Contingent capture of involuntary visual spatial attention does not differ between normally hearing children and proficient cochlear implant users

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Abstract

Purpose: Evidence suggests that deafness-induced changes in visual perception, cognition and attention may compensate for a hearing loss. Such alterations, however, may also negatively influence adaptation to a cochlear implant. This study investigated whether involuntary attentional capture by salient visual stimuli is altered in children who use a cochlear implant.

Methods: Thirteen experienced implant users (aged 8–16 years) and age-matched normally hearing children were presented with a rapid sequence of simultaneous visual and auditory events. Participants were tasked with detecting numbers presented in a specified color and identifying a change in the tonal frequency whilst ignoring irrelevant visual distractors.

Results: Compared to visual distractors that did not possess the target-defining characteristic, target-colored distractors were associated with a decrement in visual performance (response time and accuracy), demonstrating a contingent capture of involuntary attention. Visual distractors did not, however, impair auditory task performance. Importantly, detection performance for the visual and auditory targets did not differ between the groups.

Conclusion: These results suggest that proficient cochlear implant users demonstrate normal capture of visuospatial attention by stimuli that match top-down control settings.

Keywords: Cochlear implant, selective attention, spatial attention, contingent capture, children

1. Introduction

It is well established that deafness is associated with changes in visual perception, cognition and attention. Most notably, deaf observers show enhanced neural and behavioral responses to moving stimuli that are presented in the peripheral visual field (Neville and Lawson 1987a, 1987b, 1987c; Loke and Song 1991; Armstrong et al., 2002; Stevens and Neville 2006). The specificity of this effect for motion, but not color processing has been taken to suggest that motion-sensitive brain regions are more susceptible to deafness-induced reorganization (for a review, see Bavelier et al., 2006). Interestingly, such reorganization is not restricted to visual cortices (see also, Bavelier et al., 2000, 2001), but can also involve auditory areas being recruited to process visual information (Finney and Dobkins 2001,
Finney et al., 2003; Fine et al., 2005). Importantly, it has been shown that increased levels of such cross-modal plasticity between the visual and auditory systems are associated with poorer hearing outcomes following implantation of a cochlear prosthesis (e.g., Lee et al., 2001, 2005, 2007; Doucet et al., 2006). It is unclear, however, what role cognitive influences, such as selective attention, play in these effects. Here, we investigate the involuntary orienting of attention to salient visual stimuli in cochlear implant users.

Selective attention plays a fundamental role in shaping sensory perception, acting to boost neutral and behavioral responses to potentially important stimuli and suppress responses to irrelevant events (for reviews, see Corbetta and Shulman 2002; Knudsen 2007). Numerous studies have shown that visual selective attention is altered in deaf individuals; indeed, many of the changes in visual perception reported for deaf observers arise only under conditions of focused attention. For example, under conditions of focused central attention deaf observers are faster to respond to targets presented extrafoveally and show less interference from central stimuli (Parasnis and Samar 1985). This enhanced attentional sensitivity is accompanied by greater interference from peripheral distractors (e.g., Bosworth and Dobbins 2002; Proksch and Bavelier 2002; Sladen et al., 2005, Dye et al., 2007, 2009). Such changes in visual perception have been explained in terms of a redistribution of attentional resources to more peripheral locations and/or salient stimuli, which may serve a compensatory function for orienting to important environmental events in the absence of hearing (see, e.g., Lavie 2005).

