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Comparing Behavioral and Parent-Report Measures of Executive Functioning in Deaf and Typically Hearing Children

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Table of Contents

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Abstract

Executive functioning (EF) is a multidimensional aspect of development that encompasses various mental skills. Children's utilization of inhibition, in particular, has proven to be one of the most important determinants of academic success. How deafness in children impacts their EF abilities is a question that remains divisive within deaf studies. Some suggest that auditory deprivation is a direct cause of poor EF, while others posit reduced or insufficient language experience that deaf children live with harms their EF development. We sought to explore this question further with a participant sample from our larger SLaM (Study of Language and Math) project. A total of 88 participants consisting of deaf/hard-of-hearing (DHH) (n = 67) and typically hearing participants (n = 21) ages 3;1-7;6 were divided into separate language timing (Early vs. Later) and language modality (ASL vs. English) groups. Scores on a behavioral, non-standardized measure of EF (Opposites task) and a standardized parental report measure (BRIEF-P: Behavior Rating Inventory of Executive Function - Preschool) were compared separately across timing and modality groups. Additionally, potential relationships between these measurements of EF were explored. We found that earlier access to language positively impacts EF abilities on the BRIEF-P only. When language modality was considered alone, it had no apparent influence on EF abilities for either of the two tasks. Our results corroborate previous findings suggesting that behavioral non-standardized measures and standardized measures of EF do not significantly correlate with one another (Beer, Kronenberger, Castellanos, Colson, Henning, and Pisoni, 2014).

Introduction

Executive Functioning (EF)

Executive functioning (EF) encompasses a spectrum of skills and abilities that are necessary to accomplish a wide variety of tasks. Some of these skills include inhibition, cognitive flexibility, planning, goal-directed behavior, utilizing working memory, and utilizing new responses (Henry, Messer, and Nash, 2012). EF consists of mental processes used to direct thought and behavior that are necessary for children's development and success in school. EF is also essential to social functioning or aiding children in their ability to manage challenging social situations that require them to regulate their emotions, inhibit hasty actions, and comply with school rules and guidelines. Development of EF skills early in life is certainly a predictor for school readiness but has also shown to be a predictor of later academic success, such as preparedness for the transition into middle school (Hunter & Sparrow, 2012).

Ties Between Executive Functioning and Language Experience in Early Childhood

Research on inhibition, in particular, has demonstrated that it provides the strongest contribution to math abilities. Inhibition is a mental skill that requires self-regulation or engaging in internal controls to restrain and monitor certain actions and behaviors. Inhibition, effortful control, and nonverbal problem-solving skills are known for predicting achievement in mathematics in kindergarten and beyond. Spatial working memory has shown to be associated with children's early counting ability and math achievement as late as middle school. These processes are directly tied to the functional connectivity of multiple underlying brain systems used for language processing, perception, and production (Hunter & Sparrow, 2012). Marschark, Pisoni, Conway, Kronenberger, Henning, and Anaya (2012) argue that these EF processes contribute to variance observed in populations with regard to speech and language outcomes beyond conventional demographic, medical, and educational factors. Additionally, they found that several domain-general neurocognitive processes related to EF and cognitive control processes, including working memory and inhibition, are strongly associated with language outcome measures.

Hypotheses about Language Experience and Executive Functioning

This association between EF and language provides a potential explanation for why people with lower language abilities/delayed language exposure (also known as "language deprivation") display EF deficits. Both timing and quality of language access during the critical period of language acquisition are essential for healthy brain development (Hall, Levin, and Anderson, 2017). Many deaf and hard-of-hearing (DHH) individuals have experienced language deprivation and deaf children perform poorly on tasks that require EF. In other words, underdevelopment of language in deaf children could be negatively impacting their EF skills, as language is positively correlated with EF in both deaf and hearing children (Beer et al., 2014; Figueras, Edwards, and Langdon, 2008; Henry et al., 2012). Previous research has demonstrated that DHH children tend to perform poorly on tasks requiring EF and fall behind their hearing peers. A 2014 study found that deficiencies in EF in older children with CIs (cochlear implantations) begin to develop as early as preschool years. This longitudinal study involved 24 preschoolers who received CIs before 36 months of age and 21 preschoolers with normal hearing. Children were tested on normed measures of working memory, inhibition-concentration, and organization-integration, and parents completed the BRIEF-P, which is a normed parent-report measure of children's behaviors. The study demonstrated that preschoolers with CIs showed significantly poorer performance on tasks requiring inhibition-concentration and working memory than their peers with normal hearing. Interestingly, although parents reported more difficulty in daily circumstances utilizing working memory and planning/organizing skills, it was not significantly correlated with behaviorally-based performance measures of executive functioning (Beer et al., 2014).

Literature is divided on whether or not there is a direct, causal relationship between auditory deprivation and EF abilities. Auditory deprivation refers to the specific lack of auditory input that occurs with deafness, while language deprivation refers to the lack of linguistic input that deaf children often face during their formative early childhood years. Proponents of this hypothesis suggest that hearing provides necessary exposure to serially ordered events and because sound is a temporal and sequential signal, it provides a "scaffolding" or supporting framework that humans use to interpret and process sequential information (Conway, Pisoni, and Kronenberger, 2009).

The language deprivation hypothesis claims that exposure, access, and reinforcement of language are all important to EF. A number of researchers argue that deafness may not be a direct cause of poor EF in children, but that language deprivation may contribute to a lack of EF skills. In other words, the lack of EF in deaf children may result as a secondary consequence of hearing loss. This hypothesis is supported by research that has found data to be entirely consistent with the idea that early access to language is crucial to the development of EF abilities (Botting et al., 2017; Figueras et al., 2008; Hall, Eigsti, Bortfeld, and Lillo-Martin, 2018). These researchers argue that there is no strong evidence to suggest that auditory development alone has a detrimental effect on EF development.

The lack of clarity on how language acquisition impacts EF can be attributed to multiple factors. Firstly, the developmental trajectory of EF has historically been difficult to measure due to the complex nature and brain processes behind it. Kalback (2004) claims that neuropsychological perspectives on the executive system have focused on specific behavior "localization" which has led to an impairment-focused theory. This impairment-focused theory has allowed neuropsychologists to view and assess the operation of the executive system as a developmental construct. It must be noted that despite the fact that the executive system operates mainly from the frontal lobes of the human cortex, it works in association with other areas of the cortex. This gives rise to the complex nature of EF and the resulting difficulties in studying this construct.

