Predictors of hearing technology use in children

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ABSTRACT

Objective

To identify and describe predictors of daily hearing technology (HT) use in children.

Design

Retrospective review of clinical records. Multiple regression analyses were performed to identify predictors.

Study sample

The sample included 505 children (<11 years of age) using hearing aids (HAs), cochlear implants (CIs), and bone conduction hearing devices (BCHDs).

Results

Average HT use was 9.4 h a day. Bivariate analyses yielded 31 potential predictors from the 42 variables included. The general linear model ($p < 0.01$, $R^2 = 0.605$) identified 10 interacting factors that significantly associated with increased HT use. Intrinsic predictors of increased HT use included older chronological age, more severe degrees of hearing loss and older ages at diagnosis and initial HA fitting. Extrinsic predictors included the child's ability to independently use HT, at least one CI as part of the HT fitting, coordinated onsite audiological management, self-procured batteries, auditory-oral communication mode and regular caregiver intervention attendance.

Conclusions

Average HT use was high, approximating hearing hours of peers with normal hearing. CI recipients demonstrated higher HT use compared to children using other HT. The newly identified factors can predict and increase HT use in children while contributing to evidence-based intervention services that promote optimal auditory-based outcomes.

KEYWORDS: Hearing technology use; hearing aids; cochlear implants; bone conduction hearing devices; children; data logging; predictors; hearing loss; retrospective cohort study; general linear model

INTRODUCTION

Children with hearing loss have the same potential to acquire spoken language as their peers with normal hearing (Flexer & Wolfe, 2020). Since access to the acoustic speech spectrum is a prerequisite for auditory-based communication outcomes (McCreery & Walker, 2017), the "eyes open, ears on" use of hearing technology (HT) is recommended following the diagnosis of childhood hearing loss (American Academy of Audiology, 2013; Flexer & Wolfe, 2020, p. 52). While there is little direct evidence about what quantity of HT use is required in children with hearing loss (McCreery & Walker, 2017), it is reasonable to argue that HT use should approximate the hearing hours of peers with normal hearing to achieve similar spoken language and literacy outcomes. Consistent use of well-fitted hearing aids (HAs) in children with hearing loss is associated with better vocabulary, grammar (Walker, Holte, et al., 2015), speech and oral language outcomes (Tomblin et al., 2015), whereas increased cochlear implant (CI) use is associated with improved receptive vocabulary, language and speech recognition in pediatric CI users (Cesur et al., 2020; Gagnon et al., 2019; Park et al., 2019).

The recommendation and fitting of HT, however, do not necessarily guarantee full-time HT use. McCreery and Walker (2017) cautioned that all-day HT use is neither an achievable nor reasonable goal for families. Evidence suggests that, on average, HA use in children ranges between 5-8 hours a day (Jones & Launer, 2010; Muñoz et al., 2014; Walker, McCreery, et al., 2015). CI use ranges between 8-10 hours a day (Busch et al., 2017; De Jong et al., 2020; Wiseman & Warner-Czyz, 2018); a recent investigation found that it took 3-year-old pediatric CI recipients 17 months to reach the authors' definition of full-time use (80%) (Park et al., 2019). There is no available data on the average use of bone conduction hearing devices (BCHD) in children. Consequently, children who use

HT are not exposed to the same auditory experiences, both in quantity and quality, as their hearing peers (Flexer & Wolfe, 2020). When the goal is achieving equivalent auditory-based outcomes, a better understanding of the factors that influence HT use is required (Easwar et al., 2016; McCreery et al., 2015; Walker, McCreery, et al., 2015; Wiseman & Warner-Czyz, 2018).

Several factors have previously been identified that increased consistent HT use in children, including higher maternal education (Marnane & Ching, 2015), older chronological age (McCreery et al., 2015), younger age at implantation (Easwar et al., 2016), more severe degrees of hearing loss (Marnane & Ching, 2015; Walker, McCreery, et al., 2015) and more cumulative auditory experiences (Archbold et al., 2009; Cesur et al., 2020). Conversely, limited HT use is associated with the presence of additional disabilities (McCreery & Walker, 2017), limited access to healthcare services (Wiseman & Warner-Czyz, 2018), lack of perceived benefit (Muñoz et al., 2019), unsupervised contexts (Walker et al., 2013), and retention challenges (Muñoz et al., 2014).

While existing research provides insight into the usage of either HAs or CIs (Gagnon et al., 2019; McCreery et al., 2015; Walker, McCreery, et al., 2015), there is a lack of evidence comparing the objective use of different HTs or HT fitting configurations in the same study. Additionally, most evidence to date of predictive factors for HT use in children originated from high-income countries (Easwar et al., 2016; Marnane & Ching, 2015; McCreery et al., 2015; Park et al., 2019; Walker et al., 2013). Contextual research from low and middle-income countries (LMICs), where more than 90% of infants with hearing loss are born (Davis & Hoffman, 2019), is needed to guide hearing healthcare services in these regions appropriately. There is also limited investigation into other clinically relevant predictors that could influence HT use in children with hearing loss, such as the impact of multiple caregivers on HT use and the effect of aural re/habilitation (Wiseman & Warner-Czyz, 2018).

Identifying predictors of various types of HT on the HT use in children from underserved settings will contribute to evidence-based hearing healthcare services that promote optimal auditory-based outcomes. Therefore, this study investigated potential predictors of HT use and determined the prognostic significance of these factors in a diverse, unselected sample of children with hearing loss.

METHOD

This retrospective study reviewed clinical records from a database of pediatric HT users to identify variables that could influence the use of HT. The study site was an auditory-oral intervention program, namely the Carel du Toit Centre in Cape Town, South Africa. This program offers a combination of family-centered early intervention services and specialized oral schooling to children with hearing loss between birth and 11 years of age from both public and private healthcare sectors. Institutional review board clearance (HUM010/0219) was obtained before data collection commenced.

