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ORIGINAL ARTICLE

Variables Related to the Executive Function in Deaf and Hard-of-Hearing Preschoolers

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Abstract
The present study aims to examine the Executive Function (EF) skills of preschool-aged children who are deaf and hard of hearing (DHH), and explore the variables related to their EF skills. Thirty preschoolers who were DHH and an additional 35 preschoolers with typical hearing were recruited. All DHH use spoken language as their communication mode, and wore hearing devices. Results revealed that preschoolers who are DHH are delayed in some EF skills, particularly inhibitory control and cognitive flexibility. Interestingly, in working memory, they exhibit age-appropriate verbal working memory, whereas they do not have an advantage over their hearing peers in visual-spatial working memory. Correlational results showed that working memory is related to language skills, while inhibitory control is related to the age of auditory exposure and early intervention. Thus, the results highlight the importance of early auditory exposure and early intervention, as well as language, in EF development in preschoolers who are DHH.

Keywords Executive Function · Deaf and Hard of Hearing · Preschool · Language · Early intervention

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Introduction

Executive Function (EF) is a set of cognitive skills that helps us regulate ourselves and execute planned behaviors and actions. EF has three fundamental constructs: inhibitory control, working memory, and cognitive flexibility (Diamond, 2013). These three domains share similar abilities but are distinct from each other. EF plays an important role throughout our life span. EF is a fundamental skill for children's educational achievement (Duncan et al., 2007), social interaction with others (Rhoades et al., 2009), and their mental health and future quality of life (Davis et al., 2010). For example, Caporaso et al. (2019) demonstrated that preschoolers' three EF skills are related to their social competence, while other research shows that children's inhibitory control in preschool years is related to their emerging math and literacy skills (Blair & Razza, 2007). In a longitudinal study, Moffitt et al., (2011) also found that children aged 3–11 years with better inhibitory control were more likely to earn more, have happier lives, and to have committed fewer crimes by the age of 30. In other words, children with better EF skills are more likely to be successful. Notably, many studies have shown that children who are deaf and hard of hearing (DHH) with better EF skills also exhibit better language skills (Kronenberger & Pisoni, 2020) and social skills (Marschark et al., 2017a). Crucially, EF skills in children who are DHH are associated with speech perception in noise (Brännström et al., 2022). Taken together, the results of these studies indicate the importance of EF skills in children who are DHH, particularly for those of preschool age. EF is under critical and dramatic development during preschool years. Morgan & Dye (2020) suggested that early interaction facilitates the development of EF in children who are DHH. Many studies have shown that hearing parents have difficulties in obtaining interaction cues from their children who are DHH (Lederberg & Mobley, 1990); in a family-centered early intervention program, such as auditory verbal therapy, professionals train parents to interact with children who are DHH responsively, and learn to observe their children's cues; thus, early intervention may potentially play a role in the development of EF in children who are DHH.

Previous studies investigating school-aged children who are DHH have revealed mixed results regarding the three fundamental constructs of EF. Some found delays in inhibitory control but not working memory (Jones et al., 2020; Hintermair, 2013), while others revealed delays in both inhibitory control and working memory (Hall et al., 2018; Kronenberger et al., 2014; Botting et al., 2017). Only cognitive flexibility has undoubtedly been delayed in children who are DHH (Figueras et al., 2008; Hall et al., 2018; Jones et al., 2020; Botting et al., 2017; Hintermair, 2013). However, these results are mostly from school-aged children. To date, few studies have focused on preschool-aged children who are DHH. Preschool age is the critical period during which EF undergoes dramatic development (Zelazo et al., 2008); meanwhile, it is the best time to introduce early intervention program. Thus, an understanding of the EF skills of preschool-aged children who are DHH is needed.

