Sensory-Processing Disorder in Children With Cochlear Implants

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KEY WORDS
- cochlear implants
- hearing loss
- sensation disorders
- somatosensory disorders

We examined sensory-processing disorder (SPD) in children with cochlear implants and explored the relationship between SPD and duration of hearing loss or duration of cochlear implant use. Caregivers of 30 children completed the Sensory Profile Questionnaire (SPQ). Seventy percent of the children showed "at-risk" or "different" behaviors in one or more of five categories of the SPQ: auditory, visual, vestibular, tactile, and oral processing. No noteworthy relationships surfaced between duration of deafness or duration of cochlear implant use and the atypical behaviors identified. To validate these findings further, postrotary nystagmus (PRN) testing and Miller's Assessment for Preschoolers (MAP) were administered to a subset of children. PRN was atypical in all 6 children tested. MAP findings revealed atypical sensory processing in 4 of the 6 children. Findings suggested that children with cochlear implants may be at risk for SPD. The findings are discussed in light of clinician and teacher referral for occupational therapy evaluations.

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The importance of sensory experience during early postnatal life in the integration of various sensory inputs has been demonstrated in many animal and human studies. For example, Wallace, Perrault, Hairston, and Stein (2004) showed that the deprivation of visual input by rearing cats in a dark environment compromised either their ability to integrate multisensory information or their sensitivity to cross-modal events. Studies in humans have also revealed that the disruption in sensory information arriving from one or more modalities (e.g., auditory, visual) results in atypical integration of sensory information (see McGurk & McDonald, 1976; Schlumberger, Narbona, & Manrique, 2004; Summerfield, 1979).

Sensory integration disorder is characterized as abnormal sensory processing in the domains of vision, audition, balance, taction, olfaction, and gustation (Ayres, 1972). Some common symptoms include finger agnosia, problems with balance and gait, choreiform (involuntary spasmodic) movements of finger or mouth or poor graphomotor skills, tactile defensiveness, rigid behavior patterns, and auditory hypersensitivities (Dunn, 2001; Eide, 2003). In addition, people with sensory integration disorder may show problems in the areas of attention, arousal, or movement. These behaviors may lead to anxiety and may negatively affect age-appropriate learning and family relationships (see Dunn, 2001). Children with sensory integration disorder are often considered "out-of-sync" with respect to their peers (Eide, 2003). That is, when sensory processing through one modality is abnormal, it may lead to conflict in the perception of information arriving from other sensory systems. Thus, children with sensory integration disorder may experience sensory–sensory or sensory–motor mismatches in their daily lives. In recent years, sensory integration disorder has been referred to as *sensory-processing disorder* in the literature (Miller, Anzalone, Lane, Cermak, & Oste, 2007). Therefore, the term *sensory-processing disorder (SPD)*

is used throughout the remainder of the article.

SPD is known to occur in diverse populations, including children with attention deficit/hyperactivity disorder, autism spectrum disorders, schizophrenia, Fragile X syndrome, and cerebral palsy. It is also present in children raised in sensory-deprived settings such as orphanages, children born prematurely, and gifted children (see Dunn, 2001; Eide, 2003). However, it is unclear whether SPD is associated with hearing impairment.

The effects of auditory deprivation have been investigated in many studies. For instance, auditory deprivation has been shown to be associated with atypical language development, visuospatial processing, visuomotor skills, and motor development (Schlumberger et al., 2004). Auditory deprivation has also been shown to be associated with vestibular deficits such as abnormal posture, balance, and eye tracking (e.g., Brey et al., 1995; Enbom, Magnusson, & Pyykko, 1991; Selz, Girardi, Konrad, & Hughes, 1996). Moreover, studies have shown that considerable variation in visual processing exists after auditory deprivation in adults with a hearing impairment (e.g., Neville & Bavelier, 2002; Schorr, Fox, van Wassenhove, & Knudsen, 2005). Also, the lack of electrical activity in the auditory nerve in people with prelingual deafness has been shown to result in subnormal myelination of the nerve fibers (Moore & Guan, 2001). Taken together, there is evidence that sensory deprivation leads to deleterious effects in terms of maturation of the nervous system and atypical development of several cognitive and behavioral skills.