In addition to the interference effects of peripheral distractors shown in deaf adults, an impairment of sustained visual attention has been reported for children. Such effects have been shown using a continuous performance task in which target numbers must be detected in a rapid serial visual presentation (RSVP) of distractor items (Quittner et al., 1994; Mitchell and Quittner 1996; Smith et al., 1998; Horn et al., 2005). A similar deficit is found for the detection of colored shapes in RSVP streams (Dye and Bavelier 2010). Importantly, this later study avoided possible confounds due to delayed language development and/or co-morbid neurological disorders, which may have influenced the earlier results (Dye and Bavelier 2010). One explanation for these findings is that deaf children, like adults, maintain a wider focus of visual attention in order to monitor their environment, which is sub-optimal for centrally presented tasks like the continuous performance task (Quittner et al., 1994; Smith et al., 1998). If this hypothesis is correct, then children with a cochlear implant should show a normalization of sustained visual attention, as they can presumably use audition to monitor their environment. Interestingly, children who use a cochlear implant do generally show improvements in sustained visual attention compared to deaf children without an implant, but not all perform as well as their normally hearing peers (Quittner et al., 1994; Smith et al., 1998; Horn et al., 2005; Yucel and Derim 2008).

Although numerous studies have examined sustained visual attention in children who use a cochlear implant, selective visual attention has been scarcely investigated. Importantly, changes in selective visual attention, such as increased distractibility to salient stimuli, may influence how well a child learns to use a cochlear implant. Such changes in attention are also likely to present implant users, especially those attending regular schools, with a range of challenges not experienced by their normally hearing peers (Chute and Nevis 2003; Dye et al., 2008). Previous research in normally hearing adults has shown that the degree to which stimuli capture attention depends not only on the physical properties of a stimulus, but also on whether those properties match task-demands and top-down attentional control settings (e.g., Folk et al., 1992; Remington et al., 2001; Serences et al., 2005, Leblanc et al., 2008). For example, when an irrelevant stimulus shares its color with a to-be-detected target, that stimulus causes stronger interference than does a different colored stimulus or one that moves (e.g., Folk et al., 1994). This effect has been termed contingent attentional capture, as the involuntary capture of attention is contingent on the behavioral goals of the observer. The current study aimed to investigate whether such contingent capture of visual attention is altered in children who use a cochlear implant.

Children were presented with simultaneous streams of visual and auditory stimuli and were tasked with detecting targets in each modality. On each trial a visual distractor preceded the presentation of a target, which could occur in either modality (see Fig. 1). Based on the contingent capture hypothesis it was predicted that distractors possessing the target-defining characteristic (a specific color) would interfere with detection of visual targets to a greater extent than distractors without that feature. It was also hypothesized that implant users would show differences in such...
Fig. 1. Stimuli and trial design. Participants were presented with simultaneous streams of colored numbers and tonal stimuli. The task was to detect a number presented in a pre-defined color (shown for green) or a change in tonal frequency. A visual or auditory target was presented on each trial. Prior to the target, one of four lateralized visual distractors was presented (see inset) on the left or right of fixation. The example shows a trial containing a visual target and a target-colored distractor; the black background has been removed for illustrative purposes. Adapted from Kamke and Harris (2014).

contingent capture effects and be more distracted by moving stimuli. Additionally, a key question in this study was whether salient visual stimuli can interfere with auditory perception in children who use a cochlear implant, as was recently shown for adults (Champoux et al., 2009). It was hypothesized that visual distractors would have a greater impact on auditory detection performance in implant users compared to normally hearing children.

2. Methods

2.1. Participants

Data from 13 children with a cochlear implant (eight female; aged 8.6–16.0 years, median 12.0) and 13 age-matched normally hearing children (six female; aged 8.6–15.9 years, median 12.2) were included in the analysis. Data from an additional three implant users and four normally hearing children were excluded as they did not complete the task or performed at chance level in the visual and/or auditory control (no distractor) conditions (see 2.3 Stimuli). Implant users were recruited on an opportunistic basis over the duration of the study through Hear and Say (Auchenflower, Brisbane, Australia), a pediatric Auditory-Verbal Therapy early intervention and cochlear implant center. Normally-hearing children included siblings of the implant users as well as children recruited from schools in the Lockyer Valley, Queensland. Experimental procedures were approved by The University of Queensland Medical Research Ethics Committee and fully-informed, written consent was obtained from the parent/guardian of all participants (children were also invited to provide written consent).

