# Adults, but not children, benefit from a pretrial signal cue in a random-frequency, two-tone masker

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**Abstract:** This study examined the benefit of a pretrial cue, a preview of the signal, on children's (5–10 years) and adults' detection of a 1000-Hz pure-tone signal in a broadband noise or a random-frequency, two-tone masker. No cuing effect was observed with the noise masker, regardless of listener age. In contrast, all but one adult benefited from the cue with the two-tone masker (average = 9.4 dB). Most children showed no cuing effect (average = 0.1 dB) with the two-tone masker. These results suggest that, unlike adults, the provision of a pretrial cue does not promote frequency-selective listening during detection for 5- to 10-year-olds.


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**Date Received:** March 20, 2015 **Date Accepted:** May 27, 2015

## 1. Introduction

Substantial child-adult differences, as large as 50 dB, have been reported for the detection of a pure-tone signal presented simultaneously with a multi-tonal masker made up of remote-frequency component frequencies that are drawn randomly for each presentation (e.g., Lutfi *et al.*, 2003). These child-adult differences in masking have been attributed to age effects in "informational masking." Informational masking often occurs when the stimulus properties of the target and masker are perceptually similar (e.g., Durlach *et al.*, 2003), and is believed to be a result of limitations in central auditory processing, such as sound source segregation and/or selective auditory attention (reviewed by Kidd *et al.*, 2007). Sound source segregation is the process of identifying and grouping the acoustic waveforms of the signal separately from those of the masker. Selective auditory attention is the process of selecting only the signal for further processing. Immaturity in either process may explain children's increased susceptibility to informational masking relative to adults (reviewed by Leibold, 2012).

This study evaluated the extent to which children and adults benefit from a pretrial cue, a preview of the signal, for detection of a fixed-frequency sinusoid in a random-frequency, two-tone masker. A pretrial signal cue has been provided in all published developmental studies that used a simultaneous multi-tonal masking paradigm (e.g., Leibold and Neff, 2007; Lutfi *et al.*, 2003). The use of a pretrial signal cue is based on previous findings showing that cuing promotes selective listening at the signal frequency for adults (e.g., Hafter *et al.*, 1993; Richards and Neff, 2004). For example, Richards and Neff (2004) demonstrated that a pretrial signal cue reduced adults' average threshold for a 1000-Hz signal in a random-frequency, two-tone masker by 6.2 dB (range = 0 to 18 dB) relative to when no pretrial cue was provided. Richards and Neff (2004) suggested that the pretrial cue assisted most adults in focusing their attention on the signal frequency, ensuring "best" performance.

Lutfi *et al.* (2003) demonstrated that the extent to which listeners monitor frequency regions in addition to the signal in the context of multi-tonal masking experiments is related to the amount of informational masking they experience. Thus, one rationale for using a pretrial signal cue is to reduce informational masking by directing attention to the target frequency (e.g., Durlach *et al.*, 2003). Given developmental effects in susceptibility to informational masking, the benefit of a pretrial cue might be larger for children than for adults. Alternatively, two lines of evidence suggest that children may show a smaller cuing effect than adults. First, while children tend to be more susceptible to informational masking than adults (e.g., Lutfi *et al.*, 2003), there is no evidence that individual adults exhibiting the greatest susceptibility to informational masking also show the largest cuing effects (Richards and Neff, 2004). Second, in a study examining the effect of signal-masker temporal asynchrony on detection of a fixed-frequency, pure-tone signal in random-frequency, multi-tonal maskers, Leibold and Neff (2007) found that four 5- to 7-year-olds were unable to complete training. Three of these children successfully completed training when the pretrial cue was removed; suggesting that the addition of the pretrial cue may have made the task more difficult for these children to perform.

In the present study, masked detection thresholds for a 1000-Hz tone were measured for children and adults in conditions with or without a pretrial signal cue. Listeners were tested in two masker conditions: (1) a random-frequency, two-tone complex and (2) broadband noise. The two-tone masker was expected to produce substantial informational masking for most listeners. A positive cuing benefit for children with the two-tone masker would be consistent with the hypothesis that the pretrial signal cue promotes selective listening at the signal frequency for children, as previously demonstrated for adults (e.g., Richards and Neff, 2004). The broadband noise masker was not expected to produce informational masking. Thus, the pretrial signal cue was not predicted to improve detection performance with the noise masker for any age group.

