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Reception Thresholds for Sentences in Quiet, Continuous Noise, and Interrupted Noise in School-Age Children

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Abstract

Sentence recognition in noise was employed to investigate the development of temporal resolution in school-age children. Eighty children aged 6 to 15 years and 16 young adults participated. Reception thresholds for sentences (RTSs) were determined in quiet and in backgrounds of competing continuous and interrupted noise. In the noise conditions, RTSs were determined with a fixed noise level. RTSs were higher in quiet for six- to seven-year-old children (p = .006). Performance was better in the interrupted noise evidenced by lower RTS signal-to-noise ratios (S/Ns) relative to continuous noise ($p < .0001$). An effect of age was found in noise ($p < .0001$) where RTS S/Ns decreased with increasing age. Specifically, children under 14 years performed worse than adults. "Release from masking" was computed by subtracting RTS S/Ns in interrupted noise from continuous noise for each participant. There was no significant difference in RTS S/N difference scores as a function of age (p = .057). Children were more adversely affected by noise and needed greater S/Ns in order to perform as well as adults. Since there was no effect of age on the amount of release from masking, one can suggest that school-age children have inherently poorer processing efficiency rather than temporal resolution.

Key Words: Auditory development, children, noise, sentence recognition, temporal resolution

Abbreviations: HINT-C = *Hearing in Noise Test for Children*; RTS = reception threshold for sentences; S/N = signal-to-noise ratio

Sumario

Se utilizó el reconocimiento de frases en ruido para investigar el desarrollo de la resolución temporal en niños de edad escolar. Dieciocho niños con edades entre 6 y 15 años y 16 adultos jóvenes participaron. Los umbrales de recepción de frases (RTS) se determinaron en silencio y ante ruidos de fondo de competencia, continuos o interrumpidos. En condiciones de ruido, los RTS se determinaron contra un nivel fijo de ruido. Los RTS fueron más alto en silencio para los niños de seis a siete años de edad (p = .006). El desempeño fue mejor en medio de ruido interrumpido, con una tasa señal/ruido (S/N) menor para RTS, en relación al ruido continuo ($p < .0001$). Un efecto de la edad se encontró en medio de ruido ($p < .0001$) donde la S/N para RTS disminuyó conforma aumentó la edad. Específicamente, los niños menores de 14 años de edad funcionaron peor que los adultos. Se computó "liberación del enmascaramiento" sustrayendo las S/N para RTS en ruido interrumpido, de las de ruido continuo para cada participante. No existieron diferencias significativas en los puntajes de diferencia de las S/N para RTS como función de la edad (p = .057). Los niños se vieron más adversamente afectados por el ruido y necesitaron de

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mayores S/N para rendir tan bien como los adultos. Dado que no existió un efecto de la edad en la cantidad de liberación del enmascaramiento, uno puede sugerir que los niños de edad escolar tienen una eficiencia de procesamiento inherentemente más pobre que su resolución temporal.

Palabras Clave: Desarrollo auditivo, niños, ruido, reconocimiento de frases, resolución temporal

Abreviaturas: HINT-C = *Prueba de Audición en Ruido para Niños*; RTS = umbral de recepción para frases; S/N = tasa señal/ruido

It is generally accepted that the capacity of normal-hearing children to recognize speech, relative to the ability of adults, is more adversely affected in conditions of competing continuous noise and reverberation in isolation or in combination (Finitzo-Hieber and Tillman, 1978; Elliott, 1979; Elliott et al, 1979; Elliot and Katz, 1980; Nabelek and Robinson, 1982; Neuman and Hochberg, 1983; Bradley, 1986; Yacullo and Hawkins, 1987; Papso and Blood, 1989; Nittrouer and Boothroyd, 1990; Eisenberg et al, 2000; Johnson, 2000; Fallon et al, 2002; Hall et al, 2002; Blandy and Lutman, 2005; Litovsky, 2005; Nittrouer, 2005; Stuart, 2005; Stuart et al, 2006). The performance of children does not equal that of adults until around 10 to 12 years of age or when listening in more favorable signal-to-noise ratios (S/Ns) for younger age listeners (Marsh, 1973; Elliott, 1979; Elliott et al, 1979; Elliot and Katz, 1980; Papso and Blood, 1989; Eisenberg et al, 2000; Johnson, 2000; Stuart, 2005). Listening performance of children in adverse conditions of competition is exacerbated by an array of coexisting conditions including auditory processing disorder (Cameron et al, 2006), listening through a second language (Crandell and Smaldino, 1996; Nelson et al, 2005), history of recurrent otitis media (Jerger et al, 1983; Schilder et al, 1994; Hall et al, 2003), learning disability (Elliott et al, 1979; Bradlow et al, 2003), and/or attention-deficit hyperactivity disorder (Pillsbury et al, 1995).

Evaluating speech recognition in a background noise that fluctuates in level or intermittency or both is attractive for two reasons. First, relative to continuous background noise, it has more face validity since fluctuating competitors are more characteristic of what is encountered in situations in daily living. Second, it allows the examination of one aspect of auditory temporal resolution. That is, when the level or temporal continuity of the competitor is interrupted or amplitude modulated, listeners experience a perceptual advantage or "release from masking" that reflects the temporal ability of the listener to resolve speech fragments or get "glimpses" or "looks" of speech between the dips or gaps of noise that facilitates the identification of specific speech stimuli (Miller, 1947; Miller and Licklider, 1950; Dirks et al, 1969). Simply put, listeners take advantage of temporary changes in what would otherwise be continuous noise (for a review see Stuart and Phillips, 1998). The extent of the release from masking experienced by a listener in interrupted noise is dependent on the S/N, acoustic spectrum of the competing interrupted noise, temporal continuity or interruption rate of the competitor, and speech material.

Miller (1947) was the first to report on the effectiveness of an "interrupted" masker. In his seminal study he found that word recognition performance with normal hearing adult listeners improved with a reduction in the duty cycle of the interrupted white noise masker. Compare word recognition scores of approximately 5, 60, 75, 90, and 100% for noise-on-times of 100, 80, 65, 50, and 25%, respectively, for a S/N of -6 dB. Miller and Licklider (1950) first reported the effect of the interruption rate of masking noise on word recognition performance. Performance improved when the rate of interruption increased from 1 to 10 Hz. With further increases in interruption, word recognition performance decreased, however, as the interrupted noise essentially becomes a continuous in nature (i.e., the interruptions cannot be resolved). Word recognition performance was reported to be fundamentally the same whether interruptions were regular or random. Others have reported significant improvements in word recognition performance with normal hearing adults in interrupted noise compared to continuous noise at comparable S/Ns (e.g., Pollack 1954, 1955;

Carhart et al, 1966; Wilson and Carhart, 1969; Phillips et al, 1994; Rappaport et al, 1994; Stuart et al, 1995; Stuart and Phillips, 1996, 1997, 1998; Scott et al, 2001; Elangovan and Stuart, 2005).