Participant inclusion criteria

The following inclusion criteria were specified for participants:

- children (<11 years of age) enrolled at the Carel du Toit Centre between 2010 – 2018,
- diagnosed with either a unilateral or bilateral hearing loss and including all types, degrees, and onsets of hearing loss,
- fitted with digital HT (conventional HAs, CIs, and BCHDs) with data logging capabilities,
- a record of at least three data logs with the same HT during a calendar year,
- caregiver consent for anonymized data collection.

No case selection occurred, and children from the complete range of developmental, educational, and communication environments were included.

Data collection

An electronic database was developed to capture retrospective data from the available clinical records of 556 children enrolled in the intervention program between 2010 and 2018. Of these, six families declined consent for either prospective or retrospective data collection. Another 45 potential participants did not meet the criteria. The final study sample included 505 pediatric HT users. Potential prognostic factors were identified from the retrospective data set and defined as either categorical (dichotomous or polytomous) or continuous variables. For the purpose of this study the degree of hearing loss was determined using the WHO classification system (World Health Organization, 1991, 2016, 2020). Accordingly, a better ear four frequency pure tone average <26 dB HL was considered normal hearing, whereas 26-30 dB HL as mild, 30-60 dB HL as moderate, 61-80 dB

HL as severe, and >80dB HL as a profound degree of hearing loss. The characteristics of the sample population are summarized in Table 1 according to categorical and continuous variables.

Table 1. Characteristics of the sample population according to categorical and continuous variables (*N* = 505).

Categorical Variables

	% (*n*)		**% (*n*)**
Demographic and Related Factors		**Family Factors**	
Gender		Parent with HL using HT	
Male	53.1 (268)	Yes	7.2 (36)
Female	46.9 (237)	No	92.9 (469)
Population group [a]		Maternal level of education	
Black African	23.6 (119)	Primary/ high school	35.1 (176)
Coloured	49.9 (252)	Matriculated	26.8 (135)
White	26.5 (134)	Post-matric	38.1 (191)
Additional diagnosed developmental condition(s)		Family participation in intervention [b]	
Yes	33.5 (169)	Average and below (1 - 3/5)	60.0 (303)
No	66.5 (336)	Above average (4 or 5/5)	40.0 (202)
Communication mode			
Auditory-oral	86.9 (439)		
Bimodal (visual and auditory)	13.1 (66)	**Audiologic Factors**	
Language agreement (home and education)		Type of hearing loss	
Equivalent	67.5 (341)	SNHL/ ANSD	83.6 (422)
Different	32.5 (164)	Mixed /conductive HL	16.4 (83)
		Degree of HL based on best ear 4FPTA [c]	
Intervention Factors		Normal (< 26 dB HL)	1.9 (9)
The regularity of professional HT check		Mild (26-30 dB HL)	1.1 (6)
Weekly	36.6 (185)	Moderate (31 – 60 dB HL)	22.9 (114)
Daily	50.1 (253)	Severe (61 – 80 dB HL)	23.9 (121)
Irregular	13.3 (67)	Profound (> 80 dB HL)	50.2 (253)
Caregiver responsible for intervention		Chronic otorrhea	
Parent	62.8 (317)	Yes	15.3 (77)
Other	37.2 (188)	No	84.7 (428)
Caregiver intervention attendance		Known onset of HL	
Poorly/ sometimes	44.9 (227)	Congenital/early onset	83.8 (423)
Mostly/always	55.1 (278)	Progressive/acquired	16.2 (82)
Independent HT user		Newborn hearing screening	
No, low, some assistance required	64.3 (325)	Yes	32.9 (166)
Independent	35.7 (180)	No	67.1 (339)
		Audiological management	
Socio-Economic Factors		Coordinated on-site	67.5 (341)
Social disability grant recipient ($108 a month)		Off-site premise (private /public health)	32.5 (164)
Yes	53.5 (270)		
No	46.5 (235)	**Type of Hearing Technology Fittings**	
Free batteries required		Binaural Has	56.0 (283)
Required	36.8 (186)	Bilateral CIs	14.5 (73)
Non-essential	63.2 (319)	Bilateral HL and bimodal HT (CI and HA)	13.5 (68)
Traveling distance to the intervention site		Bilateral HL but monaural HT (CI/HA)	8.5 (43)
< 10 km	8.3 (42)	Unilateral HL and monaural HT (HA/BCHD)	5.4 (27)
10-50 km	77.0 (389)	Bilateral HL with BCHD HT (BCHD and HA) [d]	2.1(11)
> 50 km	14.7 (74)		

Continuous Variables

	n	***M* (age in months)**	***SD* (range)**
Chronological age	505	62.5	34.4 (3 – 133)
Age at HL diagnosis	505	29.9	22.0 (0 – 104)
Age at initial HA fitting	505	33.5	22.4 (1 – 105)
Age at CI activation	155	38.9	25.9 (4 – 122)
Age at enrollment in intervention	505	34.8	22.7 (2 – 105)
Cumulative auditory experience with HA	505	24.0	29.4 (0 – 115)
Cumulative auditory experience with CI	155	20.5	28.5 (0 – 106)

[a] *The South African population identifies as Black Africans, Coloureds, Indian/Asian or White* (*Statistics SA, 2016, 2018).*
[b] *Family Participation in Intervention scale (Moeller, 2000).*
[c] *WHO classification of degree of HL based on the better ear 4FPTA* (World Health Organization, 1991, 2016, 2020)*.*
[d] *Not included in the ANOVA and CORR procedures.*