There are also clear research deficits in studying how language acquisition impacts EF in deaf and hard-of-hearing children. These deficits can be attributed to the fact that there is a substantial variation in language instruction that deaf children receive. The vast majority of deaf children have hearing parents as opposed to deaf parents and may receive very little American Sign Language (ASL) instruction (Kalback, 2004). In addition, there are methodological limitations that create challenges in reaching conclusions on EF and language data. Some studies rely only on questionnaire data or one or two experimental tasks. Analyses are also limited by smaller sample sizes. The hearing status of parents is sometimes not reported despite it having an impact on children's performance when children of deaf parents perform better on tasks (Botting et al., 2017). Despite these barriers, it must be noted that being born deaf is not necessarily a direct cause of language impairment. However, exposure to these environmental and physiological impediments, means that deaf children are at higher risk for language difficulties than typically hearing children (Kalback, 2004).

Study of Language and Math (SLaM)

SLaM Project 1 Hypotheses & Results

Project 1 of the SLaM study investigated how language impacts children's development of number concepts. The study concluded that the timing of language exposure provides the foundation for basic number concepts. Carrigan, Shusterman, and Coppola (in preparation) argue that early access to language input drives number knowledge development. Access to either signed or spoken language from birth supports number knowledge development, whereas children with later access to language show variable, and in general, worse number concepts. Quality and quantity of discussion on number-related topics are what contribute to mathematical development in children. The majority of deaf children have hearing parents and typically do not have language access until later, but deafness itself does not delay number knowledge development (Carrigan et al., in preparation).

Assessments of EF in SLaM Project 1

Behavioral Measure (Opposites Task).

The Opposites task is a congruent-incongruent cognitive flexibility task developed by Prof. Anna Shusterman of Wesleyan University, that utilizes two handheld puppets (elephant, alligator) to test a child's ability to switch between rules when prompted to press either the same or opposite button. This task was used in Project 1 of SLaM because it is a baseline measure of EF and, given that EF is essential to achieving in a variety of mental tasks, performance on this task could provide insight into why participants may have under-performed on other tasks. The task is administered in three phases. In the first phase (elephant trials), the child was instructed to press the same button that an experimenter presses using an elephant puppet for a total of four test trials. In the second phase (alligator trials), the experimenter pressed a button using an alligator puppet and the child was instructed to press the opposite button that the experimenter did not press for another four test trials. In the final phase, mixed trials using both the elephant and alligator puppets were administered to the child for twelve test trials. The Opposites task measures two different components of inhibition. The first phase primarily tests working memory since the child is expected to press the same button the experimenter presses. The second phase primarily tests the child's ability to inhibit the first rule they learned, or task switching, as they are prompted to press the opposite button that the experimenter does not press. Finally, these two components are tested together in the mixed-trials phase (Leonard, Berkowitz, and Shusterman, 2014). Although this task is not standardized, its simple instructions and administration make it particularly useful for testing on both hearing and DHH children.

Parent-Report Measure (Behavior Rating Inventory of Executive Function - Preschool (BRIEF-P)).

The Behavior Rating Inventory of Executive Functioning-Preschool (BRIEF-P) is a standardized parent-report questionnaire developed by Gioia, Espy, and Isquith (2003) that is commonly used to assess EF and EF-related problems in behavior in preschool-aged children. During Project 1 of SLaM, the BRIEF-P was administered to parents to complete prior to testing or on-site during testing. The BRIEF-P consists of 63 questions that ask parents various questions about their child's behaviors from 6 months prior to the administration date. Questions range from asking about how often the overreacts to small problems to how often the child is aware when he/she performs a task right or wrong. These questions are arranged into five clinical scales or subscales that measure different sides of EF: Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize. These subscales form the three broader indexes of Inhibitory Self-Control (ISCI), Flexibility (FI), Emergent Metacognition (EMI), and an overall composite score called the Global Executive Composite (GEC). The ISCI index is composed of the Inhibit and Emotional Control scales, the FI is composed of the Shift and Emotional Control scales, and the EMI is composed of the Working Memory and Plan/Organize scales.

The BRIEF-P also includes two validity scales, the Inconsistency and Negativity scales, as indications of undermined validity in a child's results. The Inconsistency scale determines the extent to which the respondent answers similar BRIEF-P questions in an inconsistent manner. The Negativity scale determines the extent to which the respondent answers selected BRIEF-P items in an atypically negative pattern. These validity scales are reviewed prior to interpretation of the BRIEF-P since they are indicators of compromised validity. The BRIEF-P is a well-received and widely peer-reviewed standardized measure of EF. According to the BRIEF-P White Paper, more than 1,300 studies published in peer-review journals have mentioned or utilized the BRIEF-P assessments. The BRIEF-P is known for providing reliable results with valid interpretations in individuals with a variety of clinical conditions across different age groups. It is an extremely useful tool in determining whether or not a child is at risk of developing behavioral issues (Greene, Trujillo, Isquith, Gioia, and Espy, 2019).

Hypotheses

The clarification of the nature of the relationship between deafness and performance on measures of EF has become an increasingly important research question. Are deaf children performing worse on measures of EF than hearing children because of early language deprivation or because of auditory deprivation? We advocate for the language deprivation theory, based on conclusions made by Hall et al. (2018), and we hypothesize that the timing of language access, not language modality, impacts EF abilities. Furthermore, are behavioral (non-standardized) and parent-report (standardized) measures related to each other well enough to provide explanatory answers to this question? We examined these two different measures of EF, the Opposites task and BRIEF-P surveys, from Project 1 of SLaM and compared their relationship in assessing EF in hearing and deaf children who learned ASL at birth, ASL later in development, English at birth, and English later in development. Participants will be sorted into groups separated based on timing and language modality. These four groups are named the Early, Later, ASL, and English groups, and analyses were done comparatively for timing groups (Early and Later) and comparatively for modality (ASL and English) groups.

