MODELING THE RELATIONSHIPS AMONG SUSTAINED ATTENTION, SHORT-TERM MEMORY, AND LANGUAGE IN DOWN SYNDROME

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A DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Psychology
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2017

ABSTRACT

Introduction: Language is poorer than expected given developmental level in youth with Down syndrome (DS). This study sought to determine if predictors of language difficulty in DS include sustained attention (SA) and short-term memory (STM). Specifically, I hypothesized indirect effects of SA (auditory and visual) on language (receptive and productive vocabulary and syntax) through STM (auditory and visual) controlling for age and nonverbal ability.

Method: Thirty-five youth with DS aged 10- to 22-years-old participated in this study. To measure SA, participants completed auditory and visual SARTs in which they pressed a computer key in response to non-targets and resisted pressing a key in response to the target. Outcomes were omissions (failing to respond to non-targets) and commissions (responding to the target). Span tasks were used as measures of STM, and standardized tasks were used as measures of language and nonverbal ability. For main statistical analyses, simple mediation models were run with the bootstrapping method.

Results: Potential indirect effects of auditory SA on language through auditory STM were supported by correlations, though the same was not true for the visual domain. For auditory SA, separate models were run for omissions and commissions. All nine models considering indirect effects of auditory omissions on language through auditory STM controlling for age and nonverbal ability were significant, with point estimates ranging from -.24 to -.31 and no 95% confidence intervals crossing zero. Specifically, outcomes were general language, receptive language, productive language, vocabulary, syntax, receptive vocabulary, receptive syntax,

productive vocabulary, and productive syntax. None of nine models considering auditory commissions were significant.

Discussion: SA predicts language through STM in youth with DS. Specifically, lapses in auditory SA (as indicated by increased omissions) predict poorer receptive and productive vocabulary and syntax through auditory STM. The same was not true for the inhibitory component of SA (commissions) or for the visual modality more generally. Results have immediate implications for language therapy with youth with DS. That is, addressing auditory SA in therapy could lead to improved language outcomes in DS. Thus, interventions geared toward improving auditory SA in DS should be piloted.

DEDICATION

This dissertation is dedicated to my son Given Faught, my husband Joshua Faught, and my parents Walter and Melanie Graham. Thank you Given for arriving healthy and happy midway through this project. You are my most extraordinary blessing and greatest achievement. Thank you Joshua for your constant encouragement and remarkable patience as I worked on this project. Thank you for being my best friend. Thank you Mama and Daddy for supporting me through all my endeavors. You have always stressed the importance of education, for which I am grateful. I am blessed beyond my wildest dreams to have you all in my life.

LIST OF ABBREVIATIONS AND SYMBOLS

a	Cronbach's index of internal consistency
ADHD	Attention Deficit Hyperactivity Disorder
B	Unstandardized regression coefficient
BGQ	Background questionnaire
BRIEF-2	Behavior Rating Inventory of Executive Function – Second Edition
CA	Chronological age
CELF-P-2	Clinical Evaluation of Language Fundamentals – Preschool – Second Edition
CI	Confidence interval
CPT	Continuous Performance Task
CTOPP-2	Comprehensive Test of Phonological Processing – Second Edition
d, *g*	Indices of effect size
dB	Decibel
DS	Down syndrome
EV	Expressive vocabulary
F	Fisher's *F* ratio : a ration of two variances
FXS	Fragile X syndrome
GEC	Global executive composite
GSV	Growth scale value
IHI	Intervention history interview
KBIT-2	Kaufman Brief Intelligence Test – Second Edition

M	Mean : the sum of a set of measurements divided by the number of measurements in the set
M	Mediator (where specified)
MA	Mental age
MD	Memory for Digits
N, n	Total sample size, subgroup sample size
NR	Nonword Repetition
NSID	Nonspecific Intellectual Disability
p	Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
PPVT-4	Peabody Picture Vocabulary Test – Fourth Edition
r	Pearson correlation coefficient
R^2	Explained variance
RS	Recalling sentences
SA	Sustained attention
SART	Sustained Attention to Response Test
SD	Standard deviation
SE	Standard error
SES	Socioeconomic status
SLI	Specific Language Impairment
STM	Short-term memory
TD	Typically developing
TROG-2	Test for Reception of Grammar – Second Edition
V	Moderator

WS	Williams syndrome (introduction section)
WS	Word Structure (remaining sections)
X	Predictor
Y	Outcome
=	Equal to
<	Less than
>	Greater than

ACKNOWLEDGEMENTS

Thank you so much to my advisor and dissertation chair Dr. Fran Conners and to my committee members Drs. Ansley Gilpin, Ed Merrill, Jason Scofield, and Ted Tomeny. Thank you Fran for always being positive and encouraging while challenging me to become a better researcher, teacher, and student. I could not have achieved anything in the past five years without your constant guidance. Thank you Ansley for inspiring me to start this program of study in the first place and for being my teaching role model. Thank you Ed for always helping me build a teaching resume and for allowing me to be part of your research. Thank you Jason for helping me with my very first major project as a graduate student. Thank you Ted for teaching me the ins and outs of PROCESS and so patiently answering all of my questions. Thank you all for serving on my committee and being so wonderful! I would also like to thank the University of Alabama Intellectual Disabilities Participant Registry and coordinator Eric Cooks for helping recruit participants, as well as Lani Shellhouse for helping run participants. Last but not least, I would like to thank my past and current lab mates Marie Moore Channell, Susan Loveall Hague, Allyson Phillips, Andrew Tungate, and Jenna Reardanz, as well as my constant contributor Zach Himmelberger. You guys are so much fun and made graduate school a pleasure. I am so grateful to know you all!

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CHAPTER 1

INTRODUCTION

Down syndrome (DS) is the most common cause of intellectual disability (Parker et al., 2010), leading to a host of cognitive difficulties (Fidler, 2005; Silverman, 2007). Language in general is a difficulty in DS despite much intervention geared toward improving language skills in this population. Even after training through intervention and direct instruction, there continues to be a pattern of language strengths and weaknesses in DS (Abbeduto, Warren, & Conners, 2007). Despite strengths, the culmination of difficulties contributes to a lesser ability to comprehend language and communicate basic meaning. Multiple factors may contribute to poor language and specifically trained language (that has been taught through intervention or instruction) in DS. The current study proposed predictors include sustained attention (SA) and short-term memory (STM), particularly in the auditory modality. Modeling how these constructs operate together in DS could have implications for language therapy.

In simple terms, language requires maintaining attention to both visual and auditory information. For instance, a student might attend to vocabulary words presented on a board to learn them and to others' uses of words in spoken sentences to learn the syntax surrounding them. However, it is not enough to only attend to language. Language also requires retaining visual and auditory information in STM so it may eventually be rehearsed into long-term stores. Thus, there could be an indirect effect of SA on language through STM separately in auditory and visual modalities (see Figure 1). If this proposed mediation model was empirically supported in youth with DS, it could have a variety of implications for language therapy. Past research has described the importance of addressing poor auditory STM in language therapy with youth with DS (e.g., Faught, Conners, Barber, & Price, 2016; Buckley & Le Prevost, 2002). However, addressing STM in therapy with these youth could be addressing a symptom rather than an underlying cause of poor language in DS. That is, if STM is a mediator in the relationship between SA and language, perhaps addressing both STM and SA in language therapy with youth with DS could prove more effective than addressing auditory STM alone.

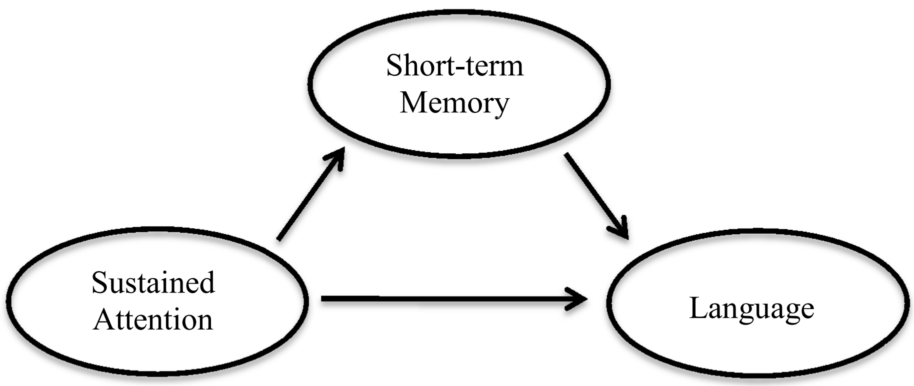

Figure 1. Relationships among SA, STM, and language: Proposed mediation model

Down Syndrome

DS is the most common cause of intellectual disability, occurring in approximately one of every 691 births in the United States annually (Parker et al., 2010). The vast majority of cases are caused by a complete triplicate of Chromosome 21 (i.e., trisomy 21) in all bodily cells. Other causes include mosaic trisomy 21 in which only some bodily cells have an extra Chromosome 21, and translocation trisomy 21 in which only an extra piece of Chromosome 21 is present in all bodily cells (Merrick, Kandel, & Vardi, 2004). Regardless of the cause, the result is a variety of physical, health, and cognitive characteristics, many of which present challenges.

Physically, individuals with DS tend to be of short stature and have specific facial characteristics, including enlarged tongues and small oral cavities that can contribute to speech difficulties (Korenberg al., 1994). Health wise, individuals with DS are at increased risks of congenital heart disease (Dykens, Hodapp, & Finucane, 2000), thyroid dysfunction (Siegfried, Pueschel, & Pezullo, 1985), certain types of cancers (Sullivan, Hussain, Glasson, & Bittles, 2007), and other diseases. Particularly troublesome, individuals with DS are prone to developing Alzheimer’s disease, which can exacerbate already existing cognitive impairments (Janicki & Dalton, 2000). Vision and hearing impairments are also common in this population (Roizen, Mets, & Blondis, 1994; Meuwese-Jongejueugd et al., 2006).

Additionally, there is a distinct cognitive profile associated with DS that includes unique patterns of memory and language. Generally, individuals with DS have better visual than auditory processing. This has particular implications for STM, with visual STM better than auditory STM in DS (Jarrold & Baddeley, 1997). However, both modalities present challenges in working memory (see Conners, Moore, Loveall, & Merrill, 2011). For language, receptive is better than productive and vocabulary is better than syntax, though productive language and receptive syntax are poorer than expected given developmental level (Næss, Halaas Lyster, Hulme, & Melby-Lervag, 2011). Lastly, individuals with DS tend to have difficulty with executive functions, a series of higher-order cognitive processes that are adaptive and goal-directed (Kogan et al., 2009; Lee et al., 2011; Rowe, Lavender, & Turk, 2006). The latest research, though, has suggested there may be a profile of strengths and weaknesses even within executive functions, which are now thought to be highly correlated rather than an unitary construct (Daunhauer et al., 2014).

Sustained Attention

SA was expected to predict language through STM in DS. It is one of three types of attention identified through neurological imaging, theoretical accounts, and factor analytic studies, with the other two being selective attention and attentional control (Manly et al., 2001;

Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991; Posner & Peterson, 1990; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996). SA is unique from selective attention, which filters stimuli entering attentional networks; and attentional control, which is a series of executive functions including goal switching and inhibition (Atkinson & Braddick, 2012).

Unlike other attentional processes, SA is the ability to maintain focus or remain vigilant to events over time, either in the auditory or visual domain. Specifically, auditory SA is the ability to maintain focus through sound, while visual SA is the ability to maintain focus through sight. Both modalities seem to draw from a central construct, as there is high agreement between auditory and visual SA task performance (Seli, Cheyne, Barton, & Smilek, 2012). This central SA is considered a fundamental requirement for cognitive development because it underlies many components of information processing, including encoding, storage, planning, and problem solving (Kung et al., 2010). Because SA underlies higher-order cognitive processes and is predominantly influenced by the right prefrontal cortex, it is thought to operate in overlap with executive functioning (Manly & Robertson, 1997; Manly et al., 2003; Molenberghs et al., 2009; Rueckert & Grafman, 1996).

SA is generally measured with one of two paradigms, either the continuous performance task (CPT) paradigm or sustained attention to response test (SART) paradigm. In the CPT paradigm, participants respond to infrequently presented targets over long periods of time, up to about 40 minutes. CPT dependent variables include number of targets detected and number of false alarms (i.e., number of responses to distracters). In the SART paradigm originally described by Robertson, Manly, Andrade, Baddeley, and Yiend (1997), participants respond to frequently presented non-targets and inhibit responses to an infrequently presented target over relatively short periods of time, as little as about 5 minutes. SART dependent variables include omission errors (omissions; i.e., failing to press a key in response to non-targets) and commission errors (commissions; i.e., pressing a key in response to the target). Omissions indicate distractions from ongoing task performance and thus lapses in SA, whereas commissions additionally indicate response inhibition difficulties (Johnson et al., 2007). Both of these paradigms indicate the duration of SA is limited, as individuals' perceptual sensitivity deteriorates when forced to remain alert over time (see meta-analysis by See, Howe, Warm, & Dember, 1995). This vigilance decrement can be exacerbated by individuals' physiological and neurological states (e.g., feeling sick or stressed, respectively; Warm, 1984). Other personal factors such as low intelligence can also limit SA duration (Tomporowski & Simpson, 1990).

Currently, there are two competing theories as to why the duration of SA is limited. Specifically, these theories attempt to explain the target detection failure in SA tasks like the CPT and SART. First, the mindlessness model proposed by Robertson and colleagues (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson et al., 1997) theorizes SA lapses are caused by task monotony and lack of exogenous attention support. Participants must therefore endogenously maintain their attention to targets but lose focus during long intervals in which targets are not present. They begin to respond automatically and make more errors as awareness disengages from the task. For SA task paradigms, it seems likely the CPT draws more on the mindlessness model than the SART, as the CPT is lengthier, requires fewer active responses, and therefore likely engages participants less than the SART (see Dillard et al., 2014).

Second, the resource depletion model theorizes SA lapses are caused by a decline in available attention resources necessary for task performance. This theory has been used to explain findings in many recent SA studies (e.g., Helton & Warm, 2008; Warm, Parasuraman, & Matthews, 2008). The basic idea is that SA tasks require participants to continuously discriminate between targets and non-targets under stressful conditions (in which participants do not know which stimulus will appear next) and with little rest. The intensity of these tasks does not allow for replenishment of cognitive resources, so they deplete over time leading to fatigue and performance declines. Given the nature of SA tasks, it seems likely both the CPT and SART draw on the resource depletion theory. This theory has particular implications for participants with reduced cognitive resources, perhaps those with intellectual disabilities. Based on this theory, individuals with intellectual disabilities might perform more poorly on SA tasks than those without intellectual disabilities, which has been found in some research (Tomporowski & Simpson, 1990).

Development of SA. To better understand how SA, STM, and language operate together, it is important to understand the development of each cognitive process. SA seems to improve across the developmental period from infancy to adolescence. However, it is important to note there are strikingly few longitudinal studies exploring SA. Rather, most past studies have relied on other methods – often analyzing cross-sectional data – to shed light on the development of SA. Thus, the development of SA is arguably poorly understood.

During infancy, Lansink and Richards (1997) proposed three phases of attention: stimulus orienting, SA, and attention disengagement. Specifically, SA in infancy is exhibited by particular electrophysical, heart rate, and behavioral responses when focus is maintained (Richards, Reynolds, & Courage, 2010). Over time, infants are thought to engage in lengthier periods of SA and be faster to enter periods of SA (see review by Reynolds & Romano, 2016). However, it is difficult to determine if this process is truly SA, as responses are typically associated with habituation and infants looking away does not necessarily reflect diminished SA (see review by Atkinson & Braddick, 2012).

It seems more likely SA becomes a primary separable component during the preschool period. In the preschool period, two attentional factors have been found instead of the usual three: executive attention and sustained selective attention (Steele, Karmiloff-Smith, Cornish, & Scerif, 2012). However, when Breckenridge and colleagues divided their sample into younger (age 3 to 4 ½ years) and older preschoolers (age 4 ½ to 6 years), older preschoolers showed a three-factor solution similar to adults. They also found SA improved over the preschool period, though other attention components showed different developmental trajectories (Breckenridge, Braddick, & Atkinson, 2013; see also Graziano, Calkins, & Keane, 2011). Interestingly, auditory and visual SA as measured with CPTs have been found to improve at similar rates from ages 3 to 6 years (Guy, Rogers, & Cornish, 2013).

Studies with school-age children have found SA to be a primary separable component of attention, as well (Kelly, 2000; Manly et al., 2001; Mirsky et al., 1991). In this period, SA continues to improve with chronological age (CA) as indicated by correlations (Cornish, Scerif, & Karmiloff-Smith, 2007). Further, Lin, Hsiao, and Chen (1999) found performance on a CPT improved substantially with increasing CA from age 6 to 15 years, consistent with the hypothesis that SA develops during school ages and adolescence (but see Betts, Mckay, Maruff, & Anderson, 2006). Interestingly, SA perhaps peaks in adolescence and declines thereafter, as indicated by CPT performance declines with increasing CA from 20 to 65 years (Chen, Hsiao, Hsiao, & Hwu, 1998). Fortenbaugh et al. (2015) found a similar decline into older adulthood, though a peak in SA in the early 40s, with a sample of over 10,000 individuals aged across the lifespan. On the other hand, SART performance appears to be more resistant to aging than CPT performance (Chan, 2001).

Sustained Attention in Down Syndrome

SA relative to developmental level. Only a few studies have considered SA in DS, and even fewer have tested SA using tasks that do not have heavy working memory loads. Studies using appropriate tasks have found that, unlike with selective attention and attentional control, youth with DS perform fairly similarly to their developmental level on SA tasks in both auditory and visual modalities (e.g., Cornish et al., 2007; Munir, Cornish, & Wilding, 2000; Breckenridge, Braddick, Anker, Woodhouse, & Atkinson, 2013).

