Listening Effort in Native and Nonnative English-Speaking Children Using Low Linguistic Single- and Dual-Task Paradigms

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Abstract

Purpose: It is not clear if behavioral indices of listening effort are sensitive to changes in signal-to-noise ratio (SNR) for young children (7-12 years old) from multilingual backgrounds. The purpose of this study was to explore the effects of SNR on listening effort in multilingual schoolaged children (native English, nonnative English) as measured with a single- and a dual-task paradigm with low-linguistic speech stimuli (digits). The study also aimed to explore age effects on digit triplet recognition and response times (RTs).

Method: Sixty children with normal hearing participated, 30 per language group. Participants completed single and dual tasks in three SNRs (quiet, -10 dB, and -15 dB). Speech stimuli for both tasks were digit triplets. Verbal RTs were the listening effort measure during the single-task paradigm. A visual monitoring task was the secondary task during the dual-task paradigm.

Results: Significant effects of SNR on RTs were evident during both single- and dual-task paradigms. As expected, language background did not affect the pattern of RTs. The data also demonstrate a maturation effect for triplet recognition during both tasks and for RTs during the dualtask only.

Conclusions: Both single- and dual-task paradigms were sensitive to changes in SNR for school-aged children between 7 and 12 years of age. Language background (English as native language vs. English as nonnative language) had no significant effect on triplet recognition or RTs, demonstrating practical utility of low-linguistic stimuli for testing children from multilingual backgrounds.

Introduction

Listening is imperative in the educational setting as 45%-75% of a school day is dedicated to listening activity (Crandell & Smaldino, 2000a; Dahlquist, 1998). However, listening and learning occur in a variety of environments, many of which are acoustically disadvantaged as a result of background noise and/or reverberation (Berg, 1993; Bistafa & Bradley, 2000; Crandell & Smaldino, 2000b). For example, the signal-to-noise ratios (SNRs) encountered in classrooms are often very unfavorable, ranging from -17 to +15 dB (Bradley & Sato, 2008; Crandell & Smaldino, 2000a; Larsen & Blair, 2008; Markides, 1986; Pearsons et al., 1977; Sato & Bradley, 2008). Background noise negatively affects speech recognition by reducing the audibility of acoustic cues that are important for understanding and distinguishing speech sounds (Nelson et al., 2008). This suggests that children in academic contexts often listen at SNRs poorer than the recommended minimum of + 15 dB SNR for educational settings (American SpeechLanguage-Hearing Association, 2005). The consequence of listening in such acoustically challenging environments includes reduced speech perception for children in addition to increased listening effort (Prodi et al., 2010).

Listening effort refers to the deliberate allocation of mental resources to overcome obstacles in goal pursuit when carrying out a task that involves listening in order to understand speech (Pichora-Fuller et al., 2016). The ease of language understanding (ELU) model (Rönnberg et al., 2013, 2008) provides a conceptual framework for listening effort. This model proposes that language understanding involves both implicit and explicit processing. Listeners will implicitly compare language segments to their long-term memory store. When an easy match between the language input and long-term memory occurs, speech understanding is obtained with minimal effort. In contrast, in situations of an input-memory mismatch (e.g., when the speech signal is masked by background noise), the listener must use explicit processing and additional cognitive resources to understand speech. Consequently, it is expected that a listener will experience increased listening effort in acoustical challenging situations (Rönnberg, 2003; Rönnberg et al., 2013, 2008). The FUEL model (Framework for Understanding Effortful Listening) extends the ELU model by adding that listening effort depends on the hearing ability of a listener, the task demands (e.g., a noisy or reverberant listening situation), as well as the listener's motivation to achieve the goal of completing a listening task (Pichora-Fuller et al., 2016).

According to the ELU model and the FUEL, another factor that can interfere with the input-memory match and thus contribute to increased listening effort is a nonnative listener's speech perception (Peelle, 2018; Pichora-Fuller et al., 2016; Rönnberg, 2003; Rönnberg et al., 2013, 2008). Multilingualism is a universal reality, and classrooms often include learners with diverse native languages leading them to communicate and learn in a nonnative language. Nonnative listeners who already perform more poorly on speech understanding tasks due to lower English-language proficiency may experience an escalation in listening effort in comparison to native listeners to understand English in adverse listening conditions (Bent et al., 2010; Bradlow & Alexander, 2007; Bradlow & Bent, 2002; Rogers et al., 2006). Between-group comparisons of listening effort in native versus nonnative speakers may be of interest as listener factors such as language abilities can contribute to increasing listening effort (Pichora-Fuller et al., 2016). However, studies reporting on the effects of these factors on listening effort are limited (Borghini & Hazan, 2018; Peng & Wang, 2019; Van Engen & Peelle, 2014). Based on findings of dual-task and subjective rating scale measures with nonnative adult listeners, which demonstrate a trend of greater listening effort for nonnative listeners compared to native listeners in adverse SNR and reverberating conditions (Peng &

Wang, 2019), it would be expected children would also exhibit increased listening effort when listening to nonnative speech.