Beer et al. (2014) were one of the first to use both performance-based tasks and the parent report scale, Behavior Rating Inventory of Executive Function (BRIEF), to assess preschool-aged children who were DHH. The two types of measurements yielded slightly different results; the performance-based tasks found that children who were DHH exhibited delay in inhibitory control compared to their hearing peers. Alternatively, according to the parent report, children who were DHH had more problems in both inhibitory control and working memory compared to their hearing peers. However, both these results indicated that preschoolers with cochlear implants (CIs) are already at risk in terms of EF abilities, particularly inhibitory control and working memory. It must be noted that cognitive flexibility was not examined in this study.

Another study recruited preschoolers who were DHH (Nicastri et al., 2021). They used tasks outlined in the Battery for Assessment of Executive Functions, which measures children's working memory, inhibitory control, and cognitive flexibility. They found that most children with CIs were able to perform within the normal range for all three EF skills. They further divided children with CI into two groups: children who were identified within 6 months of age and received CIs within 12 months of age and children who were identified later and received CIs later. Almost all children in the former group outperformed in the EF tasks, whereas children in the latter group exhibited diverse EF skills. Thus, those exposed to the auditory environment later were more likely to be at risk for all three EF skills. There was no control group in which children with typical hearing were included. Children's performances were compared with the norm of the measurements, which may have potentially led to an overestimation.

Both studies discussed above focused on children with CIs, suggesting that they are at risk of delayed EF skills even at preschool ages. Nonetheless, not only children with CIs, but also children who are DHH may be at risk of delayed EF skills. Goodwin et al. (2022) recently investigated preschool-aged children who were DHH. These children either signed or used oral communication and some were fitted with hearing devices. Those fitted with hearing devices were either fit with hearing aids (HAs) or CIs. They used the BRIEF parents report scale to assess children's EF skills. Children who were DHH with later language exposure (those with hearing parents) did not differ significantly in terms of the risk of executive dysfunction in all EF skills. However, the parent-reported questionnaire was the only tool to measure children's EF skills, which may not be comparable to other studies that also used performance-based tasks. Performance-based tasks and parental questionnaires may not assess the same construct in EF (Nin et al., 2022); this is also evident from Beer et al. (2014) study that show slightly different findings using the two types of measurements. Therefore, the present study utilized performance-based tasks to measure children's EF skills, aiming to shed some light on the EF skills of children who are DHH using both HA and/or CI.

Previous studies have demonstrated that the delay of EF abilities, including working memory, inhibitory control, and cognitive flexibility, emerges early in the preschool years. However, studies have revealed mixed results in terms of which EF skills are delayed at preschool age. Their methodological limitations also make it difficult to draw conclusions as some studies recruited participants with CIs only or with various auditory-related backgrounds, some used questionnaires only, and some did not include hearing children as a control group for comparison. Thus, the present study aims to examine the EF skills of preschoolers who are DHH using performance-based tasks and recruiting participants fitted with CIs or HAs, all of which use oral language as their communication mode.

In addition to examining the EF skills of preschoolers who are DHH, the present study aims to explore the potential factors related to their EF skills. Many factors have been suggested to be related to EF in children who are DHH. Language is one of the most important factors to discuss. Language has been suggested as critical for the development of EF (Kuhn et al., 2014; Gooch et al., 2016). Lower language abilities may result in lower EF abilities (Beer et al., 2014), and language may be a predictor of EF skills (Botting et al., 2017). In addition to language ability, the age at which language is accessed has also been argued to be related to EF. Nicastri et al. (2021) found that early identification and implantation lead to better EF skills, indicating that auditory exposure may be a factor related to EF development in children who are DHH. In contrast to Nicastri et al. (2021), Goodwin et al. (2022) demonstrated that language exposure but not auditory exposure predicts EF skills in children who are DHH. These results are similar to Hall et al. (2018) who found that school-aged children who were DHH exhibited age-appropriate EF skills with early sign language exposure. However, only 10% of children are born to deaf families and can be exposed to sign languages early on; 90% of children are born to hearing families and are exposed to either oral language or sign language much later (Mitchell & Karchmer, 2004). Therefore, language exposure for those born to hearing parents may begin once they are enrolled in an early intervention program for learning either sign or spoken language. Therefore, the age at onset when entering an early intervention program may also be a potential factor. Additionally, the quality of early interactions has been suggested to be related to EF development in children who are DHH (Morgan & Dye, 2020). Early intervention may improve parents' ability to interact with their child responsively (Smith & McMurray, 2018). As discussed above, the following three factors might play a role in the development of EF in children who are DHH – language, age at language exposure, and age at early intervention.

