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Department of Psychology, College of Liberal Arts
Rochester Institute of Technology

Accounting for the Language Variance in Executive Function

by

Jessica Contreras

A thesis in

Experimental Psychology

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Master of Science

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Abstract

Language is considered an important precursor for executive function (EF) development, with advantages shown for bilinguals. The current study explored the impact of early bilingual language experience (spoken and sign language) on executive functions. Participants were deaf college students with cochlear implants. Participants language experiences were diverse. They varied in American Sign Language (ASL) and English proficiency, reported various ages for sign language acquisition, and reported different ages of implantation. Results indicate that age of acquisition, age of implantation, and English and ASL proficiency have no effect on these participants' performance on the Color Trails Test, a measure of EF. Future recommendations would be to use a more robust measure of EF to detect differences among deaf individuals.

Keywords: Bilingualism, Executive Function, Bimodal Bilingualism, American Sign Language, Language, Cochlear Implants

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Accounting for the Language Variance in Executive Function

Executive functions (EF) are a set of cognitive processes responsible for goal-oriented behavior and learning (Diamond, 2013). These processes include inhibitory control, working memory, and cognitive flexibility. Together, they formulate higher-level executive functions such as reasoning, problem solving, and planning. Inhibition is one's ability to direct their attention to important stimuli while ignoring irrelevant stimuli. Working memory requires an individual to be able to remember information long enough to manipulate the information. Working memory goes beyond short-term memory because the information has to be re-arranged cognitively rather than just being able to memorize pieces of information. Cognitive flexibility is ones' ability to freely and appropriately adapt to changed circumstances with different demands. Executive functioning processes are not specific to one part of the brain, but rather collectively work together to facilitate behavior regulation and learning (Diamond, 2013).

The development of EF is dependent upon one's environment, genetics, biology, and experience. Executive functions develop rapidly from birth but experience a decline around puberty and stabilize around the age of 25 (Blakemore & Choudhury, 2006). This is explained by the synaptic pruning that occurs within the brain as connections that are not frequently used are pruned in order to strengthen connections more frequently used. Executive functions have been found to be important in numerous aspects of life, but appear to have a strong impact on school-age children. A study conducted with elementary school-aged children showed that children with better EF skills are able to grasp numeracy and literacy concepts in kindergarten (Blair & Razza, 2007). Children with better EF skills are able to control their attention and exhibit better cognitive flexibility (an example may be remembering information long enough to manipulate it)

that is necessary for learning. While we know that EF processes are important for academics, recent research has focused on finding the variables associated with EF development.

A study by Szameitat, Schubert, Müller, and von Cramon (2002) examined specific areas of the brain that showed executive function activity, studying individuals as they performed dual-tasks under a Functional Magnetic Resonance Imaging (fMRI) machine. The results revealed activity in the dorsolateral prefrontal cortex. Szameitat et al. (2002) indicated that dual-tasks represent the challenges we face when presented with two different paradigms requiring the use of higher cognitive processes (EF). Thus, when subjects are presented with a dual-task paradigm, they will begin to rely on EF to mediate the decision-making process to accommodate the rules of both tasks. This will then increase the neural activities in the prefrontal cortex; the area utilized when EF is required.

Research has also indicated that the environment plays a role in the development of executive function. Hackman and Farah (2009), completed a review of multiple studies that investigated the impact of socioeconomic status (SES) on EF. Their findings indicated poor language outcomes are associated with those who have low SES, and individuals who have high SES display twice the vocabulary size. The literature also shows that individuals who have low SES display worse working memory skills and poor inhibition.

The Role of Language in EF Development in Hearing Populations

Monolinguals and Executive Functioning

Some researchers have begun to look at language as a possible mediating factor of EF development. The literature seems sparse when it comes to explanations regarding why language may be an underlying factor for EF development. Hungerford and Gonyo (2007) have suggested that we regulate our EF processes through “self-talk”, which is the idea that our EF processes are

mediated through our ability to reason with ourselves internally while navigating our day to day life. For example, those with stronger language skills are perhaps better able to plan and organize, contributing to stronger EF development.

Aphasia is a specific communication disorder that impacts one's ability to understand and perceive language (Klein, 2000). While these individuals have the tools for language, there appears to be some underlying disruption to the processes that allow them to process or produce language. Individuals who have aphasia often exhibit worse EF skills when compared to those who do not have aphasia (Fridriksson, Nettles, & Davis, 2006). So if one's language skills are impacted it may also impact their cognitive abilities. The findings seem to indicate that language may be an underlying indicator of one's EF skills. Those who have Aphasia show decreased EF development-indicating language mediates our ability to maximize our cognitive processes. Spoken language abilities have an impact on the development of cognition specifically for individuals who struggle in one language (Klein, 2000).

Bilinguals and Executive Functioning

Research in executive function has found that those with dual language experience show cognitive benefits compared to individuals who are proficient in one language, or individuals who exhibit language weaknesses (Bialystok, 2005; Fridriksson et al., 2006). Bialystok (2005) showed that individuals with better language skills show better EF skills as well; furthermore, individuals who know two spoken languages have even better cognitive functioning.

Investigators who studied a population of Spanish-English bilingual children also found evidence for enhanced executive functioning (Carlson & Meltzoff, 2008). They collected data from approximately 50 kindergarten children who were bilingual, monolingual, or an immersion group. The immersion group consisted of children who received instruction in English for half a

day and Spanish or Japanese the other half of the day. The bilingual group differed from the immersion group by their parents language status—bilinguals grew up in a home exposed to both Spanish and English. Thus, the bilinguals were exposed to two languages from birth and the immersion group were exposed to a second language at a later age. Their results showed that when controlling for age, verbal ability, and socioeconomic status, bilinguals showed advantages in inhibition. Interestingly enough, the bilinguals scored significantly lower on the vocabulary assessments. When learning multiple languages early in life the child is not yet proficient until a later age. This finding is similar to studies completed by Bialystok whose research interests are bilinguals, language, and executive functioning.