The relationship between the BRIEF-P GEC score and subscales were compared to two types of scores from the Opposites task. The first score is the total Opposites score consisting of the percentage of trials correct out of 20 total trials. The second score is an Opposites Inhibition score, which we also refer to as the Inhibition subscale, consisting of the percentage of alligator trials and mixed trials correct out of 16 total trials. We hypothesized that 1) language modality would have no effect on the Opposites scores or GEC scores for all groups. However, we anticipated that 2) the timing of language access would have an effect on the Opposites scores and GEC scores. Specifically, we expected that the Early group would have higher total Opposites scores (meaning better performance) and lower GEC scores (meaning elevated risk for behavioral issues) than the Later group.

For all groups, we expected 3) negative correlations between GEC and the total Opposites scores, such that higher scores (meaning elevated risk for behavioral issues) on the GEC scores of the BRIEF-P would correlate with lower scores (meaning poorer performance) on the Opposites task and vice versa.

Since the total Opposites score includes the elephant/working memory trials and the alligator/inhibition trials, for the total Opposites scores and the five BRIEF-P subscales, we expected that 4) there would be negative correlations for all groups between the total Opposites score and Working Memory, Inhibit, and Shift subscales. We did not expect any relationships to be found between the Opposites task and other subscales.

For all groups, we expected 4) negative correlations between the GEC score and Inhibition trials of the Opposites task, such that higher scores (meaning elevated risk for behavioral issues) on the GEC scores of the BRIEF-P would correlate with lower scores (meaning poorer performance) on the Inhibition score and vice versa. Lastly, since the Inhibition score includes the alligator/inhibition trials, we expected that 5) there would be negative correlations for all groups between the Inhibition scores and Working Memory, Inhibit, and Shift subscales. We expected that no additional relationships would be found between the Inhibition scores and the other subscales.

Methods

Participants and Recruitment

The participants in the study were 88 children from ages 3;1-7;6 (years; months) with 53 females and 35 males. Participants were distributed into four groups based on language modality (ASL vs. English) and timing of language access (Early vs. Later). Children in the English Early group were typically hearing, and their parents used spoken English with them from birth (n = 21). Children in the ASL Early group were deaf or hard of hearing and each had at least one deaf parent who used ASL with them from birth (n = 21). Children in later groups did not have complete access to language immediately after birth. The ASL Later group included deaf children with hearing parents who attended signing schools; all had exposure to printed English, and many also had some access to spoken English via assistive technologies (ASL Later) (n = 19). The Later English group consisted of deaf or hard of hearing children with cochlear implants or hearing aids who attended educational programs that were focused on producing and comprehending spoken English; very few had experience with ASL (English Later) (n = 27).

The ASL Early and English Early children formed the Early group (n = 42) and the ASL Later and English Later children formed the Later group (n = 46). The ASL Early and ASL Later children formed the ASL group (n = 40) and the English Early and English Later children formed the English group (n = 48). Only participants who completed the Opposites task (scored at least 75% on the practice trials) and had completed BRIEF-P forms from Project 1 were included in the study. The BRIEF-P is normed for ages 3;0-5;11 and a total of 24 participants included in the study were too old for the BRIEF-P form. This was due to tracking error; some parents received incorrect forms during Project 1 data collection. Despite this, we decided to include these participants since 19 of them were ages 6;0-6;7 and thus were not exceedingly older than children who were 5;11. Two participants who did not meet the inclusion criteria were excluded. One ASL Early participant was excluded due to experimenter feedback on the mixed trials. Another English Early participant was excluded who refused to complete the mixed trials.

Measures

Opposites Task (Leonard et al., 2014).

This task utilizes two handheld toy puppets (elephant, 23 x 14 cm, and alligator, 22 x 15 cm) and two large tap light buttons to assess children's ability to effectively understand and switch between rules (Figure 1). The tap light buttons (with diameters of 20 cm each) sat on a base of stiff white foam board.

Figure 1. Opposites task materials. A display of the materials used in the task: an alligator puppet, an elephant puppet, and two tap lights attached to a rigid, rectangular foam board base that were used as "buttons".

BRIEF-P (Gioia et al., 2003).

Overview. The BRIEF-P is a 63-question parent-report questionnaire that asks parents questions about their children's everyday behavior over the past 6 months. The form starts with the question, "During the past 6 months, how often has each of the following behaviors been a *problem*?". This was followed by statements such as, "When given two things to do, only remember the first or last" and "Has outburst for little reason". Parents then chose "never", "sometimes", or "always" for each question. The 63 questions on the survey are organized into five subscales: Inhibit, Shift, Emotional Control (EC), Working Memory (WM), Plan/Organize (PO). BRIEF-P scores are used for the interpretation of a child's EF based on these behaviors using normative data.

Scoring. Scores are divided into the five subscales and three broad indexes. The three broad indices are Inhibitory Self-Control (ISCI), Flexibility (FI), and Emergent Metacognition (EMI) which combine together to form the Global Executive Composite (GEC) score. ISCI is composed of Inhibit and EC raw scores, FI is composed of Shift and EC scores, and EMI is composed of WM and PO raw scores. Raw scores on the subscales are converted to standardized *T* scores utilized to represent behavioral impairments, with higher scores indicating greater impairments (Figure 2).

Two validity scales, the Inconsistency and Negativity scales, are also included. The Inconsistency scale indicates the degree to which a respondent answers similar BRIEF-P questions in an inconsistent manner. The Negativity scale measures the extent to which a selection of a respondent's answers BRIEF-P questions in an unusually negative manner. Children with overly negative or inconsistent scores on these scales are excluded (Figure 2). (Greene et al., 2019).

