AUDITORY AND VISUAL SUSTAINED ATTENTION
IN DOWN SYNDROME

by

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ABSTRACT

Cognitive deficits are pervasive in youth with Down syndrome (DS) and are likely due to abnormal brain development. Alterations to the prefrontal cortex in particular suggest sustained attention may be a deficit in DS, though some psychological studies found youth with DS performed at developmental level on sustained attention tasks. The current study investigated sustained attention in DS by comparing youth with DS to typically developing (TD) youth matched for cognitive ability. Groups completed visual and auditory sustained attention to response tests (SARTs), as well as tasks to determine if sustained attention predicted their short-term memory. Results indicated groups performed similarly on both SARTs, and sustained attention predicted only a small portion of variance in their short-term memory beyond the influence of cognitive ability. Overall, these findings suggested sustained attention matches developmental level in DS, and it does not predict the pattern of poor auditory relative to visual processing characteristic of DS.

DEDICATION

This thesis is dedicated to my husband Josh Faught, my parents Walter and Melanie Graham, my little brother Parker Graham, and my girls Zola and Rue. Thank you Josh for your constant encouragement and remarkable patience as I worked on this project. Thank you Mom and Dad for supporting me through all my endeavors; you have always stressed the importance of education, for which I am grateful. Thank you Parker for being the fun in my life and helping me to remember work is not everything. Thank you Zola and Rue, my fur babies, for always making me laugh. I have been extraordinarily blessed to have you all in my life.

LIST OF ABBREVIATIONS AND SYMBOLS

ADHD	Attention Deficit Hyperactivity Disorder
ANOVA	Analysis of variance
CPT	Continuous Performance Task
CTOPP	Comprehensive Test of Phonological Processing
dB	Decibel
DS	Down syndrome
ECAB	Early Childhood Attention Battery
EEG	Electroencephalography
F	Fisher's F ratio: A ration of two variances
f	Effect size of an F -test
FXS	Fragile X syndrome
KBIT-2	Kaufman Brief Intelligence Test, Second Edition
LPP	Late Positive Potential
M	Mean: the sum of a set of measurements divided by the number of measurements in the set
MD	Memory for Digits
$N(n)$	Total sample size (group sample size)
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 product-moment correlation
ΔR^2	Change in explained variance attributed to an additional step added to a regression analysis
SART	Sustained Attention to Response Test
SD	Standard deviation
TD	Typically developing
WS	Williams syndrome
$>$	Greater than
$<$	Less than
$=$	Equal to

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CHAPTER 1

INTRODUCTION

Down syndrome (DS) is the most prevalent childhood genetic disorder and cause of intellectual disability, occurring in about one of every 691 births in the United States each year (Lamb et al., 1997; Parker et al., 2010). Ninety-two percent of DS etiology arises when a third Chromosome 21 is present upon fertilization of a zygote as a result of paired chromosomes' nondisjunction during either the egg or sperm's meiosis (Merrick, Kandel, & Vardi, 2004). Though extra genetic material presents hazards, DS is a manageable diagnosis today. Life expectancy has increased dramatically to approach 60 years old in some industrialized countries, and researchers suspect it will match that of the general population within the next generation (Bittles & Glasson, 2004). Modern medicine has alleviated some of the physical abnormalities often attributed to DS, including congenital heart defects (Stos et al., 2004). However, cognitive abnormalities remain pervasive in DS (Wang, 1996; Silverman, 2007).

It is likely that cognitive abnormalities in DS are functions of abnormal brain development. Previous research suggested youth with DS have smaller brains resulting in part from reduced prefrontal cortex volume (Jernigan, Bellugi, Sowell, & Doherty, 1993; Pinter, Eliez, Schmitt, Capone, & Reiss, 2001). The prefrontal cortex has long been associated with higher-order cognitive processing, and consequently, it has been well established that youth with DS experience particular deficits in executive functioning and language (Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010; Abbeduto et al., 2001). Because of abnormal prefrontal cortexes, as well as abnormal corpus colossal regions (Wang, Doherty, Hesselink, & Bellugi,

1992), researchers have additionally speculated that youth with DS may experience insufficient sustained attention.

Sustained Attention

Sustained attention is a cognitive process that is posited to operate in overlap with executive functioning and to be predominately influenced by the right prefrontal cortex (Manly et al., 2003; Molenberghs et al., 2009; Rueckert & Grafman, 1996) and the corpus callosum (Rueckert, & Levy, 1996). It is defined as the maintenance of attention for irregularly occurring events over extended periods of time and generally involves conscious alertness (Ashcraft & Radvansky, 2010). There are three stages of sustained attention: *attention getting* involves the initial alerting toward an environmental stimulus; *attention holding* involves the maintenance of attentional processes toward said stimulus; and *attention releasing* involves the cessation of attentional processes (DeGangi & Porges, 1990). Individuals rely on sustained attention to complete cognitively planned activities, including sequenced actions and thoughts. Thus, sustained attention is considered “a basic requirement for information processing” (Kung et al., 2010, para. 4) and is vital to cognitive development. When individuals have sustained attention deficits, they may be unable to adapt to environmental demands (DeGangi & Porges, 1990). For instance, without sustained attention in the broader sense, students would be unable to sequentially follow and learn novel information presented by teachers.

Research examining sustained attention often utilizes the continuous performance task (CPT) paradigm in which participants respond to infrequently presented targets over long periods of time (e.g., Tomporowski, Hayden, & Applegate, 1990). CPTs generally result in performance declines over time (i.e., approximately 20 to 35 minutes), indicating that duration of sustained attention is limited (See, Howe, Warm, & Dember, 1995). However, longer target duration and

more frequent target presentation improve sustained attention task performance (Warm & Jerison, 1984). Sustained attention is also impacted by individuals' physiological and neurological states (Warm, 1984). For instance, sustained attention diminishes when an individual is distracted by physiological internal stimuli (e.g., feeling nauseated), neurological internal stimuli (e.g., feeling anxious), or external stimuli (e.g., hearing a loud noise). Distractions such as these can interrupt and consequently interfere with sustained attention (DeGangi & Porges, 1990), and low intelligence can further exacerbate the essential process (Tomprowski & Simpson, 1990).

Sustained Attention in DS

Because brain regions associated with sustained attention are altered and low intelligence is characteristic of DS (Connolly, 1978), it might be expected that sustained attention is a deficit of the syndrome. If sustained attention is a deficit, youth with DS might have special difficulty maintaining their attention enough to acquire skills necessary for reading, language, or even daily living activities. However, the idea that sustained attention is a deficit in DS has not always been supported empirically. The psychological studies that compared sustained attention between youth (i.e., school-aged children and adolescents) with DS and typically developing (TD) youth, youth with Fragile X syndrome (FXS), youth with Williams syndrome (WS), or youth with nonspecific intellectual disability (NSID) provided conflicting results.

Studies Employing the CPT Paradigm. Two studies compared visual sustained attention between youth with DS and TD youth matched for mental age using the CPT paradigm. Both Munir, Cornish, and Wilding (2000) and Cornish, Scerif, and Karmiloff-Smith (2007) investigated boys with DS and TD boys using the Vigilant task employed during the Wilding Attention Test for Children (Wilding, Munir, & Cornish, 2001). In this CPT, participants were

shown a computer display portraying a river, trees, and different colored “holes” from which a target stimulus (i.e., a “monster”) appeared at 20 random irregular intervals. Participants were instructed to click monsters as quickly as possible when they appeared. Cornish et al. found that both groups accurately detected similar numbers of targets and had similar response times to targets. Munir et al. split the TD group into participants whose teachers rated them as having good attention versus those rated as having poor attention and also found similar performances for target detection between the group with DS and TD group. However, the group with DS had slower response times and made more false alarms (i.e., more often clicked distracters) than the good attention TD group. It should be noted that the group with DS and good attention TD group were not well matched, though, as the group with DS was approximately 20 months behind in verbal mental age.