Bialystok and Feng (2009) designed a two-part study investigating children and adults, by comparing individuals who were proficient in one language (English) to individuals proficient in two spoken languages (English and another language) on an executive function task. The bilingual children were raised in homes speaking Cantonese, Arabic, Korean, Spanish, Farsi, Tagalog, or Tamil, while attending school taught in English. Results indicated that the bilingual children had vocabulary weaknesses compared to monolinguals, but possible advantages on performance in a cognitive function task specifically cognitive control. The bilingual children displayed better cognitive control, specifically inhibition, when compared to monolingual children. The adult study featured a population of college students that were monolinguals or bilinguals (spoke another language on a daily basis along with English). The bilinguals, again, scored lower on a vocabulary assessment; however, when compared with monolinguals, those with better verbal abilities did better on the inhibition tasks. Those who had better language skills (proficiency in two languages) were able to recall a greater number of word lists even when presented with distractors. Perhaps the consistent switching between languages plays a role in

enhancing inhibition abilities. Bilinguals who know two spoken languages must inhibit one when speaking the other.

More recent studies that look at the effect of bilingualism on executive function have attempted to better measure language proficiency. Rosselli, Ardila, Lawani, and Velez-uribe (2015), argue that individuals can be balanced bilinguals or low proficiency bilinguals, meaning proficient in two languages or proficient in one language with low proficiency in the other, respectively. Their study attempted to better understand the difference in executive functioning among balanced bilinguals and low proficiency bilinguals. One hundred and fourteen Spanish/English speaking undergraduate students between the ages of 18-45 years old participated in the study. The researchers screened all participants to ensure they had no history of learning disabilities, other language experience (outside of Spanish/English), and performance on both verbal/nonverbal tasks. Subjects who were bilingual were assigned to one of three groups based upon their language skills: balanced high proficiency, balanced low proficiency, and low proficiency proficiency by using a median split. Subjects who were monolingual were split into high proficiency and low proficiency groups. Results indicated that language proficiency did not correlate with better EF skills using assorted verbal/nonverbal tasks for both monolinguals and bilinguals. They further showed that non-verbal IQ was a better predictor of cognitive functioning than language proficiency. Currently, there is no agreed upon way to evaluate bilingual skills. Rosselli's method of using a median split was used for the current study in an attempt to understand varying bilingual proficiency and the impact on EF skills.

Currently, the literature is ambiguous regarding whether bilingual language skills have an effect on EF development. The current study will attempt to further understand language skills in the same way by using median cut off scores to classify bimodal bilinguals into four groups- (1)

Balanced Bilinguals (high sign/spoken proficiency), (2) Spoken Dominant Bilinguals (low sign/high Spoken proficiency), (3) Sign Dominant Bilinguals (high sign/low spoken proficiency), and (4) Low proficiency Bilinguals (low sign/low spoken proficiency).

Bimodal Bilinguals and Executive Functioning

The impact of modality – whether a language is spoken or signed – on cognitive functioning is not well understood. In order to investigate how cognitive function may be impacted by language through two senses, vision and sound, Emmorey, Luk, Pyers, and Bialystok (2008), studied bimodal bilinguals who knew a spoken and signed language. The bimodal bilinguals were college-aged individuals who grew up in a home with one or two parents who are deaf and use American Sign Language (ASL) as their primary language, thus they grew up speaking English and signing ASL. On a nonverbal cognitive functioning task, the bimodal bilinguals were compared to a group of bilingual individuals who grew up speaking English and Spanish, and a control group of individuals who knew only one language. Using a flanker task they modified from a previous study, the researchers examined specific processes such as inhibition, monitoring processes, and task switching through reaction time. Their results indicated that the bimodal bilinguals did not show better processes and performed the same as monolinguals. However, similar to previous literature, individuals who knew two spoken languages showed cognitive advantages. This lends support to the idea that the bilingual advantage applies to those whose two languages share the same modality. One possible explanation is that bilinguals who know two spoken must switch between languages, whereas bimodal bilinguals are able to blend two languages simultaneously. The possible switching/inhibiting between languages may be an explanation of the enhanced functioning through continued usage.

To date the study conducted by Emmorey et al. (2008) is the only one assessing executive control in bimodal bilinguals. More work is needed for clarification on whether knowing languages in two modalities plays a role in EF in signing populations, or if cognitive benefits only exist when both languages are in the same modality. Currently, what we know indicates that bilingualism has cognitive benefits only within spoken language and those benefits do not extend to bimodal bilinguals. Additionally, studies could seek to explain the role of sign language in executive function development within deaf individuals.

The Role of Language in EF Development in Deaf Populations

Early Language Experience with Deaf parents

Gallaudet Research Institute data from 2009-2010 indicate that approximately 16% of hearing parents of deaf children communicate in sign language. Gallaudet Research Institute findings are reported on their website (https://research.gallaudet.edu/Demographics/2010_National_Summary.pdf) and are only representative of the people that actually completed their survey. Mitchell & Karchmer (2004) analyzed the reports of over 30,000 deaf students between the ages of 6-19 and showed that approximately 96% are born to hearing parents. Looking specifically into native signers' language development, Hauser, Lukomski, and Hillman (2008) suggested that those who are exposed to sign language from birth reached language milestones at the same age as hearing peers. For example, deaf mothers attention-getting strategies facilitate visual attention skills that are later important for language development. Individuals who are profoundly deaf show typical development in language through a visual modality, but there is also other research investigating the correlation of exposure to sign language and cognitive benefits with the stipulation that language access is important (Dye & Hauser, 2014).