The demographic and clinical profiles of cochlear implant users are shown in Table 1. All children had severe-to-profound hearing loss that was diagnosed by two years of age (eight from birth) and all but one child had their first implant fitted by the age of four. Implant users had a Cochlear™ prosthesis (see Table 1) and during testing used their own speech processor with their clinically-programmed map and preferred program and settings. All children had undertaken the Auditory-Verbal Therapy early intervention program prior to school entry and none used a signed language. This habilitation program focuses on developing the spoken language of a deaf child through listening and requires the active participation of parents/caregivers as the primary language teachers of their children (AG...
Table 1

Demographic and clinical profile of cochlear implant users

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Age at onset of profound deafness (years)</th>
<th>Implanted ear</th>
<th>Age at first implant (years)</th>
<th>Age at second implant (years)</th>
<th>Hearing aid</th>
<th>Implant/processor type</th>
<th>Speech perception score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.6</td>
<td>F</td>
<td>Birth</td>
<td>L</td>
<td>1.1</td>
<td>N/A</td>
<td>Yes</td>
<td>N24/Fd (L)</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>15.8</td>
<td>F</td>
<td>Birth</td>
<td>L+R</td>
<td>1.5</td>
<td>11.3</td>
<td>N/A</td>
<td>Fd/Fd (L); N22Spectra22 (R)</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>16.0</td>
<td>F</td>
<td>1.0</td>
<td>L+R</td>
<td>2.0</td>
<td>12.0</td>
<td>N/A</td>
<td>Fd/Fd (L); N24/Fd (R)</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>15.7</td>
<td>M</td>
<td>Birth</td>
<td>L+R</td>
<td>2.5</td>
<td>13.5</td>
<td>N/A</td>
<td>N22/Fd (L); Fd/Fd (R)</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>12.0</td>
<td>M</td>
<td>Birth</td>
<td>R</td>
<td>4.0</td>
<td>N/A</td>
<td>No</td>
<td>N24/Fd (R)</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
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<td>Birth</td>
<td>L+R</td>
<td>3.0</td>
<td>13.5</td>
<td>N/A</td>
<td>N24/Fd (L); Fd/Fd (R)</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>10.9</td>
<td>M</td>
<td>Birth</td>
<td>L+R</td>
<td>1.7</td>
<td>8.0</td>
<td>N/A</td>
<td>N24/Fd (L); N24/Esprit3G (R)</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>11.2</td>
<td>M</td>
<td>Birth</td>
<td>L+R</td>
<td>1.0</td>
<td>9.0</td>
<td>N/A</td>
<td>Fd/Fd (L); N24/Fd (R)</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>12.2</td>
<td>F</td>
<td>1.5</td>
<td>L</td>
<td>10.5</td>
<td>N/A</td>
<td>Yes</td>
<td>Fd/Fd (L)</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>10.3</td>
<td>M</td>
<td>Birth</td>
<td>L+R</td>
<td>1.5</td>
<td>8.0</td>
<td>N/A</td>
<td>Fd/Fd (L); Fd/Fd (R)</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>9.8</td>
<td>M</td>
<td>1.0</td>
<td>L+R</td>
<td>3.0</td>
<td>5.0</td>
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<td>N24/Fd (L); Fd/Fd (R)</td>
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</tr>
<tr>
<td>12</td>
<td>12.1</td>
<td>F</td>
<td>Birth</td>
<td>R</td>
<td>1.3</td>
<td>N/A</td>
<td>No</td>
<td>N24/Fd (R)</td>
<td>6</td>
</tr>
<tr>
<td>13</td>
<td>11.9</td>
<td>F</td>
<td>Birth</td>
<td>L</td>
<td>2.0</td>
<td>N/A</td>
<td>Yes</td>
<td>N24/Fd (L)</td>
<td>6</td>
</tr>
</tbody>
</table>

Note. For bilateral CIs, first ear implanted is underlined. Implant type: N22 and N24 = Nucleus 22 and 24, respectively; Fd = Freedom. Speech perception is scored out of nine (0–8), with higher values indicating better performance (see 2.2 Speech perception abilities of cochlear implant users).