For example, Cornish et al. (2007) and Munir et al. (2000) compared visual SA among boys with DS age 7 to 15 years, boys with fragile X syndrome (FXS) age 8 to 15 years, and typically developing (TD) boys age 4 to 10 years matched for verbal mental age (MA) as measured with receptive vocabulary. Both studies measured visual SA using the Vigilan task employed during the Wilding Attention Test for Children (Wilding, Munir, & Cornish, 2001), which requires responding to targets. In Cornish et al., groups accurately detected similar numbers of targets, suggesting SA is similar to developmental level in DS. In Munir et al., this finding was replicated and expanded. Boys with DS made fewer false alarms than boys with FXS but more false alarms than TD boys rated by teachers as having good attention. This DS vs. FXS difference can be attributed to inhibition difficulties in FXS (see Wilding, Cornish, & Munir, 2002). Perhaps the DS vs. TD difference can be attributed to slight inhibition difficulties in DS, though it should be noted the group with DS was 20 months behind in verbal MA.

Breckenridge, Braddick, Anker et al. (2013) compared youth with DS age 5 to 14 years and youth with Williams syndrome (WS) age 5 to 15 years to participants' MA-based norms on the Early Childhood Attention Battery (Breckenridge et al., 2013). This battery includes three SA subtests: visual, auditory, and dual modality. In these subtests that draw on both the CPT and

SART paradigms, participants respond to target animals over 5 minutes (visual and auditory) or 2.5 minutes (dual). Youth with DS performed similarly to their MA norms on the visual task, indicating visual SA is similar to developmental level in DS. Interestingly, though, youth with DS performed *better* than their MA norms on auditory and dual tasks despite the poor auditory processing characteristic of DS. Perhaps this pattern occurred because of comparison to MA-standardized scores rather than a MA-match control group, though youth with DS outperformed those with WS on the auditory SA task, as well.

Further, two studies utilized the SART paradigm to compare youth with DS and MA-match controls on both auditory and visual SA (Trezise, Gray, & Sheppard, 2008; Faught, Conners, & Himmelberger, 2016). First, Trezise et al. (2008) compared youth with DS to youth with nonspecific intellectual disability (NSID), both age 7 to 18 years, matched for CA and nonverbal MA. Second, Faught et al. (2016) compared youth with DS age 10 to 21 years to TD youth age 3 to 7 years matched for nonverbal MA and receptive vocabulary. In both studies' versions of the SART, researchers used eight non-target animals and one target animal (a dog). Participants were presented with animal line drawings on a computer screen for the visual SART and with animal names sounded over speakers for the auditory SART. They pressed a key when presented with any of the eight non-target animals but not when presented with the target dog.

Trezise et al. (2008) found youth with DS made similar numbers of visual omissions, auditory omissions, and auditory commissions but fewer visual commissions than youth with NSID. This suggests the ability to maintain focus as indicated by omissions is similar to CA and MA across modalities in DS, while the inhibitory component of SA is similar to CA and MA in the auditory but better in the visual modality. However, Faught et al. (2016) found youth with DS and TD youth made similar numbers of omission and commission errors in both modalities, suggesting the ability to maintain focus and the inhibitory component of SA are commensurate with developmental level in DS. Taken together, the above studies indicate SA is not a particular challenge but instead equivalent to developmental level in DS.

Development of SA in DS. Few studies have considered the development of SA in DS, and none have done so longitudinally. Perhaps this development can be inferred from studies comparing youth with DS to MA-match controls in toddlerhood, school-age years, and adolescence. Toddlers with DS may have difficulty with SA, exhibiting fewer and shorter periods of SA when compared to MA-match controls (Brown et al., 2003). However, by school-age years and adolescence, both auditory and visual SA are similar to MA comparisons (Cornish et al., 2007; Munir et al., 2000; Breckenridge, Braddick, Anker et al., 2013; Trezise et al., 2008; Faught et al., 2016). The culmination of these findings suggests improvements from toddlerhood to childhood and adolescence, as youth with DS perhaps grow to match developmental level. However, it is unclear if SA improves as a function of CA in DS. Cornish et al. (2007) found no relationship between CA and SA in school-age boys with DS. Faught (2014) found nonsignificant correlations ranging from -.31 to -.40 between CA and SART dependent variables (auditory and visual omission and commission errors) in a sample of 20 youth with DS. Breckenridge, Braddick, Anker et al. (2013) found relationships between CA and visual SA, as well as between CA and dual SA, though they did not find a relationship between CA and auditory SA in DS.

Short-Term Memory

STM was expected to mediate the relationship between SA and language in DS. It is temporary storage and retrieval of information, either in the auditory or visual domain. Specifically, auditory STM is brief memory for information heard (e.g., speech sounds), while visual STM is brief memory for information seen (e.g., writing on a board). Similar to SA, there is high agreement across modalities in STM tasks in TD samples (e.g., Carney et al., 2013), suggesting the same STM mechanisms underlie both auditory and visual STM. Even for populations that do not have high agreement across STM modalities, though, it seems both auditory and visual STM draw from a central executive (e.g., see Baddeley's multicomponent model of working memory presented below).

STM should not be confused with working memory, a traditional executive function that includes storage and retrieval *plus* simultaneous processing and manipulation. Rather, STM is a component of working memory, with the latter's additional processing component allowing information that is stored in STM to be rehearsed into long-term memory stores. STM has a highly limited capacity, with the average person being able to hold around seven (Miller, 1956) or four (Cowan, 2001) chunks of information at once. Further, because STM does not include rehearsal, forgetting occurs very quickly in this memory storage system. Much research has explored why forgetting occurs, with the two most prominent theories being decay and interference. The former theory posits memory inevitably decays over time, perhaps as quickly as one to two seconds (e.g., Baddeley & Lewis, 1984). The latter theory posits memory is interfered with by preceding (as seen with proactive interference) or subsequent (as seen with retroactive interference) events (e.g., Darby & Sloutsky, 2015).

Auditory STM is typically measured with digit or word span tasks in which participants hear sequences of digits or words and repeat them. It has also been measured with nonword repetition tasks in which participants hear nonwords and repeat them. In these tasks, the number of digits/words in sequences or phonemes/syllables in nonwords increases until performance suffers. Further, digit span and nonword repetition tasks can be combined to form a composite measure of auditory STM, as seen in the Comprehensive Test of Phonological Processing – Second Edition (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013). Similarly, visual STM is often measured with block span tasks in which participants watch an experimenter tap sequences of blocks in different spatial locations and repeat sequences immediately in the same order. Often the number of blocks in sequences increases until performance suffers. A commonly used block span task is the Corsi task (Milner, 1971).

Many theories have attempted to explain memory, though there remains one dominant and well-supported memory model that accounts for both auditory and visual STM. Baddeley's multicomponent model of working memory (Baddeley, 1986; 2000; Baddeley & Logie, 1999) proposes four components of memory: central executive, phonological loop, visuo-spatial sketchpad, and episodic buffer (see Figure 2). This model has evolved to consider language (e.g., see Baddeley, Gathercole, & Papagno, 1998) and is often used to explore STM in DS (e.g., Jarrold & Baddeley, 2001).

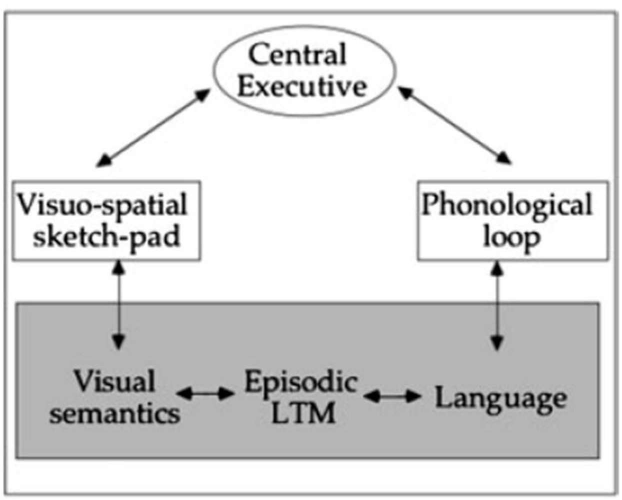

Figure 2. Baddeley's Multicomponent Model of Working Memory as shown in Baddeley (2012)

Specifically, the phonological loop is responsible for storing and processing auditory information and is composed of two subcomponents. The phonological store is the storage subcomponent (i.e., STM), while the subarticulatory rehearsal loop is the processing subcomponent (i.e., working memory). In order to remember auditory information, new information is encoded and stored for a few seconds in the phonological store before it begins to decay or is interfered. However, it can be refreshed and maintained by subarticulatory rehearsal. Evidence of this process has been found by examining the phonological similarity effect, word length effect, articulatory suppression effect, and irrelevant sound effects, among others (see review by Baddeley, 2012).

On the other hand, the visuo-spatial sketchpad is responsible for storing and processing visual information. Though Baddeley and colleagues did not theorize visuo-spatial subcomponents, subsequent researchers postulated separate components for visual and spatial information (Logie, 1995), as well as for storage (i.e., STM) and processing (i.e., working memory) (e.g., see Bruyer & Scailquin, 1998). The basic premise remains the same as with the phonological loop. That is, in order to remember visual information, this information is encoded and stored for a few seconds in a passive store before it begins to decay or is interfered. However, it can be refreshed and maintained by the processing device.

Development of Short-Term Memory. STM advances across the developmental period from childhood to early adulthood. Over school-age years, children are increasingly able to repeat longer sequences of digits and words in auditory STM tasks and blocks in visual STM tasks. Further, memory spans for auditory and visual information tend to be similar across childhood, though auditory spans become slightly longer into adolescence (Carney et al., 2013; Anderson & Lajoie, 1996; see also Baddeley, 1986). Interestingly, Hartshorne and Germine (2015) explored when multiple memory components peak in the lifespan. They found performance on digit span tasks is best from about 15 to 28 years, with a peak of approximately

22.5 years, though there was great variability in their large sample. They also found performance on block-tapping tasks is best from about 12 to 28 years, with a peak of approximately 22.5 years and little variability. In a follow-up, researchers collected data from over 10,000 participants and created cross-sectional developmental trajectories. They found span task performance generally declined following peaks, from about age 30 to 70 years. However, additional studies have found digit span is largely unrelated to age past 20 years, but word span decreases with increasing age (Fisk & Warr, 1996). Overall, though, it seems STM and SA develop similarly, with peaks in adolescence and early adulthood and declines thereafter.

Short-Term Memory in Down Syndrome

STM relative to developmental level. Unlike with SA, many studies have examined STM in DS using digit, word, and block span tasks, as well as nonword repetition tasks. These studies have found participants with DS perform below their developmental level on auditory STM tasks but at developmental level on visual STM tasks. This finding aligns with the poorer auditory than visual processing characteristic of DS more generally (see reviews by Fidler, 2005; Silverman, 2007; Davis, 2008). It should be noted that individuals with DS have difficulty completing working memory tasks given special challenges in both modalities. Further, STM has consistently been considered in the context of language in DS. Thus, to obtain valid data and link memory to language in DS, examining STM is perhaps more appropriate than examining working memory for the purposes of this study.

Auditory STM is a well-documented difficulty in DS (see reviews by Conners, 2003; Jarrold & Baddeley, 2001; Jarrold, Baddeley, & Phillips, 1999). Specifically, auditory STM is poorer than expected given developmental level in DS, as youth with DS consistently perform poorer than TD MA-match controls on digit and word span tasks (e.g., Abdelhameed & Porter, 2010; Brock & Jarrold, 2005; Frenkel & Bourdin, 2009; Jarrold & Baddeley, 1997; Kanno & Ikeda, 2002; Seung & Chapman, 2000; Jarrold, Baddeley, & Hewes, 2000; Vicari, Marotta, & Carlesimo, 2004). They also perform poorer than TD MA-match controls on nonword repetition tasks (e.g., Abdelhameed & Porter, 2010; Cairns & Jarrold, 2005; Laws & Bishop, 2003; Fabbro, Alberti, Gagliardi, & Borgatti, 2002; Costanzo et al., 2013). In fact, a meta-analysis of 15 studies comparing auditory STM in youth with DS and TD MA-match controls reported an aggregate effect size of $g = -1.24$, indicating youth with DS performed over one standard deviation below TD youth (Næss et al., 2011). Further, youth with DS perform poorer on auditory STM tasks than youth with other intellectual disabilities, indicating auditory STM is a special challenge in DS (e.g., Jarrold, Baddeley, & Hewes, 1999; 2000; Wang & Bellugi, 1994).

On the other hand, visual STM is as expected given developmental level in DS, as youth with DS consistently perform similarly to TD MA-match controls on block span tasks (e.g., Brock & Jarrold, 2005; Visu-Petra, Benga, Ţincaş, & Miclea, 2007; Jarrold & Baddeley, 1997; see review by Yang, Conners, & Merrill, 2014). Much research has investigated the cause of poor auditory relative to visual STM in DS, but no clear picture has emerged (Brock & Jarrold, 2004; Jarrold et al., 2000; Purser & Jarrold, 2005; 2013; Vicari et al., 2004; Faught et al., 2016).

Development of STM in DS. Fortunately, a number of longitudinal studies have explored the development of STM in DS unlike as seen with SA. Longitudinal studies including school-age children with DS have found auditory STM improves during this period. For example, Byrne, MacDonald, and Buckley (2002) found digit span improved over two years in children with DS age 4 to 12 years. Næss, Lervåg, Lyster, and Hulme (2015) found 6-year-olds with DS were unable to score above floor level on a nonword repetition task but able to do so by age 7 years and improved further by 8 years. Laws and Gunn (2004) also found nonword repetition improved over five years in children with DS age 5 to 13 years (see also Kay-Raining Bird, Cleave, & McConnell, 2000).

On the other hand, a longitudinal study by Hick, Botting, and Conti-Ramsden (2005b) found contrasting results to those reported above (see also Cupples & Iacono, 2000). Hick et al. compared both auditory and visual STM between youth with DS age 8 to 11 years and a TD MA-match group age 3.5 to 5 years at three time points, with six-month intervals between each time point. Researchers found auditory STM did not improve over time in youth with DS as it did in TD children, but visual STM did improve slightly over time in youth with DS but less so than in TD children.

By adolescence, auditory STM development might plateau or even decline in DS. For example, Mackensie and Hulme (1987) found digit span plateaued over two years in youth with DS age 9 to 16 years. Laws and Gunn (2004) found digit span and nonword repetition plateaued over five years in their complete sample aged 5 to 19 years; interestingly, 16 of 22 older participants aged 14 to 19 years declined (see also Chapman, Hesketh, & Kistler, 2002). In their sample of 39 adolescents with DS aged 10 to 21 years, Conners, Tungate, Abbeduto, Merrill, and Faught (under review) found nonword repetition declined over two years and digit span declined among older adolescents. Into adulthood, auditory (digit span) and visual STM appear to be stable in DS. Devenny et al. (1996) found neither skill declined over five years in adults with DS age 31 to 63 years.

Of course, several cross-sectional studies have also explored the development of STM in DS. For example, Carney et al. (2013) used Thomas et al.'s (2009) method to perform cross-sectional developmental trajectories of word span and block span over CA. Slopes of youth with DS age 10 to 21 years were compared to those of a TD MA-match group age 4 to 9 years.

Researchers found both auditory and visual STM improved as a function of increasing CA in DS. They also found visual STM performance was consistently better than auditory STM performance in DS, though performance in both modalities increased with CA at similar rates.

Relationship Between Sustained Attention and Short-Term Memory

Given the nature and development of SA and STM in DS, there is perhaps a direct relationship between these two cognitive processes separately for auditory and visual modalities. Unfortunately, little to no recent research has explored this relationship even in TD samples. Rather, studies have focused on the relationship between SA and working memory. These studies required participants to complete SA tasks in conjunction with secondary tasks that have varying degrees of working memory loads and found that even low loads disrupt SA task performance. Findings suggest SA and working memory utilize common executive resources and thus are dependent upon one another (e.g., Caggiano & Parasuraman, 2004; Helton & Russell, 2011; 2013; 2015). Considering these findings, it seems as though a relationship should exist between SA and working memory's storage and retrieval component, STM, as well.

One known study confirmed this notion. Faught (2014) found significant correlations between SA (as measured by the SART) and STM (as measured by span tasks) for both youth with DS and TD youth. For youth with DS, moderate correlations were found between auditory and visual omission errors and STM (see Table 1). Specifically, as SART errors decreased and SA improved, STM also improved. Results suggest a relationship between the ability to maintain task focus (as indicated by omissions) and STM. Somewhat weaker correlations were found between commission errors and STM, suggesting the inhibitory processing component of SA is perhaps not as strongly related to STM in DS.

Table 1

Correlations between SA and STM in a sample with DS (N =20)

	Auditory Omission Errors	Visual Omission Errors	Auditory Commission Errors	Visual Commission Errors
Digit span	-.39	-.51*	-.26	-.49*
Block span	-.47*	-.55*	-.32	-.31

Note. *p<.05

Given moderate correlations between SA and STM in DS, Faught et al. (2016) attempted to determine if SA accounted for variance in STM beyond the influence of group membership (DS vs. TD), nonverbal MA, and receptive vocabulary in the same sample presented above. To do so, this study ran separate regression analyses for each modality (auditory and visual). For auditory STM, control variables accounted for 68.5% of variance, and auditory omission errors added an additional 4% of unique variance; this finding approached statistical significance. For visual STM, control variables accounted for 49.6% of variance, and visual omission errors added an additional 6% of unique variance; this finding reached statistical significance. Commission errors did not add significantly beyond control variables. Results suggest the ability to maintain focus predicts STM. However, the mechanism underlying this relationship is unclear – whether improved SA enables better STM task performance or whether improved SA from early childhood enables better memory development.