The choice of speech stimulus is a methodological consideration important for considering outcomes in modern classrooms with children from different language backgrounds. The speech materials used for listening effort testing are usually age-appropriate, standardized, prerecorded word lists. In a multilingual context, the use of word lists, with a high-linguistic demand, could pose a challenge for younger children and for children who may not be native speakers of the language of the word lists. Instead of words or sentences, digits offer a potential solution because they are highly familiar spoken words, a closed set, and the linguistic demand is low (Kaandorp et al., 2016; Smits et al., 2013). Digit recognition in noise can be successfully and reliably used in children from as young as 4 years of age (Koopmans et al., 2018). Thus, using digit recognition in quiet and in noise in a listening effort paradigm might be a valid option for young school-aged children as well as nonnative children to assess listening effort. However, it is not clear if the use of low context, high-familiarity speech stimuli will be immune to the potential effects of using nonnative language during listening effort testing for children.

One category of behavioral listening effort methodologies involves a timed response, either speed of speech repetition or timed secondary task (Gagné et al., 2017). Such behavioral paradigms are derived from the limited cognitive capacity model of general attention (Kahneman, 1973) stating that a listener shows limited cognitive capacity when he/she must allocate attention when attending to simultaneous competing tasks. Thus, when more cognitive resources are allocated to assist with a specific task (e.g., understanding speech in noise), fewer resources are available for responding quickly. The classic dual-task paradigm requires the participant to perform two tasks simultaneously, a speech recognition task and a secondary, competing task, such as monitoring of a visual stimulus or vibrotactile pattern recognition. Thus, the outcomes from a dual-task paradigm are speech recognition performance and secondary task response times (RTs). Any performance decrement on the secondary task (reduced accuracy or increased RT) when dual tasking is interpreted as a behavioral index of listening effort (Gagné et al., 2017; Hsu et al., 2017; McGarrigle et al., 2019). Dual-task paradigms also have high ecological validity. For example, in academic contexts, learners are often required to perform dual tasking for example writing down notes, while listening to the teacher's instructions (Howard et al., 2010; McGarrigle et al., 2019).

However, some investigators have reported difficulty using dual-task paradigms with children. For example, although the results of some investigations revealed decreasing SNRs increase listening effort as expected (Gustafson et al., 2014; Picou et al., 2019, 2017; Prodi et al., 2010), other investigations suggest somewhat unexpected nonsignificant effects of changes in SNR on behavioral listening effort (Hicks & Tharpe, 2002; McGarrigle et al., 2017, 2019). The discrepancy in the literature has been attributed, in part, to secondary tasks that are not motivating or too distracting (Choi et al., 2008; McFadden & Pittman, 2008). Another possible reason for inconsistent results with dual-task paradigms in the pediatric population is because the interpretation of dual-task results relies on the assumption that specific tasks can be prioritized and/or cognitive resources be distributed among multiple simultaneous tasks (Gagné et al., 2017). This ability might not yet be fully developed in school-aged children (Choi et al., 2008).

As an alternative to a dual-task paradigm, a singletask paradigm could also be used to evaluate listening effort behaviorally. Outcomes from a single-task paradigm also include both speech recognition performance and RTs. In such a paradigm, participants repeat speech and the time between stimulus presentation and verbal response is recorded, hereafter referred to as "verbal response time." As with RTs during a secondary task, verbal RTs can also indicate listening effort and have been used in the pediatric population, with slower responses indicating more listening effort (Gustafson et al., 2014; Houben et al., 2013; McGarrigle et al., 2019; Pals et al., 2015).

Recently, McGarrigle et al. (2019) compared results with a single- and a dual-task paradigm with children (6- to 13-year-old children). Participants with normal hearing and hearing loss (unaided and aided) completed a singleand a dual-task paradigm in several SNRs. Participants were asked to respond as quickly as possible to a brief shape that appeared randomly during the consonant-vowelconsonant recognition task. The results suggested that the verbal RTs were more sensitive to the effects of SNR and hearing loss than the secondary task RTs. However, the nonsignificant findings could be the result of large variability in responses for the younger participants. Although the authors did not report the differences in RTs across the age range, previous results suggest secondary task RTs are less stable in younger children (< 12 year old) than in older children (Picou et al., 2017). In addition, it is possible that the speech recognition performance levels during the experimental tasks were too poor to be sensitive to changes in SNR; it was less than 50% for children with hearing loss. The work of Wu et al. demonstrates that RTs during listening effort tasks can reveal an inverse Ushaped function (Wu et al., 2016), where RTs progressively increase until a point of cognitive overload where participants exert less effort because cognitive demands exceed cognitive resources (e.g., Granholm et al., 1996; Zekveld et al., 2014). In adults, RTs peak around 30%-50% correct performance levels (Wu et al., 2016). Thus, it is possible that a dual-task paradigm could be as sensitive to changes in SNR as a single-task measure if word recognition performance is higher or for older children.

Therefore, the purpose of this study was to explore the effect of SNR on listening effort in school-aged children with normal hearing as measured with novel, low linguistic single- and dual-task paradigms. It was expected that, when factors such as age and speech recognition accuracy are accounted for, the single-task paradigm would be more sensitive than the dual-task paradigm to the effects of changing the SNR, based on the findings of McGarrigle et al. (2019). The study also aimed to explore age effects on triplet recognition and RTs during single- and dualtask performances. It was expected that speech recognition would improve with age and that older children would exhibit faster RTs. The results of this study were expected to elucidate the relative task sensitivity of single- and dualtask paradigms for measuring listening effort in school-aged children from multilingual backgrounds. It was expected that these single- and dual-task paradigms would not be sensitive to language differences (native English vs. nonnative English) due to the use of low linguistic speech stimuli (digit triplets).