These two studies also compared visual sustained attention between boys with DS and boys with FXS (i.e., a syndrome that also causes intellectual disability). Both studies reported similar numbers of targets detected and response times between groups. However, Munir et al. (2000) found that boys with DS made fewer false alarms (i.e., less often clicked distracters) than boys with FXS. This finding could mean that boys with DS demonstrate relatively strong sustained attention; however, this result is probably better explained in terms of inhibition weakness in FXS boys. In a separate inhibition task in the same study, Munir et al. reported that boys with FXS performed more poorly than all other groups (see also Wilding, Cornish, & Munir, 2002).

Cornish et al. (2007) additionally examined developmental trajectories of sustained attention for the group with DS, group with FXS, and TD group. As expected, number of targets detected and response speeds increased with chronological and mental age in TD boys. However,

for boys with DS, number of targets detected was not related to chronological or mental age, though response speed was related. For boys with FXS, response speed was not related to chronological or mental age, though number of targets detected was related. Findings could suggest that performance in target detection by boys with DS relative to TD boys or those with FXS depends on the level of mental age comparison. That is, the mean mental age for each of the groups may determine how comparable the means are for target detection.

Studies Employing Mixed Measures. More recent studies have veered away from use of the traditional CPT paradigm to compare groups with DS and TD groups on sustained attention. For instance, Lanfranchi et al. (2010) compared groups on the Self-ordered Pointing Task (Petrides & Milner, 1982) in which participants kept track of stimuli they pointed to on previous pages while pointing to other stimuli on additional pages. Researchers found that, though adolescents with DS completed similar numbers of pages as a TD group matched for mental age, the group with DS made more errors. Further, Costanzo et al. (2013) compared a group with DS and TD group on both visual and auditory sustained attention using the Bells Test in which participants circle targets embedded within a page of distracters (Gauthier, Dehaut, & Joannette, 1989) and the Score task in which participants count the number of auditory targets embedded within a series of distracter sounds (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999). Costanzo et al. found the group with DS performed as well as the TD group on the visual sustained attention task but worse than the TD group on the auditory sustained attention task. This pattern of results matches a more general pattern of weakness in auditory/verbal processes relative to visuo-spatial processes in DS (e.g., Wang, 1996).

Costanzo et al. (2013) also compared visual and auditory sustained attention between youth with DS and those with WS (i.e., another syndrome that causes intellectual disability)

using the same measures described previously. Researchers found that the group with DS performed as well as the group with WS on the auditory sustained attention task but worse than the group with WS on the visual sustained attention task. The latter finding could be due to a syndrome-specific strength in visual sustained attention for the group with WS or a syndrome-specific deficit for the group with DS. Because neither group's visual sustained attention differed from the TD group in this study, though, it seems more likely that this finding was due to a syndrome-specific strength in visual sustained attention for WS.

Interestingly, another study compared youth with DS to those with WS on the newly created Early Childhood Attention Battery (ECAB; Breckenridge, Braddick, & Atkinson, 2013) in which participants respond to rarely presented targets over short periods of time. Breckenridge, Braddick, Anker, Woodhouse, and Atkinson (2013) found contrasting results to those seen in Costanzo et al. (2013) and generally found that both groups performed relatively well on all three subtests of sustained attention: visual sustained, auditory sustained, and dual sustained. Specifically, researchers found no significant differences between the group with DS and group with WS on either the visual sustained or dual sustained subtests. However, they also found that the group with DS outperformed the group with WS on the auditory sustained subtest. Additionally, this study examined developmental trajectories of sustained attention for both groups. Unlike Cornish et al. (2007), Breckenridge et al. found that visual sustained performance improved with increasing chronological and mental age in the group with DS and group with WS. Dual sustained performance also improved with age in the group with DS but not the group with WS. However, auditory sustained performance did not improve with age in either group.

Study Employing the SART Paradigm. One study compared sustained attention between youth with DS and youth with NSID matched for chronological and mental age in order

to prevent results from being confounded by specific etiologies of other intellectual disabilities. Trezise, Gray, and Sheppard (2008) investigated both visual and auditory sustained attention by applying the sustained attention to response test (SART) paradigm to both modalities. Robertson, Manly, Andrade, Baddeley, and Yiend (1997) originally proposed this paradigm for the visual modality. In the SART paradigm, participants respond to frequently presented non-targets and inhibit their responses to infrequently presented targets over relatively short periods of time (e.g., six minutes). Unlike the CPT paradigm, the SART paradigm measures lapses in sustained attention while minimally affecting other cognitive processes like memory.

During Trezise et al.'s (2008) visual SART, participants were presented with sequential line drawings of common animals on a computer screen. The target animal was a dog, while non-target animals were a horse, chicken, elephant, etc. Participants were asked to press a star key when they saw non-target animals and to NOT press the star when they saw the target animal. During Trezise et al.'s auditory SART, participants heard the same animals' names spoken over computer speakers and were asked to press a star key when they heard the names of non-target animals and to NOT press the star when they heard the target animal's name. Commission errors (i.e., pressing the star when presented with the target) and omission errors (i.e., not pressing the star when presented with non-targets) were recorded, as well as participants' response times to non-targets. Specifically, commission errors measure lapses in controlled processing that lead to automatic responding and consequently diminished sustained attention (Robertson et al., 1997), while omission errors measure distractions from task participation and thus lapses in sustained attention (Johnson et al., 2007).

Trezise et al. (2008) found that youth with DS experienced fewer commission errors than youth with NSID on the visual SART, but omission errors occurred at similar rates. Results

indicated that the group with DS was better able to resist pressing the star when infrequently presented with a target and ultimately better able to maintain visual attention than the group with NSID. Further, groups did not differ in commission or omission error rates on the auditory SART. Across both tasks, groups did not differ in response times to non-targets, indicating that procedures were not biased to favor either group's processing speed abilities. Together, results suggested visual sustained attention is a relative strength in DS, as youth with DS outperformed a control group matched for chronological and mental age. Results also suggested that visual sustained attention is better than auditory sustained attention in DS, though not in NSID. This pattern matched a more general pattern of weakness in auditory/verbal processes relative to visuo-spatial processes in DS (e.g., short-term memory; Jarrold, Baddeley, & Hewes, 2000). It raised the intriguing possibility that modality effects in sustained attention may lead to modality effects in other types of cognitive processing. If it is more difficult for youth with DS to sustain attention for auditory material, this may present special difficulties for short-term memory, language comprehension, and other higher auditory functions.

Overall, the empirical evidence from sustained attention studies in youth with DS did not consistently suggest sustained attention was a particular deficit in DS as neurological studies would lead researchers to expect. However, conflicting results were common in the literature and could have been discovered because studies did not employ the same sustained attention tasks. Alarming, some of these tasks might have been invalid measures of sustained attention. For instance, Lanfranchi et al. (2010) used the Self-ordered Pointing Task that is often used as a measure of visual working memory. Costanzo et al. (2013) used the Bells Test to measure visual sustained attention, though it was created as a measure of visuospatial neglect. They also used the Score task, which could be considered a measure of working memory, as participants must

count the number of auditory tones presented over time. Though the ECAB is a valid measure of sustained attention, it was only created for use in children aged 6- to 16-years-old and thus cannot measure attention in older youth (Breckenridge et al. 2013).

Gaps in the literature were also troublesome. No available research investigated visual or auditory sustained attention differences between youth with DS and TD youth using the SART paradigm, which is perhaps one of the most valid and reliable sustained attention measures available today (see Robertson et al., 1997). Further, auditory sustained attention was addressed less often than visual sustained attention in DS. This was a pitfall in the literature because visual and auditory modalities are neuroanatomically distinct and thus have unrelated effects on cognition (Wang & Bellugi, 1994). Regarding the DS cognitive phenotype, youth with DS exhibit exceptionally poor auditory relative to visual short-term memory (Jarrold et al., 2000; Fidler, 2005). Memory theory alone has been unable to account for why auditory short-term memory appears to be a deficit in DS, so it was possible that the discrepancy between modalities was related to sustained attention rather than to an aspect of memory. Ultimately, because visual and auditory modalities uniquely affect cognition, both were worth investigating in sustained attention as they have been in short-term memory.