Taken together, children who are DHH are at risk for delayed EF skills, and the delay begins as early as preschool age. The present study aims to examine EF development in preschoolers who are DHH and explore the factors related to their EF skills. The two research questions are as follows:

1) Do children who are DHH lag behind their age-matched hearing peers on the three fundamental constructs of EF?
2) What is the relationship between the three fundamental constructs of EF (inhibitory control, working memory, cognitive flexibility), language, age at hearing aid fitting, and age at early intervention?

Method

Participants

Thirty preschoolers who were DHH participated in this study. The mean age of the participants was 5 years 3 months (SD=6.69; range=4;0–6;6), with 17 boys and 13 girls. The degree of hearing loss ranged from slight to profound. All participants were enrolled in the Auditory Verbal Therapy (AVT) program and recruited from the

Table 1 The characteristics of DHH preschoolers

	Mean	Range	SD
BEPTA	50.37	6.25-106.25	25.36
Duration of HA fitting	23.47	2–62	19.44
Duration of CI fitting	29.63	8–50	13.29
Age at Enrolling in EI program	30.13	6–66	20.29
Duration of EI program	32.53	1–63	19.76

Note. BEPTA: Better ear pure tone audiometry; EI: early intervention

[blank for anonymous purpose], where they received AVT. Twenty-two children who were DHH were fitted with HAs and eight were fitted with CIs. Among the CI users, one participant was a bilateral CI user and seven participants were bimodal users, in which they were fitted with a CI in one ear and HA in the other. All the children used oral communication and were native speakers of Mandarin Chinese. None of them had any explicit additional diagnoses, such as intellectual disability or autism. The auditory and early intervention backgrounds are shown in Table 1.

An additional 35 preschoolers with typical hearing were recruited as a control group. The mean age of the preschoolers with typical hearing was 5 years 3 months (SD = 7.77; range = 4;2–6;5), with 12 boys and 23 girls. The control group was recruited from three preschools in urban areas. All of them were native speakers of Mandarin Chinese and no explicit disorders were reported by their parents.

Tasks

The three fundamental constructs of EF were assessed using six different tasks, as described below.

Inhibitory Control

The fish-shark go/no-go game and child-friendly Flanker task were used to measure two aspects of children's inhibitory control. The former measures the inhibition of action that requires children to hold back their prepotent response, whereas the latter measures the inhibition of attention that requires selective attention (Diamond, 2013; Friedman & Miyake, 2004). Although the two types of inhibitory control are correlated, we still include both types of tasks to provide a fuller picture of children's inhibitory control.

In *the fish-shark go/no-go game* (GNG; Wiebe et al., 2012), children were instructed to catch fish by pressing a button (Go trial) and avoid catching sharks by not pressing a button (No-Go trial). There were ten different kinds of fish and three different kinds of sharks. To ensure that the children could recognize the stimuli, all fish and sharks were introduced to the child prior to the main test trials. Before beginning the task, the children were instructed to press the button in eight practice trials, including four Go trials and four No-Go trials. In the test trials, there were 40 trials in total, including 30 Go and 10 No-Go trials. In each trial, the stimulus was presented for 1500 ms; however, if the child pressed the button within 1500 ms, feedback was presented immediately and lasted for 1000 ms. In the fish trial, if the child correctly pressed the button, a fish caught in the fishnet would appear on the screen as feedback. In the shark trial, if the child incorrectly pressed the button, a shark that broke through the fishnet would appear on the screen. If there were no button-press responses, no feedback was provided. A blank screen appeared following feedback or stimulus presentation if no response was provided and prior to the presentation of the next stimulus. This inter-stimulus interval appeared for 1000 ms. The fish and shark trials were presented in a fixed order. Trials with responses shorter than 200 ms were excluded from the analysis. The proportion of correct responses in the fish and shark trials was calculated to compute the sensitivity d' score. The d' score is an index reflecting the discrimination of the two types of stimuli (Macmillan & Creelman, 2004). The higher the score, the better is the discrimination. Additionally, the mean reaction time of the fish/go trial was calculated.