Bell Academy for Listening and Spoken Language (2013).

2.2. Speech perception abilities of cochlear implant users

The speech perception abilities of the cochlear implant users were determined from a review of their clinical test results. Audition-alone speech perception testing (i.e., without visual cues) included both closed-set tests, in which a limited set of response alternatives are provided, and open-set tests, where response alternatives are not provided. Tests were administered in recorded format and/or via live voice. Each participant was assigned a speech perception score according to the Categories of Auditory Performance Index (Black et al., 2012), which has nine hierarchic classifications (numbered 0–8). Higher category numbers reflect better speech perception abilities, with a category of 8 indicating an ability to perceive speech very well through audition alone in both quiet and noisy conditions. The median speech perception score for the children in the present study was 6 (range 4–6; see Table 1), which indicates very good speech perception abilities in quiet conditions (>75% accuracy), while 4 indicates more limited open-set speech perception (<50% accuracy; for details, see Black, Hickson et al. 2012).

2.3. Stimuli

The contingent attentional capture task employed here has been used previously with normally hearing adults (Kamke and Harris 2014) and is based on that reported by Leblanc and colleagues (Leblanc and Jolicoeur 2005; Leblanc et al., 2008), with the major differences being addition of auditory stimuli and hash symbols that accompanied every visual stimulus. As shown in Fig. 1, visual stimuli consisted of six digits (2, 3, 5, 6, 8 and 9) that subtended 1.3° in height. The digits were colored blue (R, G, B; 0, 0, 225), green (0, 115, 0), purple (140, 0, 170), red (213, 0, 0) or ochre (149, 79, 0), adjusted in a laboratory setting to be of similar luminance (all within one cd/m²; ColorCAL colorimeter, Cambridge Research Systems). The digits were presented in a RSVP stream at the center of the computer screen and were flanked 2° to the left and right by a grey (85, 85, 85) hash symbol that was 1.3° in height. The digits were colored blue (R, G, B; 0, 0, 225), green (0, 115, 0), purple (140, 0, 170), red (213, 0, 0) or ochre (149, 79, 0), adjusted in a laboratory setting to be of similar luminance (all within one cd/m², ColorCAL colorimeter, Cambridge Research Systems). The digits were presented in a RSVP stream at the center of the computer screen and were flanked 2° to the left and right by a grey (85, 85, 85) hash symbol that was 1.3° in height. Visual targets were the number “3” or “8” in a pre-assigned target color and were presented on 50% of trials. Target colors were blue, green, purple or red and were counterbalanced across participants. The visual target randomly appeared at position nine, 12 or 15 in the RSVP stream and was followed by nine non-target stimuli. Non-target digits were randomly generated from all numbers used (including “3” and “8”) and all non-target colors. All stimuli were presented in Arial font on a black background using Presentation software (v14, Neurobehavioral Systems) running under
or d) one of the hash marks moving (540° clockwise rotation over the display period; ‘motion distractor’). Based on the performance of different aged children during pilot testing, two versions of the task were used. In the fast version, which was used only with the three oldest children in both groups, each digit/hash stimulus was presented for 117 ms with a stimulus onset asynchrony of 150 ms. The remainder of the children completed the slow version, in which each digit/hash stimulus was presented for 167 ms with an onset asynchrony of 200 ms. The version of the task that each child completed depended on her/his performance during practice (see 2.4 Procedure).

2.4. Procedure

Experimental sessions took place in a quiet, dimly lit room at participants’ homes, school, or at the auditory habilitation center. Experimental trials commenced with a fixation cross followed by the concurrent presentation of the visual and auditory stimuli (see Fig. 1). The participant was tasked with detecting, as quickly and accurately as possible, the number presented in a pre-defined target color or a change in tonal frequency. Responses were made via key press on a standard keyboard, labeled “3” or “8” for visual targets and “LOW” or “HI” for auditory targets. For half of the participants in each group, the visual response buttons were the D (“3”) and F (“8”) keys, pressed using the left hand, while the auditory response buttons were the J (“LOW”) and K (“HI”) keys, pressed using the right hand. The remaining participants in each group used the J (“3”) and K (“8”) keys for response to visual stimuli, and the D (“LOW”) and F (“HI”) keys for auditory responses. Feedback on accuracy was presented after each trial.