Materials and Methods

Participants

Two groups of school-aged children participated in the study: 30 children with English as a nonnative language (M = 9.4 years, SD = 1.7, range: 7-12) and 30 children with English as a native language (M = 9.6 years, SD = 1.7, range: 7-12). All participants had normal middle ear function as verified by tympanometry measures and normal otoscopic examination findings on the day of testing. All participants had normal-hearing sensitivity in both ears (<

15 dB HL for octave frequencies from 250 to 8000 Hz). No participant had otologic, cognitive, or neurological disorders, as evident from parental and/or teacher report. All participants had normal speech, language, and motor development as confirmed by parental report. Furthermore, participants had normal visual acuity as confirmed for each participant by performing a visual acuity screening test (smartphone application for Tumbling-E visual acuity testing; Rono et al., 2018). Institutional review board approval was granted for this study by the Research Ethics Committee of the Faculty of Humanities, University of Pretoria.

Dual-Task Paradigm

Primary Task

The primary task consisted of digit triplet recognition. The digit triplets used were from the digit triplets available from the South African English digits-in-noise hearing test (Potgieter et al., 2018, 2016). South African English monoand bisyllabic digits (0-9), spoken by a female speaker were selected and recorded to create digit triplets sets. A detailed description of the development of this digit-in-noise test can be found in Potgieter et al. (2018, 2016). Mono- and bisyllabic digits were used in the triplets because the recognition probabilities of all the digits are equalized so that a potential difference in recognition probabilities is eliminated (Smits, 2016). The use of a digits-in-noise test was found a reliable test to assess speech recognition abilities of normal-hearing children from the age of 4 years and older, making it applicable to a wide clinical population (Koopmans et al., 2018). Most children aged 6 years and older have the necessary auditory memory abilities for a digit span of three digits, which is required to perform the digits-in-noise test (Koopmans et al., 2018; Wechsler, 2003). Participants were required to listen to and repeat digit triplets presented in quiet and in noise. Participants were encouraged to guess if they were unsure of the digit triplet that was presented. Participants' verbal responses were recorded by a head-worn microphone and saved by a custom software program (MATLAB R2015a) in participant specific files. Percent correct scores were calculated by scoring the verbal responses to the digits.

Secondary Task

The secondary task was a measure of RT to a visual stimulus presented through a custom programming of MATLAB software (MATLAB R2015a) on a touchscreen computer (Dell OPTIPLEX 7460 AIO 23.8" touchscreen computer) placed directly in front of a participant. A colored shape (basic shapes, namely circle, triangle, or square presented in basic colors of red, blue, yellow, or green) of 10 cm in diameter appeared against a black background on the touchscreen and disappeared as soon as the participant touched on the shape on the touchscreen or after 3,000 ms. RTs to visual stimuli were automatically recorded using customized software on MATLAB and stored in participant specific files. The color and the shape of the visual stimuli in this study were varied randomly to help keep participants' interest to the listening task, but participants were not instructed to respond differently based on the color or shape.

Dual-Task Conditions

In dual-task conditions, participants completed both tasks simultaneously. Visual stimuli appeared 500 ms after digit triplet onset. The visual stimuli were programmed to appear randomly with a 50% probability rate. The measure of listening effort was the RT to the visual stimuli, hence referred to as dual-task visual RT. Participants were not asked to prioritize one task over the other, given that this strategy has been shown to be ineffective for this particular age group (Choi et al., 2008).

Single-Task, Paradigm

The speech stimuli in the single-task paradigm were the same as those in the dual-task paradigm. Thus, participants were instructed to listen to and repeat digit triplets presented in quiet and in noise (SNRs of -10 dB and -15 dB). Participants' verbal responses were recorded by a head-worn microphone. The verbal RTs were then automatically analyzed by the programming software on the custom MATLAB program and saved in specific files for each participant. RTs were automatically calculated by the MATLAB program by measuring the time elapsed from the offset of the digit triplet to the onset of the participant's response.

Test Environment

Listening effort measures were conducted in a soundattenuating booth (2.13 x 2.03 x 2.43 m). Three loudspeakers were located at 0°, 90°, and 270° at 1 m from the participant. Participants were seated in the sound-attenuating booth, 1 m from the loudspeakers, at a school desk with a touchscreen desktop computer (Dell OPTIPLEX 7460 AIO 23.8" touchscreen computer) located directly in front of the participant. Handprints were placed on the desk's surface showing participants where to place their hands during testing. Participants were instructed to keep their hands on the handprints during all tasks except when they needed to touch the screen during the dual-task conditions. Furthermore, participants were instructed to keep their head still and face forward for the duration of the testing.