Data analysis

The first step of data analysis was to calculate average HT use. HT fitting software automatically averages HT use between the previous and current date every time the HT is coupled to the programming software. Ear specific average HT use was calculated by adding multiple data logs recorded through a calendar year and dividing it by the number of recordings available. Concurrently, each child's age was calculated as the median between the age at first and last data logs recorded. Thereafter hearing hours percentage (HHP) (Gagnon et al., 2019; Park et al., 2019) was calculated. The HHP equates the amount of time the child had access to sound with their HT to the amount of time a typically developing child would be awake and have access to sound, as recommended in the Consensus Statement of the American Academy of Sleep Medicine (Paruthi et al., 2016). Accordingly, the median "awake" or hearing hours for a 4- to 12-month-old child is 10 hours a day (12-16 range), increasing to 11.5 hours (11-14 range) for a 1- to a 3-year-old child, 12 hours (10-13 range) for a 3- to 5-year-old child and 13.5 hours (9-12 range) for a 6-to 11-year-old child. Hearing hour percentage (HHP) was calculated through the following equation: *HHP = average daily HT use/total awake time per age) * 100.* (see Paruthi et al. 2016 for more about average hours awake per age). As both ears' HT use values were similar, this study followed the same process as Marnane and Ching (2015) to select the ear with the highest data logging for statistical analyses.

Descriptive and inferential statistics were calculated using the commercially available statistical software package, SAS version 9.4. Descriptive statistics (means, standard deviations, and frequencies) were utilized to summarize the study population (N = 505) in terms of 42 clinical characteristics. Six types of HT fitting subcategories were created (Table 1*, N* = 505). However, to strengthen the statistical analysis, the 11 children included in the "bilateral hearing loss with BCHD HT" category (seven bilateral BCHDs and four bimodal HA and BCHD users) were excluded for inferential statistical procedures.

Subsequently, given the number of categorical and continuous variables included in the study, bivariate analyses were completed to determine the variables associated with the outcome variable and necessary to build the GLM model. Analyses of variance (ANOVA) (α level = 0.01) was used to determine if there was a bivariate relationship between the outcome variable, average HT use, and the 35 independent (categorical) variables (Supplementary Table A1). Simultaneously, Pearson's correlations (CORR procedure) were used to evaluate the degree of association between the seven continuous variables and the outcome variable, namely HT use (Supplementary Table A2).

The bivariate analyses (ANOVA and CORR) significantly associated 31 of the 42 potential prognostic factors with children's HT use.

Table 2. Linear regression analysis results (final GLM) (*n* = 494).

GLM Predictors	*df*	Sum of Squares	Mean Square	*F* Value	Pr > F (*p*-value)	R^2
	16	3458.58	216.16	45.66	<.0001	0.605002
Type of HT fitting					<.0001	
Degree of HL					<.0001	
Older chronological age					<.0001	
Coordinated on-site audiological management					<.0001	
≥75% rehabilitation appointment adherence					<.0001	
Auditory-oral communication mode					<.0001	
Self-procured batteries					<.0001	
Child ability to independently use HT					<.0001	
Older age at HL diagnosis					0.0015	
Older age at initial HA fitting					0.0016	

df: degrees of freedom
Pr > F: p-value of the F test (with F-test testing the significance of the mode)
R^2: determination coefficient

Finally, regression analyses were completed. Two general linear models (GLMs) were constructed to investigate the categorical and continuous predictors' influence on the continuous dependent variable. In the first GLM, all 31 significant predictor variables ($p < .01$) identified through both the ANOVA and the correlation analyses were entered into the model. Following this, the final GLM was built to generate predictive factors that simultaneously had the most significant effect on HT use. This final GLM model included all variables and was derived through a manual, step-by-step procedure. The model was run multiple times, systematically removing the non-significant variables with the highest *p*-value until the model was left with the only significant predictor. Throughout the entire regression analyses, a more conservative *p*-value was utilized to indicate statistical significance ($p < .01$), owing to the relatively large sample size and specificity of the research question. This *p*-value reduced the chance of false positives while simultaneously increasing the accuracy of any significant results obtained. In addition, four-way, three-way, and two-way interaction effects were performed on the final GLM to investigate the combined or interactive influence of the categorical variables on the dependent variable, HT use.

RESULTS

HT use in children

The 505 children included in this study had average HT use of 9.4 hours a day (3.4 *SD*, 0.2-15.5 hours a day range) and a mean HHP of 74.3% (25.5 *SD*, 1.7-118.6% range). The mean period between the first and last data logging measure was 8.2 months of HT use (2.4 *SD*; 2-12 months range). Figure 1 demonstrates HT use (hours a day) across different chronological age groups and concurrent expected awake or hearing hours (Paruthi et al., 2016). Older age groups were associated with higher HT use approximating the awake time or hearing hours of children with normal hearing.