Deaf Bimodal Bilinguals and Executive Functioning

Crume and Singleton (2008) looked at behavior relation skills of a group of deaf children in a classroom. They compared children who had deaf parents (native early signers) to children who had hearing parents (late signers) presuming that deaf children born with deaf parents would have access to sign language from birth, whereas deaf children with hearing parents would have delayed language exposure. This study used classroom observation and counted the number of prompts each child received which measured overt behavior regulation. Each prompt was used to direct the child's attention to the person who was talking at the moment whether it was the teacher, or a peer. The prompts were broken down into two categories: attention-getting (when the teacher asked the child to look at the teacher) and attention-directing (when the teacher asked the child to look at their peer who was talking). They found native signers showed better behavior regulation skills and required less prompts than the late signers, indicating that early language exposure correlates with cognitive skills in primary school settings, specifically for deaf individuals born into signing families.

Dye and Hauser (2014) attempted to measure performance in specific components of executive functioning in deaf children who have been exposed to sign language from birth (Deaf native early signers). They were compared to a control group, which consisted of hearing monolingual children. They administered a Continuous Performance Task (CPT) measuring the ability of sustaining attention and selective attention. Their findings indicated that deaf and hearing children showed no differences in a sustained attention task. Their research further demonstrate that older deaf children who receive language from birth, despite lack of audio input, are able to perform the same as their hearing peers on the selective attention task. Selective attention tasks are a measure of inhibition, a component of EF. Dye and Hauser (2014) suggest

that due to hearing loss, their visual system may compensate by expanding their visual field perhaps in a way that may be seen as “distractible,” when in fact it may be useful. Past research has indicated that deaf individuals experience a wider peripheral vision, which may be indicative of brain plasticity that occurs based upon one’s experiences (Dye, Hauser, & Bavelier, 2009). Again, this area has yet to be further explored, as this is the only study conducted on native signers and executive function, though there is other research examining deaf individuals who have cochlear implants.

Early Language Experience with Cochlear Implants

A cochlear implant (CI) offers individuals an implantation that allows access to sound, by bypassing the auditory system through an external microphone that transmits to an internal processor (Gates & Miyamoto, 2003). Researchers have sought to better understand how a cochlear implant enhances language development in deaf individuals. One study compared deaf individuals who received cochlear implants to individuals with hearing aids (HA), alongside a control group consisting of hearing age-matched controls (Figueras, Edwards, & Langdon, 2008). The sample consisted of a total of 69 children between the ages of 8-12. A majority of the deaf children (those with hearing aids and cochlear implants) used only spoken English as their means of communication and not sign language. Results indicated that the language scores in the deaf groups (CI and HA) were significantly below the hearing control group. There was no difference between the CI and HA groups in language skills.

Svirsky, Robbins, Kirk, Pisoni, and Miyamoto (2000) investigated language development using a longitudinal design with a sample of 70 deaf children with and without cochlear implants. For the children with cochlear implants, they were assessed 4 months prior to receiving their implants. All children were subsequently assessed 6, 12, 18, 24, and 30 months after

implantation. Results reflected that prior to implantation all deaf children showed language abilities that were below average when compared to hearing normative data used to develop the language assessments. When closely comparing the data for language abilities for individuals who received implants to those who did not receive implants, those who received implants showed better language development at all time periods after implantation. Language abilities were synonymous with speech development. However, one must keep in mind that since language is already delayed these gains were only seen after implantation, and pre-implantation experience had an overall impact on language development milestones. The study explained that all children with better hearing developed speech better, perhaps the interpretation should have been that those who hear better will develop more speech abilities.

Miyamoto, Hay-Mccutcheon, Iler Kirk, Houston, & Bergeson-Dana (2008) focused on answering the question of whether age of implantation makes a difference in language skills in deaf individuals. Participants included 91 deaf individuals who received a cochlear implant either before the age of 1, from 1-2 years old, or from 2-3 years old. They compared their performance on a language measure and found that overall a majority of the children fell below the average language skills when compared to normative means developed based upon hearing children. Their data also indicated that individuals who were implanted after the age of 2 performed worse on language measures than those who were implanted prior to the age of 2. Individuals who were implanted before the age of 1 showed the best language outcomes compared to the other two groups, suggesting that earlier implantation is correlated with better language development.

A recent meta-analysis conducted by Lund (2015) found that deaf children with cochlear implants underperformed in spoken-language vocabulary knowledge when compared to hearing

peers. The meta-analysis totaled 52 studies that included children from the ages 4-9 and used spoken English as their primary language. Their findings indicated that despite hearing assistive devices deaf children with cochlear implants did not develop expressive or receptive vocabulary knowledge normally (when compared to hearing peers). Furthermore, the results suggested that age when implanted, duration of implantation, or age at testing did not appear to be significant factors. From the above studies, we come to understand that having a cochlear implant does not necessarily promote language development.

Type of Language used by Deaf Individuals with Cochlear Implants

Researchers have measured the type of language that deaf individuals with cochlear implants use. Hyde and Punch (2011) used a mixed method approach in answering the question of language choices in deaf children with cochlear implants in Australia. They combined information gathered from parents and teachers of the deaf children along with interview data from the children themselves. Of the parent data collected, it was noted that nearly 100% of the parents were hearing with only one deaf parent. The mean implantation age of the group according to parents was approximately 3 years old. According to parent report, less than 20% of the children communicated with their parents using sign language; a majority of them communicated through spoken English. In most cases, when sign language was combined with speech, few parents communicated with their child solely through sign language. When questioning teachers regarding language used in the school setting, statistics showed over 50% of the language used was spoken English with less than 20% using a combination of spoken English and Australian Sign Language (Auslan). Thus, based on this study, it seems the use of spoken English is dominant in children with cochlear implants.

Deaf Monolinguals with Cochlear Implants and Executive Functioning

Figueras et al. (2008) examined executive functioning in individuals with CI's. The population consisted of deaf individuals with cochlear implants or hearing aids in comparison to hearing age-matched controls. Their executive functioning measures covered skills that were closely linked to language such as planning, set shifting, working memory, and impulse control. In their results, the deaf group consisting of individuals with cochlear implants or hearing aids showed no difference from each other and were therefore combined to analyze executive functioning in comparison to the hearing group. Once combined, the deaf population showed deficits in impulse control, inhibition, and cognitive shifting. These results suggest that having limited access to language through sound may have a negative impact on the development of EF skills. Again it should be noted that the majority of this population used spoken English as their main source of communication.