The effect of interrupted masking on sentence intelligibility has also been reported. Similar to word recognition, a release from masking is observed with sentence recognition in interrupted noise relative to continuous noise (Calearo et al, 1962; Dirks et al, 1969; Nelson et al, 2003). In general, sentence recognition performance decreases as interruption rates increase and S/Ns decrease. However, an interaction exists between interruption rate, S/N, and masker level with word and sentence recognition in interrupted noise. Employing an interrupted noise with a with a duty cycle of 50%, Dirks et al (1969) examined the effect of interruption rate (i.e., 1, 10, and 100 Hz) and masking level (i.e., 50 and 90 dB SPL) as a function of S/N. First, the greatest release from masking occurred at the 1 Hz condition and decreased with increasing interruption rates for sentences at favorable S/Ns. For monosyllabic words, however, the greatest release from masking occurred at 10 Hz, followed by 1 and 100 Hz. The slope and shape of the intelligibility functions also differed. For the 100 Hz interruption rate, as the S/Ns deteriorated, performance intelligibility functions for both words and sentences resembled that found with continuous noise. With the 1 and 10 Hz interruption rates, performance intelligibility functions for sentences paralleled that of the 100 Hz rate. The performance intelligibility functions for words at the 1 Hz rate also paralleled that of the 100 Hz rate. With the 10 Hz interruption rate, performance intelligibility function for words resembled that found with continuous noise at favorable S/Ns, and then with decreasing S/Ns the slope flattened and proceeded to drop gradually. Two other differences were evident with the performance intelligibility functions for sentences and words. At the interruption rates of 1 and 100 Hz, the slopes of the sentence intelligibility functions tended to be higher. Second, regardless of interruption rate or masker intensity, sentence recognition performance was always superior to word recognition performance at equivalent S/N. These latter two points of difference have been attributed to the higher redundancy of sentence materials relative to monosyllabic words (Dirks et al, 1969; Dirks and Bower, 1971).

Sentence reception thresholds have been reported to be lower in competing interrupted white noise contrasted to continuous white noise in adults (Bacon et al, 1998; Rhebergen et al, 2006) and teenage children aged 13 to 17 years (de Laat and Plomp, 1983). In a comprehensive study, Rhebergen et al (2006) demonstrated that sentence reception thresholds worsen with increasing interruption rates (i.e., from 8 to 128 Hz) and increasing duty cycles (i.e., from 40 to 60%). An adaptive procedure was used to estimate the S/N at which sentences could be recognized at 50%. With a duty cycle of 50%, sentence reception thresholds decreased from -17.6 to -5.4 dB with interruption rates of 8 and 128 Hz, respectively. With an interruption rate of 8 Hz, sentence reception thresholds decreased from -22.8 to -11.7 dB with duty cycles of rates of 40 and 60%, respectively.

Although the effects of interrupted noise masking on speech recognition have been explored extensively with adult listeners, little work has been done with children. This recently changed with two reports by Stuart and colleagues (Stuart, 2005; Stuart et al, 2006). Word recognition performance of normal hearing preschool and school-age children with continuous and interrupted noise was investigated in an effort to reveal the development of temporal resolution. Specifically, word recognition in spectrally identical continuous and interrupted broadband noise as a function of S/N was evaluated. Since the noises differed only in temporal continuity and not spectral structure, differences in performance in interrupted relative to the continuous noise were interpreted as the ability or inability of a child to take advantage of the time structure of the interrupted masker. In this paradigm, assessing similarities or differences in temporal resolution between children and adults was done by both comparing overall performance in the interrupted noise and by examining the amount of release from masking in the interrupted noise relative to the continuous noise at equivalent S/Ns (i.e., computing a difference score where listeners' scores in continuous noise were subtracted from their scores in interrupted noise at equivalent S/Ns).

In the first study, Stuart (2005) examined word recognition performance of 80 normal hearing children between 6 and 15 years in continuous and interrupted noise at S/Ns of 10, 0, -10, and -20 dB. As expected, children performed better in interrupted noise compared to the continuous noise at poorer S/Ns (i.e., <10 dB), and performance improved with improving S/N and increasing age, irrespective of the type of background noise. Younger children were more vulnerable to noise in that they required more favorable S/Ns to perform the same as older children and adults. By 12 years of age, children performed as well as adults. In a second study, Stuart et al (2006) found the exact pattern with 16 four- to five-year-olds in the same noises with S/Ns of 10, 0, and -10 dB: Preschool children experienced a release from masking in the interrupted noise, performance was better with more favorable S/Ns, and they performed poorer than adults. Interestingly, although overall performance was worse with both the preschool and school-age children, the amount of release from masking (i.e., the difference score between interrupted and continuous noise) was the same as adults.

Recently, Hartley and colleagues (Hartley et al, 2000, 2003; Hartley and Moore, 2002; Hill et al, 2004) tackled the issue of "opposing hypotheses" with respect to auditory temporal development and temporal masking (i.e., forward and backward). Their examination of auditory temporal masking is relevant to this discussion as temporal masking influences performance in interrupted noise (i.e., the silent intervals are susceptible to forward and backward masking). Developmental changes in performance in interrupted noise parallels that of forward and backward masking performance in school-age children (Buss et al, 1999). One hypothesis, for developmental difference, is that children have poorer temporal resolution ability (i.e., the "temporal resolution hypothesis"). This view embraces the notion that children have a broader temporal window and therefore have poorer temporal acuity than older listeners. This is based on a four-stage linear model of temporal resolution. The four stages include a bank of filters, each followed by a nonlinear device (e.g., half wave rectification or square wave operation), temporal integrator or window, and a decision device (Rodenburg, 1977; Viemeister, 1979; Moore, 1993, 2003). The first two stages of these models are theorized as in the periphery (i.e., cochlea) while the subsequent levels are modeled to be the central auditory system (i.e., at the auditory nerve and above). On the other hand, Hartley and colleagues espouse 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" (Hartley and Moore, 2002, p. 2962). Hartley and colleagues suggested that children have poor processing efficiency and need a higher S/N than older listeners to detect a signal. In other words, the output of the temporal window or temporal excitation pattern must be larger in younger children in order to detect a signal. They proposed that school-age children and adult performance in temporal masking tasks could better be explained by poorer processing efficiency rather than temporal resolution per se. That is, a model where the temporal window for both adults and older school-aged children was the same but children had with poorer efficiency could best describe the data from their temporal masking studies. The difference on temporal masking tasks could be predicted by the inherent compressive nonlinearity of the basilar member or second stage in the temporal model. That is, in nonsimultaneous masking the signal and masker are not compressed independently. For an effective internal increase of the signal in the central auditory system of 5 to 6 dB, an increase in signal level in the periphery of 25 to 40 dB is required assuming a compression ratio of approximately 5:1 (for a detailed discussion see Hartley et al, 2000, 2003; Hartley and Moore, 2002; Hill et al, 2004). Hill et al suggested that children have more "internal noise" than adults and thus require higher effective S/N in order to perform equivalently. This in turn explains why children perform poorer on tasks of temporal auditory resolution.

