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Characteristics of Sensory Processing in Children with Cochlear Implants and Hearing Aids

Original scientific paper

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Abstract

Sensory processing includes perception, organization, and reaction to sensory stimuli. Research has shown that deaf and hard-of-hearing children have unique sensory processing characteristics. The aim of this study was to identify these characteristics and examine the contributions of factors such as type of amplification, chronological age, hearing age, and frequency of rehabilitation to sensory processing features. Parents of 52 children, aged 3 to 10 years old, completed the Sensory Profile questionnaire. Results showed that most children were within the typical performance range in most subscales, however, children with cochlear implants had better scores in several domains compared to children with hearing aids. Chronological age, hearing age, and frequency of rehabilitation did not contribute to overall sensory processing. These results indicate that children with cochlear implants have a more successful integration of sensory processing abilities. Early intervention and consistent rehabilitation are needed to optimize sensory outcomes in deaf and hard-of-hearing children.

Keywords: *deaf and hard-of-hearing, hearing loss, Sensory Profile, type of amplification*

Sensory processing refers to the way our central and peripheral nervous systems regulate information from seven peripheral sensory systems. It includes perception, organization, and reaction to sensory stimuli (Ayres, 2009). Efficient sensory processing leads to the successful execution of adaptive responses to meet situational demands, and thus, meaningful engagement in daily activities (Coulson Thaker, 2020; Kilroy et al., 2019). This process occurs automatically in most people, so difficulties that arise in this domain are not so obvious, which leads to problems in their detection (Ayres, 2009).

If, on the other hand, the nervous system isn't able to adequately integrate and organize sensory inputs, sensory processing disorder (SPD) can occur. Such inadequate

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processing of sensory information may result in an altered perception thereby causing the individual to perceive the world as unpredictable (Anguera et al., 2017). SPD represents a very heterogeneous group of behavioral patterns and can manifest across one or more sensory domains including auditory, visual, tactile, proprioceptive, vestibular, gustatory, and olfactory modalities (Ayres & Robins, 2005; Dunn, 1997). Children who are not able to process these stimuli adequately can have an altered perception of the environment and their own bodies. Their experience of sensory input can be atypical and intense (Anguera et al., 2017; Blanche & Gunter, 2020; Sher, 2009), significantly disrupting their daily life and functioning (Blanche & Gunter, 2020).

The core behavioral features of SPD are atypical motor, emotional, or cognitive responses to neutral, everyday stimuli. Abnormalities can occur in one or more sensory domains and may vary during the day or from day to day. Therefore, they can cause inconsistent behaviors in a child, depending on the context, ranging from extreme sensitivity to under-responsiveness (Blanche & Gunter, 2020; Bodison & Parham, 2018; Brout & Miller, 2015). Research has shown that children with SPD have difficulties in everyday functioning (Ahn et al., 2004), play (Benson et al., 2006; Bundy et al., 2007), socio-emotional skills (Ben-Sasson et al., 2009; Cosbey et al., 2010), learning (Critz et al., 2015; Whiting et al., 2023), as well as mental wellbeing, self-efficacy, and self-esteem (McCarter, 2010).

It is estimated that about 40% of deaf and hard-of-hearing (DHH) children have multiple disabilities (Cupples et al., 2018; Fortnum et al., 2002; Schum, 2004). Although the direct effects of hearing loss primarily reflect on speech and language development, communication, and social skills (McCormick, 1977. as cited in Fernandes et al., 2015), empirical research has demonstrated that hearing loss also causes abnormalities in sensory processing (Monroy et al., 2019; Levitt, 2019). Given the anatomical and phylogenetic interconnection between auditory and vestibular systems, it is anticipated that DHH children, demonstrate vestibular difficulties (Bharadwaj et al., 2012). Such difficulties can further impact motor skills (De Kegel et al., 2010; Koester et al., 2014; Sewpersad, 2014; Vitkovic et al., 2016), gaze stability (Rine et al., 2004), visual processing and spatial integration (Iversen et al., 2015; Shiell et al., 2014). Studies have also shown that DHH children may have tactile dysfunction (Coulson Thaker, 2020; Ghanbari & Jamali, 2021; Levanen & Hamdorf, 2001).