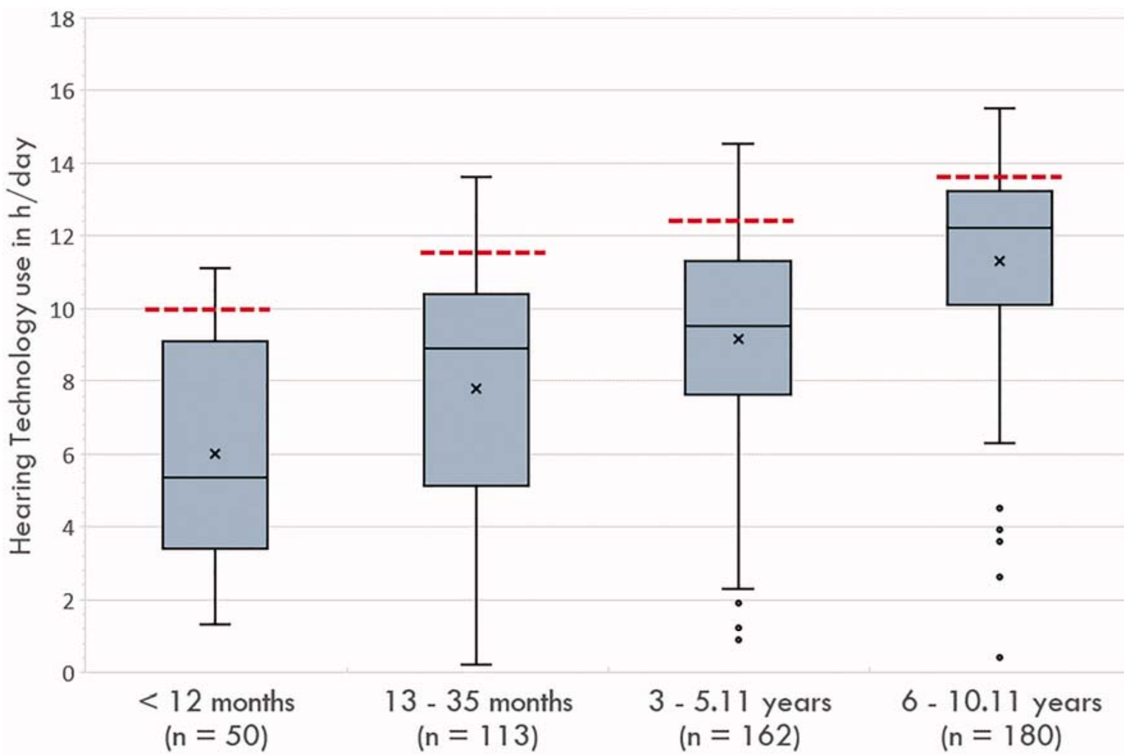

Figure 1. Average hearing technology use per day as a function of chronological age (n = 505). The box plots represent the smallest observation, lower quartile, median (line), mean (x), upper quartile, largest observation, and the outliers (>1.5 times interquartile range = •). The dotted line indicates the expected median hearing hours or time awake for each age group, as determined by Paruthi et al. (2016)

Factors that influenced HT use in children

The bivariate analyses (ANOVA and CORR) indicated that 31 of the 42 potential prognostic factors included had a significant association with children's HT use. Supplementary appendix Table A1 summarizes the ANOVA analysis results (p <.01) and Table A2 the CORR analysis results (p < .0.1).

The outcome variable was estimated using regression analyses (*p* <.01). The final GLM was highly significant (F (16,477) = 45.66; $p < .01$, $R^2 = 0.605$) and generated 10 significant predictor factors. Table 2 summarizes the ten factors (seven categorical and three continuous variables) that emerged as significant predictors of HT use (*n* = 494). Simultaneous interaction of these factors included in the model accounted for 61% of the variance in HT use. When considering the categorical variables identified through the GLM, none of the four-way, three-way, or two-way effects were significant (*p* <.01).

Table 3 summarizes the predictor estimates of the seven significant (*p* < .01) categorical factors generated by the final GLM. The effect of the type of HT fitting on HT use (*p* < .0001) could be predicted when comparing it to the reference, namely bilateral HA users. The highest HT use was predicted for bilateral CI users (72 minutes more), bimodal CI users (61 minutes more), and children fitted monaurally (either a CI or HA) but a bilateral hearing loss (18 minutes more). Children with unilateral hearing loss and monaural HT fitting (HA or BCHD) had the lowest average HT use. Their HT use on average was 68 minutes less than the children fitted with bilateral HAs. More severe degrees of hearing loss (*p* < .0001) were predictive of higher average daily HT use. HT use in children with profound hearing loss (> 80 dB HL) was estimated the highest at 16 minutes more than the estimate parameter or reference, namely severe hearing loss (60-80 dB HL). A moderate hearing loss (30-60 dB HL) was associated with 65 minutes less daily use and a mild hearing loss (< 30dB HL) with 178 minutes less daily use compared to children with severe hearing loss. Coordinated onsite audiological management (*p* < .0001) was associated with an increase in HT use of 74 minutes, compared to the HT use of children who received audiology services at other premises. Families with intervention appointment adherence records of ≥ 75% (*p* < .0001) predicted increased daily HT use of 76 minutes, compared to those children from families with less than 75% adherence. An auditory-oral communication mode (*p* < .0001) was associated with 79 minutes more daily use than a bimodal communication mode. When children required subsidized batteries (*p* < .0001), their HT use was reduced by 67 minutes per day. Lastly, children who independently used their HT (*p* < .0001) compared to those who required adult assistance increased HT use by 64 minutes a day.

Table 3. Predictor estimates of the seven categorical predictor factors generated by the final GLM (*n* = 494).

Independent Variable	Parameter	*n*	HT use Mean (h/day)	*SD* (*95%CI*)	Estimate (*SE*)
Type of HT fitting	Binaural HAs	283	8.6	3.6 (8.2 - 9.0)	Reference
	Bilateral HL but monaural HT (CI/HA)	43	9.4	3.1 (8.4 - 10.3)	0.300 (0.365)
	Bimodal HT (CI and HA)	68	11.0	2.1 (10.5 - 11.5)	1.192 (0.343)
	Bilateral CIs	73	11.4	2 (10.9 - 11.9)	1.015 (0.372)
	Unilateral HL and monaural HT	27	7.51	3.2 (6.2 - 8.8)	-1.144 (0.445)
Degree of HL	Severe (61 – 80 dB HL)	121	9.7	3.3 (9.0 - 10.3)	Reference
	Normal (< 26 dB HL)	9	5.1	3.3 (2.5 - 7.6)	-3.222 (0.761)
	Mild (26-30 dB HL)	6	6.1	2.8 (3.1 - 9.1)	-2.976 (0.923)
	Moderate (31 – 60 dB HL)	113	8.4	2.7 (7.9 - 8.9)	-1.086 (0.298)
	Profound (> 80 dB HL)	253	9.9	3.5 (9.4 - 10.3)	0.265 (0.299)
Audiological management	Off-site premise	161	8.1	4.1 (7.4 - 8.7)	Reference
	Coordinated on-site	333	10.0	2.8 (9.7 - 10.3)	1.247 (0.229)
Intervention attendance	<75% caregiver adherence	221	8.1	3.6 (7.6 - 8.56)	Reference
	≥75%r caregiver adherence	273	10.4	2.8 (10.1 - 10.7)	1.278 (0.229)
Communication mode	Auditory-oral	428	9.8	3.1 (9.5 - 10.1)	Reference
	BImodal	66	6.3	3.9 (5.3 - 7.2)	-1.321 (0.342)
Batteries	Subsidized	184	7.8	3.6 (7.2 - 8.3)	Reference
	Self-procured	310	10.3	2.9 (9.9 - 10.6)	1.121 (0.234)
Independent HT user	Dependent on adult assistance	319	8.2	3.4 (7.8 - 8.6)	Reference
	Independent	175	11.5	2.3 (11.1 - 11.8)	1.069 (0.255)