The data from Stuart (2005) and Stuart et al (2006) supports the poorer processing efficiency hypothesis. Although performance overall was worse with the children, the amount of release from masking was the same. The ability to resolve speech fragments or get glimpses of information in the silent gaps between successive bursts of noise must be the same in both children and adults (i.e., temporal resolution is the equivalent). Thus, the apparent difference between preschool and school-age 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.

In this study, the first goal was to examine sentence recognition in noise as a means to investigate auditory temporal resolution development in young children and assess the above opposing hypotheses. There are no reports of sentence recognition in children with a competing interrupted noise masker. Although similarities in performance with adults while listening to words and sentences exist as outlined above, this has not been demonstrated with school-age children. A second goal was to examine the feasibility of sentence recognition in noise as a clinical tool to assess auditory temporal processing ability of young children. The use of sentences has been advocated as having more face validity than words. Further, it may prove to be more time efficient than measuring complete psychometric functions while varying S/N with word recognition. Toward that end, the *Hearing in Noise Test for Children* (HINT-C; Nilsson et al, 1996) was utilized. This test employs an adaptive procedure as a fast and accurate means of determining reception thresholds for sentences (RTSs) and therefore is attractive clinically as being more efficient than using word lists. Specifically, the maturational time course of RTSs in quiet and in continuous and interrupted noise in normal hearing school-age children was determined and compared to young adults. Consistent with previous performance in interrupted noise (Stuart, 2005; Stuart et al, 2006), it was hypothesized that performance would be poorer in children than adults (i.e., RTSs would be higher); sentence recognition performance would reach an asymptote to adult levels sooner in quiet than in noise; and performance would be superior in the interrupted noise (i.e., RTS S/Ns would be lower, evidence of a release from masking). If the processing efficiency hypothesis holds, one would predict that RTS S/Ns for younger children would be greater than that of adults and that eventually they would equal that of adults and older children. The release from masking, however, would be the same across all age groups (i.e., differences in RTS S/Ns between continuous and interrupted noise would be the same across children and not be different than adults). If the temporal resolution hypothesis holds, one would also predict that RTS S/Ns for younger children would be greater than that of adults and that eventually they would equal that of adults with older children. The release from masking, however, would significantly improve with increasing age (i.e., differences in RTS S/Ns between continuous and interrupted noise would be the increase with age reflecting improved release from masking).

METHOD

Participants

Five groups of 16 children and one group of 16 young adults participated (n = 96). The groups of children ranged in age from 6:0 to 7:11 (years:months), 8:0 to 9:11, 10:0 to 11:11, 12:0 to 13:11, and 14:0 to 15:11.[1] All participants presented with normal hearing sensitivity defined by pure-tone thresholds at octave frequencies from 250 to 8000 Hz and spondee recognition thresholds of ≤20 dB HL (American National Standards Institute, 1996) and normal middle ear function (American Speech-Language-Hearing Association, 1997). Participants had a negative history of speech, language, and learning disorders as per parental report.

Apparatus

The stimuli employed consisted of a compact disc recording of the HINT-C (House Ear Institute - Q Sound) and a custom compact disc recording of competing backgrounds of continuous and interrupted noises. The sentence stimuli consisted of 13 lists of 10 sentences, which are appropriate for children as young as six years of age (Nilsson et al, 1996). The competing continuous and interrupted broadband noises have been described in detail elsewhere (Stuart and Phillips, 1996, 1998; Stuart, 2004). Briefly, both noises had in effect equal long-term average spectra, were normalized to have equal power, and differed only in their temporal structure. The interrupted noise had a rectangular on/off envelope with randomized gating. The noise duty cycle was 0.50. The interrupted noise was characterized with noise bursts, and silent periods between them, with durations of both varying randomly from 5 to 95 msec.

The test environment was a double wall sound-treated audiometric suite. The recorded stimuli were routed from a dual-disc compact disc player (Phillips Model CDR 765 K02) to a clinical audiometer (Grason Stadler GSI 61 Model 1761-9780XXE) and presented monaurally to the right ear of each participant through an insert earphone (Etymotic Research Model ER-3A). The same noise tracks were linked with the sentence materials to assure that all listeners had the same competing stimuli.

Procedure

RTSs were determined in quiet and in both backgrounds of competing noise. Ten sentence lists were employed with all conditions.[2] An adaptive technique, consistent with the test administration manual, was employed. In quiet, the test began with the first sentence presented at 20 dB HL. The presentation level increased in 4 dB increments until the sentence was repeated correctly. The sentence was presented 4 dB below the starting level with sentences three and four bracketed either up or down in 4 dB steps depending if the preceding sentence was incorrect or correct, respectively. Sentences five to ten followed in the same manner except the step size was 2 dB. An 11th sentence was not presented, but its presentation level, if there was one, was determined by the response on sentence 10 (i.e., 2 dB lower if correct or 2 dB higher if incorrect). RTSs were determined by averaging the presentation levels of the fifth to eleventh sentences. This value represented the presentation level at which sentences could be recognized 50% of the time (Nilsson et al, 1996). In the noise conditions, RTSs were determined with the same adaptive procedure. The level of the noises was fixed at 50 dB sensation level with reference to the spondee recognition threshold of each participant.[3] The starting presentation level of the first sentence began at -5 dB S/N. The S/N was determined at which the RTS was achieved by subtracting the presentation level of the noise from the averaged RTS presentation level of the fifth to eleventh sentences. The presentation order of quiet and noise conditions were counterbalanced across participants while HINT-C lists were randomized.[4]