Beer, Kronenberger, and Pisoni (2011) were also interested in language skills in association with cognitive functioning for individuals who are born deaf, receive cochlear implants, and have no exposure sign language. Beer et al. (2011) compared deaf non-signing cochlear implanted children to individuals who speak one language, which was their control group. Parents completed the Behavior Rating Inventory of Executive Function (BRIEF). Findings indicated differences between the deaf individual and control group. Specifically, the parents of deaf non-signing individuals with cochlear implants reported more problems in their child's ability to inhibit irrelevant stimuli, utilize working memory, and overall behavioral regulation index (consisting of a composite score made up of several EF abilities). High scores above 60 are indicative of problems in specific components of EF abilities, whereas scores below 60 indicate normal functioning of EF skills. Despite a statistical difference in means, the deaf

samples standard scores were below the significantly elevated range (scores below 60) placing them within the normal range. One should take into account that the hearing control group in this study performed below the average displaying exceptionally high executive functioning behaviors. Furthermore, when looking at the deaf individuals' language measures in correlation with EF, it was found that individuals who performed better on the language measures also displayed better EF skills. The language measures were not administered to the control group, so these findings are limited to deaf non-signing individuals with cochlear implants.

Conway, Pisoni, Anaya, Karpicke, and Henning (2011) investigated the impact of experience (sense and language) on executive functioning by comparing deaf children with cochlear implants to typically-developing hearing peers using a sequential learning task designed by Cleary, Pisoni, and Geers (2001). Their stimuli consisted of squares that were colored and the student had to replicate the exact order of presentation. The stimulus was given in two parts unbeknownst to subjects that consisted of a learning phase and a test phase; also the stimulus was designed to generate learning sets based on grammatical and ungrammatical test sequences (Cleary et al., 2001). The ungrammatical test sequences consisted of a novel sequence that was not consistent with grammar, whereas the grammatical test sequences were generated based on underlying artificial grammar in which particular colors can occur in sequence. No grammatical test sequences were present in the learning phase as this was designed to assess competency of the task at hand. The test phase contained a mixture of grammatical and ungrammatical test sequences. Results for the learning phase indicated no group differences and showed comprehension of the task. This is important to ensure that the children understood the task at hand and were able to accurately replicate visual sequences. However during the test phase, the hearing peers outperformed the deaf cochlear implant group in accurately producing correct

sequences. Not only did the hearing peers outperform the deaf individuals; they also showed better performance in the grammatical test sequences in comparison to the ungrammatical test sequences. This indicates that hearing individuals were able to improve when the test sequences followed grammatical sequences, whereas deaf individuals with cochlear implants were unable to do so. When looking at the results for the deaf individuals, they showed no improvement in either the grammatical or ungrammatical test sequences, overall performing worse than their hearing peers. The researchers believe these results indicate that deaf individuals performed worse on this task due to their inability to hear. They suggest sound serves as a scaffolding for understanding sequential series of events and without access to sound this can have a negative impact on EF.

Overall, when looking closely at the literature related to deaf individuals with cochlear implants they underperform in executive functioning compared to typically developing hearing peers. Although, when taking a closer look at the population used all the children with cochlear implants were not exposed to sign language. The current study attempts to further understand the differences that each modality-sound versus signed language makes to overall executive functioning skills in college-aged adults.

Current Study

The literature review showed that competency in one language correlated with EF and bilinguals who speak two languages showed enhanced cognitive benefits. However, when attempting to further understand the implications of bimodal bilinguals, specifically in deaf individuals, there seemed to be conflicting information. This study aimed to understand how early language experience in two modalities (signed and spoken) accounts for the variance in executive function development in deaf individuals with cochlear implants. To do so, the current

work investigated deaf individuals with cochlear implants with various language experiences (sign and spoken). The dependent variables were social economic status, age of exposure to sign language, sign language proficiency, age of implantation, and spoken language proficiency. All individuals, regardless of experience, completed language assessments in spoken English and American Sign Language to determine if the subjects were balanced bilinguals, sign dominant, or spoken language dominant.

Hypotheses

Predicting which dependent variable will contribute the most to cognitive functioning is difficult. Studies indicate a cognitive benefit for spoken bilinguals, but not bimodal bilinguals. Studies focusing on deaf populations show no cognitive benefits for those with cochlear implants, but for deaf individuals who grow up in a home using sign language. As such, we were cautious to approach all variables equally. These variables include: socioeconomic status, age of exposure to sign language, sign language proficiency, age of implantation, and spoken language proficiency. Our prediction was that all of the variables will contribute to some extent to executive functioning. The two main research questions are: (1) does age of implantation and age of exposure to sign language have an impact on EF performance? and (2) does English and sign proficiency have an impact on EF performance? The following hypotheses were made:

1. Social economic status will have an impact on EF performance, such that high SES will correlate with better EF performance.
2. Age of implantation will have an impact on EF performance, such that earlier implanted adults will have better EF performance.
3. Age of acquisition will have an impact on EF performance, such that those who learned sign language earlier will have better EF performance.

4. American Sign Language proficiency will have an impact on EF performance, such that those who are proficient in ASL will have better EF performance.
5. English proficiency will have an impact on EF performance, such that those who are proficient in English will have better EF performance.

Method

Participants

Participants were recruited from the Rochester Institute of Technology via flyers, emails, business cards, and Facebook. All participants in the study were paid \$20 for their time. This research study recruited 39 subjects who were born deaf and received cochlear implants.

Participants had no known neurological, learning, or vision difficulties through self-report and were born in the United States. Participants were between the ages of 18-32 with a mean age of 22 years ($SD= 2.805$). The study sample consisted of 69% females and 31% males.

Approximately 71% of the participants were white whereas the remaining subjects were African American, Hispanic, Asian, or other. Four participants were removed from this study for being under the influence, not being born in the United States, or for not completing the entire study (they did not show up a second time to complete one or more tasks).

