Weighting of Visual and Auditory Stimuli in Children with Autism Spectrum Disorders

Honors Research Thesis

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Abstract

Word learning requires the ability to integrate auditory information (e.g. an object's name) and visual information (e.g. the object itself). Previous research has shown that children with typical development are likely to rely on auditory information when their recognition of novel auditory-visual stimuli is tested; however, no comparable test has been administered to children with autism spectrum disorders (ASD). The purpose of this study is to determine whether children with ASD follow the same pattern of information processing as children who are typically developing. Because children with ASD's visual processing abilities are superior to their auditory processing abilities, we hypothesize that children with ASD will differ from their typically developing peers and weight the visual component of auditory-visual stimuli. In the present study, one child with ASD under four years of age was matched on language and cognitive skills with one typically developing pilot subject. Both of the children were tested on a computerized task. During the computerized task, the children were presented with auditory, visual, and combined auditory-visual stimuli and trained to look for a auditory-visual "prize" that appears in specific locations corresponding with the stimulus presented; then, their eye gazes were recorded and coded frame-by-frame. Data from the typically developing pilot subject revealed that they weighted the visual component of the combined stimuli, which was not anticipated. Contrary to our predictions, the participant with ASD also displayed a visual preference. Continued data collection will reveal whether this trend is observed across participants with ASD and will increase our understanding of language development in children with ASD.

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Introduction and Literature Review

Autism spectrum disorders (ASD) are a group of neurodevelopmental disorders of varying severity that influence communication abilities and other behaviors. Children with ASD may exhibit delays in speech and language development in addition to mild to profound impairments in communication and social interaction. Given the high prevalence rate of ASD (1:50) reported in children aged 6-17 (Blumberg et al., 2013) and the significant impairments reported in both receptive and expressive language abilities (Ellis Weismer, Lord, & Esler, 2010; Paul, Chawarska, Cicchetti, & Volkmar, 2008) in these children, an understanding of the cognitive processes underlying language development in children with ASD is necessary in order to inform potential novel language interventions of speech-language pathologists who work with children with ASD. A primary cognitive process integral to child language development is word-object pairing, which is the ability to integrate auditory information (e.g. an object's name) and visual information (e.g. the object itself). Although typically developing children follow a developmental pattern of information processing and integration that allows for successful word-object pairing, relatively little is known about this process in children with ASD. Thus, the goal of this study is to determine if children with autism spectrum disorders show significant differences from typically developing children in their processing of auditory-visual stimuli.

Robinson and Sloutsky studied auditory and visual processing in infants in three studies. In an experiment involving 14 month olds, Robinson and Sloutsky (2007) found that different types of auditory input result in different speeds of processing of a corresponding visual stimulus. In each trial, infants were presented with two visual stimuli: one to which they were familiarized, and one novel stimulus. When a novel visual stimulus was presented unimodally (with no accompanying sound) or with a word in a referential frame, infants required 64 seconds of familiarization in order to look reliably at the novel visual stimulus, while a novel visual stimulus presented with an unfamiliar sound required 128 seconds of familiarization. However, Robinson and Sloutsky (2007) found that placing unfamiliar sounds in a referential context or familiarizing the infants with sounds reduced the visual familiarization time to 64 seconds when these sounds were presented with the visual stimuli. These results suggest two important conclusions. Firstly, auditory input delays the onset of visual processing in typically developing infants. Secondly, placing unfamiliar sounds in a referential context causes these sounds to be processed similarly to words, which typically developing infants appear to assume have a referential nature (that is, certain words are used to refer to certain objects).

Another study by Robinson and Sloutksy (2008) expanded upon the previous findings, comparing the influence of auditory input on the visual processing of 10 and 16 month olds. They found that unfamiliar linguistic labels overshadowed processing of visual stimuli at 10 months, but not at 16 months. Unfamiliar nonlinguistic sounds did overshadow visual stimuli processing at 16 months, but pre-familiarization with these auditory stimuli was found to attenuate these overshadowing effects. Finally, Robinson and Sloutsky (2010) found that multimodal (combined auditory-visual) stimuli presentation attenuated 10 month olds' discrimination of the visual components of different stimuli, but did not influence their discrimination of auditory input. This study also determined that prefamiliarizing the infants to auditory input improved their processing of multimodal stimuli, but prefamiliarizing the infants to visual input did not improve their multimodal processing. Both of these findings can be explained by auditory dominance in the information processing of typically developing infants.

Sloutsky and Napolitano (2003) also examined the processing of auditory, visual, and combined auditory-visual stimuli in typically developing four year olds. The children were presented with 24 trials of auditory-visual stimuli on a computer screen, VIS_1AUD_1 and VIS_2AUD_2. The children were trained to consistently identify that a "hidden" visual prize that would appear on the same side of the computer screen as stimulus VIS_1AUD_1 (after the stimulus was presented) by pointing to the correct side of the screen. Immediately following training, the children were presented with two novel stimuli, VIS_1AUD_{NEW} and $VIS_{NEW}AUD_1$, and asked to identify the stimulus where the visual prize was "hidden." The children were more likely to rely on the auditory component of the stimulus when the auditory-visual components on which they were trained were put into conflict. This result illustrates the reliance of typically developing children on auditory information when processing auditory-visual stimuli. Additionally, when the children were briefly presented with four auditory-visual stimuli (VIS_1AUD_1, $VIS_{NEW}AUD_{NEW}$, VIS_1AUD_{NEW}, $VIS_{NEW}AUD_1$) and asked to identify whether two stimuli were the same or not, they rejected stimuli that changed auditory components at a statistically significant level, but did not reject stimuli that changed visual components above a chance level. This finding reveals that typically developing four-year-old children not only have an auditory preference, but also fail to encode visual stimuli in the presence of auditory stimuli.