Prior to the experiment, participants were given practice trials of the visual task alone (no auditory stimuli presented), the auditory task alone (no visual stimuli presented) and then the full task. To avoid floor effects in performance on the visual task, older participants (over 10 years of age) commenced practice with the faster RSVP stream, but completed the slow version for the experiment if they failed to achieve 80% accuracy in the control (no distractor) condition on the visual-only practice. To ensure that performance on the auditory task was comparable between normally hearing children and cochlear implant users, and to avoid floor and ceiling effects for this task, an auditory titration procedure also preceded the experiment proper. During the titration task, eight high and eight low oddball tones, from each of the six ratio levels (see 2.3 Stimuli), were presented randomly in two blocks. The oddball pair chosen for the experiment was the most difficult to discriminate in which the participants’ accuracy was at least 80%. Eleven implant users completed the easiest discrimination (1400/714 Hz), one the 1100/909 Hz oddballs
and one the 1050/952 Hz pairs. One normally-hearing child completed the 1400/714 Hz discrimination, four the 1200/833 Hz level, three the 1050/952 Hz oddballs and five the 1025/976 Hz pairs. No child did the most difficult discrimination. The experiment proper consisted of six blocks of 48 trials; 36 trials for each of the two target (visual or auditory) and four distractor conditions. Within each condition, trial length and distractor position (right or left) were counterbalanced. Rest breaks between blocks were self-paced and the experiment took at least 45 minutes to complete.

2.5. Statistical analysis

Prior to analysis, reaction times for correct responses that were greater than 2.5 standard deviations from the mean, or were less than 100 ms were removed. This screening procedure removed less than 3.5% of the data. Responses were then collapsed across the visual (“3” or “8”) and auditory (“Low” and “High”) target types. In general, reaction time data were moderately positively skewed and accuracy data negatively skewed, but to a smaller degree. Therefore, prior to inferential analysis reaction time data were normalized using a Log10 transformation and accuracy data using a square root transformation after reflection (Shapiro-Wilk test, \( p > 0.05 \)). These normalization procedures did not change the significance of any of the ANOVAs (note that whereas inferential results refer to the transformed data, descriptive statistics are reported using the raw data). To investigate whether children with a cochlear implant differed from normally hearing children in their temporal allocation of attention (cf., Dye and Bavelier 2010), responses to visual and auditory targets in the no-distractor control condition were compared using two-tailed \( t \)-tests. To determine whether the groups differ in contingent capture effects, responses for each individual in the no-distractor condition were subtracted from the visual distractor conditions. These difference data were then compared using mixed ANOVA with the factors Group (normally hearing, cochlear implant) and Distractor (target-colored, non-target-colored, motion). Significant main effects were followed-up using planned comparisons and Bonferroni adjusted, two-tailed \( t \)-tests (adjusted alpha level = 0.017). Statistical analysis was carried out using SPSS (v19; IBM).

3. Results

Mean reaction times and accuracy for detecting targets in the absence of visual distractors (i.e., the no-distractor control condition) are presented in Table 2. Overall, reaction times were faster, and accuracy slightly higher, in the visual compared to auditory task. Analysis of performance in the no-distractor condition revealed that there were no differences in reaction times between the groups for either the visual \(( p = 0.553)\) or auditory \(( p = 0.715)\) stimuli. Similarly, there was no difference in accuracy between groups for detecting visual \(( p = 0.525)\) or auditory \(( p = 0.723)\) targets. It should be noted that the larger variability in reaction times for the visual task in the cochlear implant group (Table 2) was principally due to lengthy responses from two participants. Removal of these participants (and their matched controls) did not change the significance of any of the \( t \)-tests.