Test Conditions

Participants were tested in a total of six conditions, which varied by listening effort task (single-task paradigm, dual-task paradigm) and by SNR (quiet, -10 dB, -15 dB). Digit triplets were presented through custom programming of MATLAB software (MATLAB R2015a), routed to an audiometer (GSI AudioStar Pro), to a loudspeaker (GSI 90 dB) located at 0° azimuth at a distance of 1 m from the participant. The audiometer was used to adjust the output intensity level of the digit triplets to 60 dB(A). Thus, the SNR was varied by adjusting the noise level and keeping the speech level at a constant intensity of 60 dB in order to resemble an average conversational intensity. Keeping the speech intensity constant and varying the noise intensity level also prevented that speech stimuli would be presented at intensities softer than average conversational loudness. The background noise was the steady state noise with the same long-term average spectrum as the South African English digits-in-noise hearing test (Potgieter et al., 2018, 2016). Noise files were stored on the audiometer and selected from the internal files for the noise conditions. During noise conditions, identical noise was routed synchronously from the audiometer to two loudspeakers (GSI 90 dB loudspeakers) placed at 90° and 270° azimuths, situated at 1 m from the child. For the noise conditions, fixed SNR levels of -10 dB and -15 dB were used; thus, noise output levels were measured at 70 dB(A) and 75 dB(A), respectively. Output levels for digit triplets and digit noise were measured by means of a sound level meter to ensure the correct output level in the sound field. During dual-task testing, the visual probes were displayed on a touchscreen computer (Dell OPTIPLEX 7460 AIO) placed directly in front of a participant. The SNRs were chosen based on pilot testing with naive participants to target triplet recognition performance levels between 50% and 80% correct.

Procedure

Before data collection, informed consent was obtained from each participant's parent/guardian and assent was obtained from the participants themselves. Standard audiometric procedures followed (otoscopic examination, tympanometry, pure-tone audiometry, and speech audiometry) to confirm normal bilateral hearing sensitivity. A visual screening test was also conducted. Listening effort measures were conducted in a sound-attenuating booth as described earlier. Training rounds were conducted prior to data collection to ensure that the participant understood the listening task. Training rounds consisted of the following: primary task in quiet and in noise, secondary task in quiet and in noise, and dual-task in quiet and in noise. Participants then performed only the secondary task again. Training lists (10-digit triplets) were not repeated during the experimental testing. After the training rounds, participants were prepared to start with data collection testing for the single- and dual-task paradigms. For data collection of both paradigms, a single 20-digit triplet list was used in each condition. Twenty-five lists consisting of 20 digit triplets each were created in order to ensure no repetition of a digit triplet list in the various test conditions. The order of the test conditions and digit triplet list were randomized across participants.

Data Analysis

Outcomes from both single- and dual-task paradigms consisted of triplet recognition scores and RT. For the singletask paradigm, the verbal RTs were taken as the measure of listening effort. RTs to visual stimuli (dual-task visual RT) were the main listening effort measure during the dual-task paradigm. For both tasks, RTs were included in the analysis if they were within ± 2.5 SDs of the mean for the participant in a given digit triplet list. As suggested by Hsu et al. (2017), RT data were included from both correct and incorrect primary task trials as it would result in better representation of the varying levels of listening effort that children might experience in real-life, noisy classroom situations. The approach of including of the full data set for analyses (i.e., results based on both correct and incorrect responses for single- and dual-task paradigms) was also followed by McGarrigle et al. (2019). Outcomes were analyzed separately for each task. Each analysis of variance (ANOVA) included a single within-participant factor (SNR; quiet, -10 dB, -15 dB) and a single between-participant factor (Language Group; English as nonnative language, English as native language). Significant interactions were explored with follow-up ANOVAs, and significant main effects were analyzed with pairwise comparisons controlling for familywise error rate with Bonferroni adjustments. Greenhouse-Geisser correction for sphericity violations were used when necessary. To explore the effects of age on single- and dual-task performance, Pearson correlation analyses were conducted between age and each outcome (triplet recognition, RTs), collapsed across Task, SNR, and Language Group, unless otherwise indicated by significant interactions in the ANOVA. Prior to analysis, triplet recognition scores were converted to rationalized arcsine units to normalize the variance near the extremes, according to the equations in Studebaker (1985). Analyses were conducted in IBM SPSS (Version 26).

Results

Single-Task Paradigm

Figure 1 displays triplet recognition (Panel A) and RTs (Panel B) obtained during the single-task paradigm for each SNR and language group. Analysis of digit triplet recognition revealed a significant main effect of SNR, $F(2, 116) = 450.34$, $p < .001$, np2 = .89 and no significant effects of Language Group or Language Group x SNR interaction ($p > .40$, np2 = .02). Analysis of RTs revealed a significant main effect of SNR $F(1.68, 97.53) = 80.20$, $p < .001$, np2 = .58 and no significant effects of Language Group ($p > .45$, np2 = .01) or Language Group x SNR interaction ($p > .29$, np2 = .02). Pairwise comparisons, displayed in Table 1, reveal digit triplet recognition performance was significantly worse, and RTs were significantly slower, with the addition of, or increase in, background noise.

