Head Angle and Elevation in Classroom Environments: Implications for Amplification

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Purpose: The purpose of this study was to examine children’s head orientation relative to the arrival angle of competing signals and the sound source of interest in actual school settings. These data were gathered to provide information relative to the potential for directional benefit.

Method: Forty children, 4–17 years of age, with and without hearing loss, completed the study. Deviation in head angle and elevation relative to the direction of sound sources of interest were measured in 40 school environments. Measurements were made on the basis of physical data and videotapes from 3 cameras placed within each classroom.

Results: The results revealed similarly accurate head orientation across children with and without hearing loss when focusing on the 33% proportion of time in which children were most accurate. Orientation accuracy was not affected by age. The data also revealed that children with hearing loss were significantly more likely to orient toward brief utterances made by secondary talkers than were children with normal hearing.

Conclusions: These data are consistent with the hypothesized association between hearing loss and increased visual monitoring. In addition, these results suggest that age does not limit the potential for signal-to-noise improvements from directivity-based interventions in noisy environments.

KEY WORDS: directional microphones, hearing aids, pediatric amplification

Several studies have shown that poor signal-to-noise ratios (SNRs), such as those typically found in classroom settings, can significantly reduce speech understanding for children both with and without hearing loss (e.g., Finitzo-Hieber & Tillman, 1978; Crandell, 1993; Crandell & Smaldino, 2000). In addition, data suggest that listeners with hearing loss require significantly better SNRs for equivalent speech recognition performance when compared with listeners with normal hearing (Boothroyd, Eran, & Hanin, 1996; Killion, 1997; Schum, 1996). Consequently, the development and refinement of amplification techniques that improve SNR in school and other environments are of considerable interest. To date, the only amplification methods that have been shown consistently to improve SNR for listeners with hearing loss are based in microphone technology. Among currently popular microphone-based approaches, the most effective approach places a microphone in close proximity to the signal of interest and then transmits the microphone’s input directly to a device (often a hearing aid) using wireless transmission such as a frequency modulated (FM) signal (e.g., Flexer, 1996; Hawkins, 1984; Lewis, Crandell, Valente, & Horn, 2004). A second general microphone-based approach is directivity based. In this second approach, sound sampled at two or more
locations is processed and combined, resulting in spatially sensitive attenuation. Directivity-based approaches are exemplified by directional hearing aids and microphone array systems (see Ricketts & Dittberner, 2002, for review).

Although there is little doubt that proximity-based systems (e.g., FM) are the preferred intervention in classroom settings in which only the teacher’s voice is of interest (Lewis et al., 2004), at least three factors limit recommendation of full-time use of such systems (Lewis, 1991; Madell, 1992). These factors include the presence of multiple talkers of interest during which passing a microphone is difficult or not possible (listening to other classmates, “overhearing” other conversations, playground and lunchroom environments), cosmetic or social concerns (especially among older children), and portability concerns. In addition, it is sometimes the case that for financial or other reasons, FM systems are not available. Consequently, the viability of directivity-based microphone systems for use in school environments remains of interest despite the fact that the magnitude of the SNR improvement provided by such devices is expected to be much smaller than proximity-based approaches (Lewis et al., 2004).

The potential for improved speech understanding in noise through directivity-based microphone approaches is clear for both children and adults across a variety of listening environments (e.g., Bentler, 2005; Gravel, Fausel, Liskow, & Chobot, 1999; Hawkins, 1984; Kuk, Kollofski, Brown, Melum, & Rosenthal, 1999; Ricketts & Hornsby, 2003; Ricketts, Henry, & Gnewikow, 2003; Ricketts, Galster, & Tharpe, in press; Walden, Surr, Cord, & Dyrlund, 2004). However, the presence and magnitude of this improvement depends in part on interactions between the sensitivity pattern of the directional microphone and the environment. Specifically, in directivity-based amplification systems, the signal output level is dependent on the elevation and angle of arrival of the sound source (Ricketts, Henry, & Hornsby, 2005). Therefore, the specific angles and elevations of arrival for the various competing signals and the signal of interest directly affect the magnitude of effective improvement in SNR. For current directional hearing aid systems, a directivity-based advantage is found when the listener is generally facing the sound source of interest and the competing noise either is behind or surrounds the listener (e.g., Ricketts, 2000a, 2000b, 2000c; Ricketts, Lindley, & Henry, 2001; Walden et al., 2004). In contrast, directivity-based systems are expected to lead to reduced performance (in comparison with traditional hearing aids) when the listener is not facing the sound source of interest. For example, Lee, Lau, and Sullivan (1998) revealed that listeners’ speech recognition for sounds arriving from directly behind was significantly poorer when fitted with a directional hearing aid than when the sound arrived from in front.