In the *Flanker task* (Eriksen & Eriksen, 1974; Oeri et al., 2019; Zelazo et al., 2013), fish were used instead of arrows to make the task child friendly. The children were shown five fish in a line. Children were asked to pay attention to the center fish while ignoring the other four surrounding flaking fish. The children were instructed to press the button according to the orientation of the central fish. In the congruent trial, all fish, including the center fish and the other four flanking fishes, faced the right side; thus, the correct response was pressing the right button. In the incongruent trial, the flanking fish still faced the right side, while the center fish faced the opposite side; thus, the correct response was to press the left button. The children completed four practice trials, with two congruent trials and two incongruent trials (Zelazo et al., 2013). In the practice trials, feedback was provided after the children responded. If the response was correct, a large smile appeared on the screen as feedback. If the response was incorrect, a big frowning face appeared as feedback. No feedback was provided during the test trials. The test trials contained 25 trials in total, with 16 congruent and 9 incongruent trials. The trials were presented in pseudo-random order, in which there were no consecutive incongruent trials and no more than three congruent trials in a row. In each trial, a fixation priming the position of the center target fish was presented for 500 ms. Then, four flanking fish were presented for 100 ms. Finally, the center target fish was presented together with the four flanking fish for 10000 ms or until the child pressed the button. A blank screen of the inter-stimuli interval was presented prior to the next trial for 800 ms. We calculated the proportion of correct responses in congruent and incongruent trials to compute the sensitivity d' score. Additionally, the mean reaction times for correct responses in the incongruent trials were calculated.

Working Memory

Two tasks were used to measure children's verbal and non-verbal working memory: digit span and Corsi block-tapping tasks, respectively.

The *digit span forward* and *backward* subtests from the Wechsler Intelligence Scale for Children, Fourth Edition were used to measure children's verbal working memory. In the task, children verbally repeated a sequence of spoken digits in either forward or backward order. There were two trials per length, each with two to eight digits. The task was terminated if the child failed to reproduce two sequences of the same digit length. The children's digit span was recorded as the longest sequence that they could reproduce.

A computerized version of the *Corsi block-tapping task* (Kessel et al., 2000) was used to assess children's visuospatial working memory using the Psychology Experiment Building Language (PEBL) software (Mueller, 2013). In this task, children were presented with nine squares on the screen, and two to nine squares would light up in a sequence. Children were required to tap on the screen in the correct sequential order. Following Kessels et al., (2000), there were two trials per length with two to nine blocks. The test was terminated if the children failed to recall two sequences of equal lengths in a row. Only a completely and correctly repeated tapping sequence was scored as correct. Children's memory span was scored as the longest length for which at least one sequence was correct. Three practice trials were conducted before the actual task.

Cognitive Flexibility

The *Dimensional Change Card Sort* (DCCS; Zelazo 2006) task was used to measure children's cognitive flexibility. In the task, children were shown two boxes with pictures on them (e.g., red car and blue bear) and were asked to sort target cards such as red and blue cars according to one dimension: color or shape. Both standard and border versions of the DCCS designed by Zelazo (2006) were used. The standard version has two phases. In the first phase, the children were asked to sort the cards based on color. If children sorted the cards correctly in five out of six trials in the first phase, they would proceed to the second phase. In the second phase, they sorted the same set of cards based on their shapes. In the second phase, if children sorted the cards correctly and consecutively in five out of six trials, they were considered to pass the task and would proceed to the border version immediately. Otherwise, they were scored zero. In the border version, children were asked to sort the same set of cards as in the standard version, except that half of the cards had a black border around them. The sorting rule for the border version was that when the card had a black border, children needed to sort the cards based on shape. If the card had no black border, the children needed to sort based on color. There were 12 trials of which 6 were with bordered and 6 without bordered cards. The bordered and non-bordered cards were presented pseudo-randomly, in which the same type of cards appeared in no more than two consecutive trials. Children needed to sort the cards correctly in 9 out of 12 trials to pass the border version. Children scored one if they passed the standard version and two if they passed the border version; otherwise, they scored zero.