Participants were given language measures meant to assess their American Sign Language and English proficiency. Median scores were used to split them into high or low in each language. Individuals who scored high in both ASL and English were placed into the balanced bilingual group. Individuals who scored high in ASL and low in English were categorized as sign dominant, whereas those who scored low in ASL and high in English were categorized as spoken dominant. Finally, individuals who scored low in both ASL and English were categorized as low proficiency.

Materials

A background questionnaire was administered to every subject. The questionnaire asked participants about their experience with assistive devices and communication. The questions of interest were “What age did you receive your implant,”; and “At what age, were you exposed to American Sign Language?” The background questionnaire also included the Hollingshead self-report scale that asks about parents’ education and occupation status. Each component corresponds with a score and are indicative of social economic status.

The Kaufman-Brief Intelligence Test (K-BIT; Kaufman, 1990) contains a portion that assesses nonverbal intelligence. Scores obtained on this assessment are able to be adapted into standard scores of each participants’ cognitive functioning. Standard scores 85 and below are considered to be below average functioning, whereas 115 and above are considered to be above average.

All participants took two language assessments, which are designed to measure their skills in American Sign Language and English. Video data was collected for the American Sign Language assessment and English assessment that were later scored by a research assistant. American Sign Language skills were assessed through the American Sign Language-Sentence Reproduction Test (ASL-SRT; Hauser, Paludneviene, Supalla, & Bavelier, 2009). The assessment consists of 20 sentences designed to measure one’s sign proficiency through comprehension and production. Individuals viewed a sentence signed and then were given a chance to reproduce the sentence accurately. Twenty sentences were administered and participants were given one point for every sentence reproduced correctly. Participants’ English was measured by subtest four of the Test of Adolescent and Adult Language-3rd Edition (TOAL-3; Hammill, Brown, Larsen, & Wiederhold, 1994). Subtest four focuses on speaking and

grammar, subjects were asked to repeat a sentence they heard as accurately as possible. TOAL-3 subtest four consists of 30 sentences and subjects receive a score of one for each correct sentence.

The sentence repetition task (SRT) was used as a measure of language skill. The use of SRT has been argued against due to the idea that rather than assessing language skills they tap into working memory skills. Klem et al. (2015) studied this claim to see whether or not sentence repetition tasks actually are dependent upon working memory. Their longitudinal study included 216 children from Norway with no learning disabilities or sensory impairments. All children were native speakers of Norwegian. Each participant was given three measures- sentence reproduction test, vocabulary assessment, and grammatical knowledge assessment. Their approach argued that if SRT measured working memory systems, then results should also serve as a predictor of growth in other language skills. If the SRT in fact does not draw upon working memory systems and serves as broad measure of language skills, then performance should correlate strongly with a unitary language factor, such as vocabulary and grammatical knowledge.

Findings indicated that sentence reproduction tasks are a complex linguistic measure reflecting language abilities on multiple levels. Results indicated SRT scores did not predict growth in language skills. Rather, SRT results correlated strongly with other measures of language abilities. The dynamic process of the reproduction tasks draws upon ones' ability to comprehend spoken items and correct sentence production. The drawback of using SRT is results are not diagnostic since they measure broad language skills. For example, if an individual has low vocabulary knowledge and has never been exposed to an item their ability to remember and reproduce the exact item may be difficult, resulting in low overall language proficiency abilities.

However, further understanding of the SRT measures allows us to use this as a broad measure of language abilities and to identify individuals who struggle with language impairments.

The Color Trails Test (CTT; D'Elia, Satz, Uchiyama, & White, 1996) is a two-part assessment of speed and accuracy of overall executive functioning. Subjects were asked to complete both parts connecting the dots in order from 1-25 as quickly as possible and to avoid making errors. In the second part, subjects had to alternate colors (pink/yellow) while marking the ascending numbers. Reaction time was measured in both conditions and converted to standard scores.

The Color Trails Test (CTT) is based upon the Trail Making Test in an attempt to reduce potential confounding effects on performance such as language differences, illiteracy, reading disabilities, or educational experience. Williams et al. (1995) examined 200 children with neurological disorder, language or learning disabilities, and learning and/or language disabilities in conjunction with ADHD using the CTT. Results indicated that the CTT was sensitive to differences in executive functioning despite neuropsychological functioning. Thus, the CTT was chosen as a broad measure of executive functioning to be used in this study to eliminate language confounds.

Procedure

Participants were scheduled based upon first come first serve basis, and testing took approximately one hour. After signing a consent form, each participant completed a background questionnaire. Upon the completion of the background questionnaire, all subjects completed the language, cognitive functioning, and intelligence measures. The assessments were randomly counterbalanced (order in which the assessments will be administered) into four conditions (A,

B, C, D) prior to administration to control for ordered effects. All scoring took place after the testing session.

Results

Since this study used a precautionary approach, correlations were used to see if there were any connections between the variables and performance on the CTT (see Table 1). There were two significant correlations that appeared. There was a moderate negative correlation between signing and spoken proficiency. Those who signed well did not speak well and vice versa. Within this sample, there was a weak positive correlation between SES and spoken English skills. Those with higher SES (parents education and occupation) had better speaking skills and those with lower SES had worse speaking skills. Looking at SES, there was no correlation with EF skills (see Table 1). Those with lower or higher SES did not show a difference in executive functioning skills.

To determine if those with early implantation performed better than those with late implantation on CTT, a repeated measures ANOVA was computed with CTT Trail as the repeated measure (Trail 1, Trail 2) and Group (Early/Late) as the between subject measure. The median of the samples age of implantation was seven years of age. Those who were in the early implantation group received implants before the age of seven and those who were in the late implantation group received implants after the age of seven. Seventeen were in the early implantation group and 18 were in the late implantation group. There were no significant differences between the two groups based on their CTT performance, $F(1, 33) = .448, p = .508$ for Trail 1. The early implantation group had the average standard score of 95.57 ($SD = 14.16$) and the late implantation group had the average standard score of 87.79 ($SD = 13.77$). For Trail 2,

the early implantation group had the average standard score of 93.43 ($SD = 12.82$) and the late implantation group had the average standard score of 95.50 ($SD = 16.27$).