Because important signals are expected to originate from a variety of angles and elevations, head orientation has especially important implications when considering directivity-based systems for children in school environments. Specifically, because directivity-based approaches selectively attenuate sounds based on their angle and elevation of arrival, positive directional benefit is only expected when children are able to orient their heads toward the sound of interest. In specific listening situations for which the sound source of interest is behind the child and the child is unable or unwilling to turn to face the sound source, directivity-based amplification is expected to be detrimental. For example, a child could place a signal of interest (such as the teacher’s voice) at a position for which the directivity-based system provides significant attenuation, through head movement. This might occur when a child turns around to face another classmate, when the teacher walks to another area of the room, or in more common cases, such as when a child looks down to his or her desk to write. In any of these cases, the reduction in signal level may reduce the amount of speech information that falls within the child’s audibility range and above the level of the background noise. Any reduction in audibility of speech is likely to result in a decrease in speech recognition performance.

Given the importance of appropriate head angle and elevation when using directivity-based systems, it is of interest to consider sound-orienting behavior in normal-hearing infants and young children. A number of studies have shown that in the newborn period, infants can turn their eyes or heads toward the source of sound in the correct hemifield (Ashmead, Clifton, & Perrin, 1987; Ashmead, Davis, Whalen, & Odom, 1991; Clifton, Morrongiello, Kulig, & Dowd, 1981; Crassini & Broerse, 1980; Morrongiello & Rocca, 1987, 1990; Muir & Field, 1979; Turkewitz, Birch, & Cooper, 1972; Wertheimer, 1961). However, this response is quite fragile, being highly dependent on the infant’s state and posture as well as the stimulus conditions (Clarkson, 1992). Interestingly, this head-turn response, present within hours of birth, disappears at approximately 2 months of age and reappears at about 4 months of age (Smith, Quittner, Oserberger, & Miyamoto, 1998). Upon its return, the head-turn response is faster, accompanied by visual search, and appears to be more accurate (Muir, Clifton, & Clarkson, 1989). Based on these data, it appears reasonable to conclude that young children are capable of approximately facing the talker of interest. However, it is not known whether children actually orient appropriately in real (i.e., nonexperimental) environments. School environments may include either one or multiple talkers of interest, and these talkers may speak for varying durations and be in various angles relative to the child’s head. Therefore, orientation accuracy, turning to brief as well as continuous utterances, and the position of sound sources
relative to the listener are all of interest. Furthermore, it is of interest to determine whether hearing loss and/or age is a factor in accuracy of orientation. This information is important both for determining candidacy and appropriateness of the use of directivity-based systems in school environments.

The purpose of this investigation was to quantify the angle and elevation of children’s heads relative to important sound sources in actual classroom environments. This quantification was completed for children aged 4–17 years to determine if age affected accuracy of orientation. Furthermore, head orientation was evaluated across children with and without hearing loss to determine if orientation accuracy was similar across these two groups.