The Current Study

The current study was designed to fill in gaps in the existing literature regarding how sustained attention is impacted in youth with DS. To do so, the study applied the SART paradigm to auditory and visual modalities and compared performances between youth with DS and TD youth matched for nonverbal ability and receptive vocabulary. Given the combined effects of neurological evidence and previous studies, the current study hypothesized the following:

1. Visual sustained attention would match developmental level in DS, while auditory sustained attention would be a particular deficit in DS. Thus, the group with DS would make similar numbers of commission and omission errors as the TD group on the visual SART, but more errors than the TD group on the auditory SART.
2. Visual sustained attention would be better than auditory sustained attention among youth with DS. Thus, it was expected that the group with DS would make fewer commission and omission errors on the visual SART than the auditory SART.
3. Sustained attention would improve with increasing chronological and mental age in TD youth but not in youth with DS. Thus, commission and omission errors would negatively correlate with chronological and nonverbal mental age in the TD group but not in the group with DS.

Furthermore, as an exploratory analysis, this study compared groups' short-term memory and investigated if sustained attention predicted the DS phenotype's poor auditory relative to visual processing. It was expected that the group with DS would perform worse on an auditory short-term memory task, but similarly on a visual short-term memory task, when compared to the TD group. It was also expected that groups' sustained attention would predict and thus explain some of the variance in their own short-term memory spans.

CHAPTER 2

METHODOLOGY

The current study used a 2 x 2 mixed design in order to analyze variances between two groups and two modality conditions. Groups included youth with DS and TD youth matched for nonverbal mental age and receptive vocabulary age. Conditions included applying the SART paradigm to visual and auditory sensory modalities. In the SART paradigm, participants must resist pressing a key in response to target items and instead press a key in response to non-target items. Thus, dependent variables were participants' numbers of commission errors (i.e., erroneously pressing a key in response to a target) and numbers of omission errors (i.e., erroneously not pressing a key in response to a non-target).

Participants

Twenty youth with DS aged 10 to 21 ($M=15.98$; 10 females) and 20 TD youth aged 3 to 7 ($M=4.84$; 14 females) completed the study. One additional participant with DS did not complete the study because of behavior problems; and two additional TD participants did not complete the study, one because the participant was discovered to be gifted and another because of behavior problems. A power analysis using the G*power computer program (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that the final sample size ($N=40$) met the estimated size required to show a large effect ($f=0.40$) of group with 0.80 power using a 2 x 2 mixed analysis of variance (i.e., ANOVA) with alpha at 0.05. It also surpassed the estimated size required to show medium effects ($f=0.25$) of modality and of group x modality interaction with 0.80 power using a 2 x 2 mixed ANOVA with alpha at 0.05.

The group with DS was recruited via email and phone call from the University of Alabama Intellectual Disabilities Registry that encompasses four states in the southeastern United States. The TD group was largely recruited via forms sent home to parents from Trinity Presbyterian Preschool in Tuscaloosa, AL. Demographics including sex, race, and socioeconomic status were not explicitly controlled for during recruitment because access to the population of interest (i.e., the group with DS) was limited. Upon recruitment, parents of youth with DS were asked to verify that their children had received DS diagnoses indicating Trisomy 21 or a translocation involving Chromosome 21. Further, parents of TD youth were asked if their children had been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) prior to participation. ADHD symptomology could have confounded results, so TD youth whose parents reported ADHD diagnoses were not eligible to participate in the study. However, parents of youth with DS were not asked if their children had ADHD because DS and ADHD are highly comorbid, with about one-third of individuals with DS meeting diagnostic criteria for ADHD and nearly half of individuals with DS exhibiting ADHD symptomology (Ekstein, Glick, Weill, Kay, & Berger, 2011; Edvardson et al., 2014). Thus, including participants with DS and ADHD made the group more representative of the DS population.

Because youth with DS often display ophthalmic disorders (Roizen, Mets, & Blondis, 1994) and hearing impairments (Van Gorp & Baker, 1984), both groups were required to pass vision and hearing screens before study inclusion. Experimenters first administered the symbols version of the LEA (LH) Near Vision Line Test (LEA-Test, Ltd.; Hyvärinen, Näsänen, & Laurinen, 1980) to participants because it adequately measures binocular acuity in individuals with low literacy, and inclusion required binocular acuity corresponding to 20/40 or better (with glasses or contacts). Two participants with DS did not pass the vision screen: one who did not

complete the study because of behavior problems so was already excluded from analyses, and another who proved he could see stimuli presented during the visual SART so was included in analyses. Experimenters then administered an informal hearing evaluation using the McCormick Toy Discrimination Test (McCormick, 1977), and inclusion required accurate performance at the 60-dB level or below. All participants passed the hearing screen. These inclusion criteria allowed for adequate participation in both visual and auditory SARTs.

Groups were matched on nonverbal mental age using the Kaufman Brief Intelligence Test, Second Edition Matrices subtest (KBIT-2; Kaufman & Kaufman, 2004). Participants who scored lower than a 4-year-old mental age were not included for nonverbal ability matching purposes because this was the lowest score possible on the KBIT-2 Matrices subtest. Because two participants with DS scored lower than 4-years-old on nonverbal mental age, participants were also matched on receptive vocabulary age using the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4; Dunn & Dunn, 2007). The PPVT can be used to produce receptive vocabulary age equivalents as young as 2-years-old.

Measures

Sustained Attention to Response Test (SART; Robertson et al., 1997). Primary measures adhered to the SART paradigm in which participants resist pressing computer keys in response to randomly presented targets and instead press keys when presented with non-targets over relatively short periods of time. Auditory and visual versions of the SART used in this study were originally created by Trezise et al. (2008) and were successfully administered to youth with DS in their study investigating sustained attention. Both versions implemented in this study were recreated using Superlab 4.5 computer software. The SART paradigm is thought to more accurately assess lapses in sustained conscious processing than the traditional CPT paradigm in

which participants press computer keys in response to randomly presented targets over long periods of time. This is because the SART requires actively responding to non-targets and remaining vigilant to the occurrence of a target. In the CPT, participants do not actively respond until a target appears.

SART performance correlates with self-reports of attentional lapses in everyday life for individuals with and without brain alterations (Robertson et al., 1997; Smilek, Carriere, & Cheyne, 2010). The SART also accurately distinguishes participants with brain injuries from participants without brain injuries and significantly predicts severity of brain injuries (Robertson et al., 1997). Further, SART performance correlates more strongly with other sustained attention tasks than it does with response inhibition tasks such as the Stroop task (Robertson et al., 1997). This supports the notion that poor performance on the SART is attributed to difficulty in maintaining attention to the task rather than difficulty in inhibiting responses to target stimuli. Thus, the SART is a valid measure of sustained attention (Robertson et al., 1997; Chan, 2001). The SART also has good test-retest reliability for commission and omission error rates, $r=0.76$ (Robertson et al., 1997). Lastly, the SART has good cross-modal reliability when comparing auditory and visual versions (Seli, Cheyne, Barton, & Smilek, 2012).

Auditory SART. Trezise et al. (2008) originally created the auditory SART that was recreated using Superlab 4.5 computer software in this study. Audio recordings of nine common animal names were presented to participants via Insignia speakers attached to a laptop. Animal names were presented with 75% available volume, individually, and serially for 500 ms each, followed by a 1500 ms silent pause. Animal names were also presented pseudo-randomly and in equal proportions. Practice sessions consisted of 18 audio recordings being presented in two continuous blocks over approximately 30 seconds. Testing sessions consisted of 225 audio

recordings being presented in 25 continuous blocks over approximately eight minutes. The target was an audio recording of the word “dog,” while non-targets were any of the other eight animal name recordings (i.e., bird, cat, elephant, fish, giraffe, horse, pig, and rabbit). Computer software yielded two scores for the auditory SART: number of commission errors out of 25 possible (i.e., pressing the spacebar in response to target stimuli) and number of omission errors out of 200 possible (i.e., not pressing the spacebar in response to non-target stimuli). Higher scores indicated more errors and thus poorer auditory sustained attention.