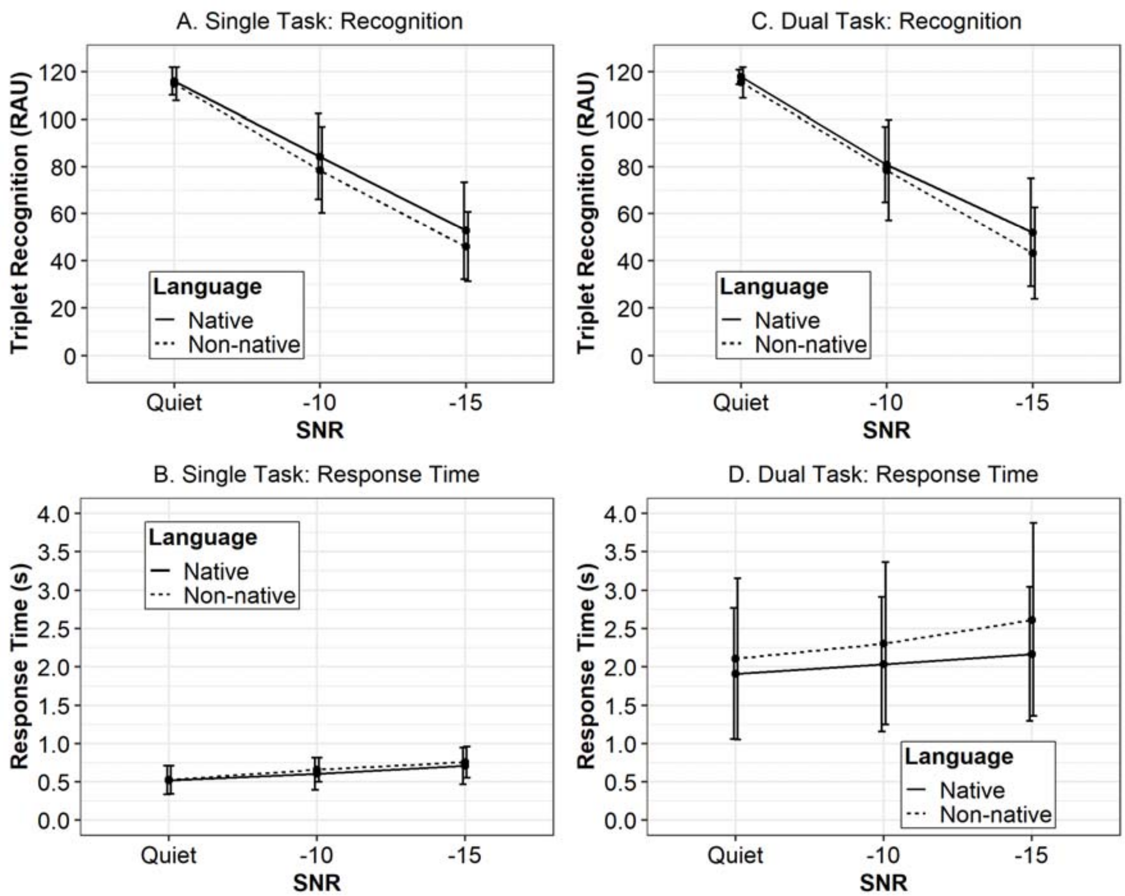

Figure 1. Panel A: Mean triplet recognition scores (RAU) for each signal-to-noise ratio (SNR) condition and language group during the single-task paradigm. Panel B: Mean response times during the single-task paradigm for each signal-to-noise ratio (SNR) and each language group. Panel C: Mean triplet recognition scores (RAU) for each SNR condition and language group during the dual-task paradigm. Panel D: Mean response times during the dual-task paradigm for each SNR and each language group. RAU = rationalized arcsine units.

Table 1. Results of pairwise comparisons of triplet recognition performance (rau) and response times (ms) for the single-task paradigm, collapsed across language groups. Significant differences are indicated by **bold** typeface.

Outcome	Comparison	*M* difference	Std Error	95% CI	*p*
Triplet Recognition	**Quiet to -10 dB**	**43.15**	**2.31**	**28.46 to 39.83**	**<.001**
	Quiet to -15 dB	**66.07**	**2.27**	**60.47 to 71.67**	**<.001**
	-10 to -15 dB	**31.92**	**2.02**	**26.96 to 36.89**	**<.001**
Response Times	**Quiet to -10 dB**	**-106**	**12**	**-137 to -76**	**<.001**
	Quiet to -15 dB	**-207**	**17**	**-249 to -164**	**<.001**
	-10 to -15 dB	**-100**	**19**	**-146 to -55**	**<.001**

Correlation analyses, displayed in Figure 2, revealed a significant relationship between age and triplet recognition (r = .24, p < .001), demonstrating that triplet recognition performance improved with age. There was no significant association between age and RT during the single task (r = -.08, p = .26). Together, these data indicate that the triplet recognition scores and RTs were sensitive to the effects of SNR, but not to language background. In addition, older children tended to demonstrate better triplet recognition performance than younger children, although RTs did not demonstrate such a pattern.