3.1. Contingent capture effects: Visual stimuli

The mean change in reaction time for detecting visual targets relative to the no-distractor control condition is presented in Fig. 2A. For both groups of children there was little change in reaction times when a motion distractor was presented, but there was a substantial slowing following a target-colored distractor. ANOVA confirmed a difference in reaction times across the distractor conditions, \( F(2, 48) = 7.344, p = 0.002, \eta^2 = 0.234, \) but no difference between the groups (all other \( p > 0.41 \)). Follow-up comparisons revealed that reaction times were significantly longer following presentation of a target-colored distractor compared to both a non-target-colored distractor \(( p = 0.010)\) and motion distractor \(( p = 0.002)\). There was no difference in reaction times between the non-target-colored and motion distractors \(( p > 0.31)\).

Analogous to reaction times, accuracy for detecting visual targets was also affected by the type of distractor presented. As shown in Fig. 2B, relative
to the no-distractor condition mean accuracy was reduced maximally following the presentation of a target-colored distractor, and this effect is larger for the normally hearing group. The difference in accuracy across the distractor conditions was found to be reliable, $F(2, 48) = 13.823, p < 0.001; \eta^2_p = 0.365$, but there was no difference between the groups (all other $p > 0.26$). Specifically, accuracy was lower following presentation of a target-colored distractor compared to both non-target-colored ($p = 0.003$) and motion ($p < 0.001$) distractors. The difference in accuracy between the non-target-colored and motion distractors did not reach significance following correction for multiple comparisons ($p = 0.033$; adjusted alpha = 0.017).

### 3.2. Contingent capture effects: Auditory stimuli

The mean change in reaction time for detecting auditory targets, relative to the no-distractor condition, is presented in Fig. 3A. For children with a cochlear implant reaction times were faster following the presentation of a distractor compared to the no-distractor condition (negative change in response time). Normally hearing children showed a similar, albeit smaller speeding of reaction times, but their responses were slowed following a target-colored distractor. ANOVA revealed, however, that there were no reliable differences in reaction times between the groups or across the distractor conditions (all $p > 0.29$). Unlike reaction times, it can be seen in Fig. 3B that there was little change in accuracy for detecting auditory targets following the presentation of a visual distractor (all $p > 0.35$).

Although the previous analysis on the auditory reaction time data revealed that there was no reliable difference across the distractor conditions, the analysis could not reveal whether reaction times were different from the no-distractor condition, as is suggested by the (negative) difference data in Fig. 3A. Consequently, exploratory analysis using a two-tailed $t$-test was undertaken in order to determine whether distractors (collapsed over type) were associated with a speeding of reaction time compared to the control condition. For the cochlear implant group, the presentation of a distractor was associated with a substantial speeding of reaction times ($M = -58.4 \text{ ms}, SE = 19.9 \text{ ms}$) that was significantly different from baseline (mean difference $= -0.0189, 95\% CI, -0.0305$ to $-0.0074$; $t(38) = -3.311, p = 0.002$). For normally hearing children, overall there was a more modest speeding of reaction times following the presentation of a visual distractor ($M = -12.8 \text{ ms}, SE = 15.3 \text{ ms}$), which did not differ from the no-distractor condition (mean
4. Discussion

This study investigated attentional control and capture in normally-hearing children and children who use a cochlear implant. It was found that implant users did not differ from age-matched normally hearing children in their temporal allocation of attention, as indexed by performance in detecting visual targets that were embedded in an RSVP stream. It was also found that there was no difference between groups in the effect of top-down attentional control settings on capture by salient visual stimuli. Specifically, in both groups of children visual target detection was poorest following the presentation of an irrelevant distractor that was the same color as the to-be-detected target. Visual distractors did not, however, interfere with detection of auditory targets.