Language and Language Development

Language is a uniquely human method of communication. There are two types of language, receptive and productive. Receptive language, the ability to comprehend language, precedes productive language, the ability to express language. For example, infants begin to comprehend words around 6 to 10 months of age, while they do not begin to produce words until around 10 to 15 months of age. Within both types of language, sounds are combined to form words, which are combined to form sentences, which are combined to form stories, conversations, etc. Thus, there are four subcomponents of language: phonological, semantic, syntactic, and pragmatic.

Semantic and syntactic development are particularly important to the aims of this study. Semantic development is central to understanding the meaning of language, including vocabulary words. Syntactic development is central to learning the rules for combining words into sentences, or syntax. Vocabulary acquisition precedes syntactical development. For example, children begin to produce words around 10 to 15 months, while they do not begin to combine words into sentences until about 24 months. Even then, these sentences are very simple, often consisting of a couple of words and excluding nonessential elements (i.e., telegraphic speech). However, by approximately age 5 years, children are capable of producing novel sentences that are grammatically correct. Of course, language becomes more refined into adulthood with education and a variety of cultural experiences.

Natural language development is thought to be largely automatic. This idea is central to the nativist approach to language development advocated by Chomsky and others. The nativist approach posits humans are born with an innate capacity for language, and this capacity includes implicit knowledge of properties common to all languages (i.e., a universal grammar). This idea is also central to the emergentist approach (see review by Abbeduto & Boudreau, 2004), which expanded upon the nativist approach by considering that language is *learned* in a process of determining which properties of language regularly co-occur. This learning is implicit, without intention or awareness, an idea that has been supported with syntactic development (e.g., Shultz & Bale, 2001). The statistical learning model of language acquisition also supports the notion that language is learned implicitly, as it posits infants learn language through learning statistical regularities in language (e.g., Saffran & Wilson, 2003; see also Perruchet & Pacton, 2006).

Given the idea that language is largely learned implicitly, it seems as though populations with language impairments could have implicit learning deficits. This notion has been supported in past studies (e.g., Klinger, Klinger, & Pohlig, 2007). Additional studies have found youth with DS in particular fail to show implicit learning in scenarios where TD youth show implicit learning (e.g., Klinger & Dawson, 2001). However, language can also be refined through more explicit or effortful learning in DS, or trained through direct instruction and language intervention. *Trained* language was considered in this study, or language that has been taught through direct instruction (as seen in schools) or intervention (as seen with speech-language pathologists). Trained language was of particular importance to this study given a sample of school-age children and adolescents with DS who had been taught language through instruction and intervention, rather than infants and toddlers with DS who were less likely to have been taught language. Of course, in considering trained language, it is impossible to tease apart the influence of naturally acquired language.

Language in Down Syndrome

Language in general is delayed in DS, despite intensive early interventions that are commonly utilized in this population. For instance, naturalistic language approaches for young children with DS are regularly administered, though randomized control trials have not found these methods to improve scores on standardized language measures (e.g., Kaiser & Roberts, 2013). Direct approaches with older children with DS have proven mildly effective in improving productive vocabulary for taught words (Burgoyne et al., 2012); syntax, semantics, and morphology (Sepúlveda, López□Villaseñor, & Heinze, 2013); productive syntax (Fawcett & Virji-Barbul, 2006; Hewitt, Hinkle, & Miccio, 2005; Schoenbrodt, Eliopoulos, & Popomaronis, 2009); and receptive language more generally (Lecas, Mazaud, Reibel, & Rey, 2011). Further, many studies have suggested the importance of addressing STM limitations (particularly auditory) in language interventions with individuals with DS (e.g., Buckley & Le Prevost, 2002; Yoder & Warren, 2004; Hewitt et al., 2005; Kumin, 2008; McDuffie, Chapman, & Abbeduto, 2008; Chapman, Sindberg, Bridge, Gigstead, & Hesketh, 2006; Burgoyne et al., 2012; Fawcett & Virji-Babul, 2006; Lecas et al., 2011; Sepúlveda et al., 2013). However, only one known study actually tested the effectiveness of auditory STM support in a language acquisition task in DS, and results were partly promising (Chapman et al., 2006).

Overall, these interventions have proven mildly effective at best, perhaps because the cause of delayed language in DS is poorly understood. Past research has discovered, though, that there is a distinct pattern of relative strengths and weaknesses in the DS linguistic profile (see reviews by Abbeduto et al., 2007; Chapman 2003; Fidler, Philofsky, & Hepburn, 2007; Martin, Klusek, Estigarribia, & Roberts, 2009; Roberts, Price, & Malkin, 2007; Ypsilanti & Grouois, 2008). Specifically, this profile includes better receptive than productive language and better vocabulary than syntax. However, relative to their developmental level, individuals with DS have poor productive vocabulary, productive syntax, and receptive syntax (e.g., Abbeduto et al., 2003; Finestack, Sterling, & Abbeduto, 2013; Martin, Losh, Estigarribia, Sideris, & Roberts, 2013). For example, with productive syntax, individuals with DS produce less complex noun phrases, verb phrases, and sentence structures than TD MA-match controls (Price et al., 2008).

Interestingly, receptive vocabulary is as expected given developmental level in DS, suggesting it is a relative linguistic strength. For instance, Næss et al. (2011) performed a meta-analysis of 15 studies comparing language skills in youth with DS and TD MA-match controls. This study reported an aggregate effect size of g = -.51 (when outlier excluded) for productive vocabulary and $g = -1.03$ for receptive syntax, indicating children with DS performed one-half and one standard deviation below MA-match controls on these skills respectively. On the other hand, the effect size for receptive vocabulary ($g = -.22$) was not significant, indicating children with DS performed similarly to MA-match controls. Despite this relative strength, poor syntax contributes to difficulty with comprehension, and poor productive language limits youth with DS to speaking only brief statements that communicate basic meaning.

Development of Language in DS. A variety of longitudinal studies have considered language development in DS. Perhaps unlike SA and STM, different language skills develop inconsistently and some even atypically in DS from toddlerhood to adulthood. In toddlerhood and preschool years, vocabulary seems to increase as a function of age. For example, Zampini and D'Odorico (2011) found young children with DS increased their single-word utterances from age 2 to 3 years and 3 to 4 years. They also found children increased the frequency and length of their word combinations from age 3 to 4 years, perhaps suggesting syntax to some degree might also improve during this period. Zampini, Salvi, and D'Odorico (2015) additionally found toddlers with DS improved in both receptive and productive vocabulary over six months as measured by the MacArthur-Bates Communicative Development Inventory.

School-age children and adolescents with DS continue to improve in receptive and productive vocabulary. For example, Næss et al. (2015) found children with DS experience improved vocabulary from age 6 to 8 years. Hick et al. (2005b) found receptive and productive vocabulary improve over one year in children with DS age 8 to 11 years. Additional research on receptive vocabulary into adolescence found improvements, as well. For example, Laws and Gunn (2004) found youth with DS age 5 to 19 years at Time 1 experienced increased receptive vocabulary across all ages. Mackensie and Hulme (1987) found receptive vocabulary improved over two years in youth with DS age 9 to 16 years. In their sample of 39 adolescents with DS age 10 to 21 years, Conners et al. (under review) found receptive vocabulary improved over two years. However, they also found productive vocabulary plateaued among younger adolescents and actually declined among older adolescents.

Syntactical development tends to show a different trajectory than vocabulary development in school-age children and adolescents with DS. Receptive syntax in particular shows modest improvement in school-age years and perhaps declines into adolescence. For example, Næss et al. (2015) found more modest increases in receptive syntax than vocabulary from age 6 to 8 years. Laws and Gunn (2004) also found modest increases in receptive syntax in their sample, with only a three-month gain in this skill over five years in youth with DS age 5 to 19 years. Byrne et al. (2002) found receptive syntax improved over one year but plateaued the following year in children with DS age 4 to 12 years. Conners et al. (under review) found receptive syntax plateaued over two years in youth with DS age 10 to 21 years. Chapman et al. (2002) found receptive syntax actually declined in DS into late adolescence and young adulthood.

On the other hand, productive syntax might plateau in school-age years and adolescence. For example, Kay-Raining Bird et al. (2000) found productive syntax plateaued over three years in children with DS age 6 to 11 years (see also Fowler, Gelman, & Gleitman, 1994). Conners et al. (under review) found productive syntax as measured by mean length of utterance plateaued among younger adolescents and declined among older adolescents in their sample age 10 to 21 years. Chapman et al. (2002) found contrasting results suggesting productive syntax improved modestly over six years in youth with DS age 5 to 20 years.

Adults with DS generally do not experience gains in vocabulary as seen in younger ages, and little is known about their syntax. Receptive vocabulary might improve into adulthood, though this seems to depend on environment and opportunity. For example, Berry, Groeneweg, Gibson, and Brown (1984) found this skill improved over five years in adolescents and adults with DS age 15 to 41 years who were in a rehabilitation program. Interestingly, Carr (2000) found receptive vocabulary generally did not improve over nine years in adults with DS age 21 to 40 years, though it did in a subset that was raised at home with higher socioeconomic status (SES). However, Burt et al. (1995) found no improvement over 4.5 years in community-dwelling adults with DS age 22 to 56 years. Productive vocabulary seems to remain stable during adulthood, as well. For example, Carr (2000) found productive vocabulary pleateaued over nine years in adults with DS age 21 to 40 years even in their subset raised at home with higher SES. Burt et al. (1995) again found no improvement over 4.5 years in community-dwelling adults with DS age 22 to 56 years.

Overall, it would seem the DS linguistic profile of poor productive language and receptive syntax relative to receptive vocabulary and developmental level becomes prominent in school-age years and adolescence. This profile occurs despite widespread early language intervention in DS and continued intervention through public schools and private sectors. Thus, it could be argued this profile is seen in *trained* language in DS. Unfortunately, causes of language difficulties in DS remain poorly understood. The current study proposed SA and STM are among contributors to the DS linguistic profile.

Predicting Language in Down Syndrome

Language requires attending to auditory and visual information about vocabulary and syntax. For instance, maintaining focus to sequences of speech sounds is essential to developing language, as well as maintaining focus to visual presentations of vocabulary words and syntax during instruction and intervention. Further, maintaining focus to both auditory and visual information is essential to performance on language measures, as many language tasks rely on participants pointing to pictures that correspond to spoken words and sentences. Thus, it seems both auditory and visual SA should predict language in DS. Language then requires briefly storing the attended information in STM to build a vocabulary and understand how order of speech sounds and words affect larger meaning. Further, similar to SA, briefly remembering both auditory and visual information is essential to performance on language measures. It has been well established that auditory STM and less so visual STM predict language in DS. Given this information combined, it seemed as though there could be an indirect effect of SA on language through STM, as STM is the key variable between simply attending to language and actually acquiring language. To better understand how all three constructs operate together in DS, though, it is important to consider how SA and STM operate independently to influence language (i.e., consider the direct effects of SA and STM on language) in DS and other populations.

SA predicting language. Little research has directly explored the relationship between SA and language, either in general or in DS samples. A recent study addressed this relationship directly in TD adults. Jongman, Roelofs, and Meyer (2015) used an individual differences approach to explore the contribution of SA to language production. They found both auditory and visual SA as measured with CPTs were related to productive language as measured by picture description latencies. Specifically, individuals with poorer SA showed an increased number of slow responses (i.e., slow phrase productions) relative to individuals with better SA. Thus, both auditory and visual SA perhaps allow for more efficient language production.

Additional studies have found correlations between SA and language in TD and DS samples. For instance, Gardner-Neblett, DeCoster, and Hamre (2014) found TD preschoolers' language was related to their visual SA. That is, making fewer errors on a visual CPT was related to improved productive and receptive language in this group (see also Faught, 2014). More importantly, though, Faught (2014) found relationships between receptive vocabulary and each of the auditory and visual SART variables in youth with DS: auditory omission errors, $r = -.41$, visual omission errors, $r = -.43$, auditory commission errors, $r = -.34$, and visual commission errors, $r = -.52$. Thus, it would seem both the ability to maintain focus to task performance and the inhibitory component of SA are related to receptive vocabulary in DS. However, receptive vocabulary is not representative of this population's overall language ability, as this skill tends to be a relative linguistic strength in DS.

Interestingly, auditory and visual SA have also been found to improve with increasing receptive vocabulary in DS at a similar rate as seen in TD youth. Faught et al. (2016) used Thomas et al.'s (2009) method to perform cross-sectional developmental trajectories of SART omission errors over Peabody Picture Vocabulary Test – Fourth Edition (PPVT-4) growth scale values (GSVs; see Dunn & Dunn, 2007). Slopes of youth with DS were compared to those of TD youth matched for nonverbal ability and receptive vocabulary. Researchers found both auditory and visual omission errors decreased as a function of increasing GSV scores, with similar rates between the group with DS and TD group (see Figure 3, 4). Thus, as the ability to maintain focus to task performance improved (as indicated by fewer omissions), receptive vocabulary improved. This finding suggests SA predicts language to some extent in DS, though again receptive vocabulary is not representative of overall language ability in DS.

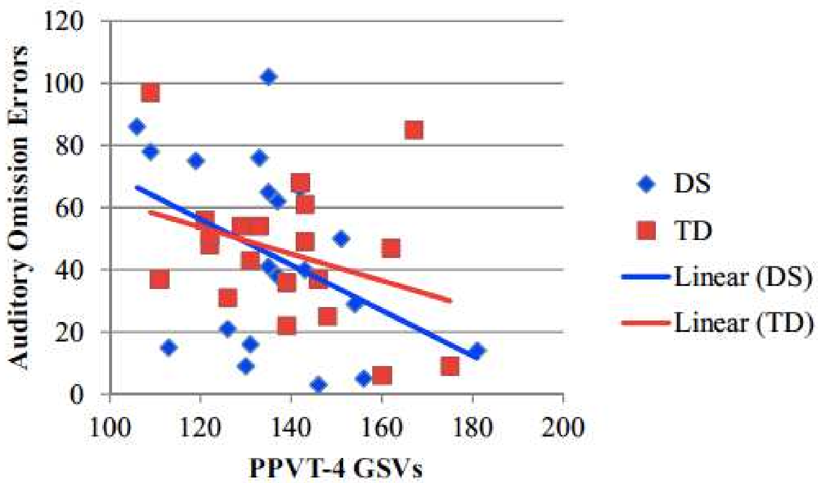

Figure 3. Faught et al.'s trajectories of auditory SA over receptive vocabulary in DS vs. TD

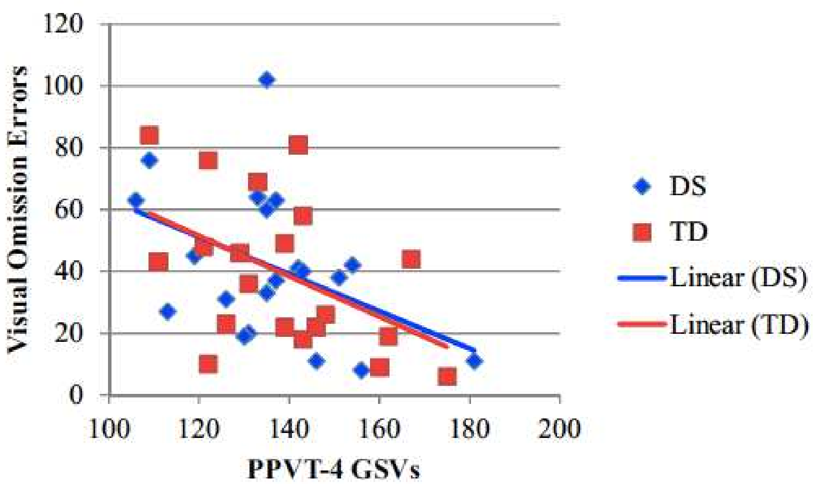

Figure 4. Faught et al.'s trajectories of visual SA over receptive vocabulary in DS vs. TD

Studies with Specific Language Impairment. Most available studies indirectly addressed the topic of SA predicting language by comparing SA in TD youth and youth with specific language impairment (SLI) matched for CA. Youth with SLI have heterogenous language impairments that cannot be attributed to other disabilities (e.g., learning or intellectual disabilities). Thus, in these studies, if SA was found to be poorer in youth with SLI than in TD youth, an argument could be made that SA in some way predicts language.

This pattern of youth with SLI performing worse than TD youth on SA tasks was found in the auditory domain (e.g., Duinmeijer, de Jong, & Scheper, 2012; Montgomery, 2008; Montgomery, Evans, & Gillam, 2009). Duinmeijer et al. (2012) additionally found a significant positive correlation between auditory SA and productive language as measured by generation of plot elements when telling a story in youth with SLI. Montgomery and colleagues additionally found a relationship between auditory SA and receptive syntax as measured by processing of simple and complex sentences in youth with SLI. Specifically, SA as measured by an auditory CPT accounted for 45% of unique variance in sentence processing performance in youth with SLI but not TD youth (Montgomery, 2008; Montgomery et al., 2009). Thus, it would seem auditory SA is related to both productive and receptive language, though this relationship might be indirect.

The pattern of youth with SLI performing worse than TD youth on SA tasks was also found in the visual domain (e.g., Finneran, Francis, & Leonard, 2009). A meta-analysis of 28 studies comparing visual SA in youth with SLI and TD youth reported an aggregate effect size of $g = .47$, indicating youth with SLI performed nearly half a standard deviation below TD peers (Ebert & Kohnert, 2011). However, this meta-analysis also showed auditory-linguistic and auditory-nonlinguistic SA impairments in youth with SLI were larger than that for visual SA (*g*s = .82 and .61, respectively). Thus, it would seem visual SA is related to language, though again this relationship might be indirect and perhaps weaker than that between auditory SA and language. Studies in this field have even gone so far as to suggest intensive intervention may improve language in SLI in part through SA improvements (e.g., Gillam et al., 2008; Gillam, Crofford, Gale, & Hoffman, 2001; Ebert & Kohnert, 2009).