A restricted number of studies investigated the connection between hearing loss and sensory processing. Koester et al. (2014) found distinctions between children with cochlear implants (CIs) and children with typical hearing in the vestibular and proprioceptive domains. Other research findings also suggest that children with CIs might be at risk for sensory processing difficulties (Alkhamra & Abu-Dahab, 2020; Baş & Yücel, 2023; Bharadwaj et al., 2009; Drobac et al., 2023). Contrary to these findings, Coulson Thaker (2020) found that children with hearing aids (HAs) show greater levels of difficulties than those using CIs. Although without significant differences compared to typically developing peers, Ghanbari and Jamali (2021) suggest that sensory processing in children with HAs is unperceivable and that hearing loss could affect sensory processing. Although the majority of their subsample showed possible or significant deviations, the authors found no significant differences when compared to children with typical hearing.

The aforementioned suggests that DHH children have specific sensory processing patterns. Researchers have identified several factors that could be related to hearing loss and could influence the sensory processing of these children. These factors include the type of hearing solution (Alkhamra & Abu-Dahab, 2020; Coulson Thaker, 2020), the length of time the hearing device has been used (Alkhamra & Abu-Dahab, 2020; Bharadwaj et al., 2009; Stevenson et al., 2017), and the timing of the onset of rehabilitation (Alkhamra & Abu-Dahab, 2020).

Hearing aids amplify sounds, whereas cochlear implants bypass the damaged parts of the cochlea and provide direct electrical stimulation to the auditory nerve. This could offer more stable and consistent auditory experiences, potentially leading to better sensory processing abilities (Coulson Thaker, 2020). Regardless of the amplification type used, receiving a device at an early age should lead to better processing efficiency because sensory input during a critical sensitive period is essential for optimal development. Findings show that early-implanted children, after several years of device use, perform more efficiently than late-implanted peers (Gilley et al., 2010). Other factors, including the availability and type of rehabilitative services, can also play a role in sensory processing outcomes. For DHH children, rehabilitation treatments appear as a crucial factor in determining the outcomes for these children (De Raeve et al., 2023), as they improve auditory perception, audiovisual processing, and behavioral outcomes (Stevenson et al., 2017). These interventions, and above all, continuous rehabilitation could positively impact overall processing abilities and functioning in DHH children.

Nevertheless, the topic of sensory processing in the population of DHH children remains limited and therefore the main aim of this study was to determine the characteristics of sensory processing in DHH children. Additionally, the study aimed to ascertain whether characteristics such as type of amplification, chronological age, hearing age (the length of time the hearing device has been used calculated in years), and frequency of rehabilitation correlate with sensory processing features in DHH children.

Material and Methods

Participants

A total of 52 DHH children (48.1% male and 51.9% female) aged 3-10 years participated in this study. All DHH children who participated in the research are included in the education system and/or hearing and speech rehabilitation programs in the territory of the Republic of Serbia. More detailed descriptions of the sample characteristics are given in Table 1 and Table 2.

Table 1
Sample characteristics (N = 52)

		f	%
Gender	M	25	48.1
	F	27	51.9
Amplification type	Cochlear implant	26	50.0
	Hearing aid	26	50.0
Frequency of rehabilitation treatments	Doesn’t attend treatments	3	5.8
	Once a week	2	3.8
	Twice a week	7	13.5
	Three times a week	13	25.0
	Four or more times a week	27	51.9

Table 2
Age structure of respondents

	CI (N = 26)				HA (N=26)			
	Min	Max	M	SD	Min	Max	M	SD
Chronological age	4	10	6,06	1,79	4	10	7,06	1,91
Hearing age	0,5	8	4,08	1,95	0,5	9	3,69	2,39