All the EF tasks were administered on a laptop with a touch screen, allowing children to respond by touching the screen rather than verbally telling the experimenter their answer or using a child-unfriendly mouse. Except for the verbal digit span task, which was presented orally by the experimenters without any visual aids, the experiments were conducted using OpenSesame (Mathôt et al., 2012) and/or PEBL (Mueller, 2013).

Language

The *Receptive and Expressive Vocabulary Test* (Huang et al., 2011) was used to measure children's language ability. The children were presented with a booklet containing pictures. The child was asked to point to pictures corresponding to the test questions when assessing language comprehension. Each child was presented with pictures in a booklet to elicit language production. The language comprehension, language production, and composite language scores were calculated.

Procedures

All parents and/or guardians of the participants signed a written informed consent form before participation. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments. The study was approved by the Chang Gung Medical Foundation Institutional Review Board, Taiwan (No. 201800297B0). The children who were DHH were tested in a quiet classroom at the Children's Hearing Foundation. Children with typical hearing abilities were tested in a quiet room at their respective preschools. All children completed EF tasks in one session and language assessments in another separate session. However, due to the pandemic outbreak, five of the children could not attend the second session and thus did not complete the language assessment.

Statistical Analysis

To address the first research question, children's performance on each EF task was compared between children who were DHH and children with typical hearing. The normality of the variables was examined using the Shapiro-Wilk test. Since all variables were not normally distributed, non-parametric statistical analyses were performed. Mann–Whitney U tests were conducted to compare the differences between children who were DHH and those with typical hearing in the performances of inhibitory control and working memory tasks. Chi-square tests were used to compare group differences in cognitive flexibility. The second research question was examined using Pearson's correlation and partial correlation to explore the relationship between the three EF fundamental constructs and other variables in children who were DHH.

Results

Comparison on EF Tasks Between Preschoolers who were DHH and Those with Typical Hearing

A comparison between preschoolers who were DHH and those with typical hearing yielded different results among the three fundamental constructs of EF. Mean scores of each task is demonstrated in Table 2. Regarding inhibitory control, the two tasks yielded different results. In the GNG task, children who were DHH were significantly less sensitive to the two types of trials compared to children with typical hearing (GNG d': $U=372.50$, $p<.05$). Regarding the reaction time for the go trials, no significant differences were found between the two groups ($U=486.00$, $p>.05$). In the Flanker task, no significant differences were found between the two groups in terms

Table 2 Mean scores and standard deviations on EF tasks of children who are DHH and typical hearing

		DHH (N=30)		Typical hearing (N=35)	
		M	SD	M	SD
Inhibitory Control	Go RT	943.01	170.81	935.63	177.63
	GNG d'	2.71	0.76	3.08	0.57
	Flanker Incongruent RT	1905.95	1052.95	1569.74	816.56
	Flanker d'	2.71	1.22	3.00	0.70
Working Memory	Corsi block span size	3.23	1.07	3.74	1.15
	Forward Span size	6.13	1.22	6.23	1.14
	Backward Span size	2.00	1.17	2.17	1.12
Cognitive Flexibility	DCCS score	0.77	0.73	1.37	0.77

of their sensitivity toward the two types of trials, the congruent and incongruent trials (Flanker d': $U=472.00$, $p>.05$). Similarly, no significant differences were found between the two groups in their reaction times in the incongruent trials ($U=432.00$, $p>.05$).

With respect to working memory, there were no significant differences between the two groups in the verbal working memory task for both the forward ($U=491.50$, $p>.05$) and backward ($U=473.00$, $p>.05$) digit spans. Nevertheless, a marginal difference was found in visual-spatial working memory, indicating that children who are DHH may not have an advantage over children with typical hearing ($U=385.50$, $p=.057$).