STM predicting language. Much research has directly explored the relationship between STM and language in DS and other populations, particularly in the auditory domain. Auditory

STM has a well-established link to language in TD samples. For instance, it has consistently been related to vocabulary knowledge and acquisition (e.g., Bowey, 2001; Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie, & Baddeley, 1992; Jarrold, Thorn, & Stephens, 2009; Michas & Henry, 1994; Gathercole, Hitch, Service, & Martin, 1997). Further, auditory STM is related to productive language more generally in TD samples (e.g., Adams & Gathercole, 1995; 1996).

Auditory STM also has a well-established link to language in DS samples, even after controlling for nonverbal ability. For receptive language, auditory STM is correlated with vocabulary and syntax (Iacono, Torr, & Wong, 2010; see also Laws, 1998). Further, auditory STM significantly predicts receptive syntax (Chapman et al., 2002), and accounts for a great deal of unique variance (i.e., 19% - 27%) in multiple measures of receptive vocabulary and syntax (Miolo, Chapman, & Sindberg, 2005). For productive language, auditory STM is correlated with syntax measures and mean length of utterance (Laws, 2004). Further, auditory STM significantly predicts productive syntax (Chapman et al., 2002), with group membership (DS, FXS, or TD), nonverbal MA, and auditory STM combined accounting for 56% of variance in productive syntax (Estigarribia, Martin, & Roberts, 2012). Interestingly, some studies have even found early auditory STM predicts later language skills in DS. For example, Laws and Gunn (2004) found early nonword repetition predicted receptive vocabulary (in their whole sample) and syntax (in a subset of younger participants) in a longitudinal study over five years.

Visual STM is also related to language in DS, though perhaps not to the same extent as auditory STM. For receptive language, visual STM is correlated with vocabulary and syntax. However, these relationships are weaker when controlling for daily functioning and nonverbal ability. For productive language, visual STM is correlated with mean length of utterance even after controlling for daily functioning and nonverbal ability (Iacono et al., 2010). Similar to auditory STM, visual STM also significantly predicts receptive and productive syntax (Chapman et al., 2002; see also Baddeley, 2003; but see Miolo et al., 2005).

Studies with Specific Language Impairment. Additional studies indirectly addressed the topic of STM predicting language by comparing STM in TD youth and youth with SLI matched for CA. Similar to SA studies, if STM was found to be poorer in youth with SLI than in TD youth an argument could be made that STM in some way predicts language. This group difference in auditory STM is consistently found (e.g., Lum, Conti-Ramsden, Page, & Ullman, 2012; Nickisch & von Kries, 2009). In fact, youth with SLI demonstrate such a severe deficit in auditory STM that it is a clinical marker for SLI (Bishop, North, & Donlan, 1996; Conti-Ramsden, 2003; Conti-Ramsden, Botting, & Farragher, 2001; Gathercole & Baddeley, 1990). These findings again suggest a link between auditory STM and language.

On the other hand, differences in visual STM between TD youth and youth with SLI are not consistently found. Some studies have found youth with SLI show slower development on pattern recall tasks than TD youth and youth with DS (Hick, Botting, & Conti-Ramsden, 2005a; 2005b). Interestingly, Nickisch and von Kries (2009) found youth with receptive-expressive SLI, but *not* expressive only SLI, performed worse on symbol sequence tasks than TD youth. This study suggests visual STM might be more strongly related to receptive rather than productive language. Further, a meta-analysis of 21 studies comparing visual STM in TD youth and youth with SLI reported an aggregate effect size of $d = .49$ for visual STM tasks, indicating TD youth performed about half a standard deviation above youth with SLI (Vugs, Cuperus, Hendriks, & Verhoeven, 2013). Importantly, Vugs et al. (2013) also ran moderator analyses and found poorer visual STM was associated with more pervasive language impairment in SLI. However, some studies found no differences between TD youth and youth with SLI on visual STM tasks (Lum et al., 2012; Baird, Dworzynski, Slonims, & Simonoff, 2010). Thus, visual STM may not be as strongly related to language as auditory STM, but the idea that visual STM could account for some variance in language in DS is worth exploring.

The Current Study

Despite research on each construct, no studies have modeled how all three cognitive / linguistic constructs – SA, STM, and language – operate together in DS. A number of studies have considered how pairs of constructs are linked, particularly in the auditory domain. Based on past research in DS, it seems there is a direct effect of SA on STM (e.g., Faught et al., 2016) and of STM on language (e.g., Chapman et al., 2002), while perhaps an indirect effect of SA on language (e.g., Ebert & Kohnert, 2011) *through* STM. Understanding how all three constructs operate together in DS is hugely important, particularly for language therapy. It could be argued that language therapy has been largely ineffective in DS given that language intervention is widely utilized in this population, but youth with DS consistently demonstrate language deficits across the lifespan. Thus, perhaps a better understanding of how SA and STM operate together to influence language in DS could lead to development of evidence-based practices that address all three constructs in language therapy.

The current study proposed to model how SA, STM, and language operate together in DS. Youth with DS completed a battery of cognitive tasks, including those that measured auditory and visual SA and STM, as well as receptive and productive vocabulary and syntax. Their parents reported on youths' backgrounds, executive functions, and language intervention histories. These variables were considered in the context of a mediation model that was broken down into subcomponents to more closely examine the unique influences of auditory and visual modalities, productive and receptive language, and vocabulary and syntax.

Hypotheses

The current study hypothesized there would be an indirect effect of SA on language through STM in youth with DS after controlling for age and nonverbal ability. This general hypothesis was based on previous research that found SA predicts STM, SA predicts language, and STM predicts language separately in DS. When considered all together, this general hypothesis was based on the conceptual notion that one must attend to and then remember vocabulary words and syntax (whether presented auditorily or visually) in order to learn language. Specifically, based on this general model, the current study hypothesized the following subcomponents:

1. There would be an indirect effect of SA on language through STM separately for auditory and visual modalities after controlling for age and nonverbal ability (see Figure 5). Considering modalities separately was important, as auditory and visual modalities are distinct in their relationships with cognition in DS (Wang & Bellugi, 1994), and youth with DS consistently demonstrate poorer auditory than visual processing and STM (see review by Fidler, 2005; Jarrold & Baddeley, 1997).

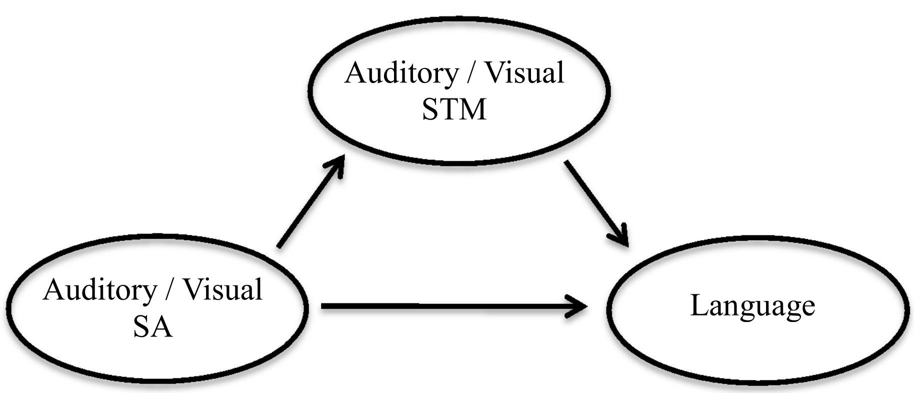

Figure 5. Proposed mediation model separately for auditory and visual modalities

2. There would be an indirect effect of SA on language through STM separately for receptive and productive language after controlling for age and nonverbal ability (see Figure 6). Considering language components separately was important, as youth with DS consistently demonstrate poorer receptive than productive language (e.g., Abbeduto et al., 2007).

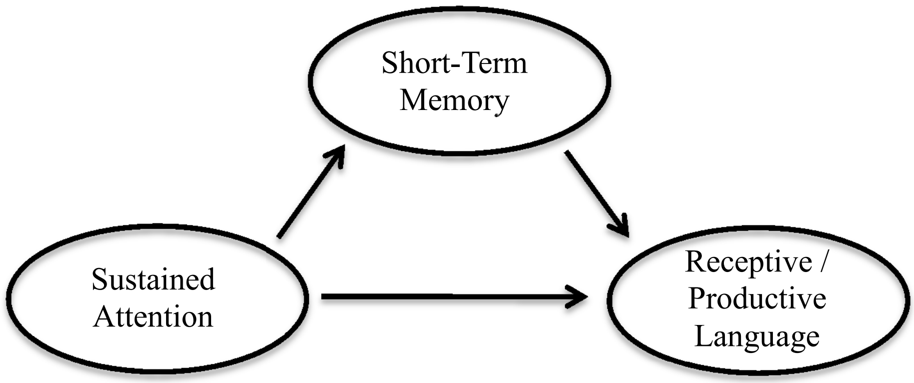

Figure 6. Proposed mediation model separately for receptive and productive language

3. There would be an indirect effect of SA on language through STM separately for vocabulary and syntax after controlling for age and nonverbal ability (see Figure 7). Considering language components separately was important, as youth with DS consistently demonstrate poorer syntax than vocabulary (e.g., Abbeduto et al., 2007).

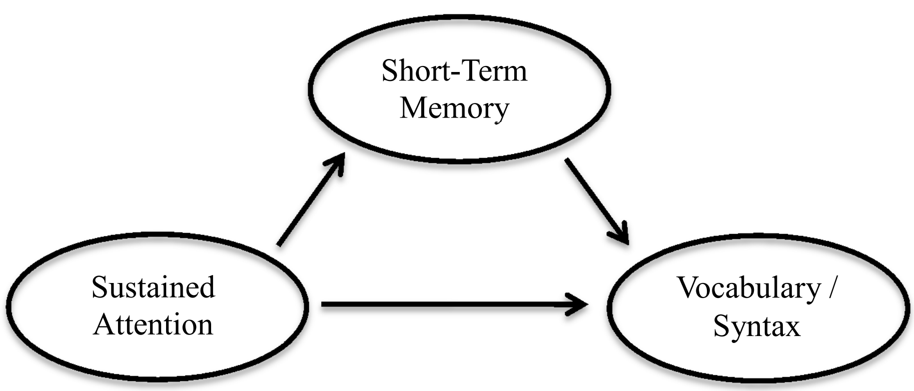

Figure 7. Proposed mediation model separately for vocabulary and syntax

Exploratory Hypotheses. In addition to the primary hypothesis and its subcomponents above, I hypothesized:

4. Parent report of executive functioning would account for variance in the proposed models, as SA operates in overlap with executive functions and STM is a component of a traditional executive function (i.e., working memory).
5. Parent report of language intervention history would moderate paths from STM to language, as well as from SA to language, in DS. Thus, there would be conditional indirect effects of STM on language and of SA on language, dependent upon language intervention history. Specifically, the magnitude of STM and SA's effects on language would increase at high levels of language intervention history.

CHAPTER 2

METHODOLOGY

The current study investigated relationships among SA, STM, and language in youth with DS. Both auditory and visual SA and STM were considered, as well as receptive and productive vocabulary and syntax, in the context of a mediation model. Specifically, I predicted an indirect effect of SA on language through STM.

Participants

Youth with DS. Thirty-five youth with DS age 10 to 22 years (*M* = 15.94; *SD* = 3.37) participated in this study. Fifteen participants were male and 20 were female. Twenty-nine participants were White, four were White-Hispanic, one was Black, and one was Italian. See Table 2 for additional demographic information. One of these 35 participants was unable to complete the visual SART, TROG-2, and CELF-P-2 RS subtest because of behavior problems, but this participant's data was otherwise included in relevant analyses to maximize power. Ultimately, this sample size was estimated to detect large effects in mediation with .80 power (Fritz & MacKinnon, 2007), was in the conventional range of *N* = 20 - 60 for bootstrapping methods (Shrout & Bolger, 2002), and successfully identified mediation in past studies (e.g., Channell, Loveall, & Conners, 2013). This age range was chosen because school-age years and adolescence are times when the DS cognitive-linguistic profile is prominent.

Table 2

Additional demographic information for youth with DS (N = 35)

YOUTH WITH DS			
Additional Diagnoses			
Attention Deficit Hyperactivity Disorder	5, *4 taking medications		
Epilepsy	2		
Learning Disability	8		
Sleep Apnea	10		
Specific Language Impairment	6		
Other	3		
Schooling Information			
Type of School Attending (select one)		**Education Programming (select all that apply)**	
Public	22	Regular Classroom	14
Private	2	Special Education Classroom	21
Residential School	2	Resource Room	8
Other	5	Home Instruction	6
N/A (Graduated)	4	Other	3
		N/A (Graduated)	4

Youth with DS were recruited from the University of Alabama Intellectual Disabilities Participant Registry. Participants of all sexes, races, socioeconomic statuses, and other demographic characteristics who agreed to participate were included. Upon recruitment, parents of youth with DS were asked if their children had accompanying diagnoses of Autism Spectrum Disorders. Autism symptomology could have confounded results, so youth whose parents reported these diagnoses were not eligible to participate in the study. Parents were also asked if their children had sufficient verbal skills to complete language measures. Youth whose parents reported their children were nonverbal were not eligible to participate in the study. Otherwise, minimal performance criteria were enforced throughout testing to allow for the broadest and most representative sample possible.

Further, youth with DS were required to pass vision and hearing screens before participating in this study. The symbols version of the LEA (LH) Near Vision Line Test (LEA-Test, Ltd.; Hyvärinen, Näsänen, & Laurinen, 1980) was used to measure binocular acuity, and participants were required to have acuity of 20/40 or better with glasses or contacts. Three participants with DS did not pass the vision screen because they were unable to accurately and consistently label symbols. All of these participants proved they could see visual stimuli presented during remaining tasks so were included in analyses to maximize power. The McCormick Toy Discrimination Test (McCormick, 1977) was used to measure hearing, and participants were required to perform accurately at the 60 dB level or below. All participants passed the hearing screen. These inclusion criteria allowed for adequate participation in all tasks. See Table 3 for parent reports of participants' vision, hearing, and language skills.

Table 3

Parent report of participants' vision, hearing, and language skills (N = 35)

	How would you describe your child's vision?	**How would you describe your child's hearing?**	**How would you describe your child's language skills?**
Good	23	24	8
Fair	10	7	19
Poor	2	4	8
	Does your child wear glasses or contacts?	**Does your child use a hearing aid?**	**Does your child currently receive speech-language therapy?**
Yes	21	4	25
No	11	30	7
Should But Doesn't	3	1	3
	How well can others understand the words your child is saying?	**How well can your child understand what others are saying?**	
Easily	5	24	
With Some Difficulty	23	10	
With Much Difficulty	7	1	

Parents of youth with DS. Thirty-five parents of youth with DS participated in this study. Parents were required to be youths' primary caregivers. All parents who completed measures were mothers: 32 biological, 2 adoptive, and 1 legal guardian. These mothers reported that, of their children's fathers, 31 were biological, 2 were stepparents, 1 was adoptive, and 1 was a legal guardian. See Table 4 for additional demographic information.

Table 4

Additional demographic information for parents (N = 35)

PARENTS OF YOUTH WITH DS			
Annual Family Income Before Taxes			
≤ \$39,000	1	\$80,000 - \$99,000	9
\$40,000 - \$59,000	3	≥ \$100,000	13
\$60,000 - \$79,000	6	No Response	3
Education	**Mother**		**Father**
Graduated High School	2		4
Completed Some College	5		11
Graduated College	13		8
Completed Some Graduate/Professional School	1		3
Graduated with a Graduate/Professional Degree	13		9
Other	1		0
Employment	**Mother**		**Father**
None, Disabled	3		0
Homemaker	10		0
Part-time	11		0
Fulltime	11		35

Youth with Down Syndrome Measures

In total, participants with DS completed 11 tasks (including subtests): two to measure SA, three to measure STM, five to measure language, and one to control for nonverbal ability. All of these tasks were successfully used with participants with DS prior to this study. They can measure functioning in 4- to 9-year-olds, the approximate MA range of my sample, thus these tasks were developmentally appropriate.

Sustained attention (20 minutes). SA was measured using the Sustained Attention to Response Test (SART; Robertson et al., 1997) paradigm. In this paradigm, participants press a computer key when presented with several non-targets and inhibit responses to a rarely presented target over relatively short periods of time. The primary dependent variable of interest in this study was omission errors (omissions) in which participants fail to respond to non-targets, while commission errors (commissions) in which participants respond to the target were also considered. Again, omissions indicate lapses in SA, whereas commissions indicate inhibition difficulties (Johnson et al., 2007). Because the SART switches automatization of responses to non-targets over a short period of time, it requires more vigilance with less memory, making the SART more valid than most SA measures.

The SART versions used in this study had high Spearman-Brown split-half (odd-even) reliability in a sample of 20 youth with DS aged 10 to 21 years, with coefficients ranging from .96 to .98 for omissions and .75 to .81 for commissions (Faught, 2014). The SART more generally has good test-retest reliability for commissions (also called false presses), $r = .76$ (Robertson et al., 1997), and good reliability across auditory and visual modalities (Seli et al., 2012). Further, the SART is a valid measure with performance better predicted by other SA tasks than by inhibition tasks (Robertson et al., 1997; see also Smilek, Carriere, & Cheyne, 2010).