To determine if those with early exposure to ASL performed better than those with late exposure to ASL on the CTT, a repeated measures ANOVA was computed with CTT Trail as the repeated measure (Trail 1, Trail 2) and Group (Early/Late) as the between subject measure. The median age of exposure was three years of age. Those who learned sign before the age of three were in the early sign exposure group and those who learned sign after the age of three were in the late sign exposure group. Sixteen were in the early sign exposure group and nineteen were in the late sign exposure group. There were no significant differences between the two groups based on their CTT performance, $F(1, 33) = .027, p = .871$. For Trail 1, the early sign exposure group had a mean standard score of 93.40 ($SD = 12.42$) and the late sign exposure group had a mean standard score of 92.08 ($SD = 15.25$). For Trail 2, the early sign exposure group had a mean standard score of 94.40 ($SD = 16.40$) and the late sign exposure group had a mean standard score of 94.20 ($SD = 13.45$).

To determine if the Balanced Bilinguals performed differently than the Sign Dominant or Spoken Dominant groups, a repeated measures ANOVA was computed with CTT Trail as the repeated measure (Trail 1, Trail 2) with Group (Low Proficiency Bilinguals, Sign Dominant, Spoken Dominant, Balanced Bilinguals) as the between subject measure. No significant differences were found between groups on the CTT, $F(1, 31) = .616, p = .610$. For Trail 1 and 2, each mean score is presented in mean standard scores. For Trail 1, the low proficiency group had a mean standard score of 92.00 ($SD = 21.47$), the spoken proficiency group had a mean standard score of 92.08 ($SD = 11.91$), the sign proficiency group had a mean standard score of 88.82 ($SD = 12.98$), and the balanced proficiency group had a mean standard score of 104.50 ($SD = 5.80$).

For Trail 2, the low proficiency group had a mean standard score of $M = 93.71$ ($SD = 17.11$), the spoken proficiency group had a mean standard score of 96.23 ($SD = 12.11$), the sign proficiency group had a mean standard score of 91.82 ($SD = 16.50$), and the balanced proficiency group had a mean standard score of 95.50 ($SD = 11.56$). Group means and SD on each variable (Age of Implantation, Age of Acquisition, Sign Proficiency, and Spoken Language Proficiency) are presented in Table 2 along with sample size for each group.

To determine if the strong ASL signers performed better than the weak ASL signers on CTT, a repeated measures ANOVA was computed with CTT Trail as the repeated measure (Trail 1, Trail 2) and Group (High/Low) as the between subject measure. The median of the samples ASL-SRT scores (Median = 4.0) was used to create the two groups. Those who scored lower than four on the ASL-SRT were placed in the low signers group and those who scored higher than four were placed in the high signers group. Eighteen were in the high signers group and seventeen were in the low signers group. There were no significant differences between the two groups based on their CTT performance, $F(1, 33) = .035$, $p = .852$. For Trail 1, the high signers had a mean standard score 93.00 ($SD = 13.38$) and the low signers had a mean standard score of 92.05 ($SD = 15.33$). For Trail 2, high signers had a mean standard score of 92.80 ($SD = 15.03$) and low signers had a mean standard score of 95.35 ($SD = 13.66$).

To determine if the strong English speakers performed better than the weak English speakers on CTT, a repeated measures ANOVA was computed with CTT Trail as the repeated measure (Trail 1, Trail 2) and Group (High, Low) as the between subject measure. The median of the samples TOAL3 scores (Median = 4.0) was used to create the two groups. Those who scored below four on the TOAL3 were placed in the low speakers group and those who scored above 4 were placed in the high speakers group. Twenty were in the high speakers group and

fifteen were in the low speakers group. There were no significant differences between the two groups based on their CTT performance, $F(1, 33) = 1.037, p = .316$. For Trail 1, high speakers had a mean standard score of 95.00 ($SD = 11.92$) and low speakers had a mean standard score of 90.06 ($SD = 16.26$). For Trail 2, high speakers had a mean standard score of 96.06 ($SD = 11.63$) and low speakers had a mean standard score of 92.56 ($SD = 16.26$).

Discussion

The current study sought to better understand the impact of language specifically in two modalities in deaf individuals with cochlear implants. The two main research questions were: (1) does age of implantation and age of exposure to sign language have an impact on EF performance? and (2) does English and sign proficiency have an impact on EF performance? Results indicated that there was no significant impact on EF for either of the main research questions. Individuals who were implanted early did not show an EF advantage. Individuals who learned sign language early did not show an EF advantage either. Individuals who were proficient in spoken English and/or American Sign Language also did not show an EF advantage. None of the five variables of interest (socioeconomic status, age of implantation, age of exposure, sign proficiency, and spoken proficiency) correlated with executive function performance. These variables showed no impact on executive function overall.

Attempting to understand how SES does not make an impact in deaf and hard of hearing adults is difficult; however, it is important to note that the sample size in this study is very small, consisting of only 35 subjects. When observing the effects of SES, this study found no significant contribution to EF development. In hearing children, past studies have shown socioeconomic status is strongly correlated with language development and EF development (Hackman & Farah, 2009). In hearing children, the role of SES was a significant factor;

however, this does not appear to hold true for the deaf and hard of hearing adults with cochlear implants in this sample. One possible explanation for SES not correlating with EF performance may be a result of early intervention services. Early intervention services may compensate for low SES eliminating this as a mediating factor in development for deaf individuals. The Early Hearing Detection and Intervention Act requires a mandatory screening of all babies at the age of one month and confirmation whether the child is deaf or hard of hearing by the age of three months. By the time the deaf or hard of hearing child is six months old they are eligible for early intervention programs.

