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Auditory Temporal Resolution In Normal Hearing Preschool Children Revealed by Word Recognition In Continuous And Interrupted Noise[a]

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Abstract

The purpose of this study was to examine temporal resolution in normal hearing pre-school children. Word recognition was evaluated in quiet and in spectrally identical continuous and interrupted noise at signal-to-noise ratios (S/Ns) of 10, 0, and -10 dB. Sixteen children four to five years of age and eight adults participated. Performance decreased with decreasing S/N. At poorer S/Ns, participants demonstrated superior performance or a release from masking in the interrupted noise. Adults performed better than children, yet, the release from masking was equivalent. Collectively these findings are consistent with the notion that preschool children suffer from poorer processing efficiency rather than temporal resolution per se.

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I Introduction

The normal development of auditory temporal processing (i.e., resolution/acuity and integration/summation) in children has been of interest to psychoacousticians and clinicians. Temporal resolution refers to the ability of a listener's auditory system to resolve/separate auditory events or perceive changes in auditory stimuli over time. Temporal integration refers to the ability of a listener's auditory system to sum acoustic information over time to improve detection, recognition, or discrimination of stimuli.[1] Those examining normal auditory temporal processing development with various test paradigms have found that the performance of normal hearing infants and children is inferior to adults.[2]

For clinicians, understanding normal development is essential for determining if the perceptual capacity of a child is abnormal. Identification of impaired auditory temporal processing is a necessary precedent for rehabilitative measures for those that implicate an underlying temporal auditory processing deficit for some communicative impairments[3-5] or for those evaluating temporal processing as part of an auditory processing test battery.[6] The early identification of a temporal processing deficit could result in the ability to begin remediation programs for such impairments, perhaps even before a child reaches school age.

Stuart and colleagues[7-15] have utilized word recognition in spectrally identical continuous and interrupted broadband noise as a function of signal-to-noise ratio (S/N) to examine temporal resolution abilities of normal hearing and impaired listeners. Listeners experience a perceptual advantage or "release from masking" in interrupted noise. Since the noises differed only in temporal continuity, better performance in interrupted noise has been attributed to the ability of listeners to get glimpses or looks of each word between silent gaps and patch the information together in order to identify the specific word.[16-18] Any release from masking observed with listeners in the interrupted noise compared to the continuous noise, at equivalent S/Ns, is evidence of auditory temporal resolution. Assessing the auditory temporal resolution capacity between groups of listeners can be done by comparing overall performance in the interrupted noise and also by examining the amount of release from masking in the interrupted noise relative to the continuous noise.

Stuart[10] recently reported the development of word recognition in continuous and interrupted noise in 80 normal hearing children aged 6 to 15 years. Word recognition performance was evaluated in quiet and in continuous and interrupted noise at S/Ns of 10, 0, -10, and -20 dB. Children displayed better performance in the interrupted noise compared to the continuous noise at poorer S/Ns (i.e., < 10 dB) and performance increased with improving S/N. Performance also improved with increasing age. Younger children were more vulnerable to noise in that they required more favorable S/Ns to perform the same as older children and adults. Children's performance in noise equated adults after 11 years of age.

The purpose of this study was to examine word recognition performance of normal hearing pre-school aged children in continuous and interrupted noise relative to adult listeners. It was of interest to see whether children of this age demonstrate a temporal perceptual advantage in the interrupted noise condition. Ultimately, it was of interest to generate a normative base for word recognition performance in continuous and interrupted noise for children aged four to five years of age. As such, this data could be used as a clinical tool to assess auditory temporal processing ability of young preschool children. It was hypothesized that performance would improve with increasing S/N, performance in the interrupted noise would be better than in the continuous noise, and children would perform poorer than adults.

II Methods

A. Participants

Sixteen preschool children (5 males and 11 females) aged four to five years (*M* = 4.8, *SD* = 0.6) and eight young adults (5 males and 3 females; *M* = 23.9, *SD* = 2.4) participated. Children were solicited through their parents whom were faculty, staff, or students at East Carolina University, Greenville, NC. All participants presented with normal hearing sensitivity as defined by pure-tone thresholds at octave frequencies from 250 to 8000 Hz and spondee recognition thresholds of ≤ 20 dB HL[19] and normal middle ear function.[20] Participants were native speakers of English and had a negative history of speech, language, cognitive, learning and vision disorders. The children presented with an age equivalent receptive vocabulary score as assessed by the *Peabody Picture Vocabulary Test-Revised* - 3rd Edition.[21]

B. Apparatus and procedure

Northwestern University - Children's Perception of Speech[22] (NU-CHIPS, Auditec of St. Louis) monosyllabic words and custom competing continuous and interrupted noises served as test stimuli. The noises are described in detail elsewhere.[9,12,15] The interrupted noise was constructed with rectangular gated noise bursts and silent periods both with durations varying randomly from 5 to 95 ms. The noise duty-cycle for the interrupted noise was 0.50. All speech and noise files were normalized to have equal power. The long-term average spectra of both noises were the same.