**Method**

Three video cameras were used to assess head position relative to sound sources of interest in classroom listening environments. The head angle and elevation of 40 students was investigated. Participants were divided into four groups of 10 based on age and presence or absence of hearing loss. Specifically, 20 of the 40 children recruited were aged 4–9 years with a mean age of 6.25 years (younger group), and the remaining 20 were aged 12–17 years with a mean age of 13.8 years (older group). Within each of these two groups, 10 listeners had normal hearing and 10 had hearing loss. The younger children with hearing loss had pure-tone average (PTA) hearing thresholds in their better ear of 36 dB HL, whereas the older children with hearing loss exhibited an average, better-ear PTA of 40 dB HL. Attempts were made to recruit children as part of a classroom pair. Specifically, 2 children of the same gender—1 child with and 1 without hearing impairment—were recruited from the same or similar classrooms. In total, 12 classroom pairs were recruited. Although the remaining sixteen children were not a strict pair from the same classroom, they did consist of eight pairs of children (one with and one without hearing loss) who were matched for gender and grade. Videotaping was scheduled to ensure that similar classroom activities occurred for both children in each pair. Children’s classrooms included 1 located in the early intervention program of the Vanderbilt Bill Wilkerson Center (2 children), 3 day care settings in the metropolitan Nashville area (6 children), and 15 classrooms in the Metropolitan Nashville Public Schools (32 children), for a total of 19 classroom environments.

The presence or absence of hearing loss was established by record review for the children with hearing loss and by parental report for the children with normal hearing. Of the children with hearing loss, teacher report indicated that 19 of the 20 children consistently wore hearing aids bilaterally and 1 child did not use hearing aids. Eighteen of the 19 children with hearing aids were evaluated while aided. Although information relative to hearing aid specifics (e.g., gain, output, type of signal processing, and processing features) was unavailable, observation of these children’s instruments revealed that all were omnidirectional, behind-the-ear (BTE) style, instruments. Eighteen of the 20 children with hearing loss were in inclusionary classroom environments, with the remaining 2 children in a self-contained classroom for children with hearing loss.

**Evaluation of Head Angle and Elevation**

Head angle and elevation in a three-dimensional space can be assessed using two cameras placed at known, fixed distances from an object in space. Head position and sound source locations were recorded in each of the classrooms through the use of three digital video cameras. One camera (Cannon ZR65MC) was mounted over the child’s head and was aimed directly down. Data from this camera were used primarily to assess head angle in the horizontal plane. A second camera (Cannon ZR65MC) was placed so that the side of the child’s head could be viewed at the approximate elevation of the child’s head. Data from this camera were primarily used to assess head angle in the vertical plane. A third camera (Cannon Optura 100 MC) was placed at the rear of the classroom to capture the teacher position and position of other sound sources relative to the participant. Individual children were videotaped for 20-min sessions. These sessions included a traditional lecture or, whenever possible, a class period that required significant interactions among the children (e.g., a collaborative project).

The specific recording session times were identified in cooperation with the classroom teachers. Prior to videotaping, three to seven small stickers were placed on the child’s head to aid in tracking the angular position. The positions of the sound sources of interest (i.e., either the teacher or other classmates) were physically measured either before or after the class period and were combined with video data in order to increase the accuracy of angular measurements. In addition, field notes relative to the position and movement of the speaker of interest and other sound sources were kept during the recording sessions. To reduce the novelty of the video recording, perhaps biasing the results, actual recording did not begin until at least several minutes after the cameras had been placed. Pilot data indicated that conducting a “practice” recording on the day prior to the actual recording did not aid in reducing the distraction caused by the presence of the cameras. Rather, the children generally ignored the cameras and the investigators within several minutes after the cameras were set up.

The output from the digital cameras was transferred to a computer for further analysis. All three video
streams were time locked by quickly turning a classroom light off and on. The three time-locked streams were viewed and analyzed frame by frame using a commercial video editing package (Sonic Foundry Vegas Video 4.0) and an onscreen protractor. One frame of each of the three streams was systematically selected and analyzed for every second of video. For example, the 10th frame of 30 was selected from each second of recording. Periods of silence longer than 10 s were not analyzed. The primary data of interest for analysis included (a) deviation in head angle from the position of the primary talker, (b) deviation in head elevation from the position of the primary talker, (c) number and position of primary talkers, (d) number and location of brief utterances, and (e) appropriate turning toward the source location of brief utterances.