Occasional reports suggest that children with hearing loss may exhibit sensory-processing difficulties in domains other than audition (e.g., Daniel, 2005; Matzke & Bragers, 1993; Rhoades & Chisolm, 2001). For example, Rhoades and Chisolm (2001) investigated language growth in a group of 40 children with hearing loss after auditory verbal therapy. Approximately 33% of the children had hearing aids, 37% wore a cochlear implant, and 30% used both a hearing aid and a cochlear implant. In their initial evaluations, Rhoades and Chisolm (2001) reported that 78% of the children in their study had difficulty with sensory processing, as evidenced by occupational therapy evaluations. Although the authors did not report the degree of sensory-processing difficulty in children who used various aids or whether the sensory-processing difficulty changed over time with language growth, the findings indicate sensory-processing difficulties may be prevalent in people with hearing loss. To date, there has been no systematic investigation examining whether SPD is present in people with hearing impairment. Moreover, the characteristics of sensory-processing difficulties in people with hearing loss have not been documented in detail. To examine these issues further, we investigated sensory-processing abilities in children with congenital, profound hearing loss who are fitted with unilateral or bilateral cochlear implant devices. Specifically, this study aimed to (1) identify atypical behaviors, if any, that represent sensory-processing difficulties; (2) describe the nature and types of sensory-processing difficulties; and (3) examine whether the length of auditory deprivation (i.e., duration of hearing loss) or the length of cochlear implant use are related to the atypical behaviors, if identified, in this population.

Methods

Participant Recruitment

Children between ages 2 and 10 who used a cochlear implant device were recruited from the North Texas cochlear implant pool. A *cochlear implant* is a computerized device surgically implanted in the inner ear such that it electrically stimulates the auditory nerve. Cochlear implants typically improve auditory responses in people with severe–profound deafness, resulting in hearing thresholds better than or equal to 25 to 35 dB HL across the frequency range from 250 Hz to 8000 Hz. Information concerning the study was circulated among families of children with cochlear implants. Families who expressed interest in participating were contacted by one of the investigators, who screened the participant for exclusion criteria. Children suspected of or diagnosed with autism spectrum disorders, developmental delays, cognitive delays, or blindness were excluded from the study. In addition, children who acquired deafness as a result of cytomegalovirus or meningitis were excluded. Institutional review board approval was sought before the initiation of this study from the Office of Compliance at the University of Texas at Dallas (IRB 05–30). Recruitment and data collection procedures of this study complied with the institutional review board at the University of Texas at Dallas.

Procedure

Before commencing the study, investigators informed participants about the study protocol. After reviewing the informed consent form, participants were given the opportunity to ask questions about the study before signing the informed consent form. All participants received a copy of the signed informed consent form.

Parents of the children completed either the Infant/Toddler Sensory Profile Questionnaire (SPQ) for ages birth to 3 years (Dunn & Daniels, 2002) or the SPQ for ages 3 to 10 years (Dunn, 1999). A rehabilitative audiologist provided instructions to the parents regarding the completion of the SPQ as described in its manual. In addition, parents and the rehabilitative audiologist recorded unusual behaviors observed in each child. The SPQ took approximately 20 to 30 min to complete.

The SPQ was scored and interpreted by a certified and licensed pediatric occupational therapist. Only five categories of SPQ were used for analysis: auditory, vestibular, oral sensory, tactile, and visual processing. These five categories were chosen because they are common across the SPQ for both age groups, 0 to 3 years and 3 to 10 years, and because the objective of the study was to evaluate sensation processing as opposed to more complex integrative behavior. The results of the SPQ for each of the sensory domains are reported in comparison to normative data in the following categories: no difference or typical (>16th percentile), probable difference or at risk (2nd–16th percentile), and definite difference or different (<2nd percentile).

The SPQ relies on parental report and identifies observable behaviors indicative of sensory-processing difficulty (see Tomchek

& Dunn, 2007). However, the results of the SPQ do not establish whether any given individual in fact has sensory-processing difficulties. To assess directly whether sensory-processing issues were indeed present, an occupational therapist administered the Miller's Assessment for Preschoolers (MAP; Miller, 1982) to a subset of 6 children with cochlear implants.

The MAP is a preschool assessment instrument designed to evaluate young children between the ages of 2.9 and 5.8 years for mild to moderate developmental delays. This tool was selected because it uses sensory-based activities to evaluate sensory processing in young children rather than evaluating end-product motor skills. Nine children in the study were in the appropriate age range for administration of the MAP; however, only 6 were able to return for testing. The following subtests of the MAP were used: walk on a line (vestibular), stereognosis and finger localization (tactile), tongue movements (oral), and figure–ground discrimination (visual). These subtests took approximately 20 min to complete. The results of the MAP are typically reported in terms of percentile ranks. A child with a percentile rank of 5 and under is referred for further evaluation. A child with a percentile rank ranging from 6 to 25 is watched carefully or followed up, and a child with a percentile rank of 26 and above is considered to be within normal limits.