The compact disc recordings of the stimuli were delivered through a dual disc compact disc player (Phillips Model CDR 765 K02) or two compact disk players (Sony Model CDP-

CE415) to a clinical audiometer (Grason Stadler GSI 61 Model 1761-9780XXE). Stimuli were presented monaurally, in a double wall sound-treated audiometric suite, to each participant's right ear through a supraaural earphone (Telephonics Model TDH-50P).

The NU-CHIPS speech stimuli were presented at 50 dB HL to the right ear of participants. Average presentation levels were 36.2 dB (SD = 3.4) and 44.0 (SD= 3.2) above the spondee recognition threshold for the children and adults, respectively. In no case was the presentation level less than 30 dB above the listener's spondee recognition threshold where age effects on performance are evident in children less than 10 years of age.[22] Eight half-lists (i.e., 25 monosyllabic words) of the four NU-CHIPS lists were employed. The speech stimuli were presented in quiet and in both noises at S/Ns of -10, 0, and 10 dB. List presentation order was counterbalanced while noise and S/N conditions were randomized across participants. Participants were instructed to point to the picture from a set of four alternatives (i.e., one stimulus and three foils) of the word that they heard.[22]

III Results

Participants' responses were scored as total whole word percent correct. Figure 1 illustrates the mean group word recognition performance in quiet and in both noises as a function of S/N and group. These proportional scores were transformed to rationalized arcsine units prior to inferential statistical analyses.[23] Violations of the analysis of variance (ANOVA) assumptions were examined before investigating differences in word recognition performance. Levene's Test of equality of error variance was significant ($p < .05$) for S/Ns of +10 for both noises and quiet. Consequently, scores for S/Ns at +10 for both noises were excluded from the omnibus analyses.

A three-factor mixed ANOVA was performed to investigate mean word recognition performance differences as a function of group, S/N, and noise condition. The results of that

ANOVA are displayed in Table 1. As expected significant main effects of group, noise and S/N were found indicating better performance by adults, better performance in the interrupted noise, and improvement in performance with increasing S/N. The significant noise by S/N interaction reflects the release from masking phenomenon. That is, as S/N deteriorates performance worsens more rapidly in the continuous noise versus the interrupted noise. The significant group by S/N interaction reflects the fact that adults' performance improves much more as S/N improves.

The extent of the release from masking that was experienced in the interrupted noise relative to the continuous noise was examined by computing a difference score where participants' scores in continuous noise were subtracted from their scores in interrupted noise at 0 and -10 dB S/N. All participants had better scores in the interrupted noise compared to continuous noise at -10 dB S/N, and with the exception of two listeners in each group, all scored better at 0 dB S/N. Those that scored better in the continuous noise at 0 dB S/N did so by only one or two words (i.e., 4% or 8%). These difference scores as a function of group and S/N are displayed in Figure 2. A two-factor mixed ANOVA was performed to investigate differences in mean word recognition difference scores as a function of group and S/N. A main effect of S/N was found [F (1, 22) = 19.05, $p < .0001$, $\eta^2 = .46$, $\phi = 0.99$] while a nonsignificant main effect of group [F (1, 22) = .001, $p = .98$, $\eta^2 = .00$, $\phi = 0.050$] and group by S/N interaction [F (1, 22) = 1.67, $p = .21$, $\eta^2 = .070$, $\phi = 0.24$] was found.

IV Discussion and Conclusions

As hypothesized, performance improved with increasing S/N, was superior in interrupted noise, and children performed poorer than adults. Most important was that children, as young as four to five years of age, demonstrated better performance in the interrupted noise relative to the continuous noise at the poorer S/Ns (i.e., < 10 dB). This is consistent with previous findings where normal hearing adult listeners experience a release from masking in interrupted noise with monosyllabic word recognition.[7-18, 24-26] This is the first demonstration in a preschool aged cohort of children of this phenomenon. Significant main effects of noise and S/N with word recognition and noise by S/N interaction in this test paradigm have been reported numerously with normal hearing adult listeners by Stuart and colleagues[7-15] and others.[16, 17, 26]

The results from this study are consistent with previous reports of three and five year old children with the same stimuli in quiet with a closed set response.[22] Performance in quiet and noise was superior to that of six to seven year olds reported by Stuart.[10] This is likely due to an open set response employed by Stuart.[10] Under similar listening conditions, NU-CHIPS performance is better in a closed versus an open set response mode.[22, 27] In only one other study utilizing the NU-CHIPS stimuli in continuous noise, Chermak et al.[28] reported a mean performance of approximately 72% for children between the ages of 9 and 10 years at 0 dB S/N with a closed set response mode. Considering that the older children in the Chermak et al.[28] study performed approximately the same as the younger four to five year olds in this study, one may suggest that differences in the recorded stimuli and competing continuous noise may have contributed to the fact that age differences were not evident. Overall preschool children performed poorer in noise compared to adults consistent with previous reports demonstrating that young children need greater S/Ns to perform at adult levels.[10, 22,27, 29-33]