Auditory SART. The auditory SART used in this study was originally created by Trezise et al. (2008) and recreated by Faught et al. (2016) with Superlab 4.5 computer software (Cedrus Corporation, 2012). Participants heard a continuous stream of animal names over Insignia speakers attached to a laptop. Animal names were presented with 75% available volume for approximately 500 ms each separated by 1500 ms silent pauses, during which time participants responded to names. Animal names were arranged in blocks, presented once per block, and randomized within each block. There were eight non-target animal names: “bird,” “cat,” “elephant,” “fish,” “giraffe,” “horse,” “pig,” and “rabbit.” The target animal name was “dog.” Practice sessions included two blocks (18 trials) presented over a maximum of 36 seconds. Testing sessions included 25 blocks (225 trials) presented over a maximum of 7.5 minutes. Superlab 4.5 produced two dependent variables for this SART: number of auditory omissions of 200 possible (i.e., failing to press the spacebar to non-targets) and number of auditory commissions of 25 possible (i.e., pressing the spacebar to the target). These raw scores and their converted *z*-scores were used in data analyses.

Visual SART. The visual SART used in this study was originally created by Trezise et al. (2008) and recreated by Faught et al. (2016) with Superlab 4.5 computer software (Cedrus Corporation, 2012). Participants saw a continuous stream of animal pictures on an 11” Apple MacBook Air laptop screen. Animal pictures were 10 cm x 10 cm line drawings (black lines on a white background) presented in the center of the screen for 500 ms each separated by 1500 ms blank pauses, during which time participants responded to pictures. Animal pictures were arranged in blocks, presented once per block, and randomized within each block. There were eight non-target animal pictures: bird, cat, elephant, fish, giraffe, horse, pig, and rabbit. The target animal picture was a dog. Practice sessions included two blocks (18 trials) presented over a maximum of 36 seconds. Testing sessions included 25 blocks (225 trials) presented over a maximum of 7.5 minutes. Superlab 4.5 produced two dependent variables for this SART: number of visual omissions of 200 possible (i.e., failing to press the spacebar to non-targets) and number of visual commissions of 25 possible (i.e., pressing the spacebar to the target). These raw scores and their converted *z*-scores were used in data analyses.

Auditory short-term memory (10 minutes). Auditory STM was measured with the Comprehensive Test of Phonological Processing – Second Edition (CTOPP-2; Wagner et al., 2013) phonological memory composite, which combines the memory for digits (MD) and nonword repetition (NR) subtests. For the MD subtest, participants heard lists of digits and repeated them immediately in the same order. Lists began with two digits and increased by one digit every fourth trial up to nine digits. Testing stopped when participants missed three consecutive trials. For the NR subtest, participants heard pronounceable nonwords and repeated them immediately. Words began with one syllable and increased in phonemic complexity. Testing stopped when participants missed three consecutive trials. Subtests' raw scores and their converted *z*-scores were used in data analyses. The CTOPP-2 has good psychometric properties. It is valid, correlating highly with other measures of auditory STM with coefficients ranging from .36 to .54 for MD and NR subtests. The CTOPP-2 is also reliable, with average internal consistency reliability of .77 for MD, .78 for NR, and .84 for the phonological memory composite. Average test-retest reliability is .81 for MD, .70 for NR, and from .84 to .92 for the phonological memory composite (Wagner et al., 2013).

Visual short-term memory (5 minutes). Visual STM was measured with the Corsi block-tapping task (Corsi task) as seen in Milner (1971) but with block-tapping sequences as seen in the Block Recall subtest of the Automated Working Memory Assessment (Alloway, 2007). Participants saw a gray board with nine blocks placed randomly on top. The experimenter tapped increasingly long sequences of blocks, and participants repeated tapping sequences immediately in the same order. Sequences began with two blocks and increased by one block every fifth trial up to nine blocks. Testing stopped when participants missed four (all) trials of the same sequence length. Raw scores and their converted *z*-scores were used in data analyses. Block-tapping tasks are commonly used in samples with DS (see Yang et al., 2014). The Corsi task version used in this study had acceptable internal consistency reliability in a sample of 20 youth with DS aged 10 to 21 years, α = .70 (Faught, 2014).

Receptive vocabulary (15 minutes). Receptive vocabulary was measured with the Peabody Picture Vocabulary Test – Fourth Edition (PPVT-4; Dunn & Dunn, 2007). Participants pointed to pictures that correspond with spoken vocabulary words in a series of 19 increasingly difficult trial blocks. The PPVT-4 covers 20 content categories and includes nouns, verbs, and adjectives. To select the start item for this special population, experimenters chose the first item in the block recommended for *half* of each participant's age up to 8 years, increasing the likelihood participants would meet basal set criterion (11 or 12 items correct in a 12-item block). Once basal set was established, participants continued through items until they made eight or more errors within a 12-item block, establishing ceiling set. Raw scores and their converted *z*-scores were used in data analyses. The PPVT-4 has good psychometric properties. It correlates highly with other language measures with ranges from .37 to .84. The PPVT-4 is also reliable with average split-half reliability of .94, internal consistency reliability of .96, and test-retest reliability of .92 (Dunn & Dunn, 2007).

Receptive syntax (10 minutes). Receptive syntax was measured with the Test for Reception of Grammar – Second Version (TROG-2; Bishop, 2003). Participants pointed to pictures that correspond with spoken sentences in a series of 20 increasingly difficult trial blocks. Each block measures one of 20 grammatical contrasts marked by inflections, function words, and word order. Testing began with the first trial in the first block. Participants were considered to have failed a block if they missed one of four items within a block, and testing was discontinued when participants failed five consecutive blocks. Raw scores and their converted *z*-scores were used in data analyses. The TROG-2 has good psychometric properties. It correlates highly with other language measures with ranges from .53 to .58. The TROG-2 is also reliable with internal consistency reliability of .88 and parallel form reliability of .74 (Bishop, 2003).

Productive vocabulary and syntax (25 minutes). Productive language was measured with the Clinical Evaluation of Language Fundamentals – Preschool – Second Edition (CELF-P-2; Wiig, Secord, & Semel, 2004) expressive language index, which combines the word structure (WS), recalling sentences (RS), and expressive vocabulary (EV) subtests. Specifically, productive syntax was measured with WS and RS subtests, while productive vocabulary was measured with the EV subtest.

For the WS subtest, participants completed spoken sentences about pictures. This subtest evaluates participants' abilities to apply syntactical rules to mark inflections, derivations, and comparison, as well as to select and use appropriate pronouns. It covers seven content categories over 24 increasingly complex trials. Testing began with the first trial and was not discontinued until the end of the subtest. For the RS subtest, participants listened to spoken sentences and repeated them. This subtest evaluates participants' abilities to repeat sentences without changing word meanings, inflections, derivations or comparison, and sentence structure. It covers five content categories over 13 increasingly complex trials. Testing began with the first trial and was discontinued when participants answered three consecutive items incorrectly (i.e., by making more than the permitted number of errors for three consecutive sentences). For the EV subtest, participants produced vocabulary words following experimenters' questions about illustrations of people (e.g., "Who is this?"), objects (e.g., "What is this?"), and actions (e.g., "What is the baby doing?"). This subtest evaluates participants' abilities to label illustrations of people, objects, and actions (i.e., referential naming). It covers 11 content categories over 20 increasingly difficult trials. Testing began with the first trial and was not discontinued until the end of the subtest. Subtests' raw scores and their converted *z*-scores were used in data analyses.

The CELF-P-2 has good psychometric properties. It correlates highly with other language measures, up to about .71. The CELF-P-2 is also reliable with average internal consistency reliability of .83 for WS, .88 for RS, .82 for EV, and .92 for the expressive language index. Average test-retest reliability is .80 for WS, .88 for RS, .88 for EV, and .93 for the expressive language index (Wiig et al., 2004).

Nonverbal ability (10 minutes). Nonverbal ability was measured with the Kaufman Brief Intelligence Test – Second Edition (KBIT-2; Kaufman & Kaufman, 2004) matrices subtest that includes conceptual reasoning and problem solving. Participants pointed to pictures that completed patterns consisting of abstract designs. Rather than beginning at the item recommended for participants' ages, testing always began with the first trial for this special population. Testing was discontinued when participants answered four consecutive items incorrectly. Raw scores and their converted *z*-scores were controlled for in data analyses. The KBIT-2 matrices subtest has good psychometric properties. It correlates highly with many other intelligence measures with ranges from .50 to .80. The KBIT-2 matrices subtest is also reliable with average internal consistency reliability of .88 and test-retest reliability of .83 (Kaufman & Kaufman, 2004).

Parent Measures

Background of youth with DS (10 minutes). Participants' backgrounds were reported with a modified background questionnaire (BGQ) developed in my lab. This questionnaire asks about parents' income, educational attainment, and occupations, as well as their children's school settings and comorbid diagnoses. Information from this questionnaire allowed me to describe the sample in detail (e.g., sex, race, SES, comorbid diagnoses).

Executive functions of youth with DS (10 minutes). Participants' executive functioning was reported with the Behavior Rating Inventory of Executive Function – Second Edition – Parent Form (BRIEF-2; Gioia, Isquith, Guy, & Kenworthy, 2015). This measure asks parents to rate their children's behaviors on a three-point frequency scale (i.e., never, sometimes, often) over 63 items. Specifically, the BRIEF-2 measures nine subdomains of executive functioning: inhibitory control, self monitoring, shifting, emotional control, initiation, working memory, planning/organizing, task monitoring, and organization of materials. The BRIEF-2 has good psychometric properties. It correlates highly with other parent behavior rating scales, including the Child Behavior Checklist (Achenbach, 1991), *r*s = .33 to .45. The BRIEF-2 is also reliable with internal consistency reliability ranging from .85 to .89 and test-retest reliability of .79 (Gioia et al., 2015). Global executive composite (GEC) raw scores and their converted *z*-scores, as well as raw scale scores, were considered in exploratory analyses.

Language intervention history of youth with DS (10 minutes). Participants' experiences with language intervention were reported with an intervention history interview (IHI) modified from the Collaborative Programs of Excellence in Autism Research Network. The interview began with an open-ended question asking parents to describe their children's language intervention histories. The experimenter followed up with specific questions to determine intervention type, length, and intensity. IHI intensity scores and their converted *z*-scores were considered in exploratory analyses.

Procedure

Written consent was requested from parents and participants with DS aged 18 years and up, and verbal assent was requested from all participants with DS. Per parents' requests, 29 participants were tested at their homes, 2 at their schools, and 4 at an alternative public location (e.g., church, visitor center).

Participants were required to pass abbreviated vision and hearing screens prior to testing. Vision was tested with the LEA (LH) Near Vision Line Test at a 16-inch distance. Participants first labeled four symbols (i.e., circle, square, house, and apple). Participants then named these symbols on the 20/63 row of a vision chart and were required to make six or fewer errors of 15 trials presented indicating binocular acuity of 20/40 or better. This criterion was adequate for all visual tasks in the study, including the visual SART, Corsi task, and language measures in which pictures were presented to participants. Hearing was tested with the McCormick Toy Discrimination Test. Participants first labeled three pairs of toys with phonologically similar names (e.g., lamb and man). Participants then listened to recordings of the six toy names they labeled previously and pointed to each toy speakers played. Recordings were 60 dB in volume, and participants were required to make zero errors at this dB level. This criterion was adequate for all auditory tasks in the study, including the auditory SART, CTOPP-2 MD and NR subtests, and language measures in which words were spoken aloud to participants.

Once deemed eligible for study inclusion, participants with DS individually completed 11 tasks (including subtests). Order of task presentation was as follows: SA, nonverbal ability, SA, *break*, STM, language, *break*, STM, and language. Within SA and STM measures, auditory and visual modalities were counterbalanced. The KBIT-2 was always administered between SARTs to reduce participant burden. Within language measures, receptive and productive language, as well as vocabulary and syntax, were counterbalanced. Here is an example of a participant's order of task presentation: auditory SART, KBIT-2 matrices subtest, visual SART, *break*, Corsi task, CELF-P-2 WS and RS subtests, CELF P-2 EV subtest, *break*, CTOPP-2 MD and NR subtests, PPVT-4, and TROG-2. Participants with DS were given stickers upon completion of each task and a t-shirt upon completion of the study. Procedures took at most two hours per participant.

While participants with DS were completing tasks, their parents also completed measures. Order of measure presentation was as follows: BGQ, BRIEF-2, and IHI. Parents were given a $10 gift card to either Amazon or Walmart upon completion of the study. Procedures took at most 30 minutes per parent.

Data Analysis Plan

Preliminary analyses. Preliminary analyses first included checking all variables to be considered in main and exploratory analyses (i.e., model variables) for outliers as determined by values outside $\pm$ 3 standard deviations from means. Second, Cronbach's alpha and Spearman Brown split-half (odd-even) reliability statistics were calculated for SART dependent variables and Corsi task raw scores to ensure these measures were reliable in my sample. Third, once outliers were removed and tasks were deemed reliable, descriptive statistics (mean, standard deviation, range, skewness, and kurtosis) were computed for model variables. Fourth, correlations among age, nonverbal ability, and model variables were computed to determine if age and nonverbal ability should be controlled for in main and exploratory analyses. Fifth, partial correlations controlling for age and nonverbal ability were computed among model variables. This was done to determine (1) which groupings of variables could be made into equally weighted composite scores, and (2) which proposed models were justified in being analyzed further. If variables proposed in models were found to be unrelated, there would be no justification for continuing into main or exploratory analyses. All of these preliminary analyses used raw scores.

All raw scores were converted to standardized *z*-scores. Equally weighted composite scores were then created by averaging *z*-scores for variables that were significantly and theoretically related. Composite scores were proposed to be created for the following variables: SA (auditory and visual omissions and commissions), auditory SA (auditory omissions and commissions), visual SA (visual omissions and commissions), STM (CTOPP-2 MD, NR, Corsi task), auditory STM (CTOPP-2 MD, NR), language (PPVT-4, TROG-2, CELF-P-2 WS, RS, EV), receptive language (PPVT-4, TROG-2), productive language (CELF-P-2 WS, RS, EV), vocabulary (PPVT-4, CELF-P-2 EV), syntax (TROG-2, CELF-P-2 WS, RS), and productive syntax (CELF-P-2 WS, RS). Note composite scores were not proposed to be created for age (CA in months), nonverbal ability (KBIT-2 matrices), visual STM (Corsi task), receptive vocabulary (PPVT-4), receptive syntax (TROG-2), and productive vocabulary (CELF-P-2 EV) because these were assessed by single measures. Finally, partial correlations among relevant composite and individual *z*-scores controlling for age and nonverbal ability were computed to again confirm which proposed models were justified in being analyzed further.

Main analyses. The current study predicted there would be an indirect effect of SA (X = predictor) on language (Y = outcome) through STM (M = mediator). Statistically, this indirect effect "estimates how much two cases differing by one unit on X are estimated to differ on Y as a result of the effect of X on M which in turn affects Y" (Hayes, 2012, pg. 6). It was tested using the bootstrapping method, which makes few assumptions about the sampling distribution and is more powerful than other methods including Baron and Kenny's Causal-Steps Test (Baron & Kenny, 1986) and the Sobel First-Order Test (Sobel, 1982; see Fritz & McKinnon, 2007). Thus, this method is sensitive to small sample sizes. Bootstrapping randomly samples cases from the data set and computes an estimated mediated effect. It repeats this process 5000 times, producing 5000 mediated effects, and then averages effects across the sample to give a point estimate and a 95% confidence interval for this point estimate. If the confidence interval does not cross zero, the effect is significant (see Preacher & Hayes, 2008).

To test my general hypothesis and its subcomponents, several simple mediation models were analyzed with the bootstrapping method using PROCESS, a macro written by Andrew F. Hayes for SPSS (see Hayes, 2012). PROCESS uses an ordinary least squares regression-based path analytic framework for estimating direct and indirect effects in simple mediation models like the ones proposed. PROCESS is highly functional, combining many of the functions seen with other statistical procedures and tools. Specifically, main analyses operated from the framework of Hayes's model 4 (see Figure 8 for a statistical diagram). Using PROCESS syntax, several simple mediation models were generated. Note that main analyses to test for mediation were limited to those supported by preliminary correlation analyses.

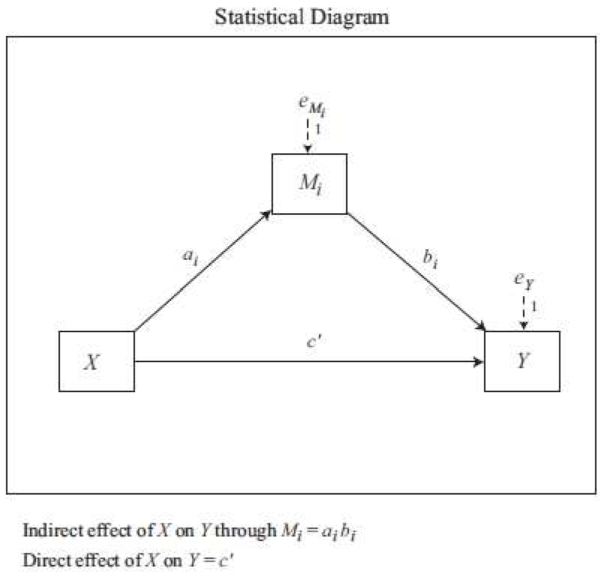

Figure 8. Hayes's model 4 statistical diagram that guided main analyses

The following models were proposed to be run with the assumption that model variables would be significantly correlated. I proposed a general model would be run with X = SA, M = STM, and Y = Language. This general model would then be broken down into several subcomponents for the auditory modality. I proposed a model would be run for the auditory modality predicting language, with X = Auditory SA, M = Auditory STM, and Y = Language. Eight additional models would then be run for the auditory modality predicting more specific language outcomes: receptive language, productive language, vocabulary, syntax, receptive vocabulary, receptive syntax, productive vocabulary, and productive syntax. I proposed the same nine models would be repeated for the visual modality, with X = Visual SA, M = Visual STM, and Y = Language, and so forth. All models would control for age and nonverbal ability.