In addition to the previously mentioned tests, the occupational therapist assessed postrotary nystagmus (PRN) in these six children using the Southern California Post Rotary Nystagmus Test (Ayres, 1975). Two trials of PRN (clockwise and counterclockwise) were performed on each child. The typical range for PRN is 13 to 24 s (±1 standard deviation [SD]) for two trials.

Results

Thirty children (ages 2–10 years) with congenital, severe–profound hearing loss participated in this study. Participants had either one or two cochlear implants. The age at which children in this study had their first cochlear implant activated ranged from 1 year to 7 years, 10 months. This timeframe represents the length or duration

of auditory deprivation. Length of cochlear implant experience at the time of study ranged from 0 to 7 years. Only 4 of the 30 children were currently attending occupational therapy. Eleven additional children were referred by the rehabilitative audiologist for an occupational therapy evaluation, although their parents did not choose to use this service.

Figures 1 and 2 represent data from the SPQ. As shown in Figure 1, a subset of 2 to 8 children showed "at-risk" behaviors for each sensory domain, whereas a subset of 1 to 5 children showed "different" behaviors for each sensory domain. Nine of the 30 children were classified as typical in all five categories. The remaining 21 children (70%) showed at-risk or different behaviors in one or more categories.

Figure 2 represents pooled data from at-risk and different classifications for each sensory domain examined. The data were pooled across at-risk and different categories because they represent varying degrees of sensory-processing difficulty (Tomchek & Dunn, 2007). As shown in the figure, the atypical behaviors in children who were classified as at risk and different were more prevalent in the areas of auditory and vestibular (40% of the sample), followed by oral and tactile (approximately 25% of the sample), and least prevalent in the visual-processing domain (10% of the sample).

Of the 30 children in the study, the number of children who showed at-risk and different behaviors for each of the

SPQ categories ranged from 3 to 12. To characterize the types of atypical behaviors demonstrated by these children, the individual items in all five categories of the SPQ were examined for those who showed at-risk and different behaviors. Any behavior that was common to 3 or more children was noted for each of the five categories. In addition, parental reports and reports from the rehabilitative audiologist regarding any unusual behaviors noted in children were considered. Table 1 represents common examples of atypical behaviors in children with cochlear implants based on the SPQ and the observations from parents and the rehabilitative audiologist. As reported in Table 1, the atypical behaviors in all five categories represent both sensory-seeking and sensory-avoiding types of behaviors.

Correlation analyses were conducted to examine whether the duration of hearing loss and the duration of cochlear implant use were related to the observed atypical behaviors. To perform these analyses, the raw scores for each of the sensory categories from all participants were converted to Z scores (distance from the population mean). A Pearson product–moment correlation coefficient was computed between the Z scores for each sensory category and (1) the duration of hearing loss and (2) the duration of cochlear implant use. It was expected that children who received a cochlear implant at a later age (e.g., after 5 years of age) and experienced auditory deprivation for a longer period might demonstrate a
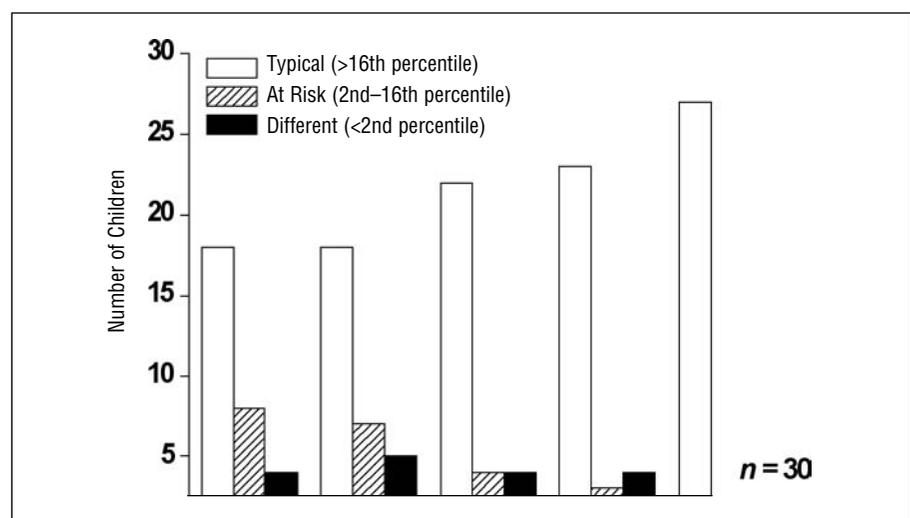