Visual SART. Trezise et al. (2008) originally created the visual SART that was recreated using Superlab 4.5 computer software in this study. Line drawings of nine common animals were presented to participants on an 11” Apple MacBook Air laptop computer screen. Line drawings were 10 cm by 10 cm large and consisted of black lines presented on a white background. Animals were presented on the center of the screen, individually, and serially for 500 ms each, followed by a 1500 ms blank screen. Animals were also presented pseudo-randomly and in equal proportions. Practice sessions consisted of 18 line drawings being presented in two continuous blocks over approximately 30 seconds. Testing sessions consisted of 225 line drawings being presented in 25 continuous blocks over approximately eight minutes. The target was a line drawing of a dog, while non-targets were any of the other eight animal line drawings (i.e., bird, cat, elephant, fish, giraffe, horse, pig, and rabbit). Computer software yielded two scores for the visual SART: number of commission errors out of 25 possible (i.e., pressing the spacebar in response to target stimuli) and number of omission errors out of 200 possible (i.e., not pressing the spacebar in response to non-target stimuli). Higher scores indicated more errors and thus poorer visual sustained attention.

Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman & Kaufman, 2004). The current study utilized the KBIT-2 Matrices subtest, a measure of nonverbal ability that includes conceptual reasoning and problem solving, to assess and match participants on nonverbal mental age. The KBIT-2 easel was used to show participants pictures and abstract designs that followed patterns but were missing one element. Participants pointed to the picture that completed the pattern for each item. The subtest included three sample trials for which experimenters provided participants feedback to ensure they understood instructions. Participants completed up to 46 trials. Testing lasted approximately 15 minutes and was stopped after participants missed four consecutive test trials. Three scores were yielded: a raw score, standard score, and age equivalent. Participants were specifically matched on age equivalent in months. Higher scores indicated greater nonverbal ability (Kaufman & Kaufman, 2004).

KBIT-2 scores are highly correlated with other intelligence test scores, with composite congruent validity ranging from 0.80 to 0.86. Composite internal consistency reliability ranges from 0.87 to 0.91, and composite test-retest reliability reaches up to 0.89 over 27 days. The Nonverbal scale (which consists only of the Matrices subtest) is high in construct and concurrent validity with participants aged 12 years and up. However, the Nonverbal scale has lower internal consistency of 0.78 at ages 4 to 5 years and lower test-retest reliability of 0.76 at ages 4 to 12 years (Kaufman & Kaufman, 2004). Despite slightly lower coefficients in younger children, the KBIT Matrices subtest was successfully administered in previous studies to assess nonverbal mental ages in youth with DS (e.g., Randolph & Burack, 2000; Trezise et al., 2008) and has been deemed an acceptable measure of intelligence in youth with cognitive impairment (Kaufman & Kaufman, 2004).

Peabody Picture Vocabulary Test – 4th edition (PPVT-4; Dunn & Dunn, 2007). The current study utilized the PPVT-4 to assess and match participants on receptive vocabulary age. The PPVT-4 easel was used to show participants four pictures per page, and participants pointed to the picture that corresponded with a word spoken by the experimenter for each page. The test included two sample questions for which experimenters provided participants feedback to ensure they understood instructions. In all, the test covered 20 content categories and included nouns, verbs, and adjectives. Testing lasted approximately 20 minutes and was stopped after participants missed eight or more items in a block. Four scores were yielded: a raw score, standard score, growth scale value, and age equivalent. Participants were specifically matched on age equivalent in months. Higher scores indicated greater receptive vocabulary ability.

The PPVT-4 is reliable in participants aged 2 to 90 years. Split-half reliability ranges from .89 to .97 for all ages and from .95 to .96 for the youngest participants reported (i.e., 2 years). Test-retest reliability ranges from .92 to .93 for all ages and is .93 for the youngest participants reported (i.e., 2 to 4 years). The PPVT-4 also correlates with other language measures, including the Clinical Evaluation of Language Fundamentals, 4th edition from .67 to .73 for ages 5 to 12 years; the Expressive Vocabulary Test from .80 to .84 for ages 2 to 81 years; and the Comprehensive Assessment of Spoken Language from .41 to .79 for ages 3 to 12 years (Dunn & Dunn, 2007).

Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999). As an exploratory measure, the current study utilized the CTOPP Memory for Digits (MD) subtest. This subtest measured participants' abilities to hear sequences of numbers and repeat numbers accurately and in order. Sequences began with two numbers and grew to

sequences of eight numbers as trials continued. Thus, the CTOPP MD subtest was a simple measure of auditory short-term memory.

Audio recordings of numbers 0 through 9 were presented to participants via Insignia speakers attached to a laptop computer. The CTOPP MD subtest included four sample trials for which experimenters provided participants feedback to ensure they understood instructions. Test trials involved three trials being administered at each sequence level (i.e., 1 through 8 digits). Testing lasted approximately 10 minutes and was stopped after participants missed three consecutive test trials. Four scores were yielded: a raw score, standard score, age equivalent, and digit span. The raw score equaled the total number of trials passed out of a possible 21 and was the primary measure used during data analysis. Higher scores indicated greater auditory short-term memory (Kaufman & Kaufman, 2004).

CTOPP MD subtest concurrent partial correlations range from 0.32 to 0.49 when controlling for age and thus are highly correlated with other measures of phonological processes. Predictive partial correlations range from 0.26 to 0.37 when controlling for age. MD subtest validity is enhanced through rapid presentation of digits that discourages rehearsal, participants being asked to forward recall, and researchers administering three trials at each span length (up to eight). The MD subtest is also reliable in youth aged 5 to 24 years with an average reliability of 0.77 and test-retest reliability ranging from 0.74 in school-aged children to 0.81 in young adults (Wagner et al., 1999). Furthermore, the subtest has been used successfully in previous studies investigating phonological processes in youth with intellectual disabilities (e.g., Channell, Loveall, & Conners, 2013).

Corsi Block-Tapping Task (Corsi Task; Milner, 1971). As an exploratory measure, the current study utilized a Corsi Task that was administered with the same procedure first outlined

in Milner (1971). This task measured participants' abilities to see sequences of block taps and repeat block taps accurately and in order. Block-tapping sequences in this study were those outlined in the Block Recall subtest of the Automated Working Memory Assessment (Alloway, 2007), which was normed for children as young as 4-years-old. Sequences began with one tap and grew to sequences of nine taps as trials continued. Thus, the subtest was a simple measure of visuo-spatial short-term memory. Variations of the Corsi Task are commonly used in samples with DS (e.g., Frenkel & Bourdin, 2009).

A board with nine cube-shaped blocks in non-symmetric positions was presented to participants. This Corsi Task included four sample trials for which experimenters provided participants feedback to ensure they understood instructions. Test trials involved four trials being administered at each sequence level (i.e., 1 through 9 blocks). When participants accurately completed at least one of four trials at a given level, the level was considered passed and administration continued to the next sequence level. Testing lasted approximately 10 minutes and was stopped after participants missed all four test trials within a sequence level. Two scores were yielded: a raw score and spatial span. The raw score equaled the total number of trials passed out of a possible 36 and was the primary measure used during data analysis. Higher scores indicated greater visual short-term memory.

Procedure

Experimenters obtained written consent from parents and verbal assent from participants. Testing sessions took place at parents' preferred location: home, child's school, or the University of Alabama's Intellectual Disabilities Lab. Before testing, experimenters administered vision and hearing screens. During the LEA (LH) Near Vision Line Test and at a 16-inch distance, participants named the first symbol on each row of a vision chart to row 20/63 where participants

named the entire row's symbols. To meet criterion for the study, participants had to have six or fewer errors in the 20/63 row. During the McCormick Toy Discrimination Test, participants first labeled seven pairs of toys with phonologically similar names (e.g., plane and plate). Participants then heard computer speakers play recordings of the toy names and pointed to each toy as the speakers played its name. Six toys were probed at each of five decibel levels (i.e., 72 dB, 66 dB, 60 dB, 54 dB, and 48 dB). To meet criterion for the study, participants had to accurately point to all six toys probed at the 60-dB level.