Table 4 summarizes the predictor estimates of the three significant ($p < .01$) continuous variables identified by the final GLM. Older chronological age ($p < .0001$), older age at diagnosis ($p = 0.0015$) and older age at initial HA fitting ($p = 0.0016$) predicted increased HT use.

Table 4. Predictor estimates of the three continuous predictor factors generated by the final GLM (*n* = 494).

Independent Variable	Age (months) Mean	*SD* (*95%CI*)	Estimate (*SE*)
Chronological age	62.7	34.6 (59.7 - 65.8)	0.038 (0.004)
Age at HL diagnosis	30.1	22.0 (28.2 - 32.1)	0.053 (0.016)
Age at initial HA fitting	33.5	22.3 (31.5 - 35.2)	0.053 (0.017)

DISCUSSION

This study is the first to investigate predictors of HT use in a heterogeneous group of children using various types of HT. Average HT use in this study (9.4 hours a day *M*; 3.4 *SD*) compared well with more recent reports indicating average HT use in children between 9-11 hours a day (Easwar et al., 2018; McCreery & Walker, 2017). HT use approximated the hearing hours of normal hearing peers (Paruthi et al., 2016) but fell short of the indicated > 10 hours a day HA use found to be the minimum required to demonstrate language development gains in preschoolers (Tomblin et al., 2015). Most children in this study did not use their HT all waking hours, which implies less equivalent auditory experiences than children with normal hearing (Flexer & Wolfe, 2020). The development of spoken language, literacy, and knowledge will be negatively influenced if insufficient quantities and qualities of auditory information reach the brain, causing non-optimal neural connections (Kral & Lenarz, 2015). The investigation into predictors of HT use and the reported poorer outcomes in children with hearing loss, regardless of Early Hearing Detection and Intervention (EHDI) (Cupples et al., 2018; Tomblin et al., 2015, 2020), can support strategies to maximize HT use for optimal auditory experiences.

Older chronological age was a strong predictor of increased HT use in this study sample. This finding was in agreement with previous reports that indicated that older age influenced HT use positively in children (Easwar et al., 2016; McCreery et al., 2015; Wiseman & Warner-Czyz, 2018). Older children are awake longer and have more opportunities to have auditory experiences (Park et al., 2019). On the other hand, typical developmental stages can influence HT use negatively, for example, reduced head and trunk support (Gagnon et al., 2019), the mouthing stage (Walker et al., 2013), as well as challenging temperament or state (Easwar et al., 2016). Retention solutions for children of younger ages in challenging situations such as car seats could combat some of the difficulty caregivers experience facilitating HT use.

Higher average HT use was also associated with more severe degrees of hearing loss. Previous studies also found a greater perceived need to use HT when children had less residual hearing (McCreery et al., 2015; Walker, McCreery, et al., 2015). By anticipating that children with unilateral and milder hearing losses may be at risk for reduced HT use, enhanced support can be provided timeously. This is especially true for slight/mild degrees of childhood hearing loss where the perceived need may be minimized because of residual hearing. Families should be counseled regarding the potential negative impact of unaided milder hearing losses on developmental outcomes, including speech and language, academic performance, social interaction, behavior, and health-related quality of life (Fitzpatrick et al., 2019).

This study was the first to demonstrate that children with a bilateral hearing loss, using at least one CI as part of their HT fitting combination (including unilateral, bilateral, and bimodal CI users) demonstrated significantly higher HT use when compared to children fitted with other HT combinations. Children with unilateral hearing loss and monaural HA/BCHD demonstrated the least HT use. Although the degree of hearing loss and type of HT is directly related and co-dependent, there is a lack of evidence comparing HT use in children using HAs and CIs employing similar methodologies. While Marnane and Ching (2015) investigated HA and CI use through subjective reports in 3-year-old children, the current study included the entire spectrum of HT types (except for ear-level remote microphone systems), utilized objective data logging as an outcome measure, and had a broader age range. Marnane and Ching (2015) proposed that CI use in children is most likely higher than HA use because the degree of hearing loss influences the need to access sound more regularly. The results of this study could suggest an additional consideration. Pediatric CI recipients generally receive more intensive intervention and follow-up appointments (Fulcher et al., 2012), allowing more opportunities to support increased HT use. Conversely, children with unilateral hearing loss using HT and those fitted with bilateral HAs with mild to moderate-severe hearing loss are more likely to receive less intervention and support as they demonstrate the most residual capacity for auditory-based outcomes (Moeller & Tomblin, 2015).