RESULTS

Mean RTSs in quiet as a function of group are presented in Figure 1. A one-factor analysis of variance (ANOVA) was undertaken to investigate mean differences of RTS in quiet as a function of age group. A significant age group effect was found [F (5, 90) = 3.45, p = .0067, η^2 = .16, ϕ = .90]. A post hoc analysis was performed with a one-tailed Dunnett t-test (Dunnett, 1955). The Dunnett t-test, while controlling for familywise error, compares differences between a control group (i.e., the adults) and experimental groups (i.e., all five groups of children). This analysis revealed a significantly higher mean RTS for the six- to seven-year-old group only (p = .006). In other words, by eight years of age the performance of children in quiet was the same as the performance of adults (p > .05).

Mean RTS S/Ns (in dB) as a function of group and competing noise are presented in Figure 2. A two-factor mixed ANOVA was employed to investigate differences in RTS S/Ns as a function of age group and competing noise. The analysis revealed significant main effects of age group [F (5, 90) = 18.27,

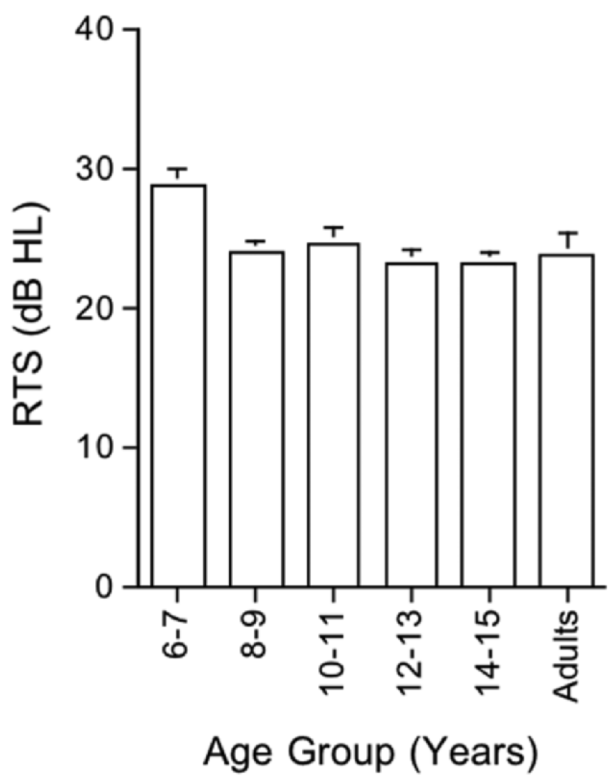

Figure 1. Mean RTSs (dB HL) in quiet as a function of age group (n = 96). Error bars represent plus one standard error of the mean.

$p < .0001$, $\eta^2 = .50$, $\phi = 1.00$] and noise [F (1, 90) = 508.62, $p < .0001$, $\eta^2 = .85$, $\phi = 1.00$]. The age group by noise interaction was not significant [F (5, 90) = 2.24, $p = .057$, $\eta^2 = .11$, $\phi = .71$]. That is, RTS S/Ns were lower in the interrupted noise, and RTS S/Ns decreased with increasing age. Post hoc analyses in the form of a one-tailed Dunnett t-test revealed significantly lower mean RTS S/Ns for the four youngest groups ($p < .0001$). In other words, by 14 to 15 years of age, performance of children in noise was the same as the performance of adults ($p > .05$).

To examine the extent of the release from masking that was experienced by listeners in the interrupted noise relative to the continuous noise, a difference score was computed in which participants' RTS S/Ns in interrupted noise were subtracted from their scores in continuous noise. These mean difference scores as a function of group are displayed in Figure 3. A one-factor ANOVA was performed to investigate differences in mean RTS S/N difference scores as a function of group. A main effect of group was not significant [F (5, 90) = 2.24, $p = .057$, $\eta^2 = .11$, $\phi = 0.71$].

DISCUSSION

Consistent with the initial hypotheses, three findings were demonstrated. First, performance was superior in the interrupted noise evidenced by lower RTS S/Ns relative to RTS S/Ns in continuous noise. This is consistent with previous data in which speech reception thresholds for sentences have been found to be significantly lower when presented in interrupted compared to continuous noise (de Laat and Plomp, 1983; Bacon et al, 1998; Rhebergen et al, 2006). Second, performance was poorer in younger children than adults in both quiet and noise. However, only the youngest group of children (i.e., six- to seven-year-olds) performed significantly poorer than adults in quiet. This is consistent with previous reports utilizing different speech materials. Performance improvements in speech recognition up to 13 years of age have been reported in quiet for children specifically for the HINT-C (Nilsson et al, 1996) and up until 10 years of age for other materials (Sanderson-Leepa and Rintelmann, 1976; Elliot et al, 1979; Elliot and Katz, 1980; Papso and Blood, 1989; Stuart, 2005). Different materials employed by various

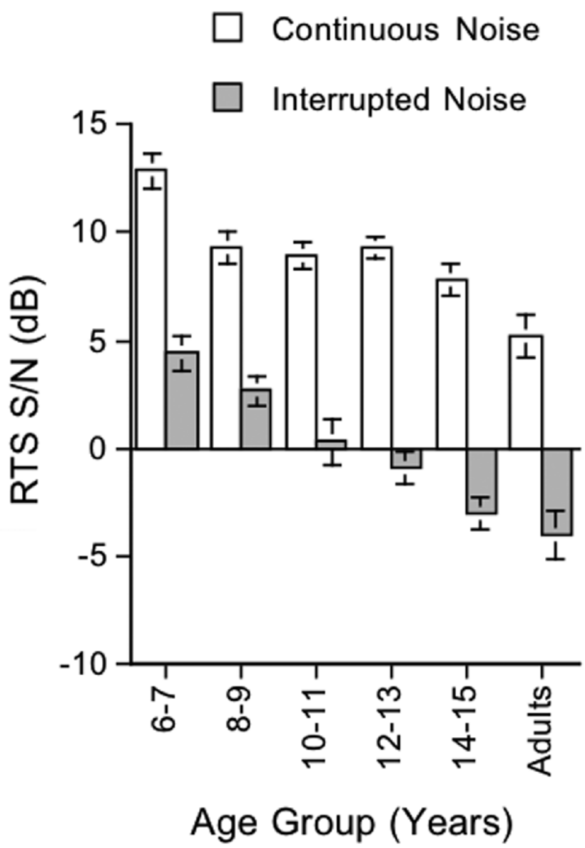

Figure 2. Mean RTS S/Ns (dB) in competing noise as a function of group ($n = 96$). Error bars represent plus/minus one standard error of the mean.