Once deemed eligible for study inclusion, participants individually completed both the auditory and visual SART separated by the KBIT-2 Matrices subtest used to match participants on nonverbal mental age. Order of SARTs was counterbalanced across the sample. After completing the SARTs and KBIT-2 Matrices subtest, participants individually completed the CTOPP MD subtest and the Corsi Task. Order of these short-term memory tasks was counterbalanced across the sample. Lastly, participants completed the PPVT-4 used to match participants on receptive vocabulary age. Participants were given an animal sticker upon completion of each of the SARTs and a toy upon completion of the entire study. On average, the study lasted approximately 75 minutes per participant.

For both the auditory and visual SART, participants were told they were playing an animal game in which they were going to “catch” animals. Participants caught animals by pressing the spacebar every time an animal name that was not “dog” was heard through speakers, or every time an animal that was not a dog was seen on screen. Specifically, for the auditory SART, experimenters instructed:

“You are going to hear different animal names. I want you to catch animals by pressing the spacebar. We’re trying to catch only animals that are not a dog, so press the spacebar only when the animal name you hear is NOT ‘dog.’ I want you

to press the spacebar when you hear ‘bird,’ ‘cat,’ ‘elephant,’ ‘fish,’ ‘giraffe,’ ‘horse,’ ‘pig,’ or ‘rabbit,’ but NOT when you hear ‘dog.’”

For the visual SART, experimenters instructed:

“You are going to see different animals on the screen. I want you to catch animals by pressing the spacebar. We’re trying to catch only animals that are NOT a dog, so press the spacebar only when the animal on screen is NOT a dog. I want you to press the spacebar when you see a bird, cat, elephant, fish, giraffe, horse, pig, or rabbit, but NOT when you see a dog.”

Participants were seated about 18 inches from the laptop screen and asked to sit as still as possible while pressing the spacebar with their preferred pointer finger in response to non-target items. During practice sessions, experimenters worked enthusiastically to help participants accurately press the spacebar in response to non-targets over two blocks (i.e., 18 trials). During testing sessions, experimenters intervened as little as possible to maintain rapport and ensure participants were not being distracted over 25 blocks (i.e., 225 trials).

CHAPTER 3

RESULTS

Preliminary Analyses

Descriptive Statistics. Descriptive statistics including sample size (n), mean, standard deviation (SD), range, skew, and kurtosis were computed for each of the practice and key measures within groups. Values are presented in Table 1 for reference throughout this chapter.

Table 1
Descriptive Statistics for Practice and Key Measures

Measure	Group	n	Mean	SD	Range	Skew	Kurtosis
KBIT-2 Matrices Age in Months	DS	18	63.78	10.91	52-93	1.69	2.74
	TD	20	63.65	18.28	48-124	2.67	7.03
PPVT-4 Age in Months	DS	20	68.95	18.89	42-127	1.36	3.81
	TD	20	71.55	19.29	44-115	.68	.00
Practice Auditory Commission Errors	DS	20	.45	.76	0-2	1.39	.41
	TD	20	.25	.44	0-1	1.25	-.50
Practice Visual Commission Errors	DS	20	.35	.59	0-2	1.52	1.64
	TD	20	.20	.41	0-1	1.62	.70
Practice Auditory Omission Errors	DS	20	4.10	2.29	1-9	.48	-.29
	TD	20	3.00	2.22	0-10	1.56	4.14
Practice Visual Omission Errors	DS	20	3.80	2.71	0-10	.54	-.08
	TD	20	2.40	2.23	0-7	.54	-.83
Auditory Commission Errors	DS	20	3.05	3.44	0-9	.80	-1.17
	TD	20	3.00	2.05	0-7	.49	-.38
Visual Commission Errors	DS	20	3.60	3.42	0-13	1.85	3.45
	TD	20	4.05	2.72	0-9	.71	-.78

Auditory Omission Errors	DS	20	44.55	30.19	3-102	.23	-1.18
	TD	20	45.80	22.45	6-97	.36	.57
Visual Omission Errors	DS	20	41.55	24.08	8-102	.75	.57
	TD	20	39.45	24.46	6-84	.46	-.89
CTOPP Memory for Digits Raw	DS	20	5.20	2.29	2-10	.52	-.42
	TD	20	8.95	2.14	6-13	.86	-.16
Corsi Task Raw	DS	20	12.95	2.69	8-18	.35	-.65
	TD	20	11.70	3.19	7-20	.70	.86

Matching groups. Two one-way ANOVAs were conducted: one to determine if groups were matched on nonverbal mental age as assessed by the KBIT-2 Matrices subtest, and another to determine if groups were matched on receptive vocabulary age as assessed by the PPVT-4. These analyses revealed that groups were successfully matched for nonverbal mental age, $F(1,36)=.001, p=.980$, and receptive vocabulary age, $F(1,38)=.185, p=.669$. Note that only 18 of 20 participants in the group with DS were included in the nonverbal mental age comparison because two participants scored lower than the minimum mental age of 48 months. All participants were included in the receptive vocabulary age comparison.

SART Reliability. To determine whether the four dependent measures were internally consistent ($r \geq .7$), Spearman-Brown split-half (odd-even) reliability was calculated for each of the four SART measures: auditory commission errors, visual commission errors, auditory omission errors, and visual omission errors. All four measures proved reliable when considering groups combined, though the reliability for commission errors ($r \geq .7$) was lower than for omission errors ($r > .9$). Further, all four measures proved reliable when considering the group with DS, but only three of them did so when considering the TD group. Reliability for auditory commission errors in the TD group was low, despite being high in the group with DS. See Table 2 for reliability coefficients.

Table 2
Reliability Coefficients for SART Measures

	Auditory Commission Errors	Visual Commission Errors	Auditory Omission Errors	Visual Omission Errors
Both Groups ($N=40$)	.700	.739	.944	.938
Group with DS ($n=20$)	.808	.747	.975	.957
TD Group ($n=20$)	.412	.739	.894	.936

SART Distributions. To determine whether statistical test assumptions were met, histograms were inspected for normal distributions within groups, and homogeneity of variance was calculated for the four SART measures between groups. In the visual modality, distributions were found to be normal within both groups, and nonsignificant Levene's tests confirmed that the assumption of homogeneity of variance was not violated for either visual commission or omission errors. In the auditory modality, distributions were found to be normal for the TD group but not for the group with DS. Significant Levene's tests confirmed that the assumption of homogeneity of variance was violated for both auditory commission errors ($p<.01$) and auditory omission errors ($p<.05$). Additionally, the four SART measures were checked for outliers, and no participants scored outside ± 3 standard deviations from the means.

Interestingly, for auditory commission errors in the group with DS, the distribution was bimodal. Specifically, 13 participants with DS made between 0 and 2 auditory commission errors, while the remaining 7 participants made between 5 and 9 errors. To better understand this bimodal distribution, the group with DS was split into low errors (< 4.5 median) and high errors (> 4.5 median) groups. As expected, a one-way ANOVA revealed a significant difference between low and high errors groups on auditory commission errors, $F(1,18)=201.065$, $p<.001$. However, when compared on the KBIT-2 Matrices subtest, PPVT-4, CTOPP MD subtest, Corsi Task, and chronological age, no significant differences were found between the low and high

errors groups ($ps > .147$). This finding suggested groups' differences in auditory sustained attention could not be attributed to differences in nonverbal ability, receptive vocabulary, auditory short-term memory, visual short-term memory, or chronological age.

Main Analyses

Main analyses included two 2 x 2 mixed ANOVAs with alpha at 0.05, one for commission errors and another for omission errors. These analyses allowed researchers to examine differences between two groups and two modality conditions. Groups included youth with DS and TD youth matched for cognitive ability. Conditions included applying the SART paradigm to auditory and visual sensory modalities. Because the assumption of homogeneity of variance was violated for auditory commission and omission errors, all four SART measures were transformed using both log10 and square root transformations and analyzed accordingly. Though these transformations slightly improved homogeneity of variance, the assumption remained violated for the two auditory measures and the pattern of results remained the same, so analyses using raw data are presented below. These analyses revealed no group differences, which are more likely to erroneously occur with heterogeneity of variance and increasing Type 1 error rate (see Moder, 2007). Thus, it seems these analyses using raw data were not exorbitantly affected by violations.