Robinson and Sloutsky replicated the previous experimental findings using a new procedure in 2004, determining again that four year olds predicted the location of prizes based on the auditory component of auditory-visual stimuli. However, when Robinson and Sloutsky made the visual stimuli less complex (presented with one geometric shape instead of three), the children were more likely to make visual-based predictions. These results indicate that auditory and visual preferences may vary depending on stimulus conditions. Finally, when Robinson and Sloutsky (2004) instructed the children to attend to their nonpreferred modality during the experiment (e.g. instructing the participant to "listen for the clues" to predict where the prize will appear when they had previously exhibited visual dominance), they found that the children still used their preferred modality to predict the location of the prize. Ultimately, these findings illustrate the existence of modality dominance in young children, suggesting that auditory and visual information may be competing for cognitive resources in the developing brain.

All of the previous studies provide evidence of the importance of auditory input in the cognitive processing of typically developing children. The researchers posit that the different attentional demands of auditory and visual stimuli may account for auditory weighting in typically developing children—because sounds are generally presented for a shorter amount of time than visual stimuli, it is more useful to allocate cognitive resources to sounds before visual stimuli. In addition, visual processing is primarily parallel, while auditory processing is largely serial. Thus, if auditory processing were not dominant, visual processing would dominate cognitive resources and make language acquisition (a process in which auditory input is crucial) incredibly difficult (Sloutsky and Napolitano, 2003). The functional advantage of auditory dominance, therefore, is apparent in infancy and early childhood when language acquisition is at its peak. This advantage for typically developing children presents a marked disadvantage for children with autism spectrum disorders, who, studies show, rely heavily on visual input during information processing.

Studies investigating the similarities and differences between the cognitive processing of children with typical development and children with ASD are necessary in order to explain why differences in language development exist between these two groups. Research has shown evidence of visual processing strengths in children with ASD, in addition to evidence of auditory processing deficiencies. Studies have also demonstrated the efficacy of visual systems in supporting the language use and social behaviors of children with ASD, and fMRI technology has revealed processing differences in the brains of these children as compared to their typically developing peers. The following will review this evidence.

Hermelin and O'Connor (1970) (as cited in Quill, 1995) first documented that children with ASD's ability to process visuo-spatial information was superior to their ability to process auditory-temporal information. It has been posited by researchers such as Quill (1995) that this difference is a key factor underlying the differences in the ways in which children with ASD communicate as compared to typically developing children. Spatially coded symbols (images and printed language) are more easily processed by children with ASD than spoken language because spoken language contains no concrete retrieval cues. When children with ASD are presented with graphic stimuli, they can process these stimuli as wholes, as opposed to spoken language, which must be processed rapidly in a serial fashion. This theory is supported by findings indicating that individuals with ASD process auditory stimuli atypically.

Various research approaches have been used to investigate abnormal auditory processing in individuals with ASD. O'Connor (2012) compiled a comprehensive review of the literature on this subject. Abnormalities in auditory processing in individuals with ASD include increased loudness sensitivity, impaired processing of prosody and affective cues, and reduced orientation to auditory stimuli from a young age. One prominent explanation of abnormal auditory processing in individuals with ASD is the Neural Complexity Hypothesis, which posits that individuals with ASD experience enhanced perception of low-level auditory stimuli, yet have difficulty processing more complex auditory information and thus display impaired performance on auditory tasks requiring higher-level cognitive skills. Because speech is a complex auditory stimulus (i.e. it is spectrally and temporally varied) and requires high-level cognitive processes (i.e. perception of prosody and comprehension of what is being said), O'Connor (2012) explained that the Neural Complexity Hypothesis appears viable. Additionally, fMRI research has revealed reduced activation in left frontal-temporal regions of the brains of individuals with ASD when presented with complex listening tasks requiring semantic and pragmatic comprehension. Some studies also found stronger activation in right frontal-temporal regions, which O'Connor (2012) explains may be reflective of a compensatory neural strategy. The visual processing strengths and auditory processing weaknesses of individuals with ASD have important detrimental impacts on their language development and communication, and practical applications of these research findings are expansive.

Quill's work provided the motivation for the use of visual augmentative systems (including words and simple pictographs), which have been found to be very effective in improving the language understanding of children with ASD. These systems allow children to form concrete visual associations with the abstract concepts communicated through spoken language (Quill, 1995). Visual prompts have also been found to improve children with ASD's expressive language. Targeted simple utterances written on sentence strips can successfully cue language use by children with ASD in communicative contexts. Visual supports can also be used to encourage social interaction (e.g. pictographic and written posters explaining how to ask someone to play or take turns), and social stories (pictographic and written short stories that explain specific social situations) can improve social understanding via explicit visual stimuli (Quill, 1995).

Dettmer, Simpson, Myles, and Ganz (2000) provided further evidence of the efficacy of visual supports. This study demonstrated the successful use of visual augmentative systems to facilitate transitions in two children with ASD. These visual supports included portable schedules (illustrations of daily activities in a photo album), a schedule with removable activity cards that could be placed into a "finished box" when the activity was completed, and timers with a red section that disappeared as the time allotted for an activity ran out. The researchers found that visual schedules significantly reduced the amount of time spent transitioning between activities, and even resulted in one child, who had previously produced mainly echolalia, giving spontaneous, full-sentence descriptions of his plans for the day. Ultimately, the visual processing strengths of children with ASD provide numerous opportunities for visually-based