## 2. Method

### *2.1 Listeners*

Listeners were nine 5- to 7-year-olds [mean = 6.8 years; standard deviation (SD) = 1.0 years], nine 8- to 10-year-olds (mean = 9.7 years; SD = 0.8 years), and nine 20- to 30-year-olds (mean = 25.8 years; SD = 3.2 years). Listeners had normal hearing sensitivity with thresholds $\leq$ 20 dB hearing level at octave frequencies from 250 to 8000 Hz, bilaterally. One additional child (5.2 years) was excluded because he could not complete training.

### *2.2 Stimuli*

Detection thresholds were measured for a 1000-Hz pure tone that was 300 ms in duration, including 5-ms, $\cos^2$ onset/offset ramps. The signal was presented in quiet or in one of two 300-ms maskers: (1) broadband noise (300 to 3000 Hz) or (2) a random-frequency, two-tone complex. Thirty samples were randomly generated and stored for each masker. Frequency components for the two-tone masker samples were randomly drawn from a uniform distribution of 300 to 3000 Hz, excluding 920 to 1080 Hz. The signal, when present, was gated on and off simultaneously with the masker. The set size of 30 samples per masker was based on previous studies showing that listeners use similar detection strategies for small and large sets of maskers (e.g., Richards *et al.*, 2002). Masker level was 60 dB sound pressure level (SPL) (57 dB/component for the two-tone masker).

Stimuli were played through a 24-bit digital-to-analog converter (Digital Audio Laboratories) at a sampling rate of 20 kHz. The experiment was controlled by a computer using custom software. Stimuli were presented to the left ear via headphones (Sennheiser HD-25).

### *2.3 Conditions and procedure*

Children sat in front of a computer monitor inside a sound-treated booth (Industrial Acoustics Company). An experimenter sat beside the child, initiated trials and entered responses. Adults sat alone, independently initiating trials and entering responses.

In four separate conditions, listeners were tested in each masker, both with and without a pretrial cue. One masker sample was presented in each interval, selected randomly from the full set of 30 samples for interval 1 and from the remaining 29 samples for interval 2. The interstimulus interval was 400 ms. The signal occurred in either interval with equal *a priori* probability. In the cue-present condition, a cue was provided before each trial. The pretrial cue was identical to the subsequent signal on each trial, including level, but was presented in quiet. A 400-ms interval separated the pretrial cue and the start of the first interval. Estimates of quiet threshold were also obtained (no pretrial cue).

Thresholds were estimated using a two-interval, forced-choice adaptive procedure that estimated 70.7% correct on the psychometric function (Levitt, 1971). The initial step size for the adaptive track was 4 dB, reduced to 2 dB after the second reversal. The track was terminated after eight reversals, with threshold being the average of the last six reversals. Starting levels for the signal were 10 to 15 dB above the expected threshold for each condition, based on pilot data and adjusted for individual listeners. Three threshold estimates were obtained for each condition. A randomized set of all conditions was completed before the next block of conditions was run. The first block of testing was used for training, and the final two blocks were averaged to calculate threshold.

## 3. Results

### *3.1 Quiet thresholds*

Quiet thresholds ranged from 5.4 to 16.9 dB SPL for 5- to 7-year-olds [mean = 11.4 dB SPL; standard error of the mean (SEM) = 1.2 dB SPL], from 2.2 to 21.2 dB SPL for 8- to 10-year-olds (mean = 9.1 dB SPL; SEM = 2.1 dB SPL), and from −5.2 to 19.0 dB SPL for adults (mean = 2.9 dB SPL; SEM = 2.3 dB SPL). A one-way analysis of variance (ANOVA) confirmed that threshold in quiet was significantly different between the three listener age groups [$F(2, 26) = 5.11$, $p = 0.01$, $\eta^2_p = 0.30$]. Subsequent *post hoc* pairwise comparisons were conducted with an $\alpha = 0.05$; reported $p$-values incorporate a Bonferroni adjustment. Quiet thresholds were significantly higher for 5- to 7-year-olds than adults ($p = 0.01$). No significant difference was found between 5- to 7-year-olds and 8- to 10-year-olds ($p = 1.00$), or between 8- to 10-year-olds and adults ($p = 0.10$). Given the variability in quiet threshold across listeners, amount of masking (AOM) was computed for the masked conditions by subtracting the quiet threshold from the masked threshold.