Exploratory analyses. The following exploratory analyses were proposed to be run with the assumption that model variables would be significantly correlated. First, I proposed exploratory analyses would include re-analyzing significant mediation models from main analyses with parent report of executive functioning (i.e., BRIEF-2 GEC scores) included as a control variable in addition to age and nonverbal ability. These analyses would determine if executive functioning accounted for significant variance in the models, as SA operates in overlap with executive functioning and STM is a component of a traditional executive function (i.e., working memory).

Second, I proposed exploratory analyses would include re-analyzing significant mediation models from main analyses with the addition of a moderator. Specifically, I proposed running *moderated* mediation models in which language intervention history (i.e., IHI intensity scores) would be a moderator in the paths from SA to language and from STM to language after controlling for age and nonverbal ability. These analyses would operate from the framework of Hayes's model 15 (see Figure 9 for a conceptual diagram). They would determine if the magnitude of SA (X) and STM's (M) effects on language (Y) depended on language intervention history (V), or if potential significant indirect effects found in main analyses were conditional upon language intervention history.

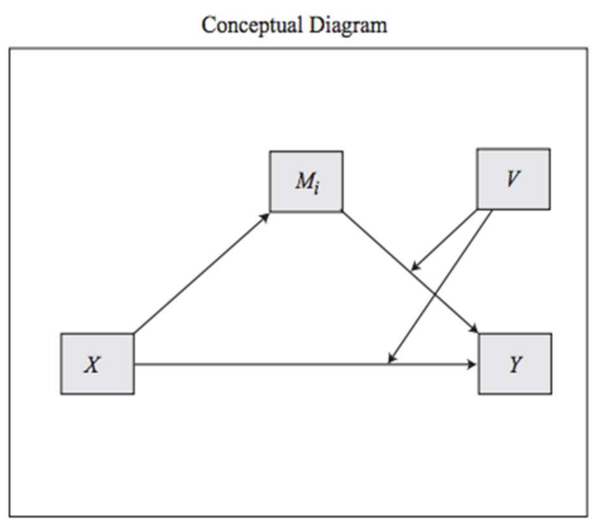

Figure 9. Hayes's model 15 conceptual diagram that guided an exploratory analysis

CHAPTER 3

RESULTS

Preliminary Analyses

Outlier management. All raw variables to be considered in main and exploratory analyses were checked for outliers as determined by values outside $\pm$ 3 standard deviations from means. The first time this procedure was done three outliers > 3 standard deviations from means were identified and removed from data analyses: one TROG-2, one CELF-P-2 RS subtest, and one IHI intensity outlier. The second time this procedure was done only one CELF-P-2 RS subtest outlier >3 standard deviations from the mean remained and was removed from data analyses. The third time this procedure was done no outliers remained.

Reliability of SART and Corsi task. Cronbach's alpha and Spearman-Brown split-half (odd-even) reliability were calculated for each of the four SART dependent variables and Corsi task raw scores. All variables were internally consistent with *r*s $\geq$ .70 and thus reliable in my sample. See Table 5.

Table 5

Reliability of SART and Corsi task variables

	SART				**Corsi Task**
	Auditory Omissions	Visual Omissions	Auditory Commissions	Visual Commissions	
Cronbach's alpha	.96	.96	.78	.94	.70
Spearman-Brown split-half (odd-even)	.96	.96	.82	.96	.93

Descriptive statistics. Descriptive statistics including sample size (*N*/*n*), mean (*M*), standard deviation (*SD*), range, skewness, and kurtosis were computed for all raw variables to be considered in main and exploratory analyses. See Table 6. All raw scores presented below were later converted to standardized *z*-scores for main and exploratory analyses.

It is important to note MA was measured as KBIT-2 age equivalent scores, which have a floor of 4 years. Eight participants scored MA < 4 years. To assign these participants MA values below, I ran a simple linear regression of KBIT-2 age equivalent scores over PPVT-4 age equivalent scores. Results suggested PPVT-4 scores significantly predicted KBIT-2 scores, $R^2 = .313$, $F(1, 25) = 11.387$, $p < .01$. So, I used the regression equation (Y = 40.092 + .338*PPVT-4 age equivalent scores) to assign MA values to those eight participants who scored below KBIT-2 age equivalent floor. This procedure was only done to better describe the sample. For all additional analyses using MA, KBIT-2 raw scores and their converted *z*-scores were used.

Table 6

Descriptive statistics for model variables

Variable (max. score possible)	***N/n***	***M***	***SD***	**Range**	**Skew**	**Kurtosis**
CA in years	35	15.94	3.37	10.49-22.91	.47	-.29
MA in years	35	5.16	1.10	4.00-9.25	2.23	5.53
KBIT-2 matrices (46)	35	14.00	4.83	6-28	.91	1.17
ASART omissions (200)	35	53.60	36.11	4-127	.73	-.44
VSART omissions (200)	34	50.71	31.77	6-142	.73	.35
ASART commissions (25)	35	3.74	3.58	0-13	1.10	.17
VSART commissions (25)	34	6.41	7.11	0-22	.78	-.84
CTOPP-2 MD (28)	35	7.97	3.27	1-13	-.48	-.48

CTOPP-2 NR (30)	35	6.40	4.71	1-16	.40	-1.33
Corsi task (36)	35	12.17	3.69	4-18	-.58	-.37
PPVT-4 (228)	35	92.40	31.93	42-171	.42	-.19
TROG-2 (80)	33	19.58	10.21	6-42	.60	-.90
CELF-P-2 EV (40)	35	23.26	9.40	7-40	-.04	-1.06
CELF-P-2 WS (24)	35	7.03	6.27	0-23	.76	-.36
CELF-P-2 RS (37)	32	4.22	3.95	0-15	1.11	.71
BRIEF-2 GEC (180)	35	113.97	16.80	72-152	-.26	.64
IHI intensity (–)	34	690.38	294.02	153-1371	.43	-.24

Note: All scores presented are raw scores unless noted otherwise.

Note: CA=chronological age; MA=mental age; KBIT-2=Kaufman Brief Intelligence Test-2nd edition; ASART=auditory Sustained Attention to Response Test; VSART=visual Sustained Attention to Response Test; CTOPP-2=Comprehensive Test of Phonological Processing-2nd edition; MD=memory for digits subtest; NR=nonword repetition subtest; PPVT-4=Peabody Picture Vocabulary Test-4th edition; TROG-2=Test for Reception of Grammar-2nd edition; CELF-P-2=Clinical Evaluation of Language Fundamentals-Preschool-2nd edition; EV=expressive vocabulary subtest; WS=word structure subtest; RS=recalling sentences subtest; BRIEF-2=Behavior Rating Inventory of Executive Function-2nd edition; GEC=global executive composite score; IHI=intervention history interview

Correlations with age and nonverbal ability. Correlations among age (as measured by CA in months), nonverbal ability (as measured by KBIT-2 matrices raw scores), and raw scores to be considered in mediation models were computed to determine if age and nonverbal ability should be controlled for in main and exploratory analyses. See Table 7. Several scores to be considered in mediation models were related to age and nonverbal ability, so these variables were controlled for in main and exploratory analyses.

Table 7

Correlations among age, nonverbal ability, and model variables

	Age (CA)	Nonverbal Ability (KBIT-2)
ASART Omissions	-.46**	-.46**
VSART Omissions	-.39*	-.50**
ASART Commissions	-.09	-.33
VSART Commissions	-.33	-.54**
CTOPP-2 MD	.17	.42*
CTOPP-2 NR	.18	.39*
Corsi task	.34*	.61**
PPVT-4	.34*	.68**
TROG-2	.18	.59**
CELF-P-2 EV	.20	.53**
CELF-P-2 WS	.12	.58**
CELF-P-2 RS	.12	.24
BRIEF-2 GEC	-.43*	-.53**
IHI Intensity	.11	.19

Note: *$p < .05$, **$p < .01$

Note: All scores presented are raw scores.

Note: CA=chronological age; KBIT-2=Kaufman Brief Intelligence Test-2nd edition; ASART=auditory Sustained Attention to Response Test; VSART=visual Sustained Attention to Response Test; CTOPP-2=Comprehensive Test of Phonological Processing-2nd edition; MD=memory for digits subtest; NR=nonword repetition subtest; PPVT-4=Peabody Picture Vocabulary Test-4th edition; TROG-2=Test for Reception of Grammar-2nd edition; CELF-P-2=Clinical Evaluation of Language Fundamentals-Preschool-2nd edition; EV=expressive vocabulary subtest; WS=word structure subtest; RS=recalling sentences subtest; BRIEF-2=Behavior Rating Inventory of Executive Function-2nd edition; GEC=global executive composite score; IHI=intervention history interview

Partial correlations among raw scores. Partial correlations among raw scores to be considered in main and exploratory analyses controlling for age (as measured by CA in months) and nonverbal ability (as measured by KBIT-2 matrices raw scores) were computed. See Table 8. This was done to determine (1) which groupings of variables could be made into equally weighted composite scores, and (2) which proposed models were justified in being analyzed further. Most importantly, I checked the degrees of relatedness among SA, STM, and language. If variables proposed in models were found to be unrelated, there would be no justification for continuing into main or exploratory analyses.

Auditory and visual SA were generally related to auditory and visual STM. First, auditory omissions and commissions were related to CTOPP-2 MD scores, *r*s = -.33 and -.48, respectively. Second, auditory omissions but not commissions were related to CTOPP-2 NR scores, *r* = -.38. Third, visual omissions but not commissions were related to Corsi task scores, *r* = -.35. These relationships supported investigating the auditory modality further with both omissions and commissions. These relationships also supported investigating the visual modality further but only with omissions.

STM was strongly related to all language measures in the auditory but not visual domain. Specifically, CTOPP-2 MD and NR scores were related to receptive vocabulary (*r*s = .57 and .63, respectively), receptive syntax (*r*s = .65 and .54, respectively), productive vocabulary (*r*s = .56 and .59, respectively), and productive syntax (*r*s = .60 to .78). However, Corsi task scores were not significantly related to any language measures. These relationships supported investigating the auditory but not visual modality further in main and exploratory analyses.

Interestingly, auditory SA was generally related to language. Specifically, auditory omissions were related to receptive syntax, *r* = -.34, and productive syntax, *r*s = -.36 to -.39.

Auditory commissions were related to receptive vocabulary, r = -.32, productive vocabulary, r = -.37, and productive syntax, rs = -.37 to -.49. These relationships again supported investigating the auditory modality further in main and exploratory analyses. If my hypotheses were correct, these relationships were indirect, occurring through auditory STM.

Table 8
Partial correlations among model variables controlling for CA in months and KBIT-2 raw scores

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1. ASART Omissions	1													
2. VSART Omissions	.45**	1												
3. ASART Commissions	.24	.25	1											
4. VSART Commissions	.24	.19	.42**	1										
5. CTOPP MD	-.33*	-.37**	-.48***	-.03	1									
6. CTOPP NR	-.38**	-.12	-.07	.03	.58***	1								
7. Corsi task	-.23	-.35*	-.48***	.04	.42**	.06	1							
8. PPVT	-.20	-.14	-.32*	-.20	.57***	.63***	.25	1						
9. TROG	-.34*	-.26	-.28	-.36**	.65***	.54***	.22	.66***	1					
10. CELF EV	-.26	-.23	-.37**	-.34*	.56***	.59***	.23	.84***	.70***	1				
11. CELF WS	-.39**	-.24	-.49***	-.32*	.65***	.60***	.16	.75***	.78***	.77***	1			
12. CELF RS	-.36*	-.18	-.37**	-.19	.70***	.78***	.30	.77***	.70***	.72***	.88***	1		
13. BRIEF GEC	-.09	-.16	.36**	-.08	-.22	.01	-.00	-.23	-.04	-.13	-.27	-.11	1	
14. IHI Intensity	.25	.11	-.01	.26	.08	.08	.21	.04	.10	.09	-.14	-.09	-.20	1

Note: *$p < .10$, **$p < .05$, ***$p < .01$

Note: All scores presented are raw scores.

Note: CA=chronological age; KBIT=Kaufman Brief Intelligence Test-2nd edition; ASART=auditory Sustained Attention to Response Test; VSART=visual Sustained Attention to Response Test; CTOPP=Comprehensive Test of Phonological Processing-2nd edition; MD=memory for digits subtest; NR=nonword repetition subtest; PPVT=Peabody Picture Vocabulary Test-4th edition; TROG=Test for Reception of Grammar-2nd edition; CELF=Clinical Evaluation of Language Fundamentals-Preschool-2nd edition; EV=expressive vocabulary subtest; WS=word structure subtest; RS=recalling sentences subtest; BRIEF=Behavior Rating Inventory of Executive Function-2nd edition; GEC=global executive composite score; IHI=intervention history interview

Creating composite scores. All raw scores for variables to be considered in main and exploratory analyses were converted to standardized *z*-scores. Equally weighted composite scores were then created by averaging *z*-scores for variables that were significantly and theoretically related. Specifically, the following composite scores were created: auditory STM (CTOPP-2 MD, NR), language (PPVT-4, TROG-2, CELF-P-2 EV, WS, RS), receptive language (PPVT-4, TROG-2), productive language (CELF-P-2 EV, WS, RS), vocabulary (PPVT-4, CELF-P-2 EV), syntax (TROG-2, CELF-P-2 WS, RS), and productive syntax (CELF-P-2 WS, RS). Note composite scores were not created for age (CA in months), nonverbal ability (KBIT-2 matrices), visual STM (Corsi task), receptive vocabulary (PPVT-4), receptive syntax (TROG-2), and productive vocabulary (CELF-P-2 EV) because these were assessed by single measures. Though proposed, composite scores were also not created for overall SA (auditory and visual omissions and commissions), auditory SA (auditory omissions and commissions), visual SA (visual omissions and commissions), and overall STM (CTOPP-2 MD, NR, Corsi task) because individual variables were not significantly related.

Partial correlations among composite and individual *z*-scores. Partial correlations among composite and individual *z*-scores to be considered in main analyses controlling for age (as measured by CA *z*-scores) and nonverbal ability (as measured by KBIT-2 matrices *z*-scores) were computed. See Table 9. This was done to again check the degrees of relatedness among SA, STM, and language – but among *composites* to be considered in models – and to again confirm which proposed models were justified in being analyzed further.

Auditory and visual SA were generally related to auditory and visual STM. First, auditory omissions and commissions were related to the auditory STM composite, *r*s = -.40 and -.31, respectively. Visual omissions but not commissions were related to Corsi task scores, *r* =

-.35. Again, these relationships supported investigating the auditory modality further with both omissions and commissions. These relationships also supported investigating the visual modality further but only with omissions.

STM was strongly related to all language measures in the auditory but not visual domain. Specifically, the auditory STM composite was related to all language composites and individual *z*-scores with correlations ranging from $r = .65$ to .80. However, Corsi task scores were not significantly related to any language composites or individual *z*-scores. Again, these relationships supported investigating the auditory but not visual modality further in main and exploratory analyses.

Interestingly, auditory SA was generally related to language composites and individual *z*-scores. Specifically, auditory omissions were related to the syntax composite, $r = -.35$, receptive language composite, $r = -.31$, receptive syntax score, $r = -.34$, productive language composite, $r = -.34$, and productive syntax composite, $r = -.36$. Auditory commissions were related to the general language composite, $r = -.38$, vocabulary composite, $r = -.36$, syntax composite, $r = -.39$, receptive language composite, $r = -.32$, receptive vocabulary score, $r = -.32$, productive language composite, $r = -.42$, productive vocabulary score, $r = -.37$, and productive syntax composite, $r = -.43$. These relationships again supported investigating the auditory modality further in main and exploratory analyses. If my hypotheses were correct, these relationships were indirect, occurring through auditory STM.

Table 9

Partial correlations among model composite and individual z-scores controlling for CA in months and KBIT-2 z-scores

	1.	2.	3.	4.	5.	6.
1. Auditory SA (Omissions)	1					
2. Visual SA (Omissions)	.45**	1				
3. Auditory SA (Commissions)	.24	.25	1			
4. Visual SA (Commissions)	.24	.19	.42**	1		
5. Auditory STM Composite	-.40**	-.28	-.31*	-.00	1	
6. Visual STM	-.23	-.35*	-.48***	.04	.27	1
7. Language Composite	-.30	-.18	-.38**	-.30	.77***	.27
8. Vocabulary Composite	-.25	-.20	-.36**	-.29	.69***	.25
9. Syntax Composite	-.35*	-.20	-.39**	-.29	.80***	.23
10. Receptive Language Composite	-.31*	-.20	-.32*	-.32*	.71***	.30
11. Receptive Vocabulary	-.20	-.14	-.32*	-.20	.67***	.25
12. Receptive Syntax	-.34*	-.26	-.28	-.36**	.68***	.22
13. Productive Language Composite	-.34*	-.19	-.42**	-.30	.77***	.27
14. Productive Vocabulary	-.26	-.23	-.37**	-.34*	.65***	.23

15. Productive Syntax Composite	-.36**	-.18	-.43**	-.26	.79***	.25

Note: *$p < .10$, **$p < .05$, ***$p < .01$

Note: Auditory SA (Omissions)=ASART Omissions; Visual SA (Omissions)=VSART Omissions; Auditory SA (Commissions)=ASART Commissions; Visual SA (Commissions)=VSART Commissions; Auditory STM Composite=CTOPP MD + CTOPP NR; Visual STM=Corsi task; Language Composite=PPVT-4+TROG-2+CELF EV+CELF WS+CELF RS; Vocabulary Composite=PPVT-4+CELF EV; Syntax Composite=TROG-2+CELF WS+CELF RS; Receptive Language Composite=PPVT-4+TROG-2; Receptive Vocabulary=PPVT-4; Receptive Syntax=TROG-2; Productive Language Composite=CELF EV+CELF WS+CELF RS; Productive Vocabulary=CELF EV; Productive Syntax Composite=CELF WS+CELF RS

Note: CA=chronological age; KBIT=Kaufman Brief Intelligence Test-2nd edition; ASART=auditory Sustained Attention to Response Test; VSART=visual Sustained Attention to Response Test; CTOPP=Comprehensive Test of Phonological Processing-2nd edition; MD=memory for digits subtest; NR=nonword repetition subtest; PPVT=Peabody Picture Vocabulary Test-4th edition; TROG=Test for Reception of Grammar-2nd edition; CELF=Clinical Evaluation of Language Fundamentals-Preschool-2nd edition; EV=expressive vocabulary subtest; WS=word structure subtest; RS=recalling sentences subtest

Note: Relationships among overlapping composite and individual *z*-scores were deleted for clarity.