Table 1
Description of the BRIEF-P Scales

Scale/index	*N* of items	Description
Clinical scale/index		
Inhibit	16	Controls impulses and behavior; appropriately stops and modulates own behavior at the proper time or in the proper context
Shift	10	Moves freely from one situation, activity, or aspect of a problem to another as the situation demands; makes transitions; solves problems flexibly
Emotional Control	10	Modulates emotional responses appropriately to situational demand or context
Working Memory	17	Holds information in mind for the purpose of completing a task or making the appropriate response; stays with, or sticks to, an activity
Plan/Organize	10	Anticipates future events or consequences; uses goals or instructions to guide behavior in context; develops or implements appropriate steps ahead of time to carry out an associated task or action
Inhibitory Self-Control Index (ISCI)	26	Composed of the Inhibit and Emotional Control scales
Flexibility Index (FI)	20	Composed of the Shift and Emotional Control scales
Emergent Metacognition Index (EMI)	27	Composed of the Working Memory and Plan/Organize scales
Global Executive Composite (GEC)	63	Composed of all clinical scales (Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize)
Validity scales		
Inconsistency	10 pairs	Indicates the extent to which the respondent answers similar BRIEF-P items in an inconsistent manner
Negativity	10	Measures the extent to which the respondent answers selected BRIEF-P items in an unusually negative manner

Figure 2. Table from the BRIEF-P White Paper (Greene et al., 2019) with descriptions of scales/indexes and the number of items.

Procedure

Opposites.

Two experimenters sat across from the child and the two tap light buttons (Figure 2). One experimenter, referred to as the facilitator, demonstrated the task by pressing the buttons with the elephant and/or alligator puppet. Another experimenter provided instructions in the child's preferred language, either ASL or spoken English. Instructions were provided by a deaf, fluent ASL user for children who preferred ASL or by a native English speaker for children who preferred English.

Figure 2. Opposites task experimental set-up. A deaf, native signing child, age 4;2, pressed a button during the alligator-only phase. The experimenter (middle) tasked with providing instructions to the child sat next to the child. The facilitator (right), tasked with pressing the buttons, sat across from the child holding the alligator puppet. Both the experimenter and facilitator were deaf, fluent ASL users.

The Opposites task was conducted in three phases (see schematic in Figure 3). In the first phase, the elephant puppet was used to press either the left or right button and the child is instructed to "press the *same* button" or "press the button that the elephant *did* press". In the second phase, the alligator puppet was used to press either the left or right button and the child was instructed to "press the *other* button" or "press the button that the alligator *did not* press". These two phases began with demonstration trials, where the facilitator pressed the buttons and the experimenter, playing the role of the child, demonstrated the correct responses. Two feedback trials were conducted afterward where the child provided responses and the facilitator provided feedback on whether the child had pressed the appropriate button. These feedback trials were occasionally repeated until the child responded correctly for both the left and right trials and demonstrated their understanding of the rules for the task. After the feedback trials, four test trials occurred for the first two phases. No feedback from the experimenters was given to the child once the test trials occurred. In the third phase of the task, the experimenters repeated the rules for each puppet to the child and conducted two demonstration trials, but no feedback trials occurred for this phase. The final phase consisted of twelve mixed test trials and both puppets were used to press the buttons in a fixed order. The entire task was videotaped.

Responses for Opposites were coded from participant videos into Excel. If the task was administered in ASL, a proficient ASL user coded the task. If it was administered in English, a native English speaker coded the task. Responses were assigned scores of “0” for incorrect, “1” for correct, or “N/A” for no response. If the child responded more than once or changed their response, only the final response was used in calculations.

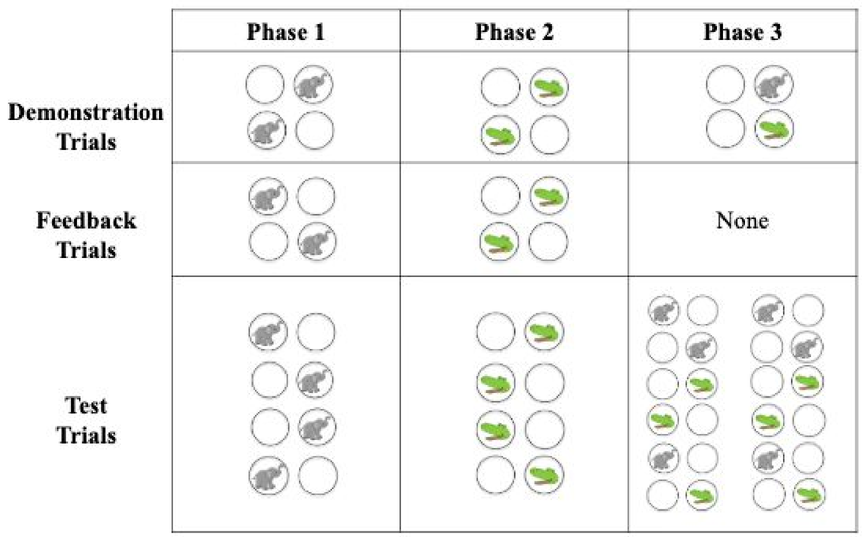

Figure 3. Opposites protocol. The facilitator followed this table for the order of pressing the buttons during each of the three phases.

BRIEF-P.

During testing for Project 1 of SLaM, parents and guardians were given BRIEF-P forms to fill out for their child. They were either distributed to parents on-site during testing or given to the child to bring home with them to their parent. Spanish-speaking parents were called and deaf parents were video called given explanations of the BRIEF-P forms in order to keep the form accessible. The form also often included a cover letter with information on the BRIEF-P.

Responses on BRIEF-P questions were either coded with “n” for “never”, “s” for “sometimes”, “a” for always, or “n/a” for no response. Responses were assigned numerical values of “1” for never, “2” for sometimes”, or “3” for always. If a parent circled more than one response or left no response for a question, a score of “1” was always given. Numerical values for responses were then scored according to the BRIEF manual protocols and raw scores were converted into T-scores.

Analyses

Independent samples t-tests were run to compare scores on the Opposites task and the parent-reported overall BRIEF-P scores between the Early and Later language access groups and the ASL and English language groups, respectively. Four different types of partial correlations were conducted for each group. Age was controlled for all partial correlations. The first group of partial correlations was between the total Opposites score (percent correct) and the BRIEF-P GEC score. The second group of partial correlations was between the total Opposites score (percent correct) and the five BRIEF-P subscales: Inhibit, Shift, Working Memory, Emotional Control, and Plan/Organize. The third group of partial correlations was between the Inhibition score and BRIEF-P GEC score. The fourth group of partial correlations was between the Inhibition scores and the BRIEF-P subscales.