For the purposes of this analysis, a brief utterance was defined as an instance of a talker who spoke for between 1 and 4 s in isolation (e.g., a child answers a question). Instances of group utterance (e.g., students in the classroom responded in unison) were not analyzed. Furthermore, very brief utterances (less than 1 s) were not analyzed because, in most cases, this short duration did not allow time for head turn. It is important to note that brief utterances were only identified based on duration, not content. Therefore, it is the case that some brief utterances were important and likely of interest to the listener (e.g., answers to a teacher question), whereas others were either less important (e.g., a nonconnected conversation between other students that might be important only for overhearing purposes) or unimportant (e.g., a classmate misbehaving). Appropriate turning toward a brief utterance location was defined as an instance when the target child participant turned his or her head in the approximate direction (±30°) of the speaker during the brief utterance.

A controlled pilot study was completed to assess the accuracy of the measurement method. Specifically, deviation in angle and elevation data obtained using the experimental method was compared with physical measures of these deviations obtained by a second experimenter for several classroom positions. These pilot data indicated that the measurement method accurately measured the actual angle and elevation to within ±3° in the horizontal and vertical planes. In addition, changes in angle were consistent between physical and video measurement methods with a tolerance of approximately 1°.

**Results**

A preliminary analysis across the individual videotaping sessions was completed to assess the frequency of time that the classroom teacher was the primary talker. This analysis revealed that the teacher spoke for an average of 69% of the analyzed time in the older children classrooms (range: 46–98%) and an average of 80% of the analyzed time in the younger children classrooms (range: 73–100%). The fact that the teacher spoke less often in the older classroom was the result of more frequent interruptions and a greater number of talkers. The high percentage of teacher speaking time reveals that the majority of the classroom environments evaluated were didactic. Because the entire school day was not observed during the recordings and because the teachers had significant input regarding which sessions were recorded, it is unclear how representative the sessions were of the school day as a whole. It is clear, however, that these data did not include periods of informal and social learning such as conversations in the hallways and cafeteria. Therefore, caution should be exercised when attempting to generalize the findings of this study beyond formal didactic classroom learning periods.

The root-mean-square (RMS) deviation of head angle and elevation relative to the primary sound source position, averaged across the four participant groups, is shown in Figure 1. The RMS deviation was selected because the general magnitude of deviation rather than the direction of the deviation was of primary interest. The square root of the average of each deviation squared provides a measure of deviation that is insensitive to the direction of deviation in contrast to measures of average deviation.

![Figure 1. The overall root-mean-square (RMS) deviation of head angle and elevation relative to the stimulus position, averaged within each of the four participant groups.](image-url)

- HI-O = participants with impaired hearing, older age group
- NH-O = participants with normal hearing, older age group
- HI-Y = participants with impaired hearing, younger age group
- NH-Y = participants with normal hearing, younger age group

Error bars represent 1 SD.
The RMS deviation in head angle and elevation was statistically evaluated using analysis of variance (ANOVA) techniques. For this analysis, the two between-subjects factors were age (older and younger) and hearing status (normal or impaired thresholds) and the within-subjects factor was RMS deviation plane (vertical or horizontal). This analysis revealed a significant Deviation Plane × Age interaction, $F(1, 36) = 4.33, p < .049$. There were no significant main effects and no other significant interactions. Post hoc analysis of the significant interaction using Tukey’s honestly significant difference (HSD) test revealed significantly smaller deviations in the horizontal plane for the older children with normal hearing than for any of the other three groups ($p < .042$). As these measures of deviation included instances in which there were brief utterances from secondary talkers, we speculated that accuracy may be affected by listener focus—that is, listeners could choose to focus on the primary talker and ignore brief utterances. This might occur if the teacher was giving important instructions and others in the classroom were talking and not paying attention. Alternatively, the listener could be interested in the brief utterances and choose to attend to them. This might occur if there was a class discussion and the listener was trying to hear answers from other students at the same time that the teacher was talking or if the listener was bored with a lecture and was more interested in listening to their friends making after-school plans. In some listening situations, it can be difficult to ascertain which of several talkers is of interest to the listener. Or the student may simply stop paying attention to a single primary talker because they are bored, distracted, or for other reasons.