The first mixed ANOVA analyzed Group (DS vs. TD) x Modality (auditory vs. visual) on the dependent variable SART commission errors. Results revealed no significant main effect of group, $F(1, 38)=.057, p=.813$, modality, $F(1, 38)=3.631, p=.064$, or group x modality, $F(1, 38)=.355, p=.555$. However, the main effect of modality became significant when using transformed data ($p<.05$), with fewer errors on the auditory than visual SART. This effect was largely carried by the TD group, $F(1,19)=4.234, p=.054$, rather than the group with DS,

$F(1,19)=.680, p=.420$. Overall, these findings suggested groups made similar numbers of commission errors on the auditory and visual SART. There was some evidence of fewer commission errors in the auditory modality than the visual modality in the TD group, though the interaction between group and modality was not significant. This pattern could suggest a small interaction effect that was not detectable given the current study's power.

The second mixed ANOVA analyzed Group (DS vs. TD) x Modality (auditory vs. visual) on the dependent variable SART omission errors. Results revealed no significant main effect of group, $F(1, 38)=.003, p=.955$, modality, $F(1, 38)=2.183, p=.148$, or group x modality, $F(1, 38)=.280, p=.600$. These findings suggested groups made similar numbers of omission errors on auditory and visual SARTs, with little influence of omission error modality within groups.

Although groups were well matched on nonverbal mental age and receptive vocabulary age, the ratio of males to females in each group was different. Sex differences in processing strategies or in domains unrelated to cognition could influence sustained attention (see Lin, Hsiao, & Chen, 1999), though Chan (2001) found sex did not influence any aspect of SART performance in his study. To determine if sex influenced the current study's results, main analyses were rerun with equalized sex distributions in groups. Specifically, 6 of 10 males with DS were randomly selected to equal the 6 TD males, and 10 of 14 TD females were randomly selected to equal the 10 females with DS. The final sample size included 16 participants per group, and groups again matched on nonverbal mental age, $F(1,29)=.005, p=.946$, and receptive vocabulary age, $F(1,30)=.120, p=.732$. For commission errors, results revealed no significant main effect of group, $F(1, 30)=.295, p=.591$, modality, $F(1, 30)=1.496, p=.231$, or group x modality, $F(1, 30)=.203, p=.655$. For omission errors, results revealed no significant main effect of group, $F(1, 30)=.608, p=.442$, modality, $F(1, 30)=.491, p=.489$, or group x modality, $F(1,$

30)=.807, $p=.376$. These findings suggested sex did not inadvertently influence main analyses presented for the total sample size, though the near significant effect of commission errors modality disappeared when the groups were equalized for sex.

Furthermore, to better understand how SART performance operated within groups, repeated measures ANOVAs were run with split groups for each of the dependent variables. These analyses compared participants' performances in the first half of the SARTs (computed as Blocks 1-13) to performances in the second half of the SARTs (computed as Blocks 14-25) as judged by each type of error: auditory commission, visual commission, auditory omission, and visual omission. Results revealed that participants made similar numbers of auditory commission errors, visual commission errors, and auditory omission errors in both halves of the SARTs ($ps > .535$). However, participants made on average three more visual omission errors in the second half than they did in the first half of the visual SART; this finding reached significance within the group with DS, $F(1, 19)=5.772$, $p=.027$, and approached significance within the TD group, $F(1, 19)=3.893$, $p=.063$. Results suggested both groups were slightly less able to sustain their attention over time on the visual SART than the auditory SART.

SART Correlations with Age. Main analyses then included calculations of Pearson correlation coefficients separately for each group to determine if groups' SART performances correlated with their chronological age, nonverbal mental age, and receptive vocabulary age. Chronological age was measured as time in months between participants' birth dates and test dates. Nonverbal mental age was measured using KBIT-2 Matrices subtest age equivalents in months, and receptive vocabulary age was measured using PPVT-4 age equivalents in months.

For the group with DS, the four SART measures did not significantly correlate with chronological age. Auditory omission errors significantly correlated with nonverbal mental age,

and visual commission errors significantly correlated with receptive vocabulary age. See Table 3 for these and additional correlations among key measures in the group with DS. Negative correlations suggested SART errors decreased as chronological age, nonverbal mental age, and receptive vocabulary age increased.

Table 3
Correlations Among Key Measures for the Group with DS

	1	2	3	4	5	6	7	8	9
1. Chronological Age	1								
2. KBIT-2 Matrices Age in Months	.39	1							
3. PPVT-4 Age in Months	.21	.23	1						
4. Auditory Commission Errors	-.31	-.31	-.34	1					
5. Visual Commission Errors	-.35	-.40	-.52*	.62**	1				
6. Auditory Omission Errors	-.40	-.52*	-.41	.50*	.59**	1			
7. Visual Omission Errors	-.38	-.36	-.43	.38	.47*	.69**	1		
8. CTOPP Memory for Digits Raw	.15	.03	.85**	-.26	-.49*	-.39	-.51*	1	
9. Corsi Task Raw	.16	.14	.62**	-.32	-.31	-.47*	-.55*	.60**	1

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

For the TD group, both auditory and visual omission errors significantly correlated with chronological age and nonverbal mental age, while only visual omission errors significantly correlated with receptive vocabulary age. See Table 4 for these and additional correlations among key measures in the TD group. Negative correlations suggested SART errors decreased as chronological age, nonverbal mental age, and receptive vocabulary age increased.

Table 4
Correlations Among Key Measures for the TD Group

	1	2	3	4	5	6	7	8	9
1. Chronological Age	1								
2. KBIT-2 Matrices Age in Months	.71**	1							
3. PPVT-4 Age in Months	.67**	.59**	1						
4. Auditory Commission Errors	-.26	-.30	-.03	1					
5. Visual Commission Errors	.17	-.20	.21	.57**	1				
6. Auditory Omission Errors	-.45*	-.64**	-.33	.60**	.48*	1			
7. Visual Omission Errors	-.71**	-.58**	-.48*	.42	.21	.72**	1		
8. CTOPP Memory for Digits Raw	.45*	.49*	.58**	-.44	.02	-.48*	-.46*	1	
9. Corsi Task Raw	.69**	.71**	.66**	-.34	-.20	-.60**	-.61**	.40	1

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

Exploratory Analyses

Exploratory analyses first included two one-way ANOVAs: one to determine if groups differed on auditory short-term memory as measured by CTOPP MD subtest raw scores, and another to determine if groups differed on visual short-term memory as measured by Corsi Task raw scores. Results revealed that groups significantly differed on auditory short-term memory, $F(1,38)=28.707$, $p < .001$, with the TD group outperforming the group with DS on the CTOPP MD subtest. Results also revealed that groups did not differ on visual short-term memory, $F(1,38)=1.793$, $p = .189$, with groups performing similarly on the Corsi Task.

Regression analyses were then performed: one to determine if auditory sustained attention predicted auditory short-term memory, and another to determine if visual sustained attention predicted visual short-term memory. Analyses included groups combined. Each analysis sought to determine if sustained attention accounted for variance in short-term memory beyond the influence of group membership and cognitive ability. Thus, for each analysis, group,

nonverbal mental age, and receptive vocabulary age were entered together in Step 1; and omission and commission errors were each entered separately in Step 2. See Table 5 for results of the two analyses. For auditory short-term memory, group and cognitive ability accounted for 68.5% of the variance, and auditory omission errors added a nearly significant portion of variance beyond that, $\Delta R^2=.035$, $F(1,33)=4.090$, $p=.051$. For visual short-term memory, group and cognitive ability accounted for 49.6% of the variance, and visual omission errors added a significant portion of variance beyond that, $\Delta R^2=.062$, $F(1,33)=4.652$, $p=.038$. Commission errors did not add significantly beyond group and cognitive ability in either analysis.