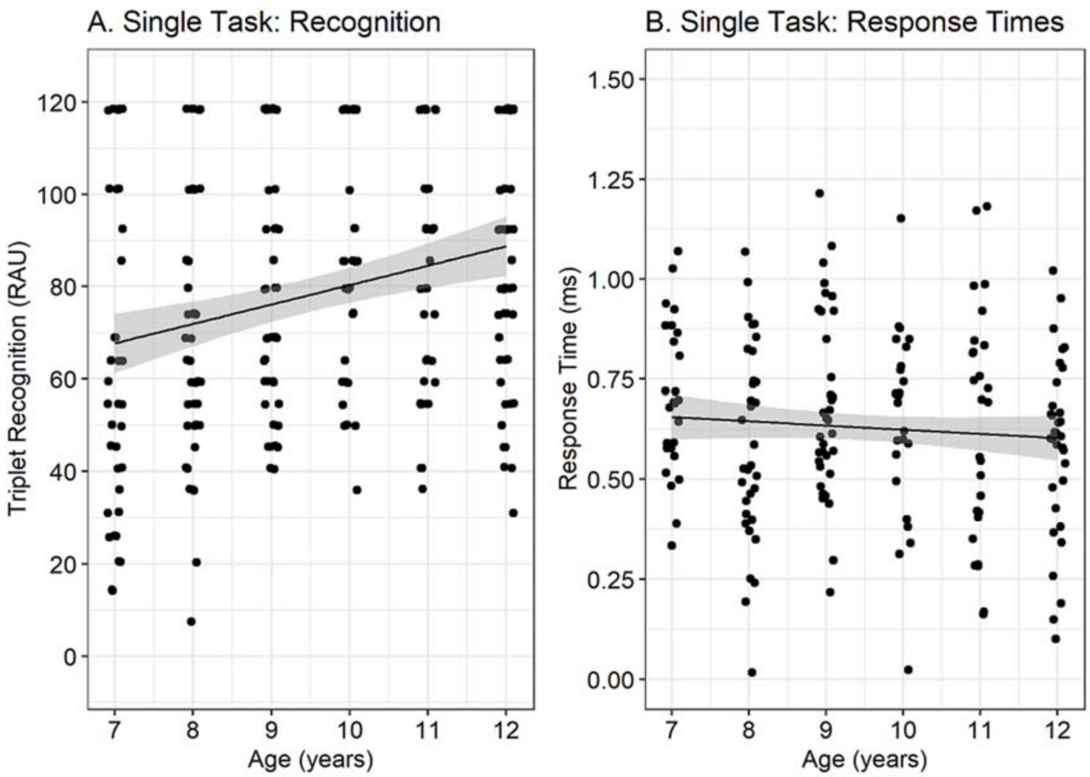

Figure 2. Triplet recognition performance and response times across participants' ages for the single-task paradigm. RAU = rationalized arcsine units.

Dual-Task Paradigm

Figure 1 displays triplet recognition (Panel C) and RTs (Panel D) obtained during the dual-task paradigm for each SNR and Language Group. Analysis of digit triplet recognition revealed a significant main effect of SNR, F(2, 116) = 332.69, p < .001, np2 = .85, and no significant effects of Language Group (p > .13, np2 = .04) or Language Group x SNR interaction (p > .38, np2 = .02). Analysis of dual-task visual RTs revealed a significant main effect of SNR, F(1.77, 102.73) = 17.22, p < .001, np2 = .23 and no significant effects of Language Group (p > .22, np2 = .03) or Language Group x SNR interaction (p > .14, np2 = .03). Pairwise comparisons, displayed in Table 2, reveal digit triplet recognition performance, and dual-task visual RTs were significantly worse with the addition of, or increase in, background noise.

Table 2. Results of pairwise comparisons of triplet recognition performance (rau) and response times (ms) for the dual-task paradigm, collapsed across language groups. Significant differences are indicated by **bold** typeface.

Outcome	Comparison	*M* difference	Std Error	95% CI	*p*
Triplet Recognition	**Quiet to -10 dB**	**37.06**	**2.48**	**30.94 to 43.17**	**<.001**
	Quiet to -15 dB	**68.94**	**2.69**	**62.31 to 75.57**	**<.001**
	-10 to -15 dB	**31.88**	**2.84**	**24.88 to 38.90**	**<.001**
Response Times	**Quiet to -10 dB**	**-162**	**54**	**-295 to -30**	**.011**
	Quiet to -15 dB	**-383**	**75**	**.567 to -199**	**<.001**
	-10 to -15 dB	**-221**	**54**	**-385 to -57**	**.005**

Correlation analysis, displayed in Figure 3, revealed a significant relationship between age and digit triplet recognition ($r = .20$, $p < .002$), in addition to significant relationship between age and dual-task visual RTs ($r = -.39$, $p < .0001$) with dual-task visual RTs generally decreasing and triplet recognition increasing with increasing age. Taken together, these data demonstrate that both single- and dualtask paradigms were sensitive to changes in the background noise. However, language background (native English, nonnative English) did not affect the pattern of RTs. The data also demonstrate a maturation effect for RTs during the dual-task, but not the single-task paradigm.

