet and noise	Broadband noise	Not Available
16	Not named (Munthuli et al., 2015)	2015	Thailand	Not mentioned	Not mentioned	Sentence	Written corpus	Not Applicable	Not Applicable	Not Applicable
17	Speech recognition in noise (Hagerman & Hermansson, 2015)	2015	Europe	Open-set	Verbal repetition	Sentence	Modification of adult test	Noise	Amplitude modulated noise	Not Available
18	Pediatric AzBio Sentence Lists (Spahr et al., 2014)	2014	USA	Open-set	Verbal repetition	Sentence	Spoken corpus	Noise	Multi-talker babble (>4 talker)	Not Available
19	Digit Speech Recognition Threshold (SRT) (Ramkissoon et al., 2014)	2014	USA	Open-set	Verbal repetition	Word	Adaptation of adult test	Quiet	Not Applicable	Not Applicable
20	Pediatric Spanish–English Speech Perception Task (Calandruccio et al., 2014)	2014	USA	Closed-set	Pointing to pictures/toys	Word	Adaptation of other paediatric test	Noise	2-talker babble	Steady State Speech Shaped Noise
21	Mandarin pediatric speech intelligibility (MPSI) test (Meng et al., 2013)	2013	China	Closed-set	Pointing to pictures/toys	Sentence	Not mentioned	Quiet and noise	Single talker sentence	Not Available
22	Toy Discrimination Test (Lovett et al., 2013)	2013	Europe	Closed-set	Pointing to pictures/toys	Word	Not mentioned	Noise	2-talker babble	Pink noise
23	Oldenburg sentence test for children (Oldenburger Kinder-Satztest; OlKiSa) (Neumann et al., 2012)	2012	Europe	Open-set	Verbal repetition	Sentence	Modification of adult test	Quiet	Not Applicable	Not Applicable

24	Polish Pediatric Matrix Sentence Test (PPMST) (Ozimek et al., 2012)	2012	Europe	Closed-set	Pointing to pictures/toys	Sentence	Frequency Dictionary	Noise	Steady State Speech Shaped Noise	Not Available
25	Not named (Xi et al., 2012)	2012	China	Open-set	Verbal repetition	Sentence	Spoken corpus	Noise	4-talker babble	Not Available
26	Words-in-Noise Test (Wilson et al., 2010)	2010	USA	Open-set	Verbal repetition	Word	Adaptation of adult test	Noise	Multi-talker babble (>4 talker)	Not Available
27	Modern Greek Word Recognition Score Test (Trimmis et al., 2008)	2008	Europe	Open-set	Verbal repetition	Word	Textbook/stories	Quiet	Not Applicable	Not Applicable
28	IHR-McCornick Automated Toy Discrimination Test (ATT) (Palmer et al., 1994)	1994	Europe	Closed-set	Pointing to pictures/toys	Word	Not mentioned	Quiet and noise	Pink noise	Not Available
29	Not named (McCullough et al., 1992)	1992	USA	Open-set and closed-set	Multi response mode	Word	Adaptation of adult test	Noise	Broadband noise	Not Available
30	DANTALE (Elberling et al., 1989)	1989	Europe	Closed-set	Pointing to pictures/toys	Word	Adaptation of adult test	Noise	Steady State Speech Shaped Noise	Not Available
31	Monosyllabic Adaptive Speech Test (MAST) (Mackie & Dermody, 1986)	1986	Australia	Closed-set	Pointing to pictures/toys	Word	Adaptation of other paediatric test	Quiet	Not Applicable	Not Applicable
32	Saudi Arabic Speech Audiometry for Children (Ashoor & Prochazka, 1985)	1985	Saudi Arabia	Closed-set	Pointing to pictures/toys	Word	Textbook/stories	Quiet	Not Applicable	Not Applicable
33	Northwestern University-Children's Perception of Speech Test (NU-CHIPS) (Chermak et al., 2017)	1984	USA	Closed-set	Pointing to pictures/toys	Word	Not mentioned	Noise	White noise	Not Available
34	Pediatric Speech Intelligibility (PSI) test (Jerger et al., 1980) (Jerger et al., 1981) (Jerger et al., 1983)	1983 1981 1980	USA	Closed-set	Pointing to pictures/toys	Word and sentence	Spoken corpus	Noise	Single talker sentence	Not Available