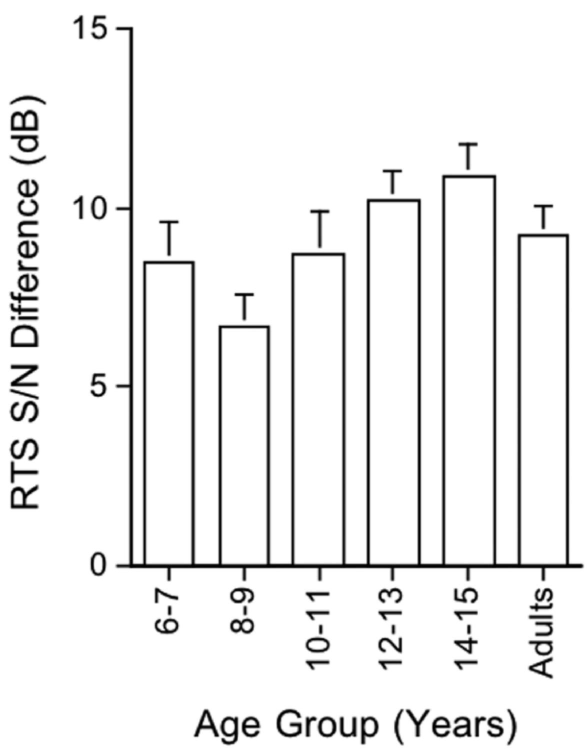

Figure 3. Mean RTS S/Ns (dB) difference scores (i.e., continuous noise minus interrupted noise score) as a function of age group ($n = 96$). Error bars represent plus one standard error of the mean.

researchers may influence when the performance of children equals that of adults. Children were also more adversely affected by noise, and they needed greater S/Ns to perform at adult levels. This is similar to numerous previously reported data (Marsh, 1973; Finitzo-Hieber and Tillman, 1978; Elliott, 1979; Elliott et al, 1979; Elliot and Katz, 1980; Bradley, 1986; Papso and Blood, 1989; Nittrouer and Boothroyd, 1990; Eisenberg et al, 2000; Johnson, 2000; Fallon et al, 2002; Hall et al, 2002; Blandy and Lutman, 2005; Litovsky, 2005; Nittrouer, 2005; Stuart, 2005; Stuart et al, 2006). The poorer performance in noise cannot be attributed to linguistic competency since only the youngest group displayed poorer performance in quiet. Third, word recognition performance reached an asymptote to adult levels sooner in quiet than in noise. RTSs in quiet and competing noise for children reach adult values after 7 and 13 years of age, respectively. The trend of maturation of listening abilities in competition has been reported to occur at approximately 10 to 12 years of age (Marsh, 1973; Elliott, 1979; Elliott et al, 1979; Elliot and Katz, 1980; Papso and Blood, 1989; Eisenberg et al, 2000; Johnson, 2000; Stuart, 2005). These findings are also consistent with previous reports utilizing different paradigms demonstrating that the temporal resolution capacity of children approaches that of adults beyond 10 years of age (Davis and McCroskey, 1980; Maxon and Hochberg, 1982; Irwin et al, 1985; Elliott, 1986; Cranford et al, 1993; Elfenbein et al, 1993; Grose et al, 1993; Buss et al, 1999).

What is the answer to the question “Is temporal resolving capacity of children, revealed by reception threshold for sentences in noise, inferior to adults?” If one looks strictly at overall performance in interrupted noise (i.e., RTS S/Ns), then for at least the younger children under 14 years of age, the answer is yes. If one looks at the amount of the release from masking, however, then the answer is no for all of the children regardless of age. There were no significant differences between groups of listeners in the release from masking, indexed by the difference scores where RTS S/Ns in interrupted noise were subtracted from scores in continuous noise. This observation supports the processing efficiency hypothesis. An additional piece of evidence was the fact that the analysis of differences in RTS S/Ns as a function of age group and competing noise failed to demonstrate a significant interaction of these two main effects. Collectively these two findings are consistent with the notion that school-age children have inherently poorer processing efficiency rather than inferior temporal resolution per se. The findings as well are contrary to the predictions from the temporal resolution hypothesis outlined above. Namely, one would have predicted, in addition to performance being poorer in younger children than in adults (i.e., RTS S/Ns be higher in children), the release from masking would significantly improve with increasing age. This would have been revealed in a group effect for differences in RTS S/Ns as a function of age and a significant interaction of the two main effects of group and noise in the analysis of RTS S/Ns (i.e., an increasing improvement in the RTS S/Ns in interrupted noise with increasing age).

The source of the developmental differences in processing efficiency that contributes to the discrepancy between children and adults while listening in interrupted noise has been ascribed to central auditory system maturation and not factors in peripheral development (Stuart, 2005). It was noted above that peripheral auditory filters are adultlike by four to six years of age with respect to temporal (Allen et al, 1989; Grose et al, 1993; Hall and Grose, 1994; Hartley et al, 2000) and spectral resolution (Hall and Grose, 1991). The inability of children to recognize speech in degraded listening conditions demands a higher S/N for children to perform at the same level as an adult. More “internal noise” in the form of elevated neuronal noise in the central temporal excitation pattern (i.e., output of the temporal window) and less efficient attention strategies have been suggested as contributors to poorer S/N in children (Hill et al, 2004). It appears that acoustic pattern recognition differences, except in children between five and seven years (Eisenberg et al, 2000), and perceptual weighting strategies in perceptual attention for recognizing speech in noise (Nittrouer, 2005) do not appear to contribute to the differences between children and adults. Recently, Buss et al (2006) reported that the performance differences between school-age children between 5 and 10 years of age and that of adults for two tasks (i.e., tone-in-noise and intensity discrimination) were consistent with the hypothesis that greater levels of internal noise limit the performance of children. Their assumption was that although the source of the noise is unknown, it must be related to "the physiological limitations associated with the encoding of the cues underlying performance" (p. 2785) and "a refinement in the auditory ability may appear to emerge at different ages simply by virtue of their sensitivity to one or a small set of variables underlying internal noise" (p. 2786).