CI – cochlear implant; HA – hearing aid

Procedure

The research was conducted from January to April 2023. A convenient sampling method was implemented, and parents of a total of 52 children were recruited. Data was collected in The „Stefan Decanski“ School for Hearing-Impaired Students, Belgrade and in the Department for Audiological Rehabilitation of Children, University Clinical Centre of Serbia. The written consent of the parents or guardians of the children was obtained for the research. Subsequently, based on the type of amplification they use, children were divided into two groups: children with cochlear implants (CI) and children with hearing aids (HA). The inclusion criteria for DHH children were that they are between 3 and 10 years old without multiple disabilities, e.g. that they only have isolated hearing loss and that they received a CI or an HA at least 6 months prior to taking participation in the study. For parents, the inclusion criteria were that they were the primary caregivers of the child.

The results were computed using the SPSS software version 26. For describing relevant parameters, descriptive statistical parameters were used, including frequencies (f), percentages (%), mean (M), standard deviations (SD), minimum (Min), and maximum (Max) scores. For data analysis, Levene’s test was used to test the equality of variation, Welch’s t-test was used to test group differences, and multiple regression analysis was conducted to determine the contribution of factors related to hearing impairment to sensory processing.

Instruments

The Short Sensory Profile (SSP, McIntosh et al., 1999b) for children aged 3 to 10 years and 11 months was used in this study to examine the function of sensory processing. SSP contains 38 items and assesses the child's reactions in a total of seven categories: Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Weak, and Visual/Auditory Sensitivity. Each of the categories contains questions that assess whether the child is hypersensitive or avoids sensations in the given domain. For example, Tactile Sensitivity questions assess how the child reacts to touch sensations, Taste/Smell Sensitivity questions assess whether the child avoids certain types of food and smells, and Visual/Auditory Sensitivity questions assess how the child reacts to strong light and sound sensations. Within the Underresponsive/Seeks Sensation category, questions assess whether the child seeks sensations of sound, touch, and movement. The Auditory Filtering category contains questions that assess how the child functions in conditions of loud sounds and noise. The Low Energy/Weak category contains questions that assess the child's muscle strength and endurance. Using a five-point Likert scale, parents rate the child's reactions in everyday life situations as 1 = always, i.e. the child shows a reaction in 100% of cases, 2 = often, i.e. in about 75% of cases, 3 = sometimes, i.e. in 50% of cases, 4 = rarely, i.e. in 25% of cases and 5 = never, i.e. in 0% of cases. Based on a predefined key for this instrument, total scores are obtained, as well as scores for each subscale individually, which clearly show whether the child has a typical response to sensory stimuli, possible, or significant deviations. It should be emphasized that higher scores indicate better sensory processing function. The internal reliability at the scale level is good, as indicated by a Cronbach’s alpha of .82. While most categories have acceptable to excellent reliability (ranging from .73 to .93), only the Tactile Sensitivity category shows a slightly lower reliability at .62.

The decision to use the SSP in this study was based on its brief administration time (10 minutes) and its effectiveness in identifying atypical sensory processing. The authors recommend the instrument for research purposes, as initial validation studies demonstrated the SSP's high discriminate validity (>95%) in differentiating between children with and without sensory modulation difficulties (McIntosh et al., 1999a).

An additional questionnaire was constructed for the purposes of this research which contained questions about the characteristics of the respondents. Data were collected on chronological age, hearing age, and frequency of rehabilitation treatments for DHH children. For the question about the frequency of rehabilitation treatments, parents chose an answer on a multiple-choice question: once a week, twice a week, three times a week, four or more times a week. The questionnaire also included a closed-ended yes or no question about the presence of multiple disabilities, on the basis of which certain respondents were excluded from the research.

