Level, spectral and temporal cues in children's detection of masked signals

Prudence Allen, Rhiannon Jones, Pamela Slaney & Louise Korpela[1]
School of Communication Sciences and Disorders,
University of Western Ontario, London, Ontario N6G 1H1.

Abstract : Preschool-aged children and adults detected masked signals in four conditions evaluating the role of level, spectral and temporal cues on performance. Performance was similar in fixed and roving level conditions for both age groups suggesting use of level-invariant cues. When the signal was moved to the spectral edge of the masker the performance of the adults improved but that of the children did not suggesting that the children did not benefit from cues provided by the off-center signal. Children's performance worsened when the signal was a narrow band noise rather than a pure tone but the adults' did not, suggesting children's reliance on temporal changes in the masker with the introduction of the signal. Analyses of the stimuli suggested that the children's thresholds corresponded to signal-to-noise ratios at which multiple cues were present at magnitudes that were large enough to be discriminable. These findings were in agreement with post hoc analyses of tonal signals presented in flat- and notched-spectrum maskers used to examine frequency resolving ability in an earlier study (Allen, Wightman, Kistler & Dolan, 1989, J. Speech Hear. Res., 32, 317-324). In that study young children's thresholds were obtained at levels for which level, frequency and periodicity values differed between the signal and no signal stimuli at magnitudes that would be discriminable, independent of the spectral qualities of the masker. [Work supported by NSERC].

Introduction

Children's masked detection thresholds are higher than those of adults and do not mature until children reach school-age. To date, no satisfactory explanation for these observations has been found. Explanations based on immature attention have been useful but are often based upon the assumption that children listen for the signals in a frequency selective manner and that their attention bands are either too broad or the child is unable to focus attention consistently at the signal frequency. However, it is possible that children may not listen in a frequency selective manner. Children may attend to non frequency specific cues that are available primarily at higher signal-to-noise ratios.

The first study reported here examined several such potential cues including average frequency (or overall pitch), periodicity and overall level. These cues were evaluated through comparisons between selected combinations of data obtained in four experimental conditions. The second study was retrospective and consisted of acoustic measurements of level, average frequency, and periodicity in stimuli used to evaluate children's frequency resolving abilities in a previously published notched-noise masking study (Allen et al., 1989). The goal was to determine what acoustic cues may have been available to the children and adults at their measured threshold levels.

Experiment 1: Signal in noise detection cues.

Preschool aged children and adults participated in four conditions in a repeated measures design. Performance was evaluated in pairs of conditions designed to estimate the role of level, frequency/pitch and periodicity.

Method. Signals were 328 msec in duration, gated simultaneously with a noise masker (800-1200 Hz bandwidth). The condition 1 signal was a 1000 Hz tone, spectrally centered in a fixed level (30 dB N_0) noise masker. Condition 2 was identical to condition 1 but level was roved ± 5 dB, re: 30 dB N_0. The signal for Condition 3 was a 1175 Hz tone which was therefore spectrally off-center in the roving level masker. The Condition 4 signal was a noise band, 50 Hz wide, centered at 1000 Hz. Masker level was roved.

Comparison of performance in conditions 1 and 2 enabled evaluation of the role of absolute level information by comparing detection of a 1000 Hz tonal signal in fixed and roving level conditions. Comparison of conditions 2 and 3 assessed the role of spectral (pitch) information by comparing detection of signals that were spectrally centered or off-center in the roving level masker. Conditions 2 and 4 were combined to evaluate periodicity cues by comparing detection of a pure tone and a noise signal, both spectrally centered in a roving level noise masker. As well, an acoustic analysis of all signal plus masker combinations was performed to determine changes in average frequency, periodicity and level as signal to noise ratio was varied.