Two points, with respect to the amount of release from masking observed in this study are worth comment. First, the observed mean release from masking collapsed across age groups was 9.0 dB (see Figure 3). This is generally less than those previously reported. For example, de Laat and Plomp (1983) reported differences in sentence reception thresholds between continuous and interrupted noise among 10 teenage normal hearing participants aged 13 to 17 years ranging from approximately 22 and 30 dB. The two competing noises presented at 85 dBA had the same spectrum of the sentences used to determine the sentence reception thresholds. The interruption rate was 10 Hz with a 50% duty cycle. They did not report the specific sentence materials employed. Bacon et al (1998) reported a 15 dB release from masking in sentence reception thresholds with 11 normal hearing adults found in interrupted speech shaped noise (i.e., with a duty cycle of 50% and interruption rate of 10 Hz) presented at 70 dB SPL relative to continuous speech shaped noise. Both noises were presented at 70 dB SPL. HINT sentence materials were used (Nilsson, 1994). Rhebergen et al (2006), utilizing sentence materials developed by Versfeld et al (2000), reported a release from masking in interrupted noise with a duty cycle of 50% of 17.6, 15.0, 11.1, 7.5, and 5.4 with interruption rates of 8, 16, 32, 64, and 128, respectively. The noises had long-term average spectrums equal to the sentence materials and were presented at a level 65 dBA. Clearly, differences in procedures (e.g., spectrum of competing noises, sentence materials, interruption rates, and presentation levels) contribute to differences in the amount of release from masking found across studies. A second issue with the release from masking is how the same cohort of participants compared in their performance across different speech materials (i.e., with monosyllabic words in Stuart [2005] and sentences herein). A direct comparison with the data from Stuart (2005) is not possible due to the nature of the differing test paradigms. The release from masking in the previous study was expressed by computing a difference score where word recognition scores in continuous noise were subtracted from scores in interrupted noise as a function of S/N. Recall the release from masking in this study was a difference in RTSs in continuous and interrupted noise. The amount of release from masking in the previous study was dependent on S/N. Stuart (2005) found mean differences scores (i.e., differences in percent correct as an index of release from masking) collapsed across age groups of 19.7, 6.2, and -0.80% for S/Ns of -10, 0, and +10 dB, respectively.[5] Recall from above, the mean release from masking in this study was 9.0 dB in RTS differences. What was consistent, however, across studies was the fact that there was no significant age effect on the amount of masking release in the same listeners measured with two paradigms and expressed by two different indices.

Finally, relative to the second goal, this data is promising in demonstrating the feasibility of sentence recognition in noise as a clinical tool to assess auditory temporal processing ability of young children. Administration of four 10-sentence lists (i.e., one practice list and one each in quiet, continuous noise, and interrupted noise) can easily be administered in less than 10 minutes. The data herein can serve as a normative base for RTS S/Ns performance in continuous and interrupted background noise for children aged 6 to 15 years of age. This could be of particular interest for assessing a child with suspected auditory temporal resolution deficits and central auditory processing disorders. Also, this data serves those who advocate improved classroom acoustics (e.g., Picard and Bradley, 2001; American National Standards Institute, 2002; Knecht et al, 2002). This is paramount for younger school-age children as they are more vulnerable to competing noises, and S/Ns typically decrease with decreasing grade level (Picard and Bradley, 2001).

NOTES

1. This was the same cohort of participants described by Stuart (2005).

2. RTSs can be determined with either a 10- or 20-sentence list protocol (Nilsson et al, 1996). The shorter 10-list protocol was employed in an effort to shorten test time, particularly for the younger children. The shorter 10-list protocol has also been employed in other research/clinical investigations (e.g., Eisenberg et al, 2004; Holt et al, 2005; Fitzpatrick et al, 2006).

3. This level of noise was consistent with that typically experienced in elementary level classrooms (Picard and Bradley, 2001; Shield et al, 2001). Spondee recognition thresholds ranged from -5 to 15 dB HL. There was no significant difference in spondee recognition thresholds of participants as a function of age group [F (5, 90) = 1.51, p = .19, η^2 = .077, ϕ = .51] and hence presentation level of the noises.

4. Word recognition performance (Stuart, 2005) and RTS testing was conducted during the same test session and were counterbalanced across participants. Adequate rest periods were provided between tasks and whenever requested.

5. The release from masking in the interrupted noise was computed by subtracting word percent correct scores in continuous noise from word percent correct scores in interrupted noise at 10, 0, and -10 dB S/N for the five groups of school-age children and adults from this previous study (Stuart, 2005, figures 1–2 and table 1). 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 (2, 180) = 172.05, p < .0001, η^2 = .66, ϕ = 1.0] while the main effect of group [F (5, 90) = 1.33, p = .26, η^2 = .069, ϕ = 0.45] and the group by S/N interaction was not significant [F (10, 180) = 0.99, p = .45, η^2 = .052, ϕ = 0.51].

REFERENCES

Allen P, Wightman F, Kistler D, Dolan T. (1989) Frequency resolution in children. *J Speech Hear Res* 32:317–322.

American National Standards Institute. (1996) *Specification for Audiometers.* (ANSI S3.6). New York: ANSI.

American National Standards Institute. (2002) *Acoustical Performance Criteria, Design Requirements and Guidelines for Schools*. (ANSI S12.60). New York: ANSI.

American Speech-Language-Hearing Association. (1997) *Guidelines for Audiologic Screening*. Rockville, MD: American Speech-Language-Hearing Association.

Bacon SP, Opie JM, Montoya DY. (1998) The effects of hearing loss and noise masking on the masking release for speech in temporally complex backgrounds. *J Speech Lang Hear Res* 41:549–563.

Blandy S, Lutman M. (2005) Hearing threshold levels and speech recognition in noise in 7-year-olds. *Int J Audiol* 44:435–443.

Bradley JS. (1986) Predictors of speech intelligibility in rooms. *J Acoust Soc Am* 80:837–845.

Bradlow AR, Kraus N, Hayes E. (2003) Speaking clearly for children with learning disabilities: sentence perception in noise. *J Speech Lang Hear Res* 46:80–97.

Buss E, Hall III JW, Grose JH. (2006) Development and the role of internal noise in detection and discrimination thresholds with narrow band stimuli. *J Acoust Soc Am* 120:2777–2788.