Table 5
Regression Analyses Predicting Short-term Memory

Step	Modality					
	Auditory			Visual		
	<i>R</i>	<i>R</i> ²	ΔR^2	<i>R</i>	<i>R</i> ²	ΔR^2
1. Group + Nonverbal Mental Age + Receptive Vocabulary Age	.828	.685	.685***	.704	.496	.496***
2. Omission Errors	.849	.720	.035*	.747	.558	.062**
2. Commission Errors	.854	.729	.009	.748	.559	.001

Note. * $p=.051$, ** $p<.05$, *** $p<.001$

CHAPTER 4

DISCUSSION

The purpose of the current study was to determine how sustained attention is impacted in youth with DS. Additionally, this study explored the possibility that sustained attention predicted the poor auditory relative to visual short-term memory typically seen in DS (see Jarrold et al., 2000). To do so, this study compared youth with DS to TD youth matched for cognitive ability. Groups participated in both auditory and visual versions of the SART paradigm, as well as both auditory and visual short-term memory tasks. The current study hypothesized that visual sustained attention would match developmental level in DS, while auditory sustained attention would be a particular deficit in DS. Further, it was expected that sustained attention would correlate with age in the TD group but not the group with DS. Lastly, it was expected that sustained attention would predict short-term memory beyond the influence of group membership and cognitive ability.

Sustained Attention Between and Within Groups

Because no group x modality interactions were found, interpretation of main effects provides a complete picture of how sustained attention operates between groups and between modalities within groups. First, main effects of group revealed there were no significant differences between the group with DS and TD group on either visual or auditory sustained attention. Expectedly, visual sustained attention was found to match developmental level in DS, as the group with DS made similar numbers of commission and omission errors on the visual SART when compared to the TD group. Unexpectedly, auditory sustained attention was also

found to match developmental level in DS, as the group with DS made similar numbers of commission and omission errors on the auditory SART when compared to the TD group.

For visual sustained attention, the current study's results were in agreement with Cornish et al. (2007), Munir et al. (2000), and Costanzo et al. (2013) despite using the SART paradigm instead of the CPT paradigm or Bells Test. All of these studies found that youth with DS performed similarly to TD youth matched for mental age by either detecting similar numbers of targets or making similar numbers of errors. However, Munir et al. included a TD group whose teachers rated them as having good attention, and the group with DS was found to more often click distracters than this TD group. The current study did not include a good attention group, but groups were better matched in this study than in Munir et al. whose group with DS was approximately 20 months behind the good attention TD group in verbal mental age. Thus, it seems that visual sustained attention matches developmental level in DS, despite neurological evidence and Lanfranchi et al. (2010) results from a task that is typically used to measure working memory. Though they did not include a TD group, Trezise et al. (2008) results also supported this notion by finding that visual sustained attention was perhaps a syndrome-specific strength in DS, as youth with DS in their study made fewer commission errors than youth with NSID on a visual SART. Concordance between sustained attention tasks further confirms that visual sustained attention matches developmental level in DS.

For auditory sustained attention, the current study's results were not in agreement with Costanzo et al. (2013) who found that TD youth outperformed youth with DS on the Score task. Rather, the current study found no group differences on an auditory SART. Perhaps conflicting results can be explained by differences in tasks. The Score task could be considered a measure of auditory working memory, as participants must both remember the number of target tones

presented and use this information to continue counting tones over time. Auditory working memory is considered a specific deficit in DS, which could explain Costanzo et al.'s finding using this task (e.g., Jarrold et al., 2000; Silverman, 2007; Wang, 1996). On the other hand, perhaps contrasting results can be explained by differences in groups' chronological ages between studies. Specifically, the group with DS was older in this study ($M=15.98$ years) than in Costanzo et al. ($M=14.5$ years), while the TD group was younger in this study ($M=4.84$ years) than in Costanzo et al. ($M=7.4$ years). This pattern of an older group with DS and younger TD group in the current study could have improved performance in DS and diminished that in TD youth, causing no differences to be found. However, this explanation is likely not comprehensive, as chronological age in the group with DS did not strongly correlate with auditory SART performance in the current study. Further, though they did not include a TD group, Trezise et al. (2008) found youth with DS performed similarly to youth with NSID matched for mental age on an auditory SART. Because both the current study and Trezise et al. found groups with DS performed at developmental level, it seems auditory sustained attention could be sufficient in DS. However, given the conflicting results in the literature, this idea should be interpreted cautiously, and future studies should continue to investigate the topic.

It should also be noted that previous studies compared youth with DS to youth with other specific etiology syndromes like FXS and WS. In Munir et al. (2000), youth with DS less often erroneously clicked distracters in a visual CPT than youth with FXS. Combined with the current study's findings, results suggested visual sustained attention matched developmental level in DS, or perhaps was a syndrome-specific strength in DS. In Breckenridge et al. (2013), youth with DS performed similarly to youth with WS on visual sustained and dual sustained subtests of the ECAB and better than youth with WS on the auditory sustained subtest. Combined with the

current study's findings, results newly suggested auditory sustained attention matched developmental level in DS, or perhaps was a syndrome-specific strength in DS. This finding also alluded to the idea that the poor auditory processing typically seen in DS does not have bearing on sustained attention.

Second, main effects of modality revealed that, within groups, there was a nearly significant difference between numbers of commission errors for the visual versus auditory modality. The general trend suggested participants across groups made slightly fewer commission errors on the auditory SART than the visual SART, though follow-ups revealed that this finding was largely carried by the TD group. Additionally, there was no significant difference between numbers of omission errors for the visual versus auditory modality within groups. Thus, unexpectedly, auditory sustained attention was found to be as sufficient as visual sustained attention in DS, a finding that contrasts those from Costanzo et al. (2013) and Trezise et al. (2008). Differences among studies could account for contrasting findings. As stated previously, Costanzo et al. utilized a task that could tap into auditory working memory as well as sustained attention, and groups in their study were different chronological ages than those in the current study. Trezise et al. included a group with NSID rather than a TD group, and simply the presence of intellectual disability in their control group could have caused conflicting results, despite groups in both studies being matched on nonverbal mental age.

For the TD group, it is not unusual that participants made on average one less auditory than visual commission error, as Seli et al. (2012) found their auditory SART generated fewer errors than their visual SART in a TD population. For the group with DS, it is unusual that participants performed similarly between tasks, given the consistent weakness seen in auditory relative to visual processing in DS. Perhaps the group with DS performed as well on the auditory

SART as the visual SART because youth with DS are equally able to sustain their attention to auditory and visual stimuli, or perhaps there is another explanation. From proceedings in the current study, it seemed the auditory SART could have been an easier task for participants, as they could look around the room during task engagement. During the visual SART, participants were more constrained, only being permitted to look at a computer screen for eight minutes and perhaps looking away from the screen more often towards the end of the task. This notion was supported by the finding that both groups made slightly more omission errors in the second half than the first half of the visual SART. Thus, distractions in the visual SART were perhaps more damaging to task performance than those in the auditory SART. Really, that is the nature of auditory processing – it is second to visual processing in humans, as vision is the dominant sense. However, this explanation is likely not comprehensive, as Seli et al. found the SART has good cross-modal reliability when comparing auditory and visual versions.

Relationship Between Sustained Attention and Age

Correlations among sustained attention measures, chronological age, nonverbal mental age, and receptive vocabulary age revealed similar patterns within groups. Expectedly, SART performance generally improved with advancing age in the TD group. Unexpectedly, SART performance also generally improved with advancing age in the group with DS, though these relationships tended to be weaker and less often reached statistical significance. It seems that a larger sample size would have given this study greater power to reveal more significant relationships between sustained attention and age and would have made interpretations of these correlations clearer. Thus, results perhaps suggested sustained attention improves over time and with cognitive ability in youth with DS, as seen in typical populations. This conclusion again highlights the idea that sustained attention is not a particular deficit in DS.

Specifically, for the TD group, the current study's results were in agreement with Cornish et al. (2007). Both studies found visual sustained attention improved with advancing chronological and nonverbal mental age in TD youth. The current study added to previous research by also finding visual sustained attention improved with advancing receptive vocabulary age, and auditory sustained attention improved with both advancing chronological age and nonverbal mental age in TD youth. Interestingly, receptive vocabulary age did not significantly correlate with auditory sustained attention. This might be due to the fact that the PPVT-4 involves participants looking at pictures to determine the meanings of spoken words, which perhaps draws more on visual than auditory sustained attention. Further, note that only omission errors correlated with age in the TD group. It seems likely that commission errors did not correlate with age because they were less reliable than omission errors in the TD group.