### *3.2 Amount of masking and cuing effects in broadband noise*

Mean AOM estimates (±1 SEM) for the broadband noise conditions are provided in Fig. 1(a). AOM in the cue-absent condition ranged from 29.5 to 57.1 dB for 5- to 7-year-olds (mean = 41.2 dB), 27.6 to 53.6 dB for 8- to 10-year-olds (mean = 39.3 dB), and 28.2 to 47.9 dB for adults (mean = 42.0 dB). Estimates of AOM were similar for the cue-present condition, ranging from 29.8 to 74.2 dB for 5- to 7-year-olds (mean = 46.8 dB), 25.5 to 53.0 dB for 8- to 10-year-olds (mean = 39.1 dB), and 25.0 to 49.0 dB for adults (mean = 41.7 dB). The cuing effect was calculated for each listener by subtracting the threshold for the cue-present condition from the threshold in the cue-absent condition. Figure 1(b) shows individual and mean cuing effects (±1 SEM) for the noise masker. The average cuing effect was −5.6 dB (range = −23.0 to 3.3 dB) for 5- to 7-year-olds, 0.2 dB (range = −8.2 to 7.1 dB) for 8- to 10-year-olds, and 0.3 dB (range = −1.2 to 3.2 dB) for adults. A repeated measures ANOVA with Cue Status (absent, present) as a within-subjects factor and Age Group (5- to 7-year-olds, 8- to 10-year-olds, adults) as a between-subjects factor was performed on AOM. This analysis indicated no significant effects: Age Group [$F(2, 24) = 0.79$, $p = 0.46$, $\eta^2_p = 0.06$]; Cue Status [$F(1, 24) = 2.52$, $p = 0.12$, $\eta^2_p = 0.09$]; and Cue Status × Age Group [$F(2, 24) = 3.24$, $p = 0.06$, $\eta^2_p = 0.21$]. Thus, listeners did not benefit from the cue in the noise masker condition, regardless of age.

Individual data are in general agreement with mean results. As shown in Fig. 1(b), only three children and one adult had a cuing effect of ≥3 dB in

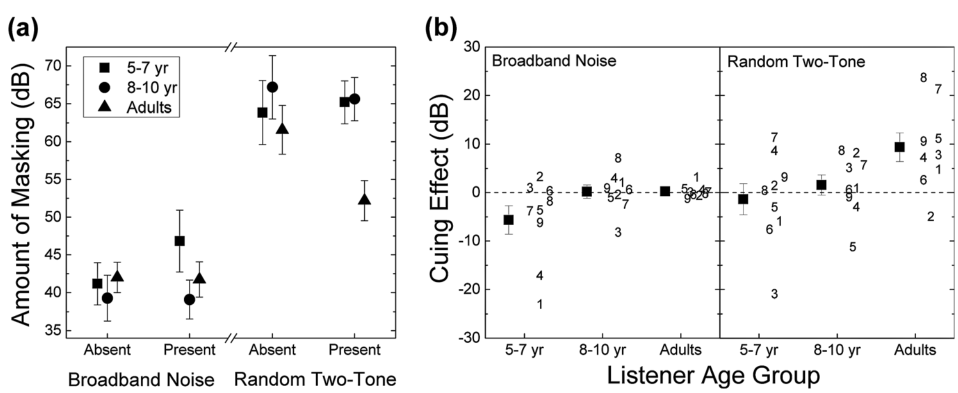


FIG. 1. (a) Average amounts of masking for each listener age group are shown as a function of the status of the pretrial signal cue (cue-absent, cue-present) and masker type (broadband noise, two-tone). Squares are 5- to 7-year-olds, circles are 8- to 10-year-olds, and triangles are adults. Error bars are ±1 SEM. (b) Individual and mean cuing effects are provided by listener age group. Data for the broadband noise masker condition are provided in the left panel and for the random-frequency, two-tone masker condition in the right panel. Mean cuing effects are indicated by the filled squares. Error bars are ±1 SEM. The error bar for the adult data is not visible with the broadband noise masker because it is smaller than the symbol. Individual data points are labeled by the listener's identification number to the right of the mean data. Listener identification numbers were assigned by rank ordering listeners by age. A horizontal dashed line is provided at 0 dB. Data points above this line indicate a benefit from the pretrial cue, whereas points below this line indicate a decrement.

broadband noise. Six children showed a decrement in performance of $\geq 3$ dB when the pretrial signal cue was provided, including two children with negative cuing effects of 23 dB (5.1 years) and 17.1 dB (6.3 years).