The basis of performance differences between younger and older listeners remains a contentious issue. Two schools of thought exist[34-37]: One embraces the notion that children have a broader temporal window and therefore have poorer temporal acuity than older listeners (i.e., the “temporal resolution hypothesis”). The other suggests that children have poor processing efficiency (i.e., the “processing efficiency hypothesis”). Processing efficiency refers to factors "aside from temporal and spectral resolution, that affect the ability to detect acoustic signals in noise... [and] is measured by the threshold signal-to-noise ratio" (p. 2962).[35] Hartley and colleagues[34-37] suggest that children have more "internal noise" than adults and thus require higher effective S/N in order to perform equivalently. This is consistent with the fact that the peripheral auditory system is adult-like by four to six years of age,[36, 38, 39] but the central auditory system is less proficient.

The data herein support the poorer processing efficiency hypothesis. Although overall performance was worse with the children, the amount of release from masking was the same as adults. This same pattern was seen with school aged children reported by Stuart.[10] We computed difference scores at 0 and -10 dB S/N for the five groups of school aged children and adults from this previous study. A two-factor mixed ANOVA was performed to investigate differences in mean word recognition difference scores as a function of group and S/N. A main effect of S/N was found [F (1, 90) = 136.67, $p < .0001$, $\eta^2 = .60$, $\phi = 1.0$] while a nonsignificant main effect of group [F (5, 90) = 1.33, $p = .26$, $\eta^2 = .069$, $\phi = 0.45$] and group by S/N interaction was [F (5, 90) = 0.91, $p = .48$, $\eta^2 = .048$, $\phi = 0.31$] found. Thus, the apparent difference between preschool and school aged children less than 12 years of age is related to more general differences in their abilities to recognize speech in degraded listening conditions in which there are a number of contributors related to the development of central audition, language, and attention. As previously stated by Stuart[10], it is important to note that younger auditory systems are not impaired in any way, rather, that they are normally developing yet have poorer processing efficiency that impairs their performance in noise relative to older listeners. Further, their inferior performance compared to normal adults is not the same as the inferior performance seen in adult listeners with auditory pathologies reported by Stuart, Phillips and colleagues. Those with noiseinduced hearing loss[40], unilateral high-frequency hearing loss[11], retrocochlear demyelinating lesions[41], and presbyacusis[12] display overall poorer performance *and* a smaller release from masking the interrupted noise relative to young normal-hearing adults. This is consistent with poorer temporal resolution in these pathologies.

In summary, this investigation demonstrated that the word recognition in continuous and interrupted noise is poorer in preschool children than adults. The release from masking observed with these preschool children in the interrupted noise compared to the continuous noise was, however, equivalent to that of adults. Collectively these findings suggest a developmental difference in processing efficiency between preschool children and adults, rather than developmental differences in temporal resolution abilities. The findings do not, admittedly, address what perceptual process or processes are responsible for the inferior performance among these children. Further research is warranted to address this question in normal and particularly impaired children. That is, the mechanisms underlying communication disorders must be understood such that remediation strategies focus on improving those mechanisms. In terms of clinical implementation, concerning time restrictions and the difficulty of maintaining children's attention at this age, it is recommended that one administer separate lists at the -10 dB S/N for each noise condition. This would only take approximately 10 minutes and would provide the most information regarding the release from masking in the interrupted noise. One caveat to this approach is that care must be taken to ensure that word lists used are equivalent. Although the NU-CHIPS lists and half-lists are equivalent in quiet[22] they are not in continuous noise.[28] List equivalency of other word recognition material has not been demonstrated[9] with the same interrupted noise and should therefore not be expected with the NU-CHIPS stimuli until demonstrated otherwise.

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Table 1

Summary Table of A Three-Factor Mixed ANOVA Investigating Differences in Word Recognition Performance as A Function of Group, Noise, and S/N.