In this study sample, an auditory-oral mode of communication significantly predicted increased HT use in children. While Archbold et al. (2019) indicated that an oral mode of communication was predictive of full-time CI use, it was based on parental report and evidence has since suggested that, at least for HAs, parents overestimate HT use by up to 3.4 hours (Muñoz et al., 2014; Walker et al., 2013). Recently, De Jong et al. (2020) examined the influence of parental communication mode on CI use in children where parental communication was classified into three categories: oral communication, a combination of oral communication and sign language, or only sign language. Their results indicated that parents using only sign language, or a combination of sign and oral language was associated with reduced CI use. The current study suggests that children using an auditory-oral communication mode rely on auditory access to communicate, possibly increasing HT use. In contrast, children using bimodal communication may rely on audition less; therefore, the need for HT use may be less. While it is best practice to adhere to the caregiver preference for communication mode in aural re/habilitation, prolonged language deprivation for children with continued reduced HT use must be limited (Hall, 2017). Bimodal communication should be promoted when full-time HT use is unattainable for families, bearing in mind that proficient sign language use could also be an unfeasible expectation for the family.

Regular caregiver intervention attendance also predicted increased HT use. While the positive impact of caregiver participation in aural re/habilitation on the language development of children with hearing loss is well known (Erbasi et al., 2017; Flexer & Wolfe, 2020), less is known about how caregiver adherence to intervention appointments could influence auditory-based outcomes. Although both attendance and caregiver participation in intervention were identified through bivariate analysis in this study, only regular attendance was included in the GLM. The reason for increased HT use with regular caregiver intervention attendance could be attributed to these caregivers being more committed to their children's needs by recognizing the benefit they receive from therapy. Additionally, these families receive more frequent reminders of the benefit of HT use when interacting with a therapist and may indicate more engaged families. This unique finding supports the call for more sensitive and specific measurement tools of parental involvement and insight into pediatric aural re/habilitation (Erbasi et al., 2017).

Access to coordinated onsite audiological management at the intervention center instead of an off-site premise was considered a strong predictive factor of increased HT use in this study. Though caregivers prefer streamlined audiological and intervention services for ease and practicality (Athalye et al., 2015), this study is the first to suggest that the coordination of services can also positively influence HT use. A collaborative service could allow daily (school) or weekly (intervention) collaboration with the audiology department to investigate and address subtle signs of problematic HT use. Additionally, an onsite audiology department could also implicitly advocate that HT use is essential and prioritized for auditory-based communication outcomes, resulting in increased HT use.

In this study sample, the children who required subsidized batteries due to socio-economic circumstances had reduced HT use compared to those able to self-procure. Although the study's bivariate analyses identified several factors associated with socio-economic circumstances as predictive factors (p <.01, see Appendix Table 1A for more information), such as accessing public health care (p <.0001), monthly family income (p = 0.0005), receiving a social disability grant (p <.0005), food parcels recipiency (p <.0001), and transport subsidies (p <.0001), the self-procurement of batteries was the only factor included in the GLM. This specific finding could be considered counterintuitive as subsidized batteries are supposed to make it easier for children to achieve better HT use, despite socio-economic status. However, Wiseman and Warner-Czyz (2018) cautioned that low-income households could experience more pressing needs than HT use, as well as access to fewer resources, such as time and support systems. The families selected for battery assistance may experience more significant challenges than what can be addressed by the donation, subsequently not causing the desired effect, which is prioritizing and maintaining their child's HT use.

Older ages at hearing loss diagnosis and initial HA fitting predicted increased HT use too. This surprising finding that later diagnosis and HA fitting predicted increased HT use is probably related to the characteristics and context of the study sample. Most studies about HT use in children are from high-income contexts with effective EHDI programs for early detection, diagnosis, and intervention of hearing loss in children (Cupples et al., 2018; Moeller & Tomblin, 2015). McCreery and Walker (2017) recognized the diminishing effect of later diagnosis on HT use due to effective EHDI implementation in their context. The impact of delayed hearing loss diagnosis and intervention on HT use in an LMIC, like South Africa, is less clearly understood. In this sample, only a third of the children received newborn hearing screening, resulting in delayed overall diagnosis (29.9 *M*, 21.9 *SD*, 0-104 months range) and initial HA fitting (33.5 *M*, 22.4 *SD*, 1-105 months range). These results could indicate increased caregiver insight into re/habilitation's impetus when children are older due to visible developmental delays. Furthermore, an auditory-oral intervention site could lay the groundwork for prominent advocacy and action regarding optimized HT use to "catch-up" on auditory experiences. However, this finding requires further investigation, especially in LMICs, where delayed diagnosis and intervention are typical.

Children in this study demonstrated increased HT use when they could handle and use their HT independently compared to those who needed adult assistance. While the positive influence of older chronological age on HT use has already been discussed, this finding could be the first to indicate that independent HT use positively influences the use of HT in children. This finding suggests that children can approximate higher HT use when not dependent on adult assistance anymore and could be regarded as the first step towards developing self-advocacy skills.

The clinical implications of the study can be summarized according to three actions. First, professionals could *anticipate* that certain children with hearing loss (such as bilateral HA users or those with unilateral, mild, or moderate degrees of hearing loss) would be at risk for limited HT use when compared to children with more severe degrees of hearing loss and those using at least one CI. In those cases, implementing immediate scaffolding strategies such as counseling and parent-to-parent support could have a positive effect. Secondly, predictors of HT use could be *manipulated* where possible to increase HT use, such as prioritizing coordinated onsite audiology services with intervention. Lastly, predictors that cannot be manipulated could be *mitigated,* such as chronological age, by incorporating multiple retention strategies for younger children. Consequently, this study's results could assist in guiding clinical services provided to children using HT and acquiring auditory-based communication outcomes.

To the authors' knowledge, the present analysis contributed the first investigation into objective HT use in children using various HT fitting configurations. Additionally, it is the first to consider a broader range of predictor variables across multiple dimensions to determine its influence on the use of HT in children. As a result, the study was able to comment on the use of different HT in children and identified predictors not previously described in the literature before. These include the type of HT fitting, an auditory-oral mode of communication, regular caregiver intervention attendance, coordinated onsite audiology management at the intervention site, self-procured batteries, older ages at hearing loss diagnosis and initial HA fitting, and the child's ability to use their HT independently. Additionally, because the study sample was diverse, unselected, and extracted from an LMIC, study results could be generalized to a broader population.