Results

Table 3
SSP Section Scores

Subscales	Cochlear implants (*N* = 26)			Hearing aids (*N* = 26)		
	Typical N (%)	Probable difference N (%)	Definite difference N (%)	Typical N (%)	Probable difference N (%)	Definite difference N (%)
Tactile Sensitivity	18 (69.2)	6 (23.1)	2 (7.7)	14 (53.8)	4 (15.4)	8 (30.8)
Taste/Smell Sensitivity	16 (61.5)	4 (15.4)	6 (23.1)	14 (53.8)	6 (23.1)	6 (23.1)
Movement Sensitivity	18 (69.2)	4 (15.4)	4 (15.4)	16 (61.5)	6 (23.1)	4 (15.4)
Underresponsive/ Seeks Sensation	11 (42.3)	5 (19.2)	10 (38.5)	8 (30.8)	4 (15.4)	14 (53.8)
Auditory Filtering	16 (61.5)	4 (15.4)	6 (23.1)	8 (30.8)	5 (19.2)	13 (50.0)
Low Energy/Weak	21 (80.8)	1 (3.8)	4 (15.4)	15 (57.7)	2 (7.7)	9 (34.6)
Visual/Auditory Sensitivity	20 (76.9)	5 (19.2)	1 (3.8)	16 (61.5)	4 (15.4)	6 (23.1)
Total Score	15 (57.7)	8 (30.8)	3 (11.5)	10 (38.5)	3 (11.5)	13 (50.0)

Note: Typical performance is defined as scores at or above 1 SD below the mean, probable difference is defined as scores between 1 SD and 2 SD below the mean, and definite difference is defined as scores 2 SD below the mean

Table 3 presents the total and section scores on the SSP for children with HAs and CIs. Scores on each subscale can be used to classify children's sensory processing based on scores from a large normative sample of typically developing children. For the total score on the SSP, a majority of 69.2% of children with CIs were classified in the category of typical performance. On the SSP subscales, the majority of children with CIs (57.7–80.8%) also scored in the typical category for Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Auditory Filtering, Low Energy/Weak, and Visual/ Auditory Sensitivity. However, 38.5% of children with CIs scored in the definite difference category for Underresponsive/ Seeks Sensation. Contrary, exactly half of the children with HAs (50.0%) were classified in the definite difference category for the total score on the SSP. The majority of children with HAs (53.8–61.5%) scored in the typical category for Tactile Sensitivity, Taste/ Smell Sensitivity, Movement Sensitivity, Low Energy/Weak, and Visual/Auditory Sensitivity. Conversely, a significant portion of children with HAs (50.0–53.8%) scored in the definite difference category for Underresponsive/Seeks Sensation and Auditory Filtering.

According to data from Table 3, certain dissimilarities can be observed between DHH children with different amplification types, so the first analyses were aimed at finding exact differences in sensory processing abilities between these groups. Since some subscales had evident violations of the equal variance assumption ($p < .05$ on Levene's test), the Welch's t test was implemented. The results are presented in the Table 4.

Table 4
Differences between children with different amplification types

Subscales	Cochlear implants (N = 26)			Hearing aids (N = 26)						
	M	SD	SE_M	M	SD	SE_M	t	df	p	d
Tactile Sensitivity	30.35	5.11	1.00	28.35	5.19	1.02	1.40	49.99	.17	.28
Taste/Smell Sensitivity	15.15	4.61	0.90	14.85	4.59	0.90	0.24	50.00	.81	.28
Movement Sensitivity	13.08	2.76	0.54	12.73	2.55	0.50	0.47	49.72	.64	.28
Underresponsive/ Seeks Sensation	26.31	6.03	1.18	23.69	5.68	1.11	1.61	49.82	.11	.28
Auditory Filtering	22.96	4.89	0.96	19.37	5.34	1.05	2.55	49.59	.01*	.29
Low Energy/Weak	28.23	3.66	0.72	24.58	6.30	1.24	2.56	40.14	.01*	.29
Visual/Auditory Sensitivity	20.96	3.00	0.59	19.00	4.18	0.82	1.95	45.37	.06	.29
Total Score	157.04	22.87	4.49	142.54	23.61	4.63	2.25	49.95	.03*	.29

*p<0.05

There were certain differences between the two groups of children. Namely, children with CIs had significantly better scores on Auditory Filtering (p = .01) and Low Energy/Weak (p = .01) subscales, and also overall total scores on SSP (p = .03). All cases had a small effect size (d = .29).