Main Analyses

Main analyses to test for mediation were limited to those supported by correlations in Table 8 and Table 9. Specifically, I analyzed potential indirect effects of auditory SA on language through auditory STM controlling for age (as measured by CA in months) and nonverbal ability (as measured by KBIT-2 matrices raw scores). Auditory SA included models for both auditory omissions and commissions. Language included models for a general language composite, receptive language composite, productive language composite, vocabulary composite, syntax composite, receptive vocabulary score, receptive syntax score, productive vocabulary score, and productive syntax composite. Thus, nine models were run investigating the indirect effect of auditory omissions on language through auditory STM, while nine additional models were run investigating the indirect effect of auditory commissions on language through auditory STM.

Indirect effects of visual SA on language through visual STM were not supported by correlations and therefore should not have been considered further. Because proposed, these mediation models were run and indirect effects were found to be nonsignificant.

Auditory omissions on language through auditory STM. All nine models investigating indirect effects of auditory omissions on language through auditory STM controlling for age and nonverbal ability were significant, with no 95% confidence intervals for point estimates crossing zero. See Figure 10 for an illustration of the most general model with language as the outcome. See Table 10 for statistics of all nine models. Specifically, Table 10 shows point estimates (depicted as unstandardized regression coefficients), standard errors, and 95% confidence intervals for indirect effects, as well as point estimates, standard errors, and *p*-values for all direct and total effects. It is important to note that nonsignificant total effects do not prevent indirect effects from being present (see Hayes, 2009). This idea is discussed further in the discussion section of this document.

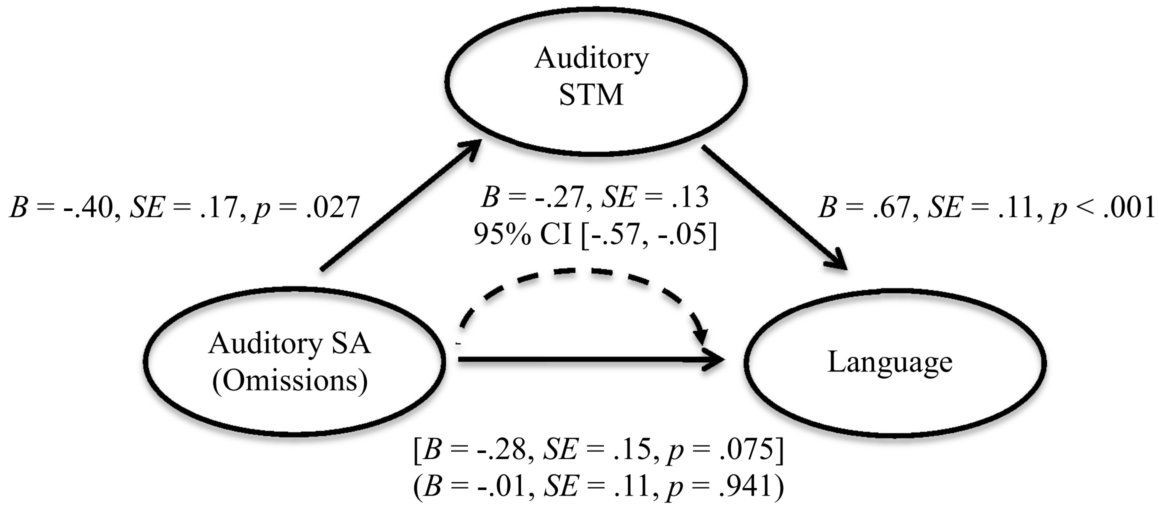

Figure 10. Mediated outcomes on general language showing indirect effects of auditory SA (omissions) through auditory STM

Note: CA and KBIT-2 scores were entered as control variables. Unstandardized regression coefficients are reported. Statistics in brackets show the total effect of predictor on outcome; statistics in parentheses show the direct effect of predictor on outcome after controlling for the indirect effect of the mediator. The indirect effect (depicted above the curved, dashed arrow) was significant based on an asymmetric 95% confidence interval with 5000 resamples with replacement.

Table 10

All mediated outcomes on language showing indirect effects of auditory SA (omissions) through auditory STM

	Indirect Effect X → Y			Total Effect X → Y			Direct Effect X → Y			Direct Effect X → M			Direct Effect M → Y		
Outcome	***B***	***SE***	**95% CI**	***B***	***SE***	***p***	***B***	***SE***	***p***	***B***	***SE***	***p***	***B***	***SE***	***p***
Language	-.27	.13	-.57, -.05	-.28	.15	.075	-.01	.11	.941	-.40	.17	.027	.67	.11	.000
Receptive Language	-.26	.12	-.52, -.06	-.26	.14	.075	-.00	.11	.998	-.42	.16	.015	.63	.12	.000
Productive Language	-.29	.14	-.62, -.05	-.34	.16	.049	-.05	.12	.678	-.40	.17	.027	.72	.12	.000
Vocabulary	-.25	.11	-.48, -.07	-.22	.16	.170	.03	.13	.813	-.39	.16	.021	.65	.13	.000
Syntax	-.29	.15	-.62, -.04	-.34	.16	.043	-.05	.11	.679	-.40	.17	.027	.73	.11	.000
Receptive Vocabulary	-.24	.11	-.48, -.06	-.18	.15	.258	.07	.13	.605	-.39	.16	.021	.63	.13	.000
Receptive Syntax	-.28	.13	-.58, -.06	-.33	.17	.054	-.05	.14	.725	-.42	.16	.015	.67	.14	.000
Productive Vocabulary	-.26	.11	-.50, -.08	-.26	.17	.141	-.00	.15	.976	-.39	.16	.021	.67	.16	.000
Productive Syntax	-.31	.16	-.68, -.06	-.38	.17	.036	-.07	.12	.563	-.40	.17	.027	.77	.13	.000

Note: X=auditory omissions; M=auditory STM; Y=outcome; *B*=point estimate shown as unstandardized regression coefficient; *SE*=standard error; *p*=*p*-value

Note: Each indirect effect was significant based on an asymmetric 95% confidence interval with 5000 resamples with replacement.

To determine if the hypothesized direction of influence was better than the reversed, I also analyzed potential indirect effects with language measures as predictors, auditory omissions as the outcome, and again auditory STM as the mediator controlling for age and nonverbal ability. When models were reversed, there was only a significant indirect effect of receptive vocabulary on auditory omissions through auditory STM, point estimate = -.37, *SE* = .17, [95% CI: -.69, -.01]. Because all other reversed indirect effects with auditory omissions were nonsignificant, it is clear the better direction of influence was that hypothesized with auditory omissions as the predictor and language measures as outcomes.

Auditory commissions on language through auditory STM. None of nine models investigating indirect effects of auditory commissions on language through auditory STM controlling for age and nonverbal ability were significant, with all 95% confidence intervals for point estimates crossing zero. As seen with auditory omissions, I reversed models and analyzed potential indirect effects with language measures as predictors, auditory commissions as the outcome, and auditory STM as the mediator controlling for age and nonverbal ability. Again no indirect effects were present.

Exploratory Analyses

Executive functioning. To determine if parent report of executive functioning accounted for variance in significant mediation models, I first inspected partial correlations among BRIEF-2 GEC scores and variables included in these models controlling for age and nonverbal ability. See Table 8. BRIEF-2 GEC scores were not related to any variables included in significant mediation models, so there was no justification for including these scores as an additional control variable. Because proposed, significant mediation models were rerun controlling for BRIEF-2

GEC scores, but the pattern of results did not change. Findings suggested parent report of participants' *global* executive functioning did not account for the significant indirect effects.

To better understand if parent report of participants' *individual* executive functions played a role in significant mediation models, I also ran partial correlations among BRIEF-2 raw subscale scores and variables included in these models controlling for age and nonverbal ability. Only BRIEF-2 working memory and CELF-P-2 RS scores were significantly related, $r = -.35$, $p = .047$. Two additional relationships approached significance: BRIEF-2 working memory and PPVT-4, $r = -.31$, $p = .081$, and BRIEF-2 task monitoring and PPVT-4, $r = -.34$, $p = .055$. Including BRIEF-2 working memory as a control variable in significant mediation models with productive syntax and receptive vocabulary as outcomes did not change the existing pattern of results. The same was true when controlling for BRIEF-2 task monitoring in the significant mediation model with receptive vocabulary as the outcome.

Language intervention history. To determine if significant indirect effects of auditory omissions on language through auditory STM were conditional upon language intervention history, I first inspected partial correlations among IHI intensity scores and variables included in significant mediation models controlling for age and nonverbal ability. See Table 8. IHI intensity scores were not related to any variables included in significant mediation models, so there was no justification for including these scores as a moderator. Because proposed, moderated mediation models were run with IHI intensity scores as a moderator in paths from SA to language, as well as from STM to language. Neither interaction term (SA x IHI or STM x IHI) was a significant predictor of language for any model. Results suggested the magnitude of indirect effects of auditory omissions on language through auditory STM was not conditional upon language intervention history.

It was possible there would be a different pattern of results if language intervention history was considered in terms of currently receiving or not currently receiving therapy. Twenty-five participants with DS were currently receiving speech-language therapy, while 10 were not currently receiving therapy. I ran partial correlations among therapy status (i.e., currently receiving or not currently receiving) and variables included in significant mediation models controlling for age and nonverbal ability. Therapy status was not related to any variables of interest, *p*s $\geq$ .173.

Additional considerations. After completing proposed analyses (both main and exploratory), a few questions remained unanswered. First, were sample demographic characteristics related to variables considered in main and exploratory analyses? I ran partial correlations controlling for age and nonverbal ability and found only two existing relationships: sex (male = 1, female = 2) with Corsi task, $r = -.60$, $p < .01$, and mother education with visual commissions, $r = .49$, $p < .01$. There were no relationships among model variables and race (white vs. nonwhite), family income, mother/father employment, and father education.

Second, was participants' sleep quality related to their performance on SA, STM, and language tasks? I ran partial correlations controlling for age and nonverbal ability and found only one existing relationship: parent report of trouble sleeping at night (yes = 1, no = 2) with auditory omissions, $r = -.54$, $p < .01$. There were no relationships among model variables and sleep apnea (diagnosed vs. not diagnosed), as well as among model variables and parent report of average number of hours slept per night.

Third, did parents accurately report on their children's language skills? I ran partial correlations controlling for age and nonverbal ability and found several relationships. Reports from the question, "How well can others understand the words your child is saying?" (easily = 1, with some difficulty = 2, with much difficulty = 3) were related to CELF-P-2 WS subtest performance, $r = -.43$, $p < .05$. Answers to this question were not significantly related to PPVT-4, TROG-2, CELF-P-2 EV, or CELF-P-2 task performances. Reports from the question, "How well can your child understand what others are saying?" (easily = 1, with some difficulty = 2, with much difficulty = 3) were related to PPVT-4, $r = -.61$, $p < .01$, TROG-2, $r = -.38$, $p < .05$, CELF-P-2 WS, $r = -.48$, $p < .01$, CELF-P-2 EV, $r = -.54$, $p < .01$, and CELF-P-2 RS, $r = -.46$, $p < .05$, task performances.

CHAPTER 4

DISCUSSION

The purpose of the current study was to determine the relationships among SA, STM, and language in youth with DS. If SA was related to language through STM, results could have implications for language therapy in DS. Youth with DS completed auditory and visual SARTs as measures of SA; nonword repetition, digit span, and block span tasks as measures of STM; and receptive and productive vocabulary and syntax tasks as measures of language. Youths' parents additionally completed measures of their children's executive functions and language intervention histories to determine how these variables might influence relationships among SA, STM, and language.

The current study generally hypothesized there would be an indirect effect of SA on language through STM in youth with DS after controlling for age and nonverbal ability. More specifically, I first hypothesized indirect effects separately for auditory and visual modalities. Results suggested an indirect effect in the auditory domain, though only when considering auditory SA as measured by omissions. I also hypothesized indirect effects separately for receptive and productive language, as well as separately for vocabulary and syntax. Results supported these hypotheses within the auditory modality. When outcomes were broken down even further into receptive vocabulary and syntax and productive vocabulary and syntax, indirect effects remained present. For all models in which indirect effects were present, the direct effects of auditory SA on auditory STM and of auditory STM on language outcomes were significant. Direct effects of SA on language outcomes after controlling for the indirect effect of STM were nonsignificant, suggesting these were complete mediations. Total effects of auditory SA on language outcomes were inconsistent. Specifically, total effects were significant when productive language, syntax, and productive syntax were outcomes, though most total effects approached significance for additional outcomes.

It is important to note that nonsignificant total effects do not prevent indirect effects from being present. In the traditional sense, if mediator *M* accounts for part of the relationship between some variables *X* and *Y*, then there should be an established relationship between *X* and *Y*. Because of this notion, it is perhaps wise to avoid the term *mediator* when describing STM's role in the relationship between SA and language here. However, according to Hayes, "a total effect is the sum of many different paths of influence, direct and indirect, not all of which may be a part of the formal model. For example, it could be that two or more indirect paths carry the effect from *X* through *Y*, and those paths operate in opposite directions" (Hayes, 2009, pg. 414). Thus, ruling out potential indirect effects in the absence of total effects can prevent researchers from understanding the full story (see also MacKinnon, Krull, & Lockwood, 2000; Shrout & Bolger, 2002).

Relationships in the Auditory Modality

Given the presence of indirect effects of auditory omissions on language outcomes through auditory STM, it is clear there is a relationship between auditory SA and language in DS. This relationship was suggested in the literature comparing SA in youth with SLI and TD youth matched for CA (e.g., Duinmeijer et al., 2012; Montgomery, 2008; Montgomery et al., 2009). To my knowledge, this is the first study with a major aim to examine this relationship in DS, and one of only two to do so at all. The only other study to examine the relationship between auditory SA and language in DS was Faught et al. (2016) in which researchers mapped cross-sectional trajectories of SART errors over PPVT-4 GSVs. Faught et al. found auditory omissions decreased as a function of increasing GSV scores in DS at a similar rate as seen in TD children. PPVT-4 GSV scores only represent receptive vocabulary. The current study newly determined relationships between auditory omissions and receptive syntax, productive vocabulary, and productive syntax in DS. Interestingly, partial correlations between auditory omissions and these language skills ranged only from -.20 to -.39 and were not always significant (see Table 8, 9). Direct and total effects of SA on language were largely nonsignificant. However, relationships became clearer when considered in the context of indirect effects through STM in DS.

Results suggest lapses in auditory SA as measured by increased omissions predict poorer receptive and productive vocabulary and syntax through auditory STM in DS. Considering exploratory findings, this relationship operated independently of parent report of youths' executive functioning and language intervention history. Thus, results supported the conceptual notion that one must first sustain attention to auditory information and then, crucially, retain vocabulary words and syntax in STM in order to learn language. This is true whether considering language in general, receptive language, productive language, vocabulary, syntax, or any possible combination of these skills (e.g., receptive syntax). Significant total effects when productive language, syntax, and productive syntax were outcomes suggest auditory SA might be particularly crucial for these language skills in DS. This is a hugely important finding, as productive language and syntax remain the most challenging of language skills in youth with DS (e.g., Abbeduto et al., 2003; Finestack et al., 2013; Martin et al., 2013). Jongman et al. (2015) also found auditory SA as measured with a CPT allowed for more efficient language production in particular, though they addressed this relationship in TD adults.

Though the main aim of this study was to determine if there was an indirect effect of SA on language through STM in DS, direct effects within these models are meaningful, as well. It should not be overlooked that there were significant direct effects of auditory omissions on auditory STM and of auditory STM on language outcomes. First, the relationship between lapses in auditory SA and auditory STM has only been found in one known study. Faught et al. (2016) found auditory omissions accounted for significant unique variance in auditory STM above and beyond the influence of group membership (DS vs. TD), nonverbal ability, and receptive vocabulary. Specifically, greater lapses in auditory SA are related to poorer auditory STM in DS. However, the mechanism underlying this relationship continues to be unclear – whether improved SA enables better STM task performance or whether improved SA from early childhood enables better memory development. This relationship should be considered in future research. Second, the relationship between auditory STM and language is less novel. Much research has supported this notion and strongly suggested the ability to retain auditory information in STM stores is particularly important to receptive and productive vocabulary and syntax in DS (Iacono et al., 2010; Laws, 1998; Chapman et al., 2002; Miolo et al., 2005; Laws, 2004; Estigarribia et al., 2012; Laws & Gunn, 2004).

Unlike with auditory omissions, there was no indirect effect of auditory SA as measured by commissions on language outcomes through STM. Results suggest the inhibitory component of auditory SA as measured by commissions does not predict receptive and productive vocabulary and syntax through auditory STM in DS. However, this study did find existing relationships between auditory commissions and language skills after controlling for age and nonverbal ability, with partial correlations ranging from -.28 to -.49 (see Table 8, 9). Thus, inhibiting auditory information does seem to serve a role in language in DS, though this relationship is not dependent upon the ability to retain auditory information in STM. Perhaps inhibiting responses to erroneous auditory information causes this information to *not* be retained in auditory STM and thus has no bearing on language through auditory STM.