Lastly, in the cognitive flexibility task, which is the DCCS, children with typical hearing outperformed children who were DHH ($\chi^2=10.23$, $p<.01$). The number of children who passed the standard and border versions was further examined. The results revealed that children who were DHH found it difficult to complete the standard version. Twelve children who were DHH failed to correctly sort in the second phase of the standard version, that is, they were unable to switch to sorting based on the second dimension.

Relationship Among EF, Language, and Other Background Factors

Since we recruited children with a wide age range, we first examined whether age was interrelated with language and EF performance. As expected, age was significantly related to the composite language score ($r=-.45$, $p<.05$). Regarding EF skills, age was either significantly or marginally related to inhibitory control and working memory, including GNG d' ($r=.31$, $p<.05$), Flanker d' ($r=.29$, $p=.060$), Corsi block span size ($r=.37$, $p<.05$), and backward digit span size ($r=.31$, $p<.05$), except for cognitive flexibility measured by the DCCS.

To eliminate the effect of age on the relationship between EF, language, and other background factors, a partial correlation was carried out while controlling for age. As shown in Table 3, the composite language score was significantly related

Table 3 Partial correlation among EF, language and background factors whilst controlling for age

	1	2	3	4	5	6	7	8	9	10	11
1. BEPTA	-										
2. HA age	−0.32†										
3. EI age	−0.28	0.97***									
4. Composite language score	0.00	0.22	0.20								
5. DCCS score	0.30	0.04	0.08	−0.06							
6. Go RT	−0.10	−0.32	−0.25	−0.33†	−0.03						
7. GNG d'	0.24	−0.16	−0.14	0.15	0.00	−0.39*					
8. Flanker Incongruent RT	−0.31	−0.06	−0.10	−0.46*	−0.03	0.39*	−0.06				
9. Flanker d	0.18	−0.50**	−0.52**	0.06	0.13	−0.07	0.40*	−0.08			
10. Corsi block span	0.15	−0.03	−0.08	0.22	0.20	−0.39*	0.33†	−0.35†	0.25		
11. Forward Span size	−0.28	0.14	0.15	0.13	0.17	−0.07	0.02	−0.12	0.35†	0.44*	
12. Backward Span size	0.00	0.13	0.05	0.45*	0.06	−0.55**	0.03	−0.44*	0.11	0.44*	0.44*

*<0.05, **<0.01, ***<0.001, † marginal significances (p-value between 0.05 ~ 0.07)

to the backward span ($r = .45$, $p < .05$). The results showed that children's language performance is significantly related to backward digit span size only, not to visual working memory measured by the Corsi block or verbal forward digit span size. Interestingly, the composite language score was also negatively related to reaction time in inhibitory tasks. The relation was either marginally similar to Go reaction time ($r = -.33$, $p = .064$) or significantly similar to Flanker incongruent reaction time ($r = -.46$, $p < .05$), indicating that better language ability resulted in faster reactions in the inhibitory control tasks.

With respect to the other background factors, no significant relationship was found between BEPTA and EF performance. HA fitting age and EI age were both significantly related to children's sensitivity in making judgements on the Flanker task as indicated by the d' score (HA age: $r = -.50$, $p < .01$; EI age: $r = -.52$, $p < .01$). The earlier the HA was fitted and earlier children entered the early intervention program, the better their sensitivity in the Flanker task. This relationship still existed after controlling for the composite language score. Marginal significance was found between the Flanker d' score and HA age ($r = -.32$, $p = .068$) and EI age ($r = -.33$, $p = .063$). Thus, the results indicated that early auditory exposure and early intervention programs may lead to better inhibitory control in preschoolers who are DHH. It is also worth noting that HA age and EI age were positively and significantly related ($r = .97$, $p < .001$).