Listeners were 11 preschool-aged children (3.7 to 5.3 years, Mean = 4.6) and 6 adults (24.7 to 25.8 years, Mean = 25.2 years). Of the 11 children, 6 produced data to which fitted psychometric functions (see Allen & Wightman, 1994, J. Speech Hear. Res., 37, 205-215, for details) showed improvements with increasing signal to noise ratio and 75% thresholds within the range levels tested. The data from these children and the adults were submitted to a Multivariate Analysis of Variance. The data from the remaining 5 children were examined independently. Inclusion of their data in individual conditions did not produce a change in the pattern of results

Results and Discussion. Children's thresholds were consistently higher than those of the adults, $F(1,10) = 193.88$, $p < .0001$, and the slopes of their psychometric functions were shallower, $F(1,10) = 58.8$, $p < .0001$. The age by condition interaction was significant only for thresholds, $F(3,30) = 3.5$, $p = .021$. Threshold data were therefore subjected to the three planned comparisons noted above but slope estimates were not. Mean thresholds (dB) and standard deviations are shown below.

Condition:	1	2	3	4
Children	33.76 (2.8)	29.21 (1.6)	27.29 (1.6)	33.87 (2.1)
Adults	19.14 (3.5)	18.83 (3.2)	11.06 (3.0)	18.35 (1.9)

Level cues. Neither the adults nor the children showed a significant change in threshold when the level was fixed (1) Vs roved (2) suggesting that listeners in both age groups were able to use level invariant cues for detection.

Spectral cues. Comparisons of performance when the signal was spectrally centered (2) or placed at the edge of the masker (3) showed no significant differences for the children. Adult listeners showed a slight but significant improvement in thresholds when the signal was placed at the spectral edge of the masker. Acoustic analyses of the signal plus masker combinations showed that the overall pitch of the noise masker changed when the signal was added at signal to noise ratios above 20 dB, higher than where most adult thresholds were measured. This argues against their use of

[1] Experiment 1 is based on Allen, P., Jones, R., & Slaney, P. , The role of level, spectral and temporal cues in children's detection of masked signals, J. Acoust. Soc. Am., in press; Experiment 2 is from an unpublished master's thesis by L. Korpela (1998).

pitch information to detect the signals. It is more likely that the adult listeners may have been able to shift their attention to the spectral edge of the masker where off-frequency listening could have improved the signal-to-noise ratios. The children, who may have reduced inability to selectively attend to specific frequency regions, were likely not able to use this additional cue.

Periodicity. Children's thresholds were approximately 5 dB higher when the signal was a narrow band of noise (4) compared to when it was a pure tone (2). The performance of the adults was unchanged. This suggests that the children may have been more sensitive to the changes in the temporal fine structure of the masker produced with the addition of the signals. Acoustic analyses of the stimuli showed that children's thresholds in all 4 conditions corresponded to the signal-to-noise ratios at which the masker alone and signal plus masker stimuli differed in overall periodicity.

Conclusions. Previous studies (Allen & Wightman, 1992, J. Speech Hear. Res., 35, 222-233) have shown that children require greater spectral shape contrast to detect and discriminate between complex signals. The overall higher thresholds for the children observed in this further argue that children's thresholds may have been elevated because they required greater cross channel differences (higher s/n ratios) to discriminate between a noise alone and signal plus noise stimulus. Also, the results suggested that periodicity may provide useful information to the children.

Experiment 2: Post-hoc analysis of signals in notched-noise masking study (Allen et al., 1989).

An acoustic analysis of signals used in a previous study of frequency resolution in which flat- and notched-spectrum masked thresholds were obtained, was conducted to determine what acoustic cues may have been present at the threshold signal-to-noise ratios measured.

Method. The signal plus masker combinations at which preschool-aged children and adults masked thresholds were obtained (Allen et al., 1989) were analyzed for changes in the acoustic features noted in Experiment 1. Two conditions were evaluated: Signal plus flat and notched spectrum noise maskers. Notch width was 40% of the signal frequency. Spectrum level was 40 dB. Signal to noise ratios corresponding to detection thresholds for adults and preschool-aged children were evaluated as was an intermediate signal-to-noise ratio. Three frequencies were analyzed, 500, 2000, and 4000 Hz.