Because of the expected differences in how focused the students were on listening to the primary talker(s), we decided to examine maximum accuracy as well as overall accuracy. In doing so, the assumption was made that the periods for which accuracy was maximum reflected those same periods over which the listener was most focused on the talker of interest. In order to examine maximum accuracy, each RMS deviation was ranked ordered within each listener. The interest in focusing on maximum accuracy was weighed against concern with overly limiting the proportion of observations. Given these goals and a total observation period of 20 min, the most accurate 33% of observations (approximately 7 min per session) were selected for further analysis. It should be noted that this technique resulted in the same number of data points per participant, and the 66% of instances in which accuracy within each individual was poorest were not included in further analyses. The relative accuracy across group, angle, and elevation after this data reduction are shown in Figure 2. Statistical analysis was again completed on this reduced data set using an ANOVA technique identical to that applied to the original data set described above. This analysis revealed no significant effects or interactions, suggesting that the maximum orientation accuracy was not affected by hearing status or age across the age range evaluated (4–17 years old). To further examine whether orientation accuracy could be affected by participant age, regression analysis was completed—after plotting accuracy in the horizontal and vertical planes for the entire data set—against age. In agreement with the ANOVA analysis, no significant correlations were found ($r = .22$ and .11 for the horizontal and vertical planes, respectively). Despite the lack of group differences in the reduced data, significant individual differences in overall RMS error were present for both angle and elevation, as evidenced by the standard deviations shown in Figure 2. Overall RMS error, averaged within individual participants, ranged from 2° to 43° for angle and from 1° to 39° for elevation.

Although the RMS deviation in angle and elevation shown in Figures 1 and 2 are of great interest in that they reflect the magnitude of the deviation without consideration of direction, it is also of interest to examine the average deviation. Unlike RMS deviation, average deviation reflects any bias in a particular direction with- out regard to the average magnitude of deviation. It might be expected that if deviations in orientation accuracy were the result of nonsystematic errors, the average across these errors would be 0°—that is, children may deviate in both directions, but these deviations may average out. The average deviation in head angle and orientation across the four participant groups is shown in Figure 3. These data reflect the overall average
deviation across all analyzed data rather than the reduced data set as in Figure 2.

The average deviation in head angle and elevation was evaluated using ANOVA techniques. For this analysis, the two between-subjects factors were, again, age (older and younger) and hearing status (normal or impaired thresholds), and the within-subjects factor was average deviation plane (vertical or horizontal). This analysis revealed a significant main effect of deviation plane, $F(1, 36) = 5.72, p < .043$, reflecting greater deviations in the vertical plane than in the horizontal plane. In addition, the analysis revealed a two-way interaction between deviation plane and age, $F(1, 36) = 11.47, p < .002$. There were no significant main effects and no other significant interactions. Post hoc analysis (Tukey’s HSD) of the significant interaction revealed that there were no significant differences across groups within the horizontal plane. Within the vertical plane, older participants demonstrated a significantly larger average deviation than younger children ($p < .047$).

The number of brief utterances ranged from 0 to 46 across the 40 participant sessions. Four of the participant sessions, each of which involved 1 participant from each of the four groups, included three or fewer brief utterances. The remaining 36 participant sessions, all of which had seven or more brief utterances, were selected for further analysis. The percentage of time that these 36 individual participants attended to brief utterances in the classroom are shown in Figure 4. Visual inspection of these data revealed that 4 of the 18 participants with normal hearing attended to 25% or more of the brief utterances, whereas 14 of 18 participants with hearing loss attended at this percentage or higher. In addition, 15 of the 18 participants in both groups (impaired and normal hearing) attended to less than 50% of the brief utterances. A two-factor (age and hearing status), between-groups ANOVA conducted on the percentage of time participants turned toward brief utterances revealed a significant main effect of hearing status, $F(1, 32) = 27.88, p < .0005$. Specifically, participants with hearing loss turned to brief utterances significantly more often than

![Image](image-url)
their counterparts with normal hearing. There were no other significant main effects or significant interactions.