Additionally, there may be other factors that play a role in language and EF development in deaf children, such as maternal sensitivity (responsiveness to child communication) and facilitative language techniques (DesJardin & Eisenberg, 2007; Pressman, Pipp-Siegel, Yoshinaga-Itano, & Deas, 1999). Parents in both of these studies completed questionnaires regarding how they responded and facilitated language development with their child with cochlear implants. Children showed better language learning with parents who were more warm and used expansion versus those children with parents who did not use those techniques. This study did not include other measures of language development skills outside of asking when a cochlear implant was received and when they were exposed to sign language. These variables were not considered in the present study and may be a possible consideration for future studies.

Lund (2015) showed in his meta-analysis that spoken language outcomes of those with cochlear implants were widely varied with few successes, and a majority of studies failing to report positive language outcomes. In his study, he included over 52 publications looking at the age implants were received and spoken language outcomes finding that there is no indication of

better or worse outcomes. Overall, the literature on cochlear implants are still conflicted and the current study findings suggest there may be other factors that have not been considered.

Deaf adults who received cochlear implants early in life did not differ in EF skills from those who received a cochlear implant later in life. The mean age of this group was seven years (prior to seven was considered early and after seven was considered late). The results of this study add to the literature that age of implantation in deaf individuals does not have an impact on EF. However, it should be strongly cautioned that the limited sample size of college-aged adults should be considered when interpreting the results. In addition, the age of seven was used as the cutoff in the current study, and is considered past the critical period. There is no clear way based upon the previous literature to split the groups and the present study was a replication of one conducted with bilingual hearing adults in which a median split was used. All students in this study were admitted into college and the sample is not representative of deaf individuals with cochlear implants on a large scale. In the current study, we did not include a hearing or bilingual control group thus we are unable to determine if those who were implanted early or late showed a deficit in EF skills, as found in other studies (Beer, et al., 2011; Cleary et al., 2001; Conway et al., 2011; Figueras et al., 2008).

Another possibility may be due to the CTT not being sensitive enough to measure an effect of EF differences between spoken and signing populations. As mentioned earlier, the CTT is a broad measure of EF skills and includes various components. The purpose of use in this study was to do an exploratory study to see if language skills contribute to EF skills on a broad level. If for example, the CTT showed a significant difference then later studies could follow up to identify specific EF components language may or may not influence. This was done in caution because a specific EF measure (inhibition, working memory, or cognitive flexibility) may not

have detected if the language is correlated with one specific component of EF. Perhaps use of specific EF measure would have been better, but given the vast literature on EF there are multiple ways to measure this skill; however, when considering deaf populations there is sparse literature on how to best measure this and what role language, specifically, a signed language may play in EF development.

Age of exposure to sign language also did not show an impact on EF skills—those who were exposed to sign early and late did not differ in their EF performance. The mean age of exposure was seven years of age. All deaf college aged students in this study had hearing parents. Thus, it is difficult to understand the quality of sign language input given the questions asked—(e.g. what age were you exposed to sign language?). Some studies allude to the role of sign language in hearing families as a possible negative impact on environment. Knoors and Marcsark (2012) indicated that using sign language can hinder family dynamics. Also, it seems that learning sign language can be difficult for some family members, especially those who are older. There were no deaf of deaf college aged adults used in this study as controls, which means it is difficult to further understand the age of exposure in deaf with cochlear implants in comparison.

Spoken language skills in deaf adults with cochlear implants also did not show an impact on EF performance. Those who spoke well showed no difference when compared to those who did not speak well in performance on the CTT. The median score was four was used to classify individuals as high or low in spoken language proficiency. This was quite low when understanding the scale goes up to 30 correct. One must also keep in mind that this measure was a broad approach to measuring spoken language proficiency, as it required comprehension and reproduction. Any mistake in either would have resulted in a score of 0. To add to this point,

there are no studies that indicate the reliability and validity of using this type of measure with deaf individuals with cochlear implants. Another factor to consider would be determining the normal average for deaf individuals with cochlear implants. Do they perform differently than a hearing individual? Or is it measuring ability to hear rather than spoken language abilities. In previous studies specific measures of spoken language abilities are used, unlike the broad measure used in this study. It is difficult to make further conclusions or understand the impact spoken language skills have on EF performance in deaf individuals with cochlear implants.

An analysis was done for High/Low proficiency in ASL. Results indicated no difference in performance on the CTT based upon sign language skills. One must also keep in mind that four out of twenty on the ASL-SRT measure appears to be quite low (less than 20% correct). There are no current norms on how deaf adults should perform on the ASL-SRT as this test is quite new and released only a few years ago. Perhaps all of the signers in this study could be considered weak because they scored very low, but at this point it is hard to understand what difference signing skills plays in EF development. The only possible difference from this study and others was that this sample of deaf individuals with cochlear implants did not come from deaf signing families (Dye et al., 2009; Dye & Hauser, 2014). This could have been an influencing factor and one wonders if we would have seen a difference if we had included the even smaller population of deaf individuals who are born with deaf parents and receive a cochlear implant. Though, there is no current literature indicating the number of deaf individuals born to deaf parents who received a cochlear implants, one can deduce that since approximately 5-10% of deaf children have deaf parents, the sample of those who receive implants would be quite small.

One significant finding in this study was that those who spoke well did not sign well and those who signed well did not speak well. This is quite interesting because it showed that deaf individuals with cochlear implants were dominant in spoken English or ASL. In this study, we had difficulty recruiting individuals who performed well in both spoken and American Sign Language measures. One possible explanation for this difference in the current sample of deaf individuals with a CI may be due to strong opinions regarding the use of sign language while trying to teach deaf children with spoken language. Some medical professionals, researchers, and audiologists fear that learning sign language will impede spoken language success (Smith & Wolfe, 2013). The thought being if you learned sign language then this would interfere or hinder one's ability to learn spoken language. This type of encouragement is based the idea of promoting spoken language success.