4.1. Temporal allocation attention

Previous studies using the continuous performance task suggest that deaf children are impaired in sustained visual attention. Continuous performance tasks typically require the allocation of attention in time in order to detect a target from amongst an RSVP of distractor numbers. Dye and Bavelier (2010) have proposed that such studies might therefore point to a deafness-induced deficit in the temporal allocation of attention. In support of this idea, they presented evidence showing that deaf children, who had normal (signed) language development and no co-morbid neurological disorders, were poorer at detecting a target-colored item that was embedded in a discontinuous RSVP of colored geometric shapes. In the present study the control (no-distractor) condition was conceptually the same as that used by Dye and Bavelier (2010), but instead of shapes children searched for a target-colored number. Results showed that implant users do not differ from normally hearing children in speed or accuracy for detecting targets embedded in a stream of distractor numbers. Thus, although the paradigm employed here has not been used with deaf children who do not have an implant, the present results are consistent with studies suggesting that sustained visual attention is improved (Quittner et al., 1994; Smith et al., 1998; Horn et al., 2005), or even normalized (Tharpe et al., 2002; Shin et al., 2007), in deaf children who use a cochlear implant.

It has been proposed that access to sound improves sustained visual attention by freeing visual resources...
The primary aim of this study was to investigate whether children who use a cochlear implant differ from their normally hearing peers in distractibility to salient visual events. To address this question, children searched for a target embedded in an RSVP of numbers while irrelevant distractors were flashed on either side of the central display. It has been shown previously that deficits in the performance of deaf children on tasks of sustained visual attention are exacerbated in the presence of irrelevant items flanking the central stream (Mitchell and Quittner 1996). Similar interference effects from irrelevant flankers on selective attention in deaf adults have been taken to indicate an increased sensitivity to extraneous presented items (Sladen et al., 2005; Dye et al., 2007). Accordingly, we predicted that children who use a cochlear implant would show increased capture by the irrelevant (flanking) distractors. Furthermore, because deaf individuals show increased sensitivity to motion stimuli (as detailed in the Introduction), it was expected that cochlear implant users would be especially captured by the moving distractors. Neither of these predictions was supported.

In the present study it was found that visual performance was degraded in the presence of target-colored distractors compared to distractors that were presented in a non-target color. Critically, colors did not differ in salience at the sensory level and, across participants, were in fact the same colors. The only difference between the target- and non-target-colored distractors was whether they matched the ‘attentional set’ of the observer. Thus, the present results show for the first time that involuntary capture of attention in children, like adults, is contingent on the behavioral goals of the observer (e.g., Folk et al., 1992; Remington et al., 2001; Serences et al., 2005). In addition, we found that target-colored distractors caused more interference than motion distractors, an effect that has also only been reported previously for normally hearing adults (Folk et al., 1994). This result further supports the contention that involuntary capture of visual attention was contingent on the attentional set of the children. Importantly, we did not find any difference in these contingent capture effects between normally hearing children and children who use a cochlear implant. In a previous study with adults that employed a contingent capture task similar to that used here it was found that irrelevant stimuli presented in the target color elicited a shift of visuospatial attention toward the location of the distractor item, as indexed by the N2pc event-related potential (Leblanc et al., 2008). Thus, our results suggest that as well as normal-like temporal attention, proficient cochlear implant users show involuntary shifts of visuospatial attention that are indistinguishable to those observed in their normally hearing peers.

Numerous studies have reported that, compared to proficient cochlear implant users and normally hearing
observers, non-proficient users show alterations in neural and behavioral responses to visual stimuli (Doucet et al., 2006; Champoux et al., 2009; Tremblay et al., 2010; Landry et al., 2012; Sandmann et al., 2012). Such effects have been explained in terms of deafness-induced plasticity in visual and auditory brain regions, which may limit the neural capacity for learning to integrate the input provided by a cochlear implant (see also, Lee et al., 2005, 2007). For pre-lingually deafened individuals, early access to sound, even if it is highly impoverished and unnatural (Moore and Shannon 2009), combined with appropriate auditory habilitation may be sufficient to avoid such maladaptive plasticity effects. It does not follow, however, that selective visual attention should also be normal in proficient implant users. Specifically, because of the impoverished nature of the auditory input provided by a cochlear implant, users tend to rely more heavily on visual speech information than their normally hearing peers (e.g., Schorr et al., 2005; Rouger et al., 2007). Such dependence, as well as any associated learning-induced plasticity, could alter visual attention even in proficient implant users. The current results suggest, however, that early implantation and good hearing outcomes are also associated with normal visual attentional capture and control.