Results

Influence of Timing and Modality on the Opposites Task and BRIEF-P

Timing.

Early vs. Later Access to Language Differences on the Opposites Task and BRIEF-P. Independent samples t-tests were run to compare performance on the Opposites task and the parents' reporting on the BRIEF-P between the Early and Later language access groups. There was no difference between the Early group (M = .90, SD = .13) and Later group (M = .86, SD = .13) on performance in the Opposites task $t(86) = 1.601$, $p = .11$ (Figure 4). The Early group scored significantly lower (better) on the BRIEF-P (M = 46, SD = 12.68) than the Later group (M = 54, SD = 13.65), $t(86) = -2.983$, $p = .004$ (Figure 5).

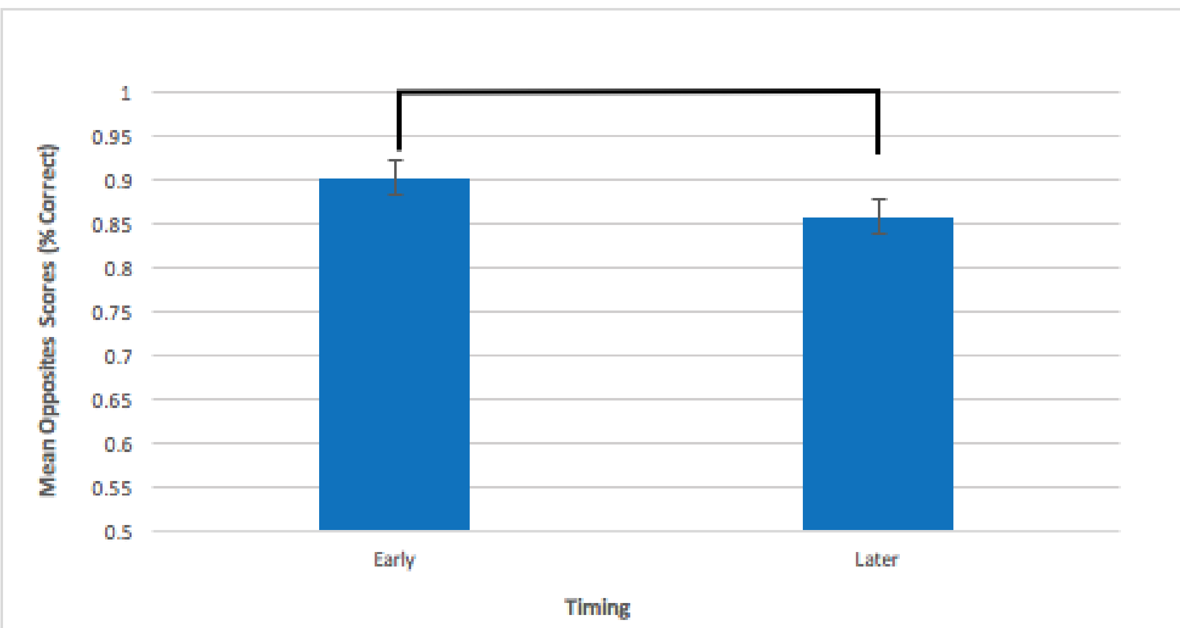

Figure 4. Total Opposites Scores (% correct) across language timing groups. The Early and Later groups did not differ significantly. Error bars show mean +/- SE. *$*p < .05$, $**p < .01$, $***p < .001$.*

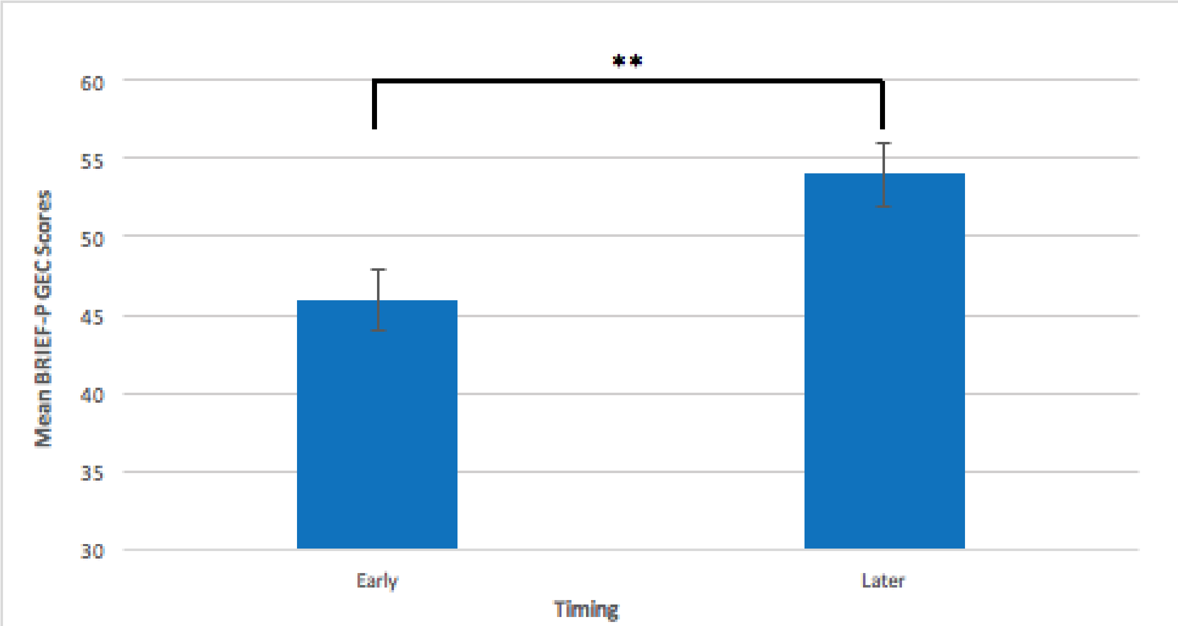

Figure 5. BRIEF-P GEC scores across timing groups (Early vs. Later). Error bars show mean +/- SE. **p* < .05, ***p* < .01, ****p* < .001.

Modality.