Figure 1. Number of children classified as typical, at risk, and different in the following sensory-processing domains: auditory, vestibular, oral, tactile, and visual.
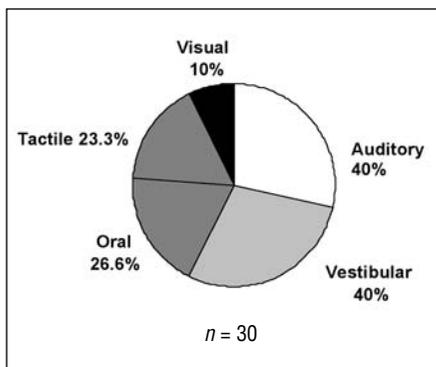
Figure 2. Percentage of children classified as either "probably" or "definitely different" in the following sensory-processing domains: auditory, vestibular, oral, tactile, and visual.

Table 1. Common Behaviors of "At-Risk" or "Different" Children With Congenital, Profound Hearing Loss

AUDITORY
1. Has trouble completing tasks in the presence of background noise.
2. Does not respond to sounds in the environment despite adequate use of hearing technology with appropriate settings.
3. Enjoys producing or listening to strange noises.

VESTIBULAR
1. Twirls, spins, wiggles, and rocks unconsciously.
2. Has a high activity level.
3. Resists or seeks tipping head back.
4. Has poor balance for age.

ORAL
1. Refuses to try new foods and avoids certain foods based on taste, texture, or temperature.
2. Mouths, chews, or licks nonfood objects excessively for age.
3. Seeks food with unusual or strong flavors.

TACTILE
1. Expresses distress during grooming or face or hair washing.
2. Reacts emotionally to touch or withdraws from touch.
3. Touches people or objects to the point of irritation.
4. Will not touch or play with sticky or creamy materials.

VISUAL
1. Expresses discomfort with or avoids bright light.
2. Avoids eye contact or stares intensely at objects and people.
3. Enjoys looking at moving or spinning objects.
4. Prefers fast-paced, brightly colored TV shows.

greater number of atypical behaviors compared with children who received a cochlear implant at younger ages (e.g., age 1–2 years). Similarly, it was expected that with increasing length of cochlear implant use, children would demonstrate fewer atypical behaviors. As shown in Table 2, correlation analyses did not reveal any significant relationship between the duration of hearing loss and the observed atypical behaviors in any of the sensory categories. However, a significant, low negative correlation ($r = -.3$, $p < .0001$) was found between the duration of cochlear implant use and the observed atypical behaviors for the vestibular category, supporting the parental reports of atypical behaviors, representing vestibular deficits somewhat diminished with increasing length of cochlear implant use. The remaining correlations were low or insignificant.

Data from the MAP showed abnormal sensory processing in 4 of the 6 children. The 2 children who were found to be typically developing on all five categories of the SPQ were also found to be within normal limits in all the tested categories of the MAP. The four children who were found to have atypical sensory processing on the MAP were also found to have at-risk or different behaviors on the SPQ, but not necessarily for the same sensory categories. As indicated in Table 3, the following sensory-processing difficulties were noted in 4 children on the MAP: difficulty localizing fingers; difficulty moving the tongue up, down, left, right, or around; and difficulty

walking in a line. As expected from the SPQ scores, none of the 6 children showed any difficulties with visual processing. Also, as anticipated, all 6 children showed highly reduced PRN (scores ranging from –2.7 to –2.0 SD), suggesting abnormal vestibular processing.

Discussion

We examined whether atypical behaviors considered to represent SPD are prevalent in children with cochlear implants. Data from the SPQ suggested the presence of SPD to some degree in 70% of the children with cochlear implants. These findings are somewhat similar to the findings of Rhoades and Chisolm (2001), which indicated that 78% of the children with hearing loss in

their study exhibited sensory-processing difficulties to some degree.

The data also showed that atypical behaviors were present in all domains but were most prevalent in auditory and vestibular processing, followed by oral and tactile processing, and least prevalent in visual processing.