Discussion

The goal of the present study was to understand the development of EF in children who are DHH and explore the relationship between EF, language, age at HA fitting, and age at early intervention. Unlike the two recent studies that found that preschoolers who were DHH were not delayed in terms of risk ratio (Goodwin et al., 2022) or away from the norm scale (Nicastri et al., 2021), our results showed mixed results among the three fundamental constructs of EF, in that preschoolers with hearing loss were delayed in some EF skills, but not all. We discuss the development of each EF construct and its potential relationships with other variables below.

Our results revealed that ***cognitive flexibility*** in children who are DHH is delayed compared with that in children with typical hearing, which is consistent with previous studies. Other than Goodwin et al., (2022) and Nicastri et al. (2021), all other studies that measured cognitive flexibility found delayed EF in preschool- (Liu et al., 2018) and school-aged (Botting et al., 2017; Jones et al., 2020; Figueras et al., 2008) children. Liu et al., (2018) demonstrated that children who are DHH at preschool age have delayed cognitive flexibility. They also found a strong relationship between cognitive flexibility and language performance. Nevertheless, the present study did not reveal any variables that were significantly related to the cognitive flexibility of children who were DHH, which may require further examination. In the present study, children who were DHH were mostly stuck when they were asked to switch to the new sorting dimension, that is, they still sorted the cards based on the previous dimension and were not able to proceed to the more advanced border version. One potential reason might be that children may not pay attention to listening to the new rule; thus, after observing this phenomenon, the examiner asked a few children who were DHH to repeat the rule before beginning the new sorting phase. Although these children could correctly repeat the rules verbally, they still sorted the cards based on the old rule. Another reason might be related to the developmental trajectory of EF skills. Cognitive flexibility is an EF construct that emerges late (Muller & Kerns, 2015) as it is assumed to require some level of working memory and inhibitory control; thus, it is considered the most difficult of the three fundamental constructs.

In terms of ***working memory***, children who were DHH exhibited age-appropriate performance in verbal working memory. Children with typical hearing tended to outperform children who were DHH in visual-spatial working memory tasks. According to the sensory compensation hypothesis, we tend to assume that individuals who are DHH have better visual abilities than their typically hearing peers, such as visual-spatial working memory; however, many studies have shown that individuals who are DHH often perform no better and sometimes even worse when compared with their typically hearing peers (Marschark et al., 2017b).Thus, those who are DHH do not have an advantage in visual-spatial working memory and may even have delayed visual-spatial working memory (Botting et al., 2017; Jones et al., 2020; Hall et al., 2018). As shown in the current study as well as in Beer et al. (2014), children who are DHH, even as young as in their preschool age, may not have an advantage over their hearing peers. Children who are DHH show a tendency toward worse performance compared to their hearing peers. One potential reason might be that the rules of the task, such as the Corsi block tapping task, may be relatively difficult to understand and require more advanced verbal language ability to follow. Some children tapped on the blocks immediately without waiting for the trial demonstration to finish, and some of them were not able to follow the rule correctly in the practice trials.

Verbal working memory, on the other hand, is expected to be delayed, as shown in Kronenberger et al., (2014), since this ability is highly related to children's language ability, in which the language of those who are DHH tends to be delayed. In contrast to previous findings, our results revealed that the children exhibited age-appropriate verbal working memory. Both forward and backward digit spans were not delayed. One potential reason for this might be their training in early intervention programs. As in the early intervention program, children are often engaged in activities that require holding verbal information in mind and acting out later. However, the correlational analyses did not reveal a significant relationship between age at enrollment in the early intervention program. Another potential reason might be that the differences between children who are DHH and their hearing peers may not be revealed in behavioral tasks. Heinrichs-Graham et al. (2021) showed that those who were DHH and their hearing peers did not exhibit different performances in behavioral tasks. While executing the verbal working memory task, those who are DHH have different neural processing activities, in that they utilize different brain regions during verbal working memory tasks. This difference in brain regions may also be related to language function. Indeed, language is significantly related to backward digit span. Diamond (2013) suggested that only backward digit span tests real working memory, in that the task requires children to hold information and utilize it later. Although our results did not find significant differences in verbal working memory between children who were DHH and their typically hearing peers, language still played a role in verbal working memory.