Further, this study made clear there is a distinction between SART omission and commission errors beyond what is generally suggested in the literature. For example, Robertson et al. (1997) considered false presses (i.e., commission errors) the only SART error score. Researchers concluded this score represented drift of controlled processing into automatic responding, which in turn demonstrated impaired SA. However, omissions and commissions should be considered separate components of a more central SA given 1) the lack of relatedness between these error types in both modalities, and 2) the presence of an indirect effect with auditory omissions and absence with commissions in this study. Johnson et al. (2007) considered omissions to reflect distractions from ongoing task performance and thus lapses in SA and commissions to reflect inhibition difficulties. If this is indeed the case, the current study suggests the two components of SA operate differently in terms of language in DS.

Relationships in the Visual Modality

A different pattern was found in the visual than auditory modality. In the visual modality, nonsignificant partial correlations did not warrant additional analyses of potential indirect effects (see Table 8, 9). It seems neither lapses in visual SA nor the inhibitory component of visual SA predict receptive and productive vocabulary and syntax through visual STM in DS. Thus, results do not support the conceptual notion that one must first sustain attention to visual information and then retain vocabulary words and syntax presented visually in visual STM in order to learn language. However, this study did find weak relationships between visual commissions (though not omissions) and language skills after controlling for age and nonverbal ability, with partial correlations ranging from -.19 to -.36 (see Table 8, 9). Thus, like the auditory domain, inhibiting visual information does seem to serve a role in language in DS, though this relationship again is not dependent upon the ability to retain visual information in STM. Perhaps inhibiting responses to erroneous visual information causes this information to *not* be retained in visual STM and thus has no bearing on language through visual STM.

Results suggest there is a degree of relatedness between visual SA and language skills in DS (see also Jongman et al., 2015; Gardner-Neblett et al., 2014; Faught, 2014; Faught et al., 2016; Finneran et al., 2009), but it might be weaker in the visual than auditory domain. For example, in their meta-analysis of 28 studies comparing visual SA in youth with SLI and TD youth, Ebert and Kohnert (2011) found auditory-linguistic and auditory-nonlinguistic SA impairments in youth with SLI were much larger than that for visual SA. It is possible there remains a small effect of visual SA and language that this study did not have the power to detect. Future studies with larger samples of youth with DS should continue to explore this relationship.

Further, relationships between visual SA and visual STM and between visual STM and language are worth considering, as little research has done so. First, visual omissions but not commissions were related to visual STM. Similarly, Faught et al. (2016) found visual omissions (but not commissions) accounted for unique variance in visual STM above and beyond the influence of group membership (DS vs. TD), nonverbal ability, and receptive vocabulary. Specifically, greater lapses in visual SA are related to poorer visual STM in DS. However, again, the mechanism underlying this relationship is unclear – whether improved SA enables better STM task performance or whether improved SA from early childhood enables better memory development. There is a clear need for future research on this topic.

Second, visual STM was unrelated to language skills in DS. This finding contrasted those found in a few previous studies that examined this relationship (e.g., Chapman et al., 2002). Perhaps differences were due to the use of different visual STM measures. This study used a block span task, while Chapman et al. (2002) measured visual STM with the Stanford-Binet (4^{th} ed.) Bead Memory subtest. However, Iacono et al. (2010) found their relationship between visual STM and receptive language in particular dissipated when controlling for daily functioning and nonverbal ability. Controlling for age and nonverbal ability here could have minimized any existing relationship between visual STM and language in DS. Further, the current study's finding was in agreement with Miolo et al. (2005) who found visual STM accounted for significant variance in zero of five measures of receptive language. Studies comparing youth with SLI and TD youth also do not consistently find group differences in visual STM (e.g., Lum et al., 2012; Baird et al., 2010), again suggesting there may truly be no or only a weak relationship between visual STM and language.

Roles of Executive Functioning and Language Intervention History

Neither executive functioning nor language intervention history served roles in the indirect effect of auditory omissions on language through auditory STM in DS. Specifically, executive functioning did not account for variance in these indirect effects, and indirect effects were not conditional upon language intervention history. Even more, neither BRIEF-2 GEC scores nor IHI intensity scores were significantly related to SA, STM, and language variables, with the lone exception of BRIEF-2 scores and auditory commissions (see Table 8).

First, it was surprising that BRIEF-2 GEC scores were largely unrelated to SA and STM measures considering SA is thought to overlap with executive functioning (e.g., Manly & Robertson, 1997; Manly et al., 2003; Molenberghs et al., 2009; Rueckert & Grafman, 1996) and

STM is a component of a traditional executive function (i.e., working memory). Perhaps this result was an artifice of using parent report of executive functioning, as parent report might be unrelated to youths' scores on performance-based tasks of executive functioning (McAuley, Chen, Goos, Schachar, & Crosbie, 2010). Or perhaps this result truly suggested no relationship among global executive functioning, SA, and STM in youth with DS, unlike as seen in TD samples. There was a chance individual executive functions were related to SA and STM in DS, as executive functioning is not a unitary construct (see Daunhauer et al., 2014), though again these relationships were nonsignificant.

Second, it was surprising that language intervention history was unrelated to all language outcomes in this study. Perhaps this result was again an artifice of relying on parent report, as parents were asked to recall *all* language therapy their children had received over their lifetimes and could have therefore been inaccurate. Or perhaps intensity of language therapy has little bearing on language outcomes in DS. For example, current language therapy techniques could be ineffective in DS (e.g., Kaiser & Roberts, 2013). Or this finding could be influenced by the likelihood that those youth with DS who have the poorest language receive the most therapy and might not have the ability to improve as much as those with better language. There was a chance youths' language outcomes depended on whether they were currently receiving language therapy, though again these relationships were nonsignificant. Regardless of the reasons for these odd exploratory findings, future research should continue to examine how executive functioning and language therapy influence language in DS, whether through SA and STM or additional cognitive processes.

Possibility of Alternative Directions of Influence in Models

It is important to consider the fact that these data are correlational, and alternative directions of influence could exist in models. For instance, additional mediation analyses could have revealed the same indirect relationships found in this study but with language as the predictor and SA as the outcome. When reversed models were run with auditory omissions and commissions, indirect effects were largely nonsignificant, suggesting the better direction of influence was from SA to language. However, there are several additional alternatives other than those in my premise, as all paths could be reversed and the third variable problem is inevitable with correlational data.

The possibility of alternative directions of influence persists in much research. For instance, there is controversy in the TD literature about the direction of influence between auditory STM and language (e.g., Gathercole et al., 1992). Additional studies could address this problem by determining longitudinally if early task performance predicts different outcomes years later. For instance, the path between SA and language in DS could be better understood if SA and language were assessed in early childhood and at different time points over middle childhood and adolescence in youth with DS. If early SA predicted later language skills, this would support the direction of influence posited in this study.

Implications for Language Therapy

This study has particularly important implications for language therapy in DS. Much past research has described the importance of addressing poor auditory STM in language therapy with youth with DS (e.g., Faught, Conners, Barber, & Price, 2016; Buckley & Le Prevost, 2002; Yoder & Warren, 2004; Hewitt et al., 2005; Kumin, 2008; McDuffie et al., 2008; Chapman et al., 2006; Burgoyne et al., 2012; Lecas et al., 2011; Sepúlveda et al., 2013). This study newly suggests the importance of addressing auditory SA in language therapy with youth with DS, considering its indirect effect on language through auditory STM. Unfortunately, few studies have developed or tested procedures to improve SA in any population, and none have specifically considered the effectiveness of addressing auditory SA in language intervention.

It seems as though general health behaviors including getting enough sleep, participating in aerobic exercise, and even drinking milk might lead to improved SA among other cognitive functions in TD samples (e.g., Arnal et al., 2015; Leong, Moghadam, & Hashim, 2015). In fact, the current study found parent report of trouble sleeping at night was related to increased auditory omissions on the SART, suggesting improved sleep is related to improved SA in youth with DS. Interestingly, meditation may also lead to improved SA; Cardeña, Sjöstedt, and Marcusson-Clavertz (2015) found Zen meditators responded faster to SART stimuli and reported fewer task-related interferences than non-meditators (but see Verhoeven, Vrijsen, van Oostrom, Speckens, & Rinck, 2014).

Further, a few studies have considered how SA task performance may be improved upon in TD samples, for example by offering participants rest breaks (Arrabito, Ho, Aghaei, Burns, & Hou, 2015) or through biofeedback-based self-alert training (Braun, Debener, Sölle, Kranczioch, & Hildebrandt, 2015). However, these studies are not particularly useful in understanding how to improve SA more generally. Perhaps video game training could prove promising. For example, De Giglio et al. (2015) found a home-based cognitive rehabilitation program using the video game Dr. Kawashima's Brain Training improved SA in patients with multiple sclerosis.

A couple of studies have attempted to train SA in children and adults with intellectual and developmental disabilities. First, Doughty and Williams (2013) sought to improve performance on a modified CPT in four participants with intellectual disabilities across conditions including instructions, response feedback, and accuracy-dependent money delivery. They found accuracy-dependent money delivery consistently improved SA for each participant regardless of feedback. Results suggest training participants with incentives might improve upon SA task performance, but it has not been determined if this training would generalize to real-world contexts. Second, Kirk, Gray, Ellis, Taffe, and Cornish (2016) used a computerized attention training program with children with intellectual and developmental disabilities aged 4 to 11 years. The program targeted attention skills with four activities delivered on a tablet. Each activity was adaptive to the ability level of each child, provided support and encouragement, and included a reward system. Unfortunately, researchers found this program did not improve SA in their participants, though it did improve selective attention. More generally, computer-based cognitive training has proven largely ineffective in groups with poor attention (e.g., ADHD; see meta-analysis by Rapport, Orban, Kofler, & Friedman, 2013).

The SLI literature has suggested language could be improved upon in part through SA improvements (e.g., Gillam et al., 2008; Gillam et al., 2001; Ebert & Kohnert, 2009). However, to my knowledge no studies have actually developed programs to address SA in language therapy. The current study suggests a need to address auditory SA in language therapy with youth with DS, thus future studies should work to develop interventions that do so. Perhaps addressing auditory SA *in addition to* auditory STM would lead to greater improvements in language than addressing either cognitive process alone.

Limitations of the Current Study

Limitations of this study included small sample size, an unbalanced sample in terms of demographics, and reliance on parent report of executive functioning and language intervention history. First, it is possible the sample size did not allow for enough power to detect potential small indirect effects in the visual modality, as visual SA might be related to language but less so than auditory SA (e.g., Ebert & Kohnert, 2011). A larger sample could have also allowed for clearer interpretations of correlations among model variables.

Second, the sample was unbalanced in terms of demographics, with the majority being White with high SES. The mode annual family income selection was >$100,000, and most mothers graduated college or earned a graduate degree. However, this study found no relationships among model variables and race (white vs. nonwhite), family income, mother employment, father education, or father employment. The lone exception among SES indicators was a significant correlation between mother education and visual commissions, which actually suggested increased mother education was related to *increased* commission errors. Thus, outcomes seemed to be largely uninfluenced by family social demographics.

Lastly, reliance on parent report of executive functioning and language intervention history potentially added degrees of invalidity and unreliability to this study's exploratory analyses. For example, parent report of executive functioning and BRIEF scores in particular have been found to be unrelated to youths' scores on performance-based tasks of executive functioning (McAuley et al., 2010). Thus, the use of executive function tasks could have revealed a different pattern of results when controlled for in median analyses. Further, parent report of language intervention history was perhaps inaccurate, as parents were asked to recollect all instances of language therapy over the spans of their children's lives. Measuring language intervention history from official records of therapy providers could have revealed a different pattern of results when language intervention history was considered as a potential moderator in significant mediation models. However, it is important to note that parent report of participants' language skills was related to youths' language task performance in this study. Thus, parent report cannot be assumed to be completely unreliable and invalid.

Directions for Future Research

Based on the results of the current study, there are several directions for future research. The greatest need is to develop an intervention that improves language in DS in part through addressing auditory SA. Unfortunately, few studies have even attempted to improve upon SA in any population, so this may be the first step. Additional areas of need include further examining the roles of the visual domain and inhibition, as well as of executive functioning and intervention history, in language in DS.

First, future studies with larger samples should continue to explore how visual processing – including both SA and STM – affects language in DS. Perhaps this study found an absence of indirect and direct effects because the sample size was too small to detect potentially small effects. Second, future studies should continue to explore how inhibition affects language in DS. This study found a relationship between the inhibitory component of SA and language in DS independent of STM in both auditory and visual modalities. It is important to determine the specific nature of this relationship, as inhibition might be another cognitive process that should be addressed in language therapy in DS. Lastly, future studies should continue to explore how executive functioning and intervention affect language in DS. Perhaps this study found no relationships among these variables because it relied on parent report. Future studies should directly measure executive functioning with cognitive tasks and should more reliably measure language intervention history in order to determine if there are existing relationships.

Conclusion

Language remains a challenge in youth with DS despite much intervention. This study found both SA and STM contribute to language in DS. Specifically, there was an indirect effect of auditory SA on language through auditory STM that operated independently of executive functioning and language intervention history in youth with DS. Results have important implications for language therapy. Perhaps addressing auditory SA – in addition to the more commonly addressed auditory STM – in language intervention with youth with DS could improve outcomes. Future research should develop methods of doing so. Improving language in DS could ultimately improve youths' educational and occupational outlooks, as well as ease their daily living more generally.

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APPENDIX

Office for Research

Institutional Review Board for the
Protection of Human Subjects

THE UNIVERSITY OF
ALABAMA
RESEARCH

July 8, 2015

Gayle Graham Faught
Department of Psychology
College of Arts & Sciences
Box 870348

Re: IRB# 15-007
"Modeling the Relationships among Sustained Attention, Short-Term Memory, and Language in Down Syndrome"

Dear Ms. Faught:

The University of Alabama IRB has received the revisions requested by the full board on 6/19/15. The board has reviewed the revisions and your protocol is now approved for a one-year period. Please be advised that your protocol will expire one year from the date of approval, 6/19/15.

If your research will continue beyond this date, complete the IRB Renewal Application by the 15th of the month prior to project expiration. If you need to modify the study, please submit the Modification of An Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, please complete the Request for Study Closure Form.

Please use reproductions of the IRB approved stamped consent/assent forms to provide to your participants.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number.

Good luck with your research.

Sincerely,

[redacted]

Stuart Usdan, PhD
Chair, Non-Medical Institutional Review Board

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Office for Research
Institutional Review Board for the Protection of Human Subjects

THE UNIVERSITY OF ALABAMA
RESEARCH

November 25, 2015

Gayle Graham Faught
Department of Psychology
College of Arts and Sciences
Campus Box 870348

Re: IRB Approval # 15-007 (Revision): **"Modeling the Relationships among Sustained Attention, Short-Term Memory, and Language in Down Syndrome"**

Dear Ms. Faught:

The University of Alabama Non-Medical Institutional Review Board recently reviewed the revision request for your protocol. The Board has approved the changes to your protocol.

Please remember that your approval period expires one year from the date of your original IRB approval (6/19/2015), not the date of this revision approval.

Please use reproductions of the IRB-approved/stamped consent forms to provide to your participants.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB approval number.

Good luck with your research.

Sincerely,

[redacted]

Stuart Usdan, Ph.D.
Chair, Non-Medical Institutional Review Board

cc: Dr. Frances Conners

358 Rose Administration Building
Box 870127
Tuscaloosa, Alabama 35487-0127
(205) 348-8461
FAX (205) 348-7189
TOLL FREE (877) 820-3066

Office for Research

Institutional Review Board for the
Protection of Human Subjects

THE UNIVERSITY OF
ALABAMA
RESEARCH

February 2, 2016

Gayle Graham Faught
Dept. of Psychology
College of Arts & Sciences
Box 870348

Re: IRB# 15-007 (Rev 2)
"Modeling the Relationships among Sustained Attention, Short-Term Memory, and Language in Down Syndrome"

Dear Ms. Faught:

The University of Alabama Institutional Review Board has reviewed the revision to your previously approved full board protocol. The board has approved the minor change in your protocol.

Please remember that your approval period expires one year from the date of your original approval, 06/19/15 not the date of this revision approval.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number.

Good luck with your research.

Sincerely,

[redacted]

358 Rose Administration Building
Box 870127
Tuscaloosa, Alabama 35487-0127
(205) 348-8461
FAX (205) 348-7189
TOLL FREE (877) 820-3066

THE UNIVERSITY OF ALABAMA | Office of the Vice President for Research & Economic Development
Institutional Review Board for the Protection of Human Subjects

June 17, 2016

Gayle Graham Faught
Department of Psychology
College of Arts & Sciences
Box 870348

Re: IRB Application # 15-007-R1 "Modeling the Relationships among Sustained Attention, Short-Term Memory, and Language in Down Syndrome"

Dear Ms. Faught:

The University of Alabama Non-Medical IRB recently met to consider your renewal application. The IRB voted to approve your protocol for a one year period.

Your application will expire on June 16, 2017. If your research will continue beyond this date, complete the IRB Renewal Application. If you need to modify the study, please submit the Modification of An Approved Protocol Form. **Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants.** When the study closes, please complete the Request for Study Closure.

Please use reproductions of the IRB approved stamped consent/assent forms to obtain consent from your participants.

Should you need to submit any further correspondence regarding this application, please include the above application number.

Good luck with your research.

Sincerely,

[redacted]

Stuart Usdan, PhD
Chair, Non-Medical Institutional Review Board

358 Rose Administration Building | Box 870127 | Tuscaloosa, AL 35487-0127
205-348-8461 | Fax 205-348-7189 | Toll Free 1-877-820-3066