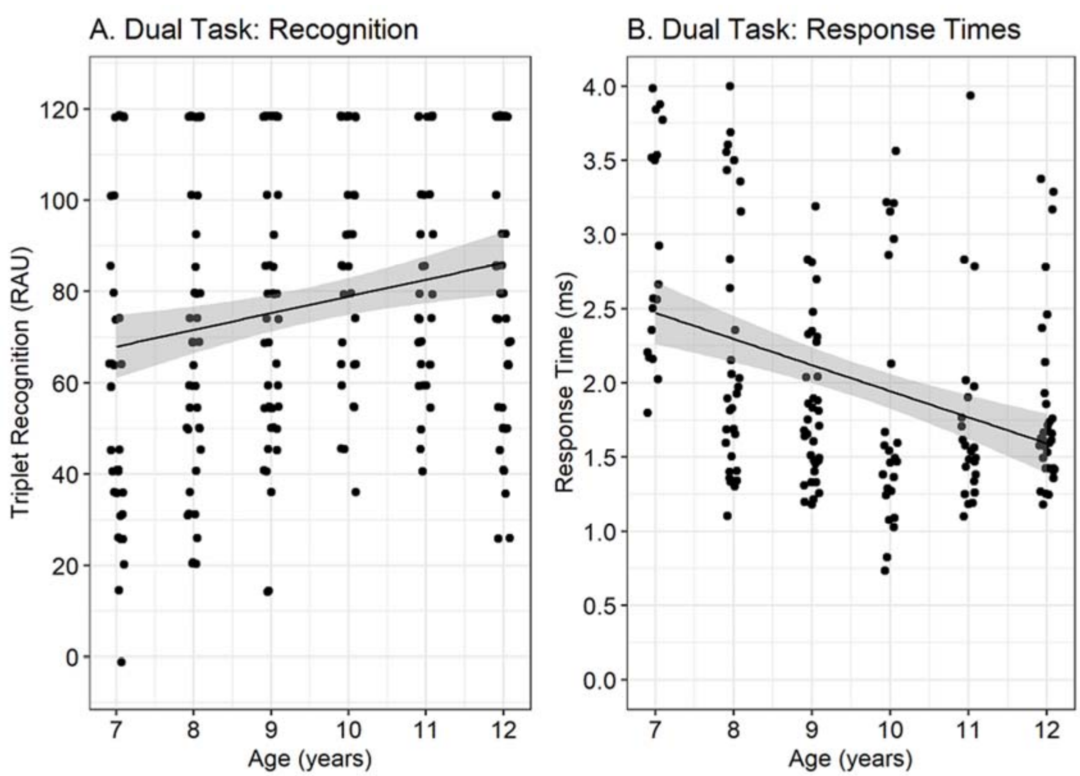

Figure 3. Triplet recognition performance and response times across participants' ages for the dual-task paradigm. RAU = rationalized arcsine units.

Discussion

The objective of this study was to explore the effects of SNR on listening effort in normal-hearing school-aged children with English native language and English as nonnative language as measured with a novel, low linguistic single- and dual-task paradigms. The effects of SNR, age, and language groups on digit triplet recognition and RTs will be considered separately below. It was hypothesized that speech recognition would decrease, and RTs would increase as SNR decrease and that the single-task paradigm would be more sensitive to the effects of SNR. It was also hypothesized that older children would have better speech-recognition-m-noise performance and that their RTs would be shorter than younger children. In addition, it was hypothesized that both low linguistic single- and dualtask paradigms would be unaffected by the possible effect of language differences on speech recognition as well as on RTs.

Effect of SNR on Digit Triplet Recognition and RTs

Recognition of digit triplets followed the expected pattern of poorer performance with decreasing SNR even for children with normal hearing (e.g. Bess et al., 1986; Crandell & Smaldino, 2000b).

The effects of SNR on RTs were evident with both the single- and dual-task paradigms. With both paradigms, increased RTs were evident between quiet and noise conditions as well as when the noise was increased from -10 dB SNR to -15 dB SNR. This pattern of results is consistent with previous reports, which indicate that increasing background noise increases RTs (dual task and/or single task), reflecting an in increase in listening effort in adults (Fraser et al., 2010; Picou et al., 2017; Picou & Ricketts, 2014; Picou et al., 2011, 2013; Sarampalis et al., 2009) and children (Gustafson et al., 2014; Howard et al., 2010; Hsu et al., 2017; Lewis et al., 2016; McGarrigle et al., 2019; Picou et al., 2019, 2017). The findings of this study are somewhat inconsistent with recent findings by McGarr&0131;gle et al. (2019) who demonstrated that verbal RTs (as a single-task measure) were more sensitive to changes in SNR than RTs during a dual-task paradigm in school-aged children.

Discrepancy in dual-task paradigm results across studies can be attributed to substantial methodological differences. The performance level achieved in the primary task may be a potential explanation of discrepancy in results among studies regarding the effect of SNR on listening effort as measured by dual-task paradigms (McGarrigle et al., 2019). According to Pichora-Fuller et al. (2016), a listening effort threshold exists, referring to the trend where RTs will generally increase until a speech recognition task becomes too difficult at which level listening effort will likely decrease as evident in faster RTs. This is also described as a point of cognitive overload (Wu et al., 2016). As noted by McGarrigle et al. (2019), the more challenging SNRs employed in their study (particularly for children with a hearing loss, resulting in < 50% word recognition) may have resulted in more frequent incidences of cognitive overload. In contrast with the findings of McGarrigle et al. (2019) of insignificant effects on listening effort with decreasing SNRs, the results of Howard et al. (2010) correspond with the current study results where significant effects of SNR on secondary task RTs were found. Interestingly, the targeted speech recognition scores of 50%-80% correct in the current study corresponded to scores found in the study by Howard et al. (2010) who also reported significant effects of SNR on listening effort in children with normal hearing. Thus, it is possible that a dual-task paradigm could be as sensitive to changes in SNR as a single-task measure if the targeted speech recognition performance is higher. However, in the study by Hicks and Tharpe (2002), the average word recognition performance of 85% resulted in nonsignificant effects of SNR in listening effort. Thus, the targeted speech recognition performance, SNRs, and type of material used in the primary and secondary tasks should be viewed as important methodological considerations for dual-task paradigms used in school-aged children. Furthermore, factors such as cognitive resource allocation and attention allocation abilities are associated with the interpretation of dual-task results, and these abilities are still developing in school-aged children and thus could contribute to the general variance in dual-task performance (McGarrigle et al., 2019).