On the contrary, the multi-factorial influence of predictors on HT use was evident as uninvestigated factors still accounted for 39% of the sample's remaining variation. The study had additional limitations; for example, it could not create a distinctive type of HT fitting category for the children fitted with BCHD to be included in the multiple regression analyses. Further studies with more specific research questions and stringent inclusion criteria could address these, such as investigating the use of BCHD in children with chronic otorrhea.

CONCLUSION

Although HT use is a multi-factorial outcome measure, this study identified an extensive range of predictive factors that could predict and increase HT use in children. Intrinsic predictors of increased HT use in children included older chronological age, more severe hearing loss, and older ages at diagnosis and initial HA fitting. Extrinsic predictors of increased HT use identified included the child's ability to independently use HT, at least one CI as part of the HT fitting, coordinated onsite audiological management, self-procured batteries, auditory-oral communication mode, and regular caregiver intervention attendance. While factors like the degree of hearing loss and chronological age cannot be manipulated or modified, identifying, and manipulating malleable predictors of HT use, such as caregiver appointment attendance and independent HT use, could positively influence children's developmental outcomes. This study identified a range of newly described predictor factors of HT use a diverse, unselected sample of children with hearing loss.

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REFERENCES

American Academy of Audiology. (2013). American Academy of Audiology Clinical Practice Guidelines: Pediatric Amplification. *American Academy of Audiology*, *June*, 5–60. www.audiology.org

Archbold, Nikolopoulos, T. P., Lloyg-Richmond, H., Archbold, S., Nikolopoulos, T. P., & Lloyg-Richmond, H. (2009). Long-term use of cochlear implant systems in pediatric recipients and factors contributing to non-use. *Cochlear Implants International*, *10*(1), 25–40. https://doi.org/10.1002/cii.363

Athalye, S., Archbold, S., Mulla, I., Lutman, M., & Nikolopoulous, T. (2015). Exploring views on current and future cochlear implant service delivery: The perspectives of users, parents and professionals at cochlear implant centres and in the community. *Cochlear Implants International*, *16*(5), 241–253. https://doi.org/10.1179/1754762815Y.0000000003

Busch, T., Vanpoucke, F., & van Wieringen, A. (2017). Auditory environment across the life span of cochlear implant users: Insights from data logging. *Journal of Speech, Language, and Hearing Research*, *60*(5), 1362–1377. https://doi.org/10.1044/2016_JSLHR-H-16-0162

Cesur, S., Yüksel, M., & Çiprut, A. (2020). Data logging variables and speech perception in prelingually deafened pediatric cochlear implant users. *International Journal of Pediatric*

Otorhinolaryngology, *133*. https://doi.org/10.1016/j.ijporl.2020.110003

Cupples, L., Ching, T., Button, L., Seeto, M., Zhang, V., Whitfield, J., Gunnourie, M., Martin, L., & Marnane, V. (2018). Spoken language and everyday functioning in 5-year-old children using hearing aids or cochlear implants. *International Journal of Audiology*, *57*, S55–S69. https://doi.org/10.1080/14992027.2017.1370140

Davis, A. C., & Hoffman, H. J. (2019). Hearing loss: Rising prevalence and impact. *Bulletin of the World Health Organization*, *97*(10), 646-646A. https://doi.org/10.2471/BLT.19.224683

De Jong, T., van der Schroeff, M., & Vroegop, J. (2020). Child- and environment-related factors influencing daily cochlear implant use. *Ear & Hearing*, *Publish Ah*(Ci), 1–8. https://doi.org/10.1097/aud.0000000000000911

Easwar, V., Sanfilippo, J., Papsin, B., & Gordon, K. (2016). Factors affecting daily cochlear implant use in children: Datalogging evidence. *Journal of the American Academy of Audiology*, *27*(10), 824–838. https://doi.org/10.3766/jaaa.15138

Easwar, V., Sanfilippo, J., Papsin, B., & Gordon, K. (2018). Impact of consistency in daily device use on speech perception abilities in children with cochlear implants: Datalogging evidence. *Journal of the American Academy of Audiology*, *29*(9), 835–846. https://doi.org/10.3766/jaaa.17051

Erbasi, E., Hickson, L., & Scarinci, N. (2017). Communication outcomes of children with hearing loss enrolled in programs implementing different educational approaches: A systematic review. *Speech, Language and Hearing*, *20*(2), 102–121. https://doi.org/10.1080/2050571X.2016.1238611

Fitzpatrick, E. M., Coyle, D., Gaboury, I., Durieux-Smith, A., Whittingham, J. A., Grandpierre, V., Na, E., & Salamatmanesh, M. (2019). Service preferences of parents of children with mild bilateral or unilateral hearing loss: A Conjoint analysis study. *Ear and Hearing*, *40*(3), 671–679. https://doi.org/10.1097/AUD.0000000000000651

Flexer, C., & Wolfe, J. (2020). Auditory brain development and auditory verbal therapy. In W. Estabrooks, H. M. Morrison, & K. MacIver-Lux (Eds.), *Auditory-Verbal Therapy: Science; research; and practice*. Plural Publishing, Inc.