### *3.3 Amount of masking and cuing effects in a random-frequency, two-tone complex*

Positive cuing effects were seen for most adults with the two-tone masker [Fig. 1(b)]. AOM in the cue-absent condition ranged from 42.6 to 73.0 dB for adults (mean = 61.6 dB), compared with 37.8 to 65.1 dB (mean = 52.2 dB) in the cue-present condition. Thus, the average cuing effect for adults was 9.4 dB (range = −4.9 to 23.7 dB). In contrast, AOM for both age groups of children were similar for the cue-present and cue-absent conditions. AOM in the cue-absent condition ranged from 38.1 to 76.0 dB for 5- to 7-year-olds (mean = 63.8 dB) and from 49.4 to 86.0 dB for 8- to 10-year-olds (mean = 67.2 dB). Similarly, AOM in the cue-present condition ranged from 47.3 to 77.6 dB for 5- to 7-year-olds (mean = 65.2 dB) and 53.9 to 77.8 dB for 8- to 10-year-olds (mean = 65.6 dB). Thus, the average cuing effect was−1.4 dB (range = −20.9 to 11.4 dB) for 5- to 7-year-olds and 1.6 dB (range = −11.2 to 8.7 dB) for 8- to 10-year-olds. A repeated measures ANOVA with the within-subjects factor of Cue Status (absent, present) and the between-subjects factor of Age Group (5- to 7-year-olds, 8- to 10-year-olds, adults) was performed on AOM. Neither main effect was significant: Cue Status [$F(1, 24) = 3.93$, $p = 0.06$, $\eta^2_p = 0.14$] and Age Group [$F(2, 24) = 2.68$, $p = 0.09$, $\eta^2_p = 0.18$]. However, the Cue Status × Age Group interaction [$F(2, 24) = 3.94$, $p = 0.03$, $\eta^2_p = 0.25$] was significant. Follow-up pairwise comparisons (Bonferroni, $\alpha = 0.05$) were conducted on estimates of AOM across Cue Status for each age group. All *p*-values reported below incorporate a Bonferroni adjustment. While AOM for adults was significantly lower in the cue-present than the cue-absent condition ($p = 0.003$), AOM was not significantly different with and without the cue for 5- to 7-year-olds ($p = 0.63$) or 8- to 10-year-olds ($p = 0.58$).

Substantial individual differences in cue benefit are evident with the two-tone masker, but individual data shown in Fig. 1(b) are consistent with the mean cuing effects. Cuing effects ranged from−4.9 to 23.7 dB for adults, with 7/9 adults showing a $\geq$3 dB effect. Note that two adults had cuing effects of >20 dB. In contrast to the adult data, only 3/9 5- to 7-year-olds and 4/9 8- to 10-year-olds showed a $\geq$3 dB cuing effect. Of these seven children, only one (a 7.8-year-old) showed an effect of $\geq$10 dB, compared with four adults. Overall, these individual data indicate that more than half of children tested did not benefit from the provision of a pretrial cue and that the children who did benefit tended to show a more modest improvement relative to adults. For some listeners the cue resulted in a decrement in performance for the cue-present compared with the cue-absent condition. A negative cuing effect of $\geq$ 3 dB was seen for four 5- to 7-year-olds, one 8- to 10-year-old, and one adult. The maximum decrement measured was 20.9 dB for a 6.2-year-old.[1]

## 4. Discussion

It has been posited a pretrial signal cue directs adults' attention to the signal frequency in multi-tonal masking paradigms, thus improving sensitivity and providing a release from informational masking (e.g., Richards and Neff, 2004). In contrast to adults, results from the present study indicate that the majority of 5- to 10-year-old children did not benefit from a pretrial signal cue for detection of a 1000-Hz tone in a random-frequency, two-tone masker. The average cuing effect was 9.4 dB for adults, compared with −1.4 dB for 5- to 7-year-olds and 1.6 dB for 8- to 10-year-olds. As predicted for the broadband noise condition, children and adults did not benefit from the pretrial cue in broadband noise which was not expected to produce informational masking.