ASL vs. English Modality Differences on the Opposites Task and BRIEF-P. Independent samples t-tests were run to compare performance on the Opposites task and parents' reporting on the BRIEF-P between the ASL and English language groups. No significant differences were found between the ASL group (M = .86, SD = .15) and the English group (M = .89, SD = .12) on the Opposites task, $t(86) = -1.078$, $p = .28$ (Figure 6), or the BRIEF-P (M = 52, SD = 14.89) (M = 49, SD = 12.84), $t(86) = .823$, p = .41 (Figure 7).

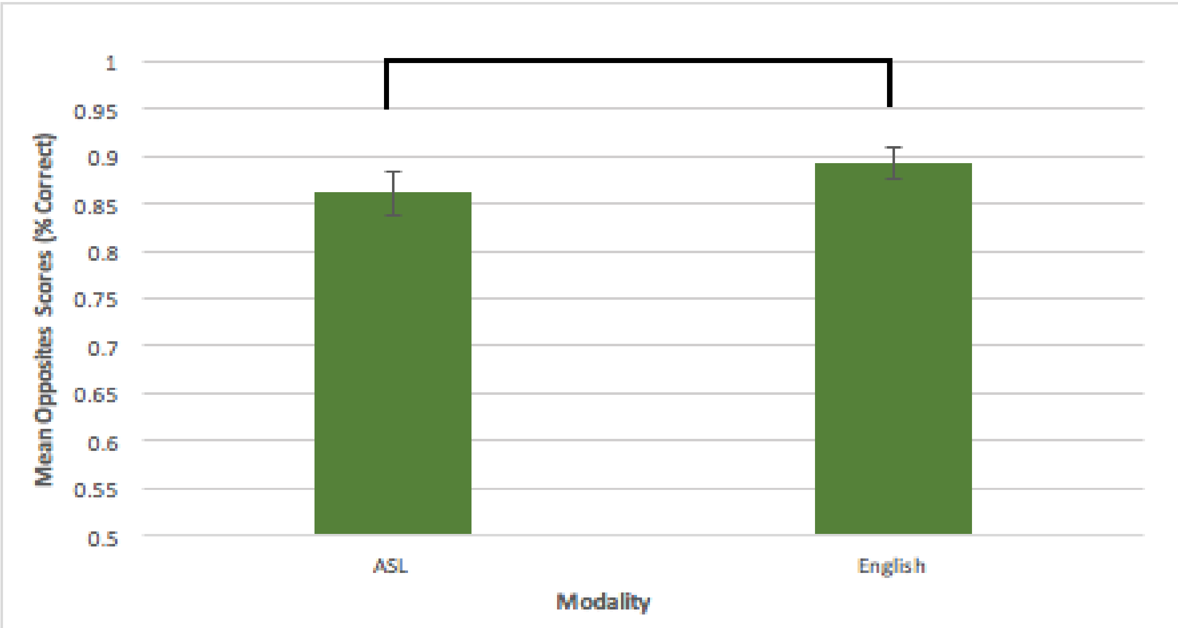

Figure 6. Total Opposites scores (% correct) across language modality groups. The ASL and English groups did not differ significantly. Error bars show mean +/- SE. *$*p < .05$, $**p < .01$, $***p < .001$.*

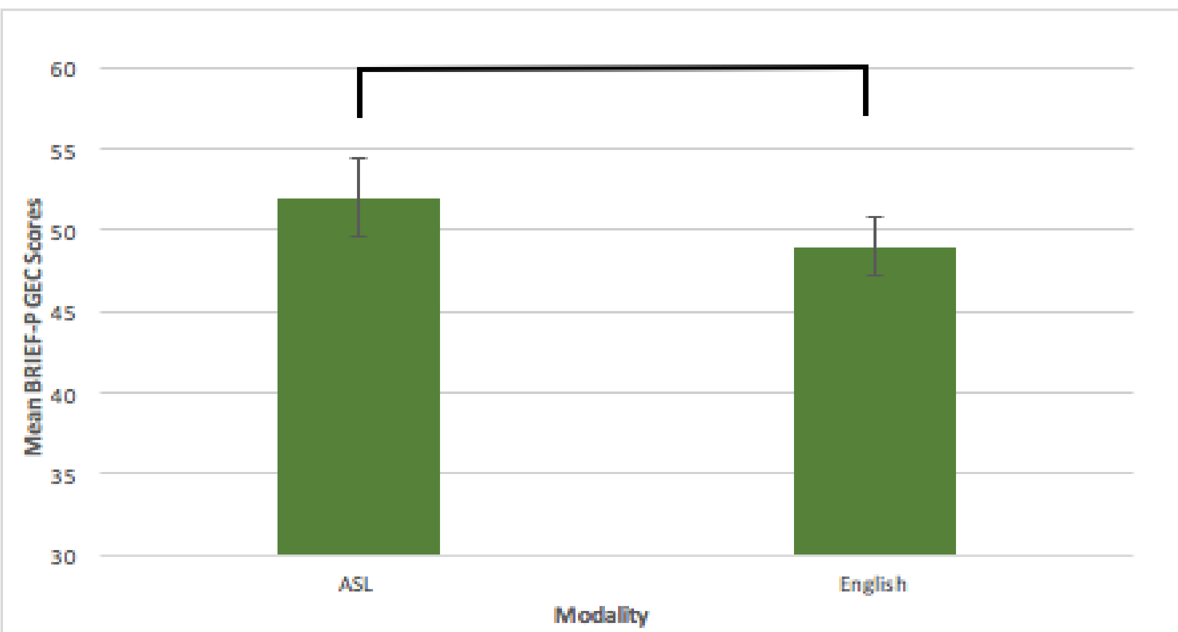

Figure 7. BRIEF-P GEC scores across language modality groups. The ASL and English groups did not differ significantly. Error bars show mean +/- SE. *$*p < .05$, $**p < .01$, $***p < .001$.*

Correlations between the Opposites Task and BRIEF-P

Partial correlations were run to explore the relationships between the study variables while controlling for age. As aforementioned, lower scores on the BRIEF-P indicate superior EF, whereas higher scores on the Opposites task represent superior inhibition. As such, we expected that all groups would produce partial negative correlations between the Opposites task and BRIEF-P as they should display an inverse relationship.