A key question in the present study was whether salient visual stimuli interfere with auditory perception in cochlear implant users. In this context there is a wealth of evidence demonstrating cross-modal links in attention and perception in normally hearing individuals (for reviews, see Driver and Spence 2004; Spence, McDonald et al. 2004), including interference effects in both adults and children (e.g., Escera et al., 1998; Gumenyuk et al., 2004). Recently, Champoux and colleagues reported that the speech perception performance of non-proficient cochlear implant users is degraded in the presence of incongruent lip movements and moving dots, but not by a color change (Champoux et al., 2009). It is perhaps not surprising to find that implant users have an increased susceptibility to incongruent lip movements (see also, Desai et al., 2008; Rouger et al., 2008), as the impoverished sound signal provided by a cochlear implant places a larger reliance on visual speech information (Giraud et al., 2001). It is not so clear, however, why moving dots should interfere with speech perception. One possibility is that cross-modal plasticity between visual motion and auditory areas directly interferes with sound processing. Another (non-mutually exclusive) possibility is that highly salient visual stimuli capture attention and thus interfere with auditory perception.

Using the task employed in the present study, we have recently shown that target-colored distractors interfere with detection of both visual and auditory stimuli in normally hearing adults (Kamke and Harris 2014). Accordingly, we hypothesized that, compared to their normally hearing peers, auditory detection in children who use a cochlear implant would be poorer following presentation of a target-colored distractor (exaggerated top-down attention effect) and be impacted by irrelevant moving stimuli (bottom-up plasticity effect). In contrast to this prediction, auditory target detection in cochlear implant users was speeded following the presentation of all visual distractors. This speeding may be explained by the fact that, although the lateral visual distractors were irrelevant to the central task, those distractors were nonetheless temporally predictive of a target. It is therefore possible that all distractors had an alerting value, but for visual targets any related cueing effect (response facilitation) was counteracted by an involuntary shift of visuospatial attention toward the distractor item (Hickey et al., 2006). Moreover, when that distractor matched top-down attentional control settings (i.e., was target colored), the item could have gained access to a limited-capacity stage of processing that interfered with visual target detection (Ghorashi et al., 2003). On this argument, for the auditory task the visual distractors also acted as a cue, but any associated shift in visuospatial attention would not be expected to interfere with tone detection. Thus, nontarget-colored and motion distractors could cue the target and reduce reaction times. The target-colored distractor, however, should still interfere with auditory task performance because it causes a bottleneck at a higher-level stage of processing (Kamke and Harris 2014). We found just such a pattern of decrements for normally hearing children in the present study (viz. poorest performance in both the visual and auditory task following a target-colored distractor; see Figs. 2A and 3A), whereas cochlear implant users showed a facilitation of auditory target detection across all distractor conditions. This result may indicate a greater degree of independence in the higher-level processing of auditory and visual stimuli in cochlear implant users, but further work is required to test this speculation as a difference between the groups was only found in the exploratory analysis.
5. Conclusion

In summary, we have shown for the first time that children demonstrate similar visual contingent attentional capture effects as do adult observers. This result suggests that distractibility and attentional control related to task-demands mature at an early age. Importantly, children who use a cochlear implant did not differ from their normally hearing peers in these attention effects. It was also shown that auditory perception in children who are proficient cochlear implant users is not harmed by salient visual stimuli, at least for simple sounds presented in quiet conditions. The same children, however, may show some differences in cross-modal attentional effects compared to their normally hearing counterparts. Ultimately, a better understanding of how selective attention influences visual and auditory processing in individuals who hear with a cochlear implant will help to inform habilitation strategies.

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Conflict of interests

The authors declare that they have no conflict of interests regarding the publication of this article. Dr Gabriella Constantinescu is employed by Hear and Say.

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