**Discussion**

The primary findings of this study support the potential for benefit from directivity-based interventions across a broad range of school-aged children. For optimal performance in noisy environments, it has been shown that directivity-based systems require that the users accurately orient their head toward the sound source of interest (Lee et al., 1998; Ricketts, 2000a; Ricketts et al., 2001; Walden et al., 2004). Although considerable individual variability was present, the current study revealed a relatively high level of orientation accuracy across children aged 4–17 years, both with and without hearing loss. Specifically, the average RMS error was approximately 12–16°, regardless of hearing loss status, for the 33% portion of the analyzed data that were most accurate. With regard to the potential for directional benefit, previous studies of adult listeners have found no differences in directional hearing aid benefit for deviations in head angle of 15° or less (Ricketts, 2000c; Henry & Ricketts, 2003). In addition, average hearing aid directivity is not significantly affected by deviations in elevation of 10° or less and is only minimally affected by deviations of 20° (Ricketts & Dittberner, 2002). Furthermore, there was no significant correlation between age and orientation accuracy—that is, these data do not support the consideration of age as a factor related to the maximum potential benefit from directivity-based interventions in school-aged children.

In contrast to the reduced data set, examination of the entire data set revealed significantly poorer accuracy in the horizontal plane for the older students with impaired hearing in comparison with the peers with normal hearing. The potential for directional benefit is lessened when the listener is not focused on the sound source of interest (i.e., their head is not pointed in the direction of the sound source), and these results suggest that instances of reduced focus occur significantly more often in younger students (both with normal and impaired hearing) and older students with hearing impairment than in older students with normal hearing. As a consequence, it is expected that the proportion of time that optimal directional benefit may be achieved is likely limited. Unfortunately however, the actual proportion of the school day for which directional benefit might be expected is not available from these data because of the limited length of the observation periods and the exclusion of many listening environments including less formal noninstructional environments such as the cafeteria, hallway, and playground. Regardless, if directional hearing aids are found to be an appropriate intervention for school-aged children, it is expected that teaching appropriate head orientation relative to the sound source of interest will be critical for maximizing directional benefit.

Despite these limitations, these data clearly show that there is some potential for directional benefit during at least some portion of the school day. This, of course, does not necessarily indicate that directivity-based interventions are appropriate for school-aged children. Further work is necessary to determine if the same improvement in SNR will lead to similar speech recognition in noise improvements across children of various ages. More importantly, the full-time use of directivity-based hearing aid systems has not been supported in adult listeners (Ricketts et al., 2003), and it is not expected to be supported for children. Recent work with school-aged children has indicated that although directivity-based systems (e.g., directional hearing aids) can be quite beneficial in some settings, they may be detrimental in other environments, even in the presence of noise (Ricketts et al., in press). These findings increasingly support providing both directional and omnidirectional hearing aid modes for both children and adults in order to obtain an optimal aided listening experience throughout the course of the day. The fact that optimal speech recognition will be obtained in either the directional or omnidirectional mode, depending on the listening situation, highlights the importance of appropriate switching (either manual or automatic) between microphone modes. Therefore, the effect of both the ability to switch appropriately between directional and omnidirectional modes and/or the switching accuracy of the automatic directional switching modes that are available in many modern commercial hearing aids in classroom settings also needs to be evaluated.

The large individual differences in orientation accuracy are also of interest. It is hypothesized that the task-specific demands and listener focus were most directly responsible for individual differences in accuracy of head orientation. For example, accuracy might be expected to be different when children are listening to a story than when they are required to take notes. The task-dependent nature of the orientation accuracy was supported by visual inspection of the videotaped segments that varied the most in orientation accuracy—that is, large orientation errors were often related to a specific task, such as turning around to borrow a piece of paper. The effect of the specific task type on orientation accuracy is further supported by examining the average orientation errors of individual participants that were summarized in Figure 3. These data for individual participants revealed that children seated on the right side of the classroom (15 listeners) demonstrated an average deviation to the right of approximately 20°, whereas those seated on the left (16 listeners) demonstrated a similar 20° deviation to the left. Not surprisingly, when these groups were combined together along with the remaining
9 listeners seated approximately in the center of the room, average deviation error was less than 8° across the four listener groups. With regard to orientation in the vertical plane, average error was –25° and –16° (downward error) for students in the older and younger groups, respectively. Visual inspection of the videotapes revealed that this error was likely the result of children looking down at their desk (to take notes) during times when the teacher was speaking. Note-taking was more common in the older children’s classrooms, reflecting the higher average errors.