The further analyses aimed to determine the extent to which characteristics of DHH children, such as chronological age, hearing age, and frequency of rehabilitation, contribute to their sensory processing. The intercorrelation matrix is presented in Table 5 and the results of the regression analysis are presented below the table.

Table 5
Intercorrelation matrix

	Chronological age	Hearing age	Frequency of rehabilitation
Chronological age	-		
Hearing age	.77***	-	
Frequency of rehabilitation	-.52***	-.41**	-
Total score	-.13	-.11	.06

*** $p < .001$; ** $p < .01$

The results of multiple regression analysis showed that a set of predictor variables that measured different characteristics of DHH children cannot explain variances of total SSP scores (F = 0.26, $df1$ = 3, $df2$ = 48, p = .85, adjusted R^2 = -.05). The partial contributions of predictors also had no statistical significance (p > .05).

Discussion

The main aim of this study was to determine the differences in sensory processing features between DHH children with different amplification types. The analysis of sensory processing abilities reveals notable differences. The data indicated that children with CIs generally have fewer sensory processing difficulties compared to those with HAs. Although most of the DHH children in both subsamples were classified into the typical performance range in most subscales, the percentages were lower for those with HAs. Also, a significant portion of children with HAs exhibited pronounced difficulties. Analyses further revealed significant differences in several domains, including Auditory Filtering, Low Energy/Weak, Total SSP Score, and a borderline significance in Visual/Auditory Sensitivity.

Although only a few studies investigated sensory processing in DHH children, the results generally indicate that this function is significantly weaker compared to children with typical hearing (Alkhamra & Abu-Dahab, 2020; Bharadwaj et al., 2009; Coulson Thaker, 2020). However, when it comes to differences regarding amplification types, different studies point to rather contradictory results. Coulson Thaker (2020), for instance, indicates that children with HAs have more difficulties in sensory processing on the Sensory Profile compared to children with CIs. Further, the group of authors (Koester et al., 2014) in their research found that children with CIs exhibited typical responses on the Sensory Profile. Both results are consistent with the findings of this study. Contrary to these results, in our previous study (Drobac et al., 2023) the results showed that children with CIs had difficulties in several sensory processing domains. Alhamra and Abu-Dahab (2020) also found that children with CIs tend to exhibit more signs of SPD measured via the Sensory profile compared to children with HAs. However, it should be noted that in the previous study (Drobac et al., 2023), only 25% received the device in the first year of life, while that number is even lower and amounts to 16% in Alhamra and Abu-Dahab (2020) study. In the current study, that number is significantly higher (42.3%) which may serve as an explanation for different results. Interestingly, in this research, the CI group was younger (the mean age was 1 year lower in the CI group), which suggests that earlier intervention with CIs might contribute to more typical sensory processing development. Receiving a CI at an early age could be the reason why this function is somewhat better in these children and closer to typically hearing children than to DHH children.

Contrary to the aforementioned, results of one Iranian study show that there are no differences in sensory processing features between children with HAs and children with typical hearing (Ghanbari & Jamali, 2021). Although the majority of their subsample showed possible or significant deviations, the authors found no significant differences when compared to children with typical hearing. Unlike our research, this study included children within a very small chronological age range (three to six years), which may explain the differing findings.

This study also investigated the contribution of some characteristics of DHH children to their sensory processing features. The results indicated that these factors do not contribute to overall scores on the SSP. Although the findings are unexpected, they could stem from individual variations in the severity and onset of hearing loss, as well as differences in rehabilitation methodologies.