The finding of vestibular processing deficits in the current sample of children supports findings of several studies that also demonstrated vestibular deficits in people with hearing loss (Brey et al., 1995; Enbom et al., 1991; Selz et al., 1996). In fact, Selz and colleagues (1996) showed vestibular deficits in children with both hereditary and acquired deafness. Selz and colleagues suggested that the etiologic factors responsible for congenital and acquired hearing

Table 2. Correlation (r values) Between Z Scores for Each of the Sensory Domains of the Sensory Profile Questionnaire and Duration of Hearing Loss and Duration of Cochlear Implant Experience

Duration of	Auditory	Visual	Vestibular	Tactile	Oral
Hearing loss	0.08	0.17	−0.2	0.05	0.07
Cochlear implant experience	−0.13	0.17	−0.3	−0.07	0.13

Table 3. Percentile Scores for Subtests of Miller's Assessment for Preschoolers (MAP) and Standard Deviation (*SD*) Values for Postrotary Nystagmus (PRN) for 6 Participants (S1–S6)

MAP Subtests	S1	S2	S3	S4	S5	S6
Stereognosis	55	80	80	34	60	60
Finger localization	42	30	80	10	70	15
Walks line	20	30	8	3	30	35
Visual figure-ground	42	60	95	60	50	45
Tongue movements	27	40	65	25	55	70
PRN (SD)	–2.5	–2	–2.6	–2.5	–2.7	–1.1

loss may also affect the vestibular system, given the proximity of the cochlea to the vestibular end organ.

The fact that only a small subset of children was classified as at risk or different for visual processing is supported by many studies that in fact show enhancement in visual processing in this population. For example, it has been shown that adults with congenital deafness demonstrate enhanced early processing of visual events in peripheral space compared with normal control participants. Moreover, this behavioral compensation has been suggested to be mediated by the enhanced recruitment of multimodal areas of the cortex (Bavelier & Neville, 2002; Neville & Lawson, 1987). However, the fact that a small subset of children actually showed atypical visual processing might be explained by other findings in the literature that suggest people with hearing impairment have to monitor their environment visually and, therefore, might show decreased visual attention to the task at hand (e.g., Smith, Quittner, Osberger, & Miyamoto, 1998). These issues need further examination.

A small subset of children was also evaluated on the MAP by an occupational therapist to examine whether sensory-processing difficulties were present in auditory, vestibular, tactile, oral, and visual processing domains. Overall, the results of the MAP corresponded with those of the SPQ in that they both showed tactile, vestibular, and oral processing difficulties while revealing minimal or no visual processing difficulties in this group of children with cochlear implants. Thus, the findings of the current study add to the body of knowledge that children with hearing loss frequently have SPD in other domains in addition to the vestibular system. Moreover, based on the findings of this study, we were able to generate a list of atypical behaviors present

in children with cochlear implants (see Table 1). Some of the behaviors under the subsections of auditory, tactile, vestibular, and oral processing are also reported to be present in children with autism (see Tomchek & Dunn, 2007). The presence of these behaviors may warrant referral for further evaluation.

Data from the SPQ and the MAP suggest the presence of SPD in a subset of children with cochlear implants. Findings do not support the idea that the duration of hearing loss or the duration of cochlear implant use are strongly related to atypical behaviors. It is not clear at this point whether SPD merely coexists in a subset of children with hearing loss or whether it is a consequence of auditory deprivation. Because all the children in the study had severe–profound hearing loss, it is not clear at this point whether SPD is present in children with moderate or mild hearing loss. Continued research is needed to explore further the extent of the relationship between atypical sensory processing and hearing impairment. One factor of possible significance that was not assessed in the current study is the status of hearing at birth. It is possible that hearing during fetal development may influence sensory processing. It might be important for future research to compare the sensory-processing skills of children who did and did not pass their newborn hearing screenings. Further research is also needed to document the benefits of occupational therapy in children with hearing loss who demonstrate sensory-processing difficulties. Three of the four children who were attending occupational therapy at the time of the study also showed sensory-processing problems in one or more areas. Although these children did not stand out from the other children who did not attend occupational therapy, the benefits of con-

tinued therapy in advancing their daily life skills cannot be ruled out. Because of the limited sample size, this issue could not be explored further in the current study. Research has shown that occupational therapy has resulted in improvement in postural control, motor skills, attention skills, cognitive and social functions, and language comprehension in people with SPD and language and learning disabilities (e.g., Ayres & Mailloux, 1981; Miller, Coll, & Schoen, 2007; Sugden & Dunford, 2007). Thus, it is possible that improving children's sensory performance and functional skills will enhance their ability to benefit from speech–language intervention.

In conclusion, although the data are quite preliminary, they do suggest that some pediatric users of cochlear implants demonstrate SPD and atypical behaviors. If such behaviors that interfere with daily life (see Table 1) are noted in children with hearing loss, referral to an occupational therapist should be considered. Future studies are needed to (1) document the nature and types of sensory-processing issues in a large sample of children and adults with mild to profound hearing loss, (2) document the prevalence of SPD in people with hearing loss using hearing aids and cochlear implants, and (3) explore the relationship between SPD and hearing, speech, or language functions. ▲

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