Buss E, Hall III JW, Grose JH, Dev MB. (1999) Development of adult-like performance in backward, simultaneous, and forward masking. *J Speech Lang Hear Res* 42:844–849.

Calearo C, Teatini GP, Pestalozza G. (1962) Speech intelligibility in the presence of interrupted noise. *J Auditory Res* 2:179–186.

Cameron S, Dillon H, Newall P. (2006) The listening in spatialized noise test: an auditory processing disorder study. *J Am Acad Audiol* 17:306–320.

Carhart R, Tillman TW, Johnson KR. (1966) Binaural masking of speech by periodically modulated noise. *J Acoust Soc Am* 39:1037–1050.

Crandell C, Smaldino JJ. (1996) Speech perception in noise by children for whom English is a second language. *Am J Audiol* 5(3):47–51.

Cranford JL, Morgan M, Scudder R, Moore C. (1993) Tracking of "moving" fused auditory images by children. *J Speech Hear Res* 36:424–430.

Davis SM, McCroskey RL. (1980) Auditory fusion in children. *Child Dev* 51:75–80.

de Laat JAPM, Plomp R. (1983) The reception threshold of interrupted speech for hearing impaired listeners. In: Klinke R, Hartman R, eds. *Hearing - Physiological Bases and Psychophysics*. Berlin: Springer-Verlag, 359–363.

Dirks DD, Bower DR. (1971) Influence of pulsed masking on spondee words. *J Acoust Soc Am* 50:1204–1207.

Dirks DD, Wilson RH, Bower DR. (1969) Effect of pulsed masking on selected speech materials. *J Acoust Soc Am* 46:898–906.

Dunnett CW. (1955) A multiple comparison procedure for comparing several treatments with a control. *J Am Stat Assoc* 50:1096–1121.

Eisenberg LS, Kirk KI, Martinez AS, Ying EA, Miyamoto RT. (2004) Communication abilities of children with aided residual hearing. *Arch Otolaryngol Head Neck Surg* 130:563–569.

Eisenberg LS, Shannon RV, Martinez AS, Wygonski J, Boothroyd A. (2000) Speech recognition with reduced spectral cues as a function of age. *J Acoust Soc Am* 107:2704–2710.

Elangovan S, Stuart A. (2005) Interactive effects of high-pass filtering and masking noise on word recognition. *Ann Otol Rhinol Laryngol* 114:867–878.

Elfenbein JL, Small AM, Davis JM. (1993) Developmental patterns of duration discrimination. *J Speech Hear Res* 36:842–849.

Elliot LL. (1979) Performance of children aged 9 to 17 years on a test of speech intelligibility in noise using sentence material with controlled word predictability. *J Acoust Soc Am* 66:651–653.

Elliot LL. (1986) Discrimination and response bias for CV syllables differing in voice onset time among children and adults. *J Acoust Soc Am* 80:1250–1255.

Elliot LL, Connors S, Kille E, Levin S, Ball K, Katz D. (1979) Children's understanding of monosyllabic nouns in quiet and in noise. *J Acoust Soc Am* 66:12–21.

Elliot LL, Katz DR. (1980) *Development of a New Children's Test of Speech Discrimination*. St. Louis, MO: Auditec.

Fallon M, Trehub SE, Schneider BA. (2002) Children's use of semantic cues in degraded listening environments. *J Acoust Soc Am* 111:2242–2249.

Finitzo-Hieber T, Tillman TW. (1978) Room acoustics effects on monosyllabic word discrimination ability for normal and hearing-impaired children. *J Speech Hear Res* 21:440–458.

Fitzpatrick E, McCrae R, Schramm D. (2006) A retrospective study of cochlear implant outcomes in children with residual hearing. *BMC Ear Nose Throat Dis* 6:7.

Grose JH, Hall III JW, Gibbs C. (1993) Temporal analysis in children. *J Speech Hear Res* 36:351–356.

Hall III JW, Grose JH. (1991) Notched noise measures of frequency selectivity in adults and children using fixed-masker-level and fixed-signal-level presentation. *J Speech Hear Res* 34:651–660.

Hall III JW, Grose JH. (1994) Development of temporal resolution in children as measured by the temporal modulation transfer function. *J Acoust Soc Am* 96:150–154.

Hall III JW, Grose JH, Buss E, Dev MB. (2002) Spondee recognition in a two-talker masker and a speech-shaped noise masker in adults and children. *Ear Hear* 23:159–165.

Hall III JW, Grose JH, Buss E, Dev MB, Drake AF, Pillsbury HC. (2003) The effect of otitis media with effusion on perceptual masking. *Arch Otolaryngol* 129:1056–1062.

Hartley DE, Hill PR, Moore DR. (2003) The auditory basis of language impairments: temporal processing versus processing efficiency hypotheses. *Int J Pediatr Otorhino* 67 (Suppl. 1):S137–S142.

Hartley DE, Moore DR. (2002) Auditory processing efficiency deficits in children with developmental language impairments. *J Acoust Soc Am* 112:2962–2966.

Hartley DE, Wright BA, Hogan SC, Moore DR. (2000) Age-related improvements in auditory backward and simultaneous masking in 6- to 10-year-old children. *J Speech Lang Hear Res* 43:1402–1415.

Hill PR, Hartley DE, Glasberg BR, Moore BC, Moore DR. (2004) Auditory processing efficiency and temporal resolution in children and adults. *J Speech Lang Hear Res* 47:1022–1029.

Holt RF, Kirk KI, Eisenberg LS, Martinez AS, Campbell W. (2005) Spoken word recognition development in children with residual hearing using cochlear implants and hearing AIDS in opposite ears. *Ear Hear* 26(4, Suppl.):82S–91S.

Irwin RJ, Ball AKR, Kay N, Stillman JA, Rosser J. (1985) The development of auditory temporal acuity in children. *Child Dev* 56:614–620.

Jerger S, Jerger J, Alford BR, Abrams S. (1983) Development of speech intelligibility in children with recurrent otitis media. *Ear Hear* 4:138–145.

Johnson CE. (2000) Children's phoneme identification in reverberation and noise. *J Speech Lang Hear Res* 43:144–157.

Knecht HA, Nelson PB, Whitelaw GM, Feth LL. (2002) Background noise levels and reverberation times in unoccupied classrooms: predictions and measurements. *Am J Audiol* 11:65–71.