Timing.

Early Access to Language Group.

Opposites Task. For the Early group, a moderate, negative partial correlation was found between the Opposites task and the overall BRIEF-P scores that was statistically significant (r = -.34, p = .030). Unexpectedly, a moderate, positive partial correlation was also found between the overall Opposites task and Inhibition subscale (r = .40, p = .010). No significant correlations were found between the Opposites task and any of the BRIEF-P subscales (Table 1).

Opposites Inhibition Subscale. All correlations calculated between the Inhibition subscale and BRIEF-P subscales were negative, however, no significant correlations emerged between the Inhibition subscale and the overall BRIEF-P or any of the BRIEF-P subscales (Table 1).

Table 1

Early Group Partial Correlations

Variables	1	2	3	4	5	6	7	8
1. Opposites	1.00							
2. Inhibition Sub	.40*	1.00						
3. BRIEF-P GEC	-.34*	-.12	1.00					
4. Inhibit	-.13	-.26	.77***	1.00				
5. Shift	-.12	-.15	.47**	.49**	1.00			
6. Emotional Control	-.008	-.12	.53***	.63***	.56***	1.00		
7. Working Memory	.023	-.19	.63***	.63***	.33**	.45**	1.00	
8. Plan/Organize	-.04	-.13	.59***	.72***	.70***	.70***	.70***	1.00

Note. Age is controlled for all partial correlations. $*p < .05$, $**p < .01$, $***p < .001$

Later Access to Language Group.

Opposites Task. All partial correlations calculated between the Opposites task and BRIEF-P subscales were negative. However, unexpectedly, The Later group produced a strong, negative correlation between the Opposites task and the Working Memory subscale of the BRIEF-P that was statistically significant (r = -.45, p = .002) (Table 2).

Opposites Inhibition Subscale. All partial correlations calculated between the Inhibition subscale and overall BRIEF-P/subscales were negative. No significant correlations were found between the Inhibition subscale and any of the other measures (Table 2).

Table 2

Later Group Partial Correlations

Variables	1	2	3	4	5	6	7	8
1. Opposites	1.00							
2. Inhibition Sub	.16	1.00						
3. BRIEF-P GEC	-.16	-.15	1.00					
4. Inhibit	-.12	-.16	.81***	1.00				
5. Shift	-.08	-.06	.65***	.59***	1.00			
6. Emotional Control	-.20	-.14	.72***	.66***	.61***	1.00		
7. Working Memory	-.45**	-.15	.62***	.56***	.24	.44**	1.00	
8. Plan/Organize	-.28	-.13	.82***	.75***	.58***	.73***	.70***	1.00

Note. Age is controlled for all partial correlations. *$p < .05$, **$p < .01$, ***$p < .001$

Modality

ASL.

Opposites Task. Like the Early group above, the ASL group, a moderate, negative partial correlation was found between the Opposites task and the BRIEF-P (r = -.336, p = .037) (Table 3).

Opposites Inhibition Subscale. A moderate, negative correlation was found between the Opposites Inhibition subscale and the Inhibit subscale that was statistically significant (r = -.39, p = .013). Additionally, a moderate, negative correlation was found between the Inhibition subscale and the Working Memory subscale that was statistically significant (r = -.38, p = .018) (Table 3). No significant correlation emerged between the Inhibition subscale and the BRIEF-P.

Table 3

ASL Group Partial Correlations

Variables	1	2	3	4	5	6	7	8
1. Opposites	1.00							
2. Inhibition Sub	.14	1.00						
3. BRIEF-P GEC	-.34*	-.23	1.00					
4. Inhibit	-.16	-.39*	.83***	1.00				
5. Shift	-.10	-.11	.58***	.59***	1.00			
6. Emotional Control	-.05	-.27	.67***	.67***	.65***	1.00		
7. Working Memory	-.19	-.38*	.62***	.62***	.30	.48**	1.00	
8. Plan/Organize	-.21	-.26	.70***	.66***	.57***	.75***	.66***	1.00

Note. Age is controlled for all partial correlations. $*p < .05$, $**p < .01$, $***p < .001$.

English.

Opposites Task. For the English group, a positive partial correlation was found between the Opposites task and Inhibition subscale that was statistically significant ($r = .33$, $p = .024$). A moderate, negative partial correlation was found between the Opposites task and the Emotional Control subscale that was statistically significant ($r = -.35$, $p = .016$). Additionally, a moderate, negative correlation was found between the Opposites task and Plan/Organize subscale that was statistically significant ($r = -.38$, $p = .012$).

Opposites Inhibition Subscale. No partial correlations calculated between the Inhibition subscale and BRIEF-P subscales were significant. Interestingly, the direction of the correlation between the Inhibition subscale and Plan/Organize subscale was negative (Table 4).

Table 4

English Group Partial Correlations

Variables	1	2	3	4	5	6	7	8
1. Opposites	1.00							
2. Inhibition Sub	.33*	1.00						
3. BRIEF-P GEC	-.23	.05	1.00					
4. Inhibit	-.18	.04	.77***	1.00				
5. Shift	-.28	.001	.66***	.49***	1.00			
6. Emotional Control	-.35*	.09	.66***	.63***	.56***	1.00		
7. Working Memory	-.27	.13	.63***	.63***	.28	.45**	1.00	
8. Plan/Organize	-.37*	-.04	.83***	.72***	.70***	.70***	.70***	1.00

Note. Age is controlled for all partial correlations. *$p < .05$, **$p < .01$, ***$p < .001$.

Discussion

The purpose of this study was to examine the relationship between the Opposites task, a non-standardized behavioral measure of EF, and the BRIEF-P, a standardized parent-report measure of EF. We also sought to further explore if group differences would indicate whether the timing of language access and language modality affect EF abilities, and inhibition in particular, in deaf and hearing children. To reiterate, we expected that the Opposites task and its Inhibition subscale would relate to the BRIEF-P and that only the timing of language access would have an impact on children's scores on these measures.