A more specific example of the effect that environment-specific task had on orientation accuracy is shown in Figure 5. These figures show an 8-min example of one child’s raw angle (see Panel A) and elevation deviation data (see Panel B). The child in this example was 12 years old and had hearing loss. The data revealed that this student’s head was consistently pointed lower than, and to the left of, the talker. Not surprisingly, the video record revealed that these data were collected while this student was taking notes and the teacher was lecturing. The bias to the left was present because the student was seated on the left-hand side of the classroom (from the student’s perspective) and the teacher was standing in the middle. If the time course of the head angle and elevation are followed, it is also evident that the student occasionally oriented her head directly toward the teacher. This is most clearly evident during the circled time frame (see Figure 5) during which the student consistently oriented her head toward the teacher for a period of approximately 30 s.

One of the most interesting results of this study was the finding that children with hearing loss were much more likely to attend to brief utterances made by secondary talkers than were children with normal hearing (see Figure 4). Although the reason for this difference is unclear, it is hypothesized that it may result from a need for increased visual information for enhancing speech perception, or environmental monitoring. If increased visual monitoring is associated with hearing loss, this behavior may have a complex effect on listening related to brief utterances. Specifically, one might assume that not orienting to a brief utterance would generally be detrimental, especially for listeners with impaired hearing who have an increased need for the visual channel in order to optimize speech recognition. This, however, assumes that all brief utterances are important to hear, which of course is untrue. Visual monitoring for brief utterances may, in fact, have negative consequences in some cases if it detracts from the focus on other, more important, speech signals. Interestingly, however, students with and without hearing loss revealed a similar propensity for not attending to more than 50% of the brief utterances (30 of 36 participants). These data provide support that both groups may avoid orienting toward brief utterances when the message is clearly not important.

The hypothesis that the increased attention to brief utterances results from a need for increased visual monitoring is consistent with the conclusions reached by Smith et al. (1998) after examining the development of visual attention in 5- to 13-year-olds who differed in their access to sound (normal hearing, prelingually deaf, prelingually deaf with a cochlear implant). Specifically, based on differences between the three groups on tasks in which participants were asked to respond to some visual signals and not others, the authors speculated that visual attention in children with deafness was more distributed than in children with normal hearing.

An association between increased hearing loss and increased visual monitoring is also indirectly supported by the overall RMS deviation data of the current experiment shown in Figure 1. Specifically, children with normal hearing revealed a decrease in overall RMS deviation in the horizontal plane with increasing age,
revealing that these participants looked around less with increasing age. This behavior is consistent with studies showing that sustained attention continues to improve until age 10 years and then plateaus, with only minor improvements thereafter (Betts, McKay, Maruff, & Anderson, 2006). In contrast, participants with hearing loss in the current study showed similar overall RMS deviation with increased age. It is speculated that this lack of overall improvement may reflect a different pattern of development of visual attention in children with hearing loss and a greater reliance on visual information by this population. However, further work is clearly needed to support such speculation.

Conclusions

The results of this study support the potential for benefit from directivity-based intervention in some school environments. The proportion of the total school day for which this potential for directional benefit exists remains unknown, however. This potential for benefit does not appear to be limited by age, as similar deviations in head orientation were evident across the age range investigated when focusing on the most accurate 33% of the analyzed time. Significant individual variations in head angle and elevation (relative to the position of the primary sound source) were also evident. The data are consistent with the hypothesis that variation in head angle accuracy in real classroom environments is highly dependent on the listening task—that is, children appear to be able to orient their heads accurately toward a sound source of interest but are not always able or willing to do so because of the specific task demands. Tasks such as note-taking, drawing, and so forth, do not allow for accurate head orientation toward the sound source of interest. These data further strengthen the recommendation for FM use when a single talker of interest is present, as auditory benefits from FM systems are generally unaffected by head angle (although a loss of visual cues may occur).

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