Litovsky RY. (2005) Speech intelligibility and spatial release from masking in young children. *J Acoust Soc Am* 117:3091–3099.

Marsh DH. (1973) Auditory figure-ground ability in children. *Am J Occup Ther* 27:218–225.

Maxon AB, Hochberg I. (1982) Development of psychoacoustic behavior: sensitivity and discrimination. *Ear Hear* 3:301–308.

Miller GA. (1947) The masking of speech. *Psychol Bull* 44:105–129.

Miller GA, Licklider CR. (1950) The intelligibility of interrupted speech. *J Acoust Soc Am* 22:167–173.

Moore BC. (1993) Temporal analysis in normal and impaired hearing. *Ann N Y Acad Sci* 682:119–136.

Moore BCJ. (2003) *An Introduction to the Psychology of Hearing*. 5th ed. London: Academic Press.

Nabelek AK, Robinson PK. (1982) Monaural and binaural speech perception in reverberation for listeners of various ages. *J Acoust Soc Am* 71:1242–1248.

Nelson PB, Jin SH, Carney AE, Nelson DA. (2003) Understanding speech in modulated interference: cochlear implant users and normal-hearing listeners. *J Acoust Soc Am* 113:961–968.

Nelson P, Kohnert K, Sabur S, Shaw D. (2005) Classroom noise and children learning through a second language: double jeopardy? *Lang Speech Hear Serv Sch* 36:219–229.

Neuman AC, Hochberg I. (1983) Children's perception of speech in reverberation. *J Acoust Soc Am* 73:2145–2149.

Nilsson MJ, Soli SD, Gelnett DJ. (1996) *Development of the Hearing in Noise Test for Children (HINT-C)*. Los Angeles, CA: House Ear Institute.

Nilsson M, Soli SD, Sullivan JA. (1994) Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *J Acoust Soc Am* 95:1085–1099.

Nittrouer S. (2005) Age-related differences in weighting and masking of two cues to word-final stop voicing in noise. *J Acoust Soc Am* 118:1072–1088.

Nittrouer S, Boothroyd A. (1990) Context effects in phoneme and word recognition by young children and older adults. *J Acoust Soc Am* 87:2705–2715.

Papso CF, Blood IM. (1989) Word recognition skills of children and adults in background noise. *Ear Hear* 10:235–236.

Phillips DP, Rappaport JM, Gulliver JM. (1994) Impaired word recognition in noise by patients with noised-induced cochlear hearing loss: contribution of a temporal resolution defect. *Am J Otol* 15:679–686.

Picard M, Bradley JS. (2001) Revisiting speech interference in classrooms. *Audiology* 40:221–244.

Pillsbury HC, Grose JH, Coleman WL, Conners CK, Hall III JW. (1995) Binaural function in children with attention-deficit hyperactivity disorder. *Arch Otolaryngol* 121:1345–1350.

Pollack I. (1954) Masking of speech by repeated bursts of noise. *J Acoust Soc Am* 26:1053–1055.

Pollack I. (1955) Masking by a periodically interrupted noise. *J Acoust Soc Am* 27:353–355.

Rappaport JM, Gulliver JM, Phillips DP, Van Dorpe RA, Maxner CE, Bhan V. (1994) Auditory temporal resolution in multiple sclerosis. *J Otolaryngol* 23:307–324.

Rhebergen KS, Versfeld NJ, Dreschler WA. (2006) Extended speech intelligibility index for the prediction of the speech reception threshold in fluctuating noise. *J Acoust Soc Am* 120:3988–3997.

Rodenburg M. (1977) Investigation of temporal effects with amplitude modulated signal. In: Evans EF, Wilson JP, eds. *Psychophysics and Physiology of Hearing*. London: Academic Press, 429–437.

Sanderson-Leepa ME, Rintelmann WF. (1976) Articulation functions and test-retest performance of normal-hearing children on three speech discrimination tests: WIPI, PBK-50, and NU Auditory Test No.6. *J Speech Hear Dis* 41:503–519.

Schilder AG, Snik AF, Straatman H, van den Broek P. (1994) The effect of otitis media with effusion at preschool age on some aspects of auditory perception at school age. *Ear Hear* 15:224–231.

Scott T, Green WB, Stuart A. (2001) Interactive effects of low-pass filtering and masking noise on word recognition. *J Am Acad Audiol* 12:437–444.

Shield B, Dockrell J, Jeffery R, Tachmatzidis I. (2001) *The Effects of Noise on the Attainments and Cognitive Performance of Primary School Children*. London: South Bank University and Institute of Education, University of London.

Stuart A. (2004) An investigation of list equivalency of the Northwestern University Auditory Test No. 6 in interrupted broadband noise. *Am J Audiol* 13:23–28.

Stuart A. (2005) Development of auditory temporal resolution in school-age children revealed by word recognition in continuous and interrupted noise. *Ear Hear* 26:78–88.

Stuart A, Givens GD, Walker LJ, Elangovan S. (2006) Auditory temporal resolution in normal hearing preschool children revealed by word recognition in continuous and interrupted noise. *J Acoust Soc Am* 119:1946–1949.

Stuart A, Phillips DP. (1996) Word recognition in continuous and interrupted broadband noise by young normal-hearing, older normal-hearing, and presbycusic listeners. *Ear Hear* 17:478–489.

Stuart A, Phillips DP. (1997) Word recognition in continuous noise, interrupted noise, and in quiet by normal-hearing listeners at two sensation levels. *Scand Audiol* 26:112–116.

Stuart A, Phillips DP. (1998) Deficits in auditory temporal resolution revealed by a comparison of word recognition under interrupted and continuous noise masking. *Semin Hear* 19:333–344.

Stuart A, Phillips DP, Green WB. (1995) Word recognition performance in continuous and interrupted noise by normal-hearing and simulated hearing-impaired listeners. *Am J Otol* 16:658–663.

Versfeld NJ, Daalder L, Festen JM, Houtgast T. (2000) Method for the selection of sentence materials for efficient measurement of the speech reception threshold. *J Acoust Soc Am* 107:1671–1684.

Viemeister NF. (1979) Temporal modulation transfer functions based on modulation thresholds. *J Acoust Soc Am* 66:1364–1380.

Wilson RH, Carhart R. (1969) Influence of pulsed masking on the threshold for spondees. *J Acoust Soc Am* 46:998–1010.

Yacullo WS, Hawkins DB. (1987) Speech recognition in noise and reverberation by school-age children. *Audiology* 26:235–246.