Based on the analyses conducted, we can conclude that there is a relationship between the overall Opposites task and the overall BRIEF-P for all groups tested. Better EF is indicated by higher scores on the Opposites task and lower scores on the BRIEF-P. While the correlations for all groups were not significant, the Early and ASL groups did demonstrate a significant relationship between these two measures, which suggests that the overall Opposites task was tapping into an aspect (or aspects) of EF as scored by the BRIEF-P. The lack of relationships between these two measures for the Later and English groups is perhaps due to some level of variation in these groups that was not fully accounted for when we created the Inhibition subscale of the Opposites task.

When examining inhibition, we found that only the ASL group demonstrated a significant relationship between the Opposites Inhibition subscale and the Inhibit subscale of the BRIEF-P. Since this subscale of the Opposites task measures a more specific EF component, we anticipated that it would relate to the Inhibit subscale for all groups. This suggests that the

Opposites Inhibition subscale itself may not be specific enough to inhibition in order to correspond to the Inhibit subscale on the BRIEF-P.

We hypothesized that earlier access to language positively impacts EF abilities. Although we found this to be true, group differences on both the Opposites task and BRIEF-Ps also produced an unexpected result. The Early group demonstrated, on average, better EF on the BRIEF-P than the Later group. However, the differences between the timing groups on the Opposites task were not significant, thus our hypothesis was only partially supported. We also expected that the Early group would show significantly better scores than the Later group on both the Opposites task and BRIEF-P, but this was only the case for the BRIEF-P. Since the BRIEF-P is standardized, we believe that it is still accurate to conclude that earlier access to language is associated with better scores.

With regards to modality, the ASL group did not differ from the English group on the Opposites task. The ASL group also did not demonstrate significantly higher executive dysfunction than the English group on the BRIEF-P. These results demonstrate that language modality does not significantly influence scores on these two tasks. Rather, we see that earlier access to language leads to better scores on a standardized measure of EF. This pattern of children with earlier access to language performing better on standardized measures of EF partially supports the language deprivation hypothesis.

The lack of modality differences in EF on the Opposites task and the BRIEF-P may potentially highlight one of the problems that emerge from the comparison of a behavioral and parent-report measure of EF. Although both are measures of EF, parents answer detailed questions on the BRIEF-P about their children's behavior. The BRIEF-P, as a parent-report questionnaire, is a much more comprehensive measure and covers more aspects of EF than the Opposites task does. In contrast, although the Opposites task is a good measure of EF, it is a non-standardized and simple behavioral measure. In Beer et al. (2014), researchers also found that their non-standardized behavioral measure did not fully correspond to the standardized parent-report measure used, possibly due to these structural differences.

Strengths and Limitations.

Our study demonstrates that although both the Opposites task and BRIEF-P can be used together to further investigate the effects of language deprivation on EF, caution should be used when utilizing non-standardized measures such as the Opposites task. We have provided support for the language deprivation hypothesis as our results have shown that language modality does not influence performance on non-standardized or standardized measures of EF. Language modality the language deprivation hypothesis, but our study shows that timing groups do test this hypothesis. As mentioned previously, the Opposites task tests different aspects of EF such as working memory and inhibition. Although we have provided a more specific measure within the Opposites task for analyzing its inhibition component in addition to its overall measure of EF, our results have indicated that the measure we chose may need to be utilized differently in order to be more specific to inhibition in a way that corresponds with the BRIEF-P's Inhibit subscale.

This study has also shown that there are important differences between the two measures that should be accounted for when considering their relationship. The fact that only one significant between-group difference was found for either of the measures, which turned out to be the BRIEF-P for the timing groups, suggests that there are differences between the two measures that should have been more carefully considered.

First, the structural differences between the two measures are divergent enough that they may have affected our results. The Opposites task measures children's EF through their performance on a task that takes a few minutes, while the BRIEF-P measures their EF through parent-reported behaviors over a period of six months. Perhaps if the Opposites task was repeatedly tested over a similar longer period and their average performance was used, a better assessment of performance on the task could have emerged. The BRIEF-P is also an indirect measure of EF while the Opposites task is a direct measure of behavioral performance.

Second, the experimental set-up of the Opposites task may have influenced children's performance on the task. The Opposites task was videotaped and children were sometimes hesitant to choose buttons during the trials until they were persuaded by the experimenter. It can also be argued that this difference should not have played an influential role in performance since there were other tasks in the Project 1 battery that were also filmed and were more challenging than the Opposites task.

Our sample size of 88 children may have also limited our findings. Due to tracking error that occurred during Project 1 data collection, only 90 of the 201 children tested in SLaM Project 1 had the BRIEF-P form completed, 88 of whom met our inclusion criteria as well. It is possible that the smaller sample size may not have had a negative role in examining the relationship between the two measures overall since our language deprivation hypothesis was supported. On the other hand, the unexpected results we found when examining the relationship between the components of these two measures emphasize the importance of a larger sample size. When discussing sample size, we must mention that the bulk of research in deaf studies is limited by smaller sample sizes (Hall, Eigsti, Bortfeld, and Lillo-Martin, 2017).

Implications for Future Research.

This study demonstrated that the influence of timing of language access in deaf children in non-standardized measures of EF needs to be further explored. As mentioned earlier, the Opposites task was used as a control in the larger SLaM study. We expected it to show that children who struggled on this task may be demonstrating executive dysfunction. Our results seem to suggest that the simplicity of this measure could actually be an obstacle in this particular study, as it may not be fully capturing the inhibition aspect of EF.

Given the support this study has shown for the language deprivation hypothesis as opposed to the auditory deprivation hypothesis, we hope that future research will focus on shedding light on how access to language from birth is crucial to the development of EF in children. We must reiterate that both timing and quality of language access, both parts of broader language experience, are crucial to the healthy development of EF abilities in deaf children (W. Hall et al., 2017). Although this study was primarily focused on the timing of language access, research on other components of language learning, like quality, is also essential to understanding how language deprivation impacts EF in deaf children.

Inquiry and discovery into how EF dysfunction develops in deaf children and its association with early access to language are necessary to understand why deaf children struggle in school, and especially in mathematics. Determining the causes behind deaf children's lack of EF abilities has a tremendous impact on their school achievement, but also their social and emotional intelligence. Through this work, we hope to provide additional insight as research continues to approach a question which has demonstrated impact on improving our understanding of deaf children's developmental needs.

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