Assessing individuals based upon their language skills in signing and spoken English proficiency indicated no differences. There were no differences between those who signed or spoke, nor those who were fluent in both. Lastly, there was no difference between individuals who displayed low proficiency in sign and spoken English. The method of splitting the sample into groups based on their language proficiency was replicated from Rosselli et al., (2015). In their study, they did not find differences between language groups as well. One should take into consideration that Rossellis' study had far more participants– 125 versus only 35 within the present study.

Overall, none of the variables predicted performance on the CTT measurement. Currently this fits with a previous study by Emmorey and colleagues (2008), which found that bilingual advantages do not extend to hearing adults who are proficient in a signed and spoken language. Perhaps the bilingual advantage does not extend to a visual modality. This data also fits with the

previous findings that deaf individuals who have cochlear implants do not show better cognitive performance than hearing individuals (Cleary et al. 2001; Conway et al., 2011). The main difference is that this study attempted to look at those exposed to sign language and spoken English to see if differences in EF could be attributed to language skills; however, no significance was found. Perhaps if there were more individuals who had participated in this study the results would have been different.

Limitations

This study showed that the CTT may not be a sensitive measure for the current research question. Future recommendations would be to use a more robust measure such as the one used by Bialystok (2005) that would be sensitive to group differences. Bialystok (2005) used a flanker task and this may be sensitive enough to detect differences in executive function performance. The flanker task measures specific components such as inhibition and cognitive flexibility. The measure used in this study was broad and included several components of EF. Focusing on a specific component may be beneficial because it can help us specify which components of EF are related to language.

Additionally, the sample in this study had very few balanced bilinguals (those who sign and speak well). Careful recruitment should be a focus in future studies to ensure that each group is well represented. A factor of interest would be to find deaf individuals with cochlear implants who are born to deaf signing parents—perhaps this would make a difference in further understanding the impact of early sign language experience on executive function.

Background measures should include a question related to early intervention. This may or may not be a factor to consider, however it may be worthwhile to investigate as this is a type of service all parents of deaf children receive for free, in essence removing the SES barrier that

exists for hearing children. As mentioned earlier there may be maternal sensitivity and facilitative language techniques may also play a role beyond SES within deaf children with cochlear implants. Future studies may include more intensive background questionnaires to see what type of language learning environments deaf adults with cochlear implants were raised within to see if this may correlate with language development and/or EF.

A majority of the students recruited in this sample were proficient in either sign or spoken language—which may have impacted the results. This study did not include a control group, which limits the amount of interpretation regarding language proficiency. Perhaps use of children of deaf adults (CODA's) would be a useful control group because this population grows up with exposure to sign and speech. This would help with generalization for future studies.

Conclusion

The above findings appear to indicate there are other factors playing a role in deaf EF development. Language exposure and skills do not correlate with EF development in either spoken or sign language. Modality appears to not make a difference. These findings are important to consider as they add to the literature of language abilities specifically in an auditory and visual modality. Lastly, SES did not appear to have an impact on EF development. This in itself is quite interesting as to date there are no studies examining the impact of SES in deaf children/adults. Further understanding of this issue would definitely be useful as this can lend some insight on the impact of early intervention services for children at a broader level rather than just those who are deaf. Future studies should include questions asking about early intervention services and attempt to see if there are any other factors that should be included to study EF development. The importance of these findings adds to the literature that currently exists when understanding EF development in deaf individuals. Further understanding of how

language impacts EF development can allow us to develop specific interventions on a broader level. Using the deaf population adds a unique factor of how modality may or may not play a role in language skills' impact on EF.

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Table 1

Correlation Matrix

Measures	1	2	3	4	5	6	7
1. AOI	-	-.270	.020	-.045	-.165	-.059	-.013
2. AOE	-.270	-	.200	-.170	.129	-.154	.041
3. ASL-SRT	.020	.200	-	-.537**	-.189	-.097	-.118
4. TOAL-3	-.045	-.170	-.537**	-	.398*	.244	.020
5. SES	-.165	.129	-.189	.398*	-	.039	.019
6. K-BIT	-.059	-.154	-.097	.244	.039	-	.027
7. CTT SS	-.013	.041	-.118	.020	.019	.027	-

Note. Intercorrelations for Deaf individuals with cochlear implants (n=35) are presented above.

AOI = Age of Implantation; AOE = Age of Acquisition; ASL-SRT = American Sign Language-Sentence Repetition Test; TOAL-3 = Test of Adolescent and Adult Language; SES = Social economic status; K-BIT = Kaufman Brief Intelligence Test; CTT SS = Color Trails Test

Standard Scores. * indicates a significance less than .05. ** indicates a significance less than .01.

Table 2

Language groups

Conditions	<i>n</i>	AOI <i>M</i> (<i>SD</i>)	AOE <i>M</i> (<i>SD</i>)	KBIT <i>M</i> (<i>SD</i>)	SES <i>M</i> (<i>SD</i>)	ASL-SRT <i>M</i> (<i>SD</i>)	TOAL-3 <i>M</i> (<i>SD</i>)
Balanced Bilinguals	4	7.75 (6.40)	.75 (1.50)	103.75 (20.07)	43.38 (11.26)	9.50 (1.00)	10.75 (5.68)
Sign Dominant	11	8.64 (6.71)	4.33 (5.50)	92.36 (29.65)	36.55 (10.99)	9.36 (2.38)	1.00 (1.73)
Spoken Dominant	13	9.62 (7.01)	3.25 (2.48)	99.31 (24.53)	48.89 (10.73)	.62 (.96)	13.00 (5.15)
Low Proficiency	7	6.57 (4.43)	3.00 (2.00)	99.57 (16.59)	40.14 (10.75)	3.14 (.90)	1.43 (1.81)

Note. Means and Standard Deviations for Deaf individuals with cochlear implants (n=35) are presented above. AOI = Age of Implantation; AOE = Age of Acquisition; ASL-SRT = American Sign Language-Sentence Repetition Test; TOAL-3 = Test of Adolescent and Adult Language; SES = Social economic status; IQ = Intelligence Quotient.