Fulcher, A., Purcell, A. A., Baker, E., & Munro, N. (2012). Listen up: Children with early identified hearing loss achieve age-appropriate speech/language outcomes by 3 years-of-age. *International Journal of Pediatric Otorhinolaryngology*, *76*(12), 1785–1794. https://doi.org/10.1016/j.ijporl.2012.09.001

Gagnon, E. B., Eskridge, H., & Brown, K. D. (2019). Pediatric cochlear implant wear time and early language development. *Cochlear Implants International*, *0*(0), 1–6. https://doi.org/10.1080/14670100.2019.1670487

Hall, W. C. (2017). What You Don't Know Can Hurt You: The Risk of Language Deprivation by Impairing Sign Language Development in Deaf Children. *Maternal and Child Health Journal*, *21*(5), 961–965. https://doi.org/10.1007/s10995-017-2287-y

Jones, C., & Launer, S. (2010). Pediatric fittings in 2010: The Sound Foundation Cuper project. In R. Seewald & J. Bamford (Eds.), *Sound Foundation through Early Amplification: Proceedings of the 2010 International Conference.* (pp. 187–192). http://www.phonakpro.com/content/dam/phonak/gc_hq/b2b/en/events/2010/Proceedings/Pho_Chap_12_Jones_Final.pdf

Kral, A., & Lenarz, T. (2015). How the brain learns to listen: deafness and the bionic ear. *E-Neuroforum*, *6*(1), 21–28. https://doi.org/10.1007/s13295-015-0004-0

Marnane, V., & Ching, T. (2015). Hearing aid and cochlear implant use in children with hearing loss at three years of age: Predictors of use and predictors of changes in use. *International Journal of Audiology*, *54*(8), 554–551. https://doi.org/10.3109/14992027.2015.1017660

McCreery, R. W., & Walker, E. A. (2017). *Pediatric Amplification. Enhancing Auditory Access*. Plural Publishing, Inc.

McCreery, R. W., Walker, E. A., & Spratford, M. (2015). Understanding limited use of amplification in infants and children who are hard of hearing. *Perspectives on Hearing and Hearing Disorders in Childhood*, *25*(April), 15–23. http://successforkidswithhearingloss.com/wp-content/uploads/2013/07/Understanding-Limited-Use-of-Amp-in-Infants-and-Children-who-are-HOH-Sig-9-Perspectives-4_15.pdf

Moeller, M. P., & Tomblin, J. B. (2015). Epilogue: Conclusions and implications for research and practice. *Ear and Hearing*, *36*, 92S-98S. https://doi.org/10.1097/AUD.0000000000000214

Muñoz, K., Larsen, M., Nelson, L., Yoho, S., & Twohig, M. (2019). Pediatric amplification management: Parent experiences monitoring children's aided hearing. *Journal of Early Hearing Detection and Intervention*, *4*(1), 73. https://doi.org/10.26077/a049-v107

Muñoz, K., Preston, E., & Hicken, S. (2014). Pediatric hearing aid use: How can audiologists support parents to increase consistency? *Journal of the American Academy of Audiology*, *25*(4), 380–387. https://doi.org/10.3766/jaaa.25.4.9

Park, L. R., Gagnon, E. B., Thompson, E., & Brown, K. D. (2019). Age at full-time use predicts language outcomes better than age of surgery in children who use cochlear implants. *American Journal of Audiology*, *28*(4), 986–992. https://doi.org/10.1044/2019_AJA-19-0073

Paruthi, S., Brooks, L. J., Ambrosio, C. D., Hall, W. A., Kotagal, S., Lloyd, R. M., Malow, B. A., Maski, K., Nichols, C., Quan, S. F., Rosen, C. L., Troester, M. M., & Wise, S. (2016). Consensus statement of the American Academy of Sleep Medicine on the recommended amount of sleep for healthy children: Methodology and discussion. *Journal of Clinical Sleep Medicine*, *12*(11), 1549–1561. https://doi.org/10.5664/jcsm.6288

Tomblin, J. B., Harrison, M., Ambrose, S. E., Walker, E. A., Oleson, J. J., & Moeller, M. P. (2015). Language outcomes in young children with mild to severe hearing loss. *Ear and Hearing*, *36*(1), 76S-91S. https://doi.org/10.1097/AUD.0000000000000219

Tomblin, J. B., Oleson, J., Ambrose, S. E., Walker, E. A., & Moeller, M. P. (2020). Early literacy predictors and second grade outcomes in children who are hard of hearing. *Child Development*, *91*(1), e179–e197. https://doi.org/10.1111/cdev.13158

Walker, E. A., Holte, L., McCreery, R. W., Spratford, M., Page, T., & Moeller, M. P. (2015). The influence of hearing aid use on outcomes of children with mild hearing loss. *Journal of Speech, Language, and Hearing Research : JSLHR*, *58*(5), 1611–1625. https://doi.org/10.1044/2015_JSLHR-H-15-0043

Walker, E. A., McCreery, R. W., Spratford, M., Oleson, J. J., Van Buren, J., Bentler, R., Roush, P., & Moeller, M. P. (2015). Trends and predictors of longitudinal hearing aid use for children who are hard of hearing. *Ear and Hearing*, *36*(1), 38–47. https://doi.org/10.1097/AUD.0000000000000208

Walker, E. A., Spratford, M., Moeller, M. P., Oleson, J., Ou, H., Roush, P., & Jacobs, S. (2013). Predictors of hearing aid use time in children with mild-to-severe hearing loss. *Language Speech and Hearing Services in Schools*, *44*(1), 73–88. https://doi.org/10.1044/0161-1461(2012/12-0005)

Wiseman, K. B., & Warner-Czyz, A. D. (2018). Inconsistent device use in pediatric cochlear implant users: Prevalence and risk factors. *Cochlear Implants International*, *19*(3), 131–141. https://doi.org/10.1080/14670100.2017.1418161

World Health Organization. (1991). *Report of the Informal Working Group on Prevention of Deafness and Hearing Impairment Programme Planning, Geneva, 18-21 June 1991.*

World Health Organization. (2016). *Childhood hearing loss: Strategies for prevention and care*. http://www.who.int/about/licensing/copyright_form/index.html

World Health Organization. (2020). *Basic ear and hearing care resource*. http://apps.who.int/iris