Effect of Age on Digit Triplet Recognition and RTs

The effect of age on speech-recognition-in-noise abilities is evident in this study's results. These findings support results demonstrating speech-in-noise-recognition abilities for children with normal hearing continue to develop and improve into late childhood and adolescent years (Elliott, 1979; Koopmans et al., 2018). Adultlike performance for speech perception in noise can be reached between the ages of 10 and 12 years of age (Buss et al., 2006; Hall et al., 2004; Holder et al., 2016; Koopmans et al., 2018). This effect of age on speech perception in noise is also apparent in the current study with improved digit triplet recognition performance during both tasks as the children get older.

Age effects for RTs seen in the results were task specific as it was only evident during dual-task measures. It should be noted that the dual-task visual RTs demonstrated more variability than verbal RT from the single-task paradigm. The dual-task method relies on assumptions of cognitive resource allocation (Kahneman, 1973). However, as school-aged children could still show unpredictable attention or cognitive resource allocation, this may contribute to the overall performance variability as seen in the dual-task conditions that requires high-level attentional and cognitive processing compared with a simpler task of speech recognition alone (McGarrigle et al., 2019). The dual-task paradigm has ecological validity as multitasking is a common required skill in everyday classrooms situations and thus may be an important skill to be developed for academic progress. During dual-task measures, the faster RTs to visual stimuli that were evident with an increase in the age of the participants can be due to improved multitasking ability with age. This can reflect that dual-task measures are more sensitive to maturation effects whereas single-task measures appeared to be immune to the effect that age could possibly have on RTs. This is an important aspect that should be considered in study design in the pediatric population. Therefore, a single-task paradigm such as verbal RT measures could be used in school-aged children from the age of 7 years, whereas participant age needs to be accounted for with dual-task paradigms if participants are younger than 13 years old.

Effect of Language Group on Digit Triplet Recognition and RTs

The aim of the study was not to compare listening effort between native and nonnative English-speaking schoolaged children but rather to explore stimuli that can be useful in behavioral measures of listening effort in children from multilingual backgrounds. In terms of language group differences between the participants, there was no systematic effect of language group on triplet recognition or RTs, as hypothesized. These findings are inconsistent with behavioral measures of listening effort in adults who are nonnative listeners (Peng & Wang, 2019). This may relate to the fact that digits, used as speech stimuli, are universal concepts, have a low linguistic load, and are often even familiar to persons who do not speak the language (Potgieter et al., 2016). Furthermore, digit recognition stems from a closed set speech recognition task that is easier than an open-set speech recognition task that involves monosyllabic words. The results of this study indicate that the novel low linguistic single-task and dual-task paradigms can be performed on young school-aged children from a multilingual context.

Future Directions

There are several areas revealed by this study that warrant future direction. First, only children with normal hearing were included. Future studies should be done to determine if these novel low linguistic paradigms are sensitive behavioral measures of listening effort for school-aged children with hearing loss. Future studies can also consider including children younger than 7 years of age as digit recognition in noise abilities can emerge as young as the age of 4 years (Koopmans et al., 2018). The latter could result in a more comprehensive investigation on age-related changes in listening effort in the pediatric population. Second, the digit noise used was steady state and speech shaped. It did not contain temporal modulations or informational masking, both of which might affect listening effort (Desjardins & Doherty, 2013; Koelewijn et al., 2014). Future research should also consider the impact of different types of masker noise with these low linguistic listening effort paradigms (e.g., steady state, speech-shaped noise vs. informational masking noise). Although the speech and noise signals were presented from spatially separated loudspeakers, the fact that the noise presented from the side loudspeakers were identical, the perception might have been that of a centrally localized single noise source. Thus, participants could have perceived the speech and noise signals to be spatially coincident (Kendall, 2010). Future studies can explore the effects on speech recognition and listening effort where noise from side loudspeakers are uncorrelated.

It should be noted that there is a visual trend for the nonnative English group to perform slightly worse during the dual-task paradigm, but the effect size is small (np2 = .025; mean RT differences between language groups were ~302 ms across listening conditions). Future studies comparing listening effort between native and nonnative children with bigger participant numbers could help to better clarify the possible group difference. In addition, future studies should also consider using speech material with a higher linguistic load if the effect of language background on listening effort in school-aged children wants to be examined as it might result in more significant group differences between native versus nonnative children.

Conclusion

In total, the results of this study demonstrate that the single- and dual-task paradigms with low linguistic speech material can be sensitive to changes in listening condition (quiet vs. noisy conditions) for school-aged children between 7 and 12 years of age. Language background (English as native language vs. English nonnative language) had no significant effect on triplet recognition or RTs. Thus, these novel listening effort measures could be useful for evaluating listening effort in children from multilingual contexts. Furthermore, a maturation effect for speech recognition in noise and RTs (only with dual-task paradigm) is evident. The latter indicates that speech-in-noise recognition abilities improve with age for school-aged children, as expected. Furthermore, as multitasking skills develop, older children tend to exert less listening effort as reflected in shorter RTs during dualtask measures. Children have to develop important cognitive, language, and academic skills in the classroom. Therefore, the results also suggest that due consideration should be given to the negative effects of increased listening effort in acoustic challenging situations (e.g., classrooms with high noise levels) even for young school-aged children with normal hearing as it increases listening effort, which could deter academic learning.

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