However, ***inhibitory control*** yielded mixed results. Children who were DHH were only delayed in their ability to inhibit their prepotent action, as measured by the GNG task, but not selective attention, as measured by the Flanker task. This result partially replicates that of Beer et al. (2014), who also found that inhibitory control was delayed in those who were DHH. Our results provide further evidence that not all types of inhibitory control are delayed. Interestingly, the correlation analyses in the present study revealed that inhibitory control in children who were DHH is related to their age at HA fitting and age at early intervention, although this is only limited to selective attention in inhibitory control. Goodwin et al. (2022) argued that the age of language exposure cannot predict inhibitory control. However, the age of language exposure in Goodwin et al. (2022) was identified in hearing and native-signing children, who were exposed to language from birth. This was not identical to the age of language exposure in our study, which was at the beginning of the early intervention program.

Note that EI age and HA age are significantly related. The earlier they were fitted with HAs, the earlier the children enrolled in the early intervention program. In the early intervention program, children who are DHH are often trained to follow classroom rules and pay attention to the task they are working on; thus, they may be trained in terms of inhibitory control. Additionally, it has been suggested that EF might be related to children's inner speech, and children before seven years of age would be able to speak out loud their inner speech (Kray et al., 2004). Interestingly, when taking the EF task, some children indeed speak out loud to remind themselves. For example, in the GNG task, some children would read "fish" when they saw fish on the screen and "shark" when they saw sharks to remind themselves that they should not react when sharks appeared on the screen. This verbal reminder works well for these children, and the results revealed a significant relationship between language and the reaction time of their responses, which might be supporting evidence showing that language plays a role in inhibitory control, and language might speed up their inhibitory control. Indeed, verbal prompts help children perform better on EF tasks (Kray et al., 2004; Wallace et al., 2017). Prior studies have also shown that children with better inhibitory control skills may be able to come up with adequate sentence representations and inhibit inappropriate expressions (Gandolfi & Viterbori, 2020; Ye & Zhou, 2009). Our results revealed a significant negative correlation between reaction times in inhibitory control tasks and composite language scores. Reaction time reflects the latency of inhibitory control, which is the cognitive effort required in inhibitory control (Faja & Nelson, 2019; Fishburn et al., 2019). Some researchers even suggest that shorter reaction times indicate better inhibitory control (Montgomery et al., 2022). Our results demonstrate significant relationship between language and reaction times in inhibitory control tasks. This suggests that when children require less effort to inhibit their prepotent behavior, they may also require less effort to inhibit inappropriate language expressions, resulting in better language skills.

Limitations

The present study has some limitations. First, the number of participants was relatively small; thus, only limited statistical analyses could be conducted. Other large-scale studies could analyze their data using regression to conduct mediation analyses, which may provide a better picture and stronger evidence to support the role of early auditory exposure, early intervention, and language in EF development. Second, the cross-sectional design in the present study limited us to predicting the direction of the impact of the variables on EF constructs. For the above two reasons, the present study can only provide correlational results.

Conclusion

Preschoolers who are DHH are delayed in some EF skills, particularly inhibitory control and cognitive flexibility. Interestingly, in working memory, they exhibit age-appropriate verbal working memory, whereas they do not have an advantage over their hearing peers in visual-spatial working memory. Correlational results revealed that although language is related to working memory, it is not related to the other two EF skills. More importantly, inhibitory control is related to the age of auditory exposure and early intervention. Thus, the results highlight the importance of early auditory exposure and early intervention, as well as language, in EF development in preschoolers who are DHH.

Declarations

Disclosure of Potential Conflicts of Interest The authors report no declarations of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments. The study was approved by the Chang Gung Medical Foundation Institutional Review Board, Taiwan (No. 201800297B0).

Informed Consent Written informed consent was obtained from the parents and/or guardians of the participants.

Research Data Statement The data that support the findings of this study are available on request from the corresponding author C.-Y. Chu. The data are not publicly available due to them containing information that could compromise research participant consent.

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