Regarding the age of participants, in contrast to this study, certain authors (Armstrong et al., 2013; Davies et al., 2009; Engel-Yeger, 2008) indicate differences in sensory processing relative to age, suggesting that in certain domains, sensory processing function is more developed in older children. These findings suggest that there is a maturational course of sensory processing, that is somewhat different in children with SPD (Davies et al., 2009). Ayres (2009) suggests that the maturation of sensory integration is completed by the time children start school. Bearing in mind that a large number of our participants from the DHH subsample are 7 years old or older (44.2%), it is possible that their maturation has been completed, which might explain why chronological age did not contribute to SSP scores. The same results can be found in a study conducted on a population of children with Down syndrome (Wuang & Su, 2011), where there is also a lack of correlation between age and sensory processing. In order to confidently evaluate the developmental course of sensory processing function, it is necessary to monitor it over a longer period of time. It is also important to assess whether certain children are engaged in sensory integration treatments that lead to improvements in sensory processing. Commonly, research on DHH children involves very small, conveniently selected samples, and this factor should be considered when interpreting the results. When it comes to the hearing age, Alkhamra and Abu-Dahab (2020) found a correlation between sensory processing and the age at which the child received the hearing device. In contrast, the results of another study (Bharadwaj et al., 2009) showed that sensory processing isn't significantly correlated with the duration of CI use, which is in accordance with these findings. The reason for such results could stem from the data regarding early implantation in a large number of children with CIs from this research. Consequently, the sample dispersion is not large enough to achieve a significant correlation with sensory processing. It seems that some other factors could contribute more to weaker sensory processing in this group. This should be verified in future research.

The frequency of rehabilitation treatments also didn't contribute to SSP scores, however, this does not provide a definitive explanation as to whether the contribution truly exists. Namely, the clear effects of rehabilitation treatments can only be examined longitudinally, and the results of such studies (May-Benson et al., 2023; Tung et al., 2013) indicate positive effects of rehabilitation. It should also be considered whether there were changes in the treatment dynamics for some children. If certain children, due to advancements in speech and language development, reduced the frequency of treatment sessions, this could also explain why a statistically significant correlation was not found in the present study.

Although small sample sizes aren't unusual when it comes to DHH children, it should be considered whether the results would be different with a larger sample. In order to obtain an accurate picture of sensory processing in the DHH group, it is also necessary to equalize the subsamples regarding their demographic characteristics (chronological age, gender, family size, number of siblings) and specific characteristics of hearing status (age at which rehabilitation began, hearing age, frequency of rehabilitation, method of speech/language/auditory therapy).

Despite the limitations, some clinical implications emerged from this study. Implementing a multidisciplinary rehabilitation approach is a crucial element for optimal outcomes in DHH children. In terms of rehabilitation, the findings from this study could contribute to the assessment of sensory integration as a part of child differential diagnosis, which could lead to a more effective implementation of sensory integration therapy. Findings emphasize the need to adjust a child's environment based on the profile of sensory needs. It is also important to note that a potential benefit of the present study is the introduction of a new field of empirical research in the DHH population, considering that the majority of studies on sensory processing have primarily been on children with autism spectrum disorder. The results of such research would explain sensory processing in conditions of auditory deprivation in more detail, which would certainly lead to the improvement of treatment and the process of rehabilitation. This research also raises a number of additional questions that should be addressed by future research in this area.

Conclusion

The results of this study undoubtedly suggest that sensory processing abilities are somewhat lower in DHH children compared to typically developing ones. Particularly, children with HAs demonstrated more difficulties than children with CIs in several domains. The absence of significant difficulties in children with CIs highlights the potential for successful integration of sensory processing abilities in this group. Interestingly, this study did not find significant contributions of chronological age, hearing age, or frequency of treatments to SSP scores in DHH children. Nevertheless, these results highlight the complexity of sensory processing development in DHH children and emphasize the need for early intervention and consistent rehabilitation to optimize sensory outcomes. Moving forward, further investigation into these findings is crucial for advancing our understanding of sensory processing in diverse populations.

These results must be interpreted with caution. To obtain a complete picture of sensory processing in the population of DHH children, it is necessary to examine sensory processing function in more detail, as well as various factors that could contribute, and using various instruments. This highlights the need for future research to consider these limitations and, accordingly, to improve empirical frameworks.

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