For the group with DS, the current study's results were again in agreement with Cornish et al. (2007) if strictly observing those correlations that reached statistical significance. Both studies found that visual sustained attention did not significantly correlate with chronological age or nonverbal mental age in youth with DS. However, the current study's results were not in agreement with Breckenridge et al. (2013) in finding that visual sustained attention only significantly correlated with receptive vocabulary age, while auditory sustained attention only significantly correlated with nonverbal mental age. Given conflicting results, additional research with a larger sample size is required to determine if sustained attention consistently improves with age in DS.

Sustained Attention Predicting Short-term Memory

Exploratory analyses first revealed there was no significant difference between groups on visual short-term memory but a significant difference between groups on auditory short-term

memory. Specifically, groups performed similarly on the Corsi Task, while the TD group outperformed the group with DS on the CTOPP MD subtest. These findings match the general consensus that visual short-term memory matches developmental level in DS, while auditory short-term memory is a particular deficit in DS (e.g., Fidler, 2005; Jarrold et al. 2000). Because there was no group difference on auditory sustained attention, it is clear that auditory sustained attention cannot adequately explain the group difference on auditory short-term memory. Thus, future research should continue to explore why auditory short-term memory remains weaker than visual processing in DS, as this discrepancy was not found to be due to sustained attention in the current study.

However, exploratory analyses then revealed sustained attention predicted short-term memory beyond the influence of group membership and cognitive ability. Specifically, auditory omission errors predicted auditory short-term memory by contributing an additional 4% of explained variance, making the combination of group membership, cognitive ability, and auditory sustained attention account for a total of 73% of auditory short-term memory variance. Visual omission errors predicted visual short-term memory by contributing an additional 6% of explained variance, making a combination of group membership, cognitive ability, and visual sustained attention account for a total of 56% of visual short-term memory variance. Again, note that commission errors did not predict short-term memory, perhaps because these errors were less reliable than omission errors. Also note that more variance in short-term memory was explained in the auditory modality than the visual modality, a finding likely caused by the group difference on auditory short-term memory.

Overall, these results suggest a link between sustained attention and performance on short-term memory tasks, though future research is required to determine the exact nature of this

link. It could be that better sustained attention allows for better task performance. Alternatively, better sustained attention from a young age could enable better development of memory structures and processes. As previously mentioned, though, the current study's results do not suggest that the impairment in auditory short-term memory that is characteristic of DS is due to impairment in auditory sustained attention.

Limitations of the Current Study

Limitations of this study consisted of small sample size, inclusion of youth diagnosed with ADHD in the group with DS, and reliability of auditory SART commission errors in the TD group. First, the sample size did not allow for enough power to detect a medium effect ($f=.25$) of group or small effects ($f=.10$) of modality and group x modality interactions. It is possible that with a larger sample size this study could have detected a small effect of group x commission errors modality, as there was evidence of fewer commission errors in the auditory modality when compared to the visual modality in the TD group. Further, interpretations of correlations among key measures within groups could have been clearer with a larger sample size.

Second, inclusion of youth with DS and ADHD could have negatively affected results for the group with DS because youth with both intellectual disability and ADHD generally perform worse on sustained attention tasks than those with intellectual disability alone (e.g., Pearson, Yaffee, Loveland, & Lewis, 1996). Thus, inclusion of youth diagnosed with ADHD in the group with DS could have caused SART performances in this group to suffer unnecessarily. However, because the group with DS performed as well as the TD group on the SARTs, it does not appear this study was adversely affected by inclusion of youth diagnosed with ADHD in the group with DS. In fact, inclusion of participants with DS and ADHD made the current study's sample more generalizable to the DS population, as it is not unusual for someone with DS to be diagnosed

with ADHD. Including these participants also increased the power of this study, as only permitting youth with DS but not ADHD to participate would have further constricted the already limited sample. Thus, while inclusion of participants with DS and ADHD could be seen as a limitation, it could also be seen as a strength of this study.

Lastly, reliability of auditory SART commission errors for the TD group was surprisingly low ($r=.412$) considering it was high for the group with DS. Perhaps it was low because the TD group had to be young (i.e., mostly aged 3 to 5 years) in order to match groups on nonverbal mental age and receptive vocabulary age, and young participants tend to perform less consistently than older participants. However, this explanation is not comprehensive given that all other SART measures proved reliable for the TD group. Low reliability for auditory commission errors in the TD group could also be due to the simple fact that there were only 25 possible commission errors, while there were 200 possible omission errors in the SARTs. Again, this is not comprehensive given that visual commission errors were reliable in the TD group. Regardless of the reason, the unreliable nature of auditory commission errors in the TD group was a limitation of the current study that could potentially be addressed in future studies.

Directions for Future Research

In addition to the suggestions stated throughout this paper, there are two very clear directions for future research. First, future research should examine the developmental trajectory of sustained attention in DS across the lifespan. The current study found youth with DS aged 10 to 21 years performed at developmental level on sustained attention tasks. However, a cross-sectional or longitudinal design could additionally determine if sustained attention matches developmental level in young children or adults with DS. Perhaps youth in this study only performed at developmental level because their age was an advantage on sustained attention

tasks, as many were students and likely practicing methods to sustain attention on a daily basis. It seems different results could be found given different developmental periods, and these are worth exploring to better understand how sustained attention is impacted in DS.

Second, future research should add a neuropsychological component when measuring sustained attention in DS as previous studies have done in TD populations (e.g., Gable & Adams, 2013). For instance, electroencephalography (EEG) could be used to measure sustained attention in DS by providing information on sustained late positive potentials (LPPs). LPPs are thought to measure motivational attentional processing, which is increased in response to task-relevant stimuli like targets, or in the SART's case, non-targets (Ferrari, Codispoti, Cardinale & Bradley, 2008; Weinberg, Hilgard, Bartholow, & Hajcak, 2012). Augmented LPPs from 1000-2000 ms after stimulus onset are indicative of sustained attention to task-relevant stimuli, which would be non-targets in the SART (Gable & Adams, 2013). Thus, future studies could have participants complete both auditory and visual SARTs as seen in the current study but incorporate EEG technology to additionally obtain a neuropsychological measure of sustained attention. In this way, sustained attention could potentially be even more reliably measured, and measures could possibly unveil additional effects.

Conclusion

Sustained attention is a basic requirement for cognitive processes and is essential to daily life. For instance, without sustained attention in the broader sense, students would be unable to learn novel information presented by teachers or even comprehend language. Thus, it is imperative to understand how sustained attention is impacted in youth with DS. This study found that both auditory and visual sustained attention matched developmental level in DS, as youth with DS performed similarly to TD youth matched for cognitive ability on sustained attention

tasks. This study also found that auditory sustained attention was as sufficient as visual sustained attention in DS, despite the typical deficit seen in auditory relative to visual processing in DS.

The topic of sustained attention in DS should be further investigated, perhaps by examining developmental trajectories or incorporating neuropsychological measures. Better understanding of how sustained attention operates in DS could improve this special population's quality of life, whether through advancing how parents interact with their children, how teachers present information to their students, or how therapists work with their clients who have DS.

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APPENDIX

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

July 25, 2013

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

Re: IRB Application # 13-016 Differential Impacts of Down Syndrome on
Auditory and Visual Sustained Attention

Dear Ms. Graham:

The University of Alabama Non-Medical IRB has granted initial approval of
the above application for a one year period.

Your application will expire on July 18, 2014. You will receive a notice of the
expiration date 90 days in advance. 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 form.**

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

**Please note that prior to commencement of research activities at each of
your study sites you are required to submit a letter of site approval from
each location.**

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

Good luck with your research.

Sincerely,

Stuart Usdan, PhD
Chair, Non-Medical IRB
The University of Alabama

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

August 27, 2013

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

Re: IRB Application # 13-016 (Revision)
"Differential Impacts of Down Syndrome on Auditory and Visual
Sustained Attention"

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, 7/19/2013 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,

Carpaneto T. Myles, MSM, CIM
Director & Research Compliance Officer
Office of Research Compliance
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