Signals were analyzed as a whole unit, without filtering, and at several filtered conditions meant to simulate frequency selective listening. Filtering was set at 1000, 500, and 250 Hz bandwidths to evaluate the potential impact of varying degrees of frequency selective attention.

Results and Discussion.

4000 Hz.

Flat spectrum masker. At the level at which children's thresholds were observed for the 4000 Hz signal in the flat spectrum masker (79 dB) there were large level (6dB) and periodicity (.23) differences in the noise alone and signal plus noise stimulus without any degree of frequency selective listening (filtering). Frequency differences were small (69 Hz) but may have been discriminable. Had even nominal filtered listening been in place (1000 Hz wide), level differences of 6 dB were present at signal levels much below that where the children's thresholds were measured. At the adult detection threshold a potentially discriminable level difference (4.8 dB) was present but the periodicity and frequency differences were quite small. As filtering was employed, the level cue increased but the magnitude of the other cues remained the same or decreased. This argues that the adults as well as the children could have discriminated between the noise alone and signal plus noise stimulus purely on the basis of level without any frequency selective listening.

Notched spectrum masker: Children's thresholds had been observed at the same levels as with the flat spectrum masker (79 dB) in spite of the large spectral notch present at the signal frequency. At these levels the cues were large (6 dB level, .37 periodicity difference, and 300 Hz frequency). The magnitude of all three cues decreased with signal level such that at the adult threshold levels (59 dB) there were no frequency or periodicity differences and the level cue was reduced to 2.5 dB. Had either group of listeners used even a nominal filtering (1000 Hz), the magnitude of the level cue would have been equal to the signal level as most of the noise would have been removed and performance should have been observed at much lower levels. This argues that the children, and possibly the adults, detected the signals in these notched maskers with little or no frequency selective listening and a reliance on level differences.

2000 Hz data. Flat masker: At the levels where the children's thresholds were measured (79 dB), there were large level (6dB), frequency (228 Hz) and periodicity (.42) differences. Had 1000 Hz filtering been employed discriminable differences would have been present at much lower intensities of the signal and thresholds would have been lower. At the adult's thresholds (67 dB), the level difference was 2.7 dB and the periodicity and frequency differences were likely not discriminable.

Notched spectrum masker. At the children's thresholds (68 dB) there were likely no discriminable cues without the need for at least some filtering. With 1000 Hz filtering an 8 dB level cue was available as well as a periodicity cue of .23. Thus, at least some degree of frequency selective listening must have been employed. The adult thresholds were measured at a level (56 dB) where a 2.8 dB intensity cue was available without filtering suggesting that frequency selective listening was not necessary.

500 Hz data:

Flat spectrum masker. At the children's thresholds (76 dB) there was a large frequency cue (631 Hz) in an unfiltered condition. With only minimal filtering (1000 Hz) large level (9 dB) and periodicity (.45) cues were available but the frequency difference would have been reduced. At slightly lower levels the level cue would have been small and likely not detectable. For the adults, there was a 2.7 dB level cue available without filtering. The magnitude of this cue would not have changed significantly with filtering.

Notched spectrum masker. At the level of children's thresholds (68 dB) a frequency difference (158 Hz) was available without filtering but the periodicity and level cues would have been below threshold. Only with filtering of at least 500 Hz bandpass would a large level difference (6dB) have been present. At wider filtering (1000 Hz) only a periodicity cue would have been present. For the adult threshold levels (51 dB) a 2.3 dB level cue would have been available with no filtering. Cue values at that level did not change with filtering.

General Discussion

In spite of the large differences in threshold values measured from the children with different frequency and masker combinations, there were consistently large level cues available that would have likely been discriminable. Frequency and periodicity cues were also sometimes available at these levels. Frequency selective listening would only have been necessary to achieve these discriminable level cues at the very low frequencies. For adults level differences of 2.0 dB or greater were consistently present regardless of frequency or masker. Thus, level differences in the signal plus masker and masker alone stimuli could have been responsible for both children's and adult's detection performance.