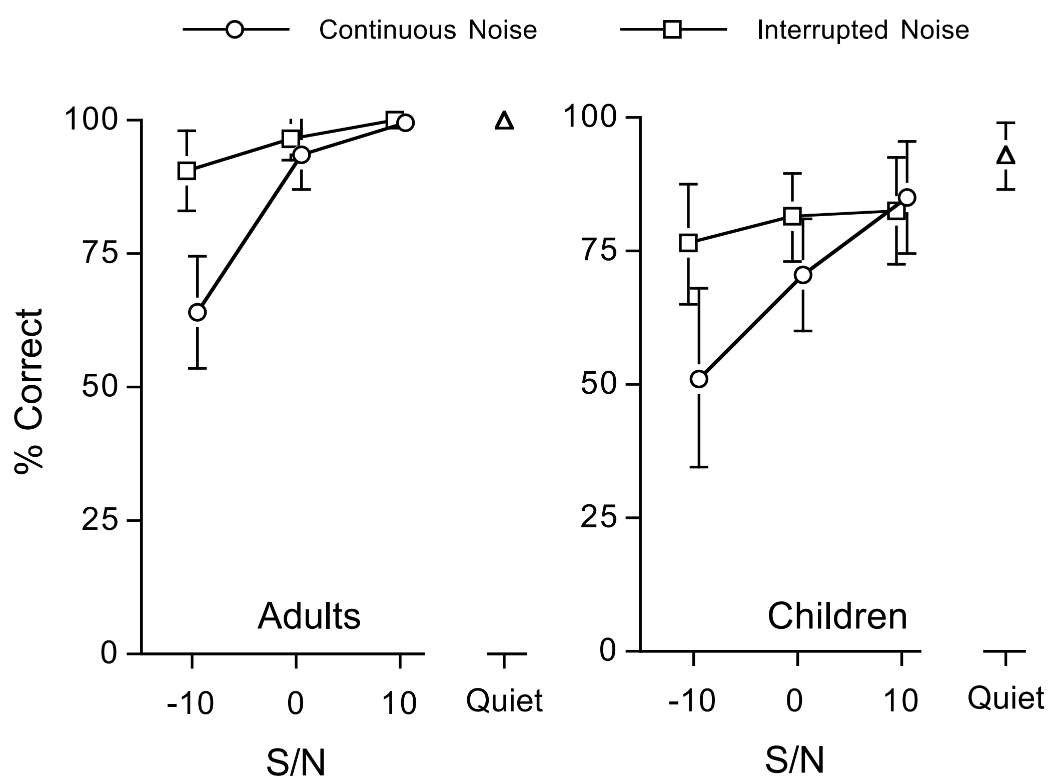
Source	*df*	*F*	*p*	η^2	ϕ
Group	1	31.22	<.0001*	.59	1.0
Noise	1	130.18	<.0001*	.86	1.0
S/N	1	65.19	<.0001*	.75	1.0
Noise X Group	1	0.001	.98	.00	.050
S/N X Group	1	7.49	.012*	.25	.74
Noise X S/N	1	19.05	<.0001*	.46	.99
Noise X S/N X Group	1	1.66	.21	.07	.24

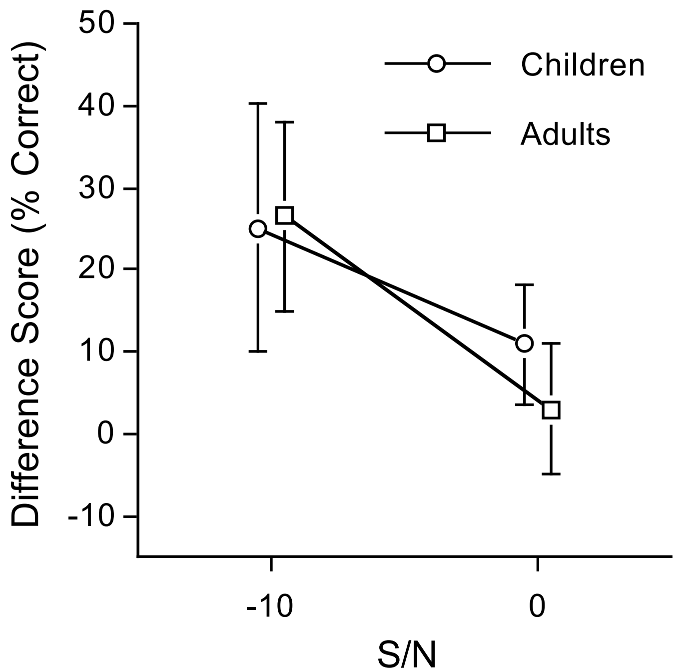
Note. *Significant at $p < .05$.

Figure Caption

Figure 1. Mean percent correct word recognition scores in quiet and noise as a function of group, noise type, and S/N. Error bars represent plus/minus one standard deviation of the mean.

Figure 2. Mean percent correct word recognition difference score (i.e., interrupted noise minus continuous noise score) as a function of group and S/N.


Continuous Noise
Interrupted Noise
% Correct
100
75
50
25
0
Adults
-10
0
10
Quiet
S/N
100
75
50
25
0
Children
-10
0
10
Quiet
S/N


Children
Adults
Difference Score (% Correct)
50
40
30
20
10
0
-10
-10
0
S/N