Both the mean and range of the cuing effect in the present study was larger than observed for adults tested by Richards and Neff (2004). Our adults showed an average cuing effect of about 9 dB, with individual benefit scores ranging from −4.9 to 23.7 dB. Richards and Neff (2004) reported an average cuing effect of about 6 dB for detection of a 1000-Hz signal in a random-frequency, two-tone masker, with individual cuing effects ranging from 0 to 18 dB. One notable difference between the two studies is that adults tested by Richards and Neff (2004) completed a minimum of 20 threshold runs per condition, whereas listeners in the present study completed only three runs per condition. The reduced number of stimulus presentations in the present study compared with Richards and Neff (2004) may account for the higher estimates of AOM and cue benefit observed here. Note, however, no evidence of improvement was evident in the data across the three runs in the present study.

The question raised by the results of the present study is why most children do not benefit from the provision of a pretrial signal cue with the random-frequency, two-tone masker. One possible explanation is that the children were biased to respond to the signal in the first interval, failing to take advantage of the pretrial cue when the signal occurred in the second interval. This possibility was examined by calculating the proportion of trials in which interval 1 was chosen by the listener, following the approach described by Richards *et al.* (2004). Neither age group of children demonstrated an interval bias, a finding inconsistent with the idea that children only benefitted from the pretrial cue if the subsequent signal occurred in the first interval.[2] A second possible explanation for the lack of a strong cuing effect in the children's data is that children may have relied on a loudness cue to detect the 1000-Hz signal, rather than a detection strategy based on frequency. Previous results suggest that adults do not rely on overall stimulus loudness, even when that information is available (e.g., Richards and Neff, 2004). Nonetheless, children may rely more heavily on overall level information than adults in these conditions, a possibility that requires additional investigation. A third possible explanation for the lack of a cuing effect in the children's data is that it is a consequence of immaturity in the ability to selectively monitor the auditory filter centered on the signal frequency and/or disregard frequencies remote in frequency relative to the signal, even when an exact preview of the pure-tone signal is provided. It is well established that infants and young children listen unselectively in frequency during relatively simple detection tasks (e.g., Werner and Bargones, 1991; Leibold and Neff, 2011), a strategy that persists into adolescence for more complex tasks such as the multi-tonal paradigm used in the present study (e.g., Lutfi *et al.*, 2003). For example, Lutfi *et al.* (2003) measured children's (4–16 years) and adults' detection of a cued, 1000-Hz pure-tone signal embedded in a random-frequency, multi-tonal masker. Results from a principal component analysis indicated that listeners most susceptible to informational masking, including the majority of children, were influenced to a greater extent by information in irrelevant auditory filters. Children's inability to benefit from the pretrial signal cue in the present study suggests this unselective listening strategy persists for children even when *a priori* knowledge about the signal is provided via pretrial cuing.

The present results indicate that a reexamination of findings from previous developmental studies is warranted. Previous studies examining children's susceptibility to simultaneous random-frequency, multi-tonal maskers have provided listeners with a pretrial signal cue. The results of the present study indicate a larger child-adult difference for detection of a 1000-Hz tone in a random-frequency, two-tone masker with (13.2 dB) than without (4.0 dB) a pretrial signal cue. The discrepancy in the age effect between cue-present and cue-absent conditions in the present study suggests that previous studies involving children, all using a pretrial signal cue, may have overestimated developmental effects in informational masking relative to conditions without a pretrial cue. Further research is needed with a larger sample size and a wider age range to determine the magnitude of the child-adult differences both with and without a pretrial cue.

**Acknowledgments**

This work was supported by the NIH (Grant No. NIDCD R01 DC011038). We appreciate comments from Emily Buss on a previous version of this article.

**References and links**

[1]One possible reason for this child's substantial decrement is that he had a low AOM estimate in the cue-absent condition (38.1 dB). This case may be an outlier based on the examination of its anomaly index (SPSS; criterion $\geq$2.0). However, removal of this child's data from the ANOVA did not change the pattern of results.

[2]A repeated measures ANOVA was conducted on interval bias for the two-tone masker condition with the within-subjects factor of Cue Status (absent, present) and the between-subjects factor of Age Group (5- to 7-year-olds, 8- to 10-year-olds). No significant effects were found: Cue Status [$F(1, 16) = 0.84$, $p = 0.37$, $\eta^2_p = 0.05$]; Age Group [$F(1, 16) = 1.88$, $p = 0.19$, $\eta^2_p = 0.11$]; and Cue Status × Age Group [$F(1, 16) = 4.27$, $p = 0.06$, $\eta^2_p = 0.21$]. Collapsing across the two groups of children, interval 1 was selected on 49.2% of trials in the cue-present condition and 47.5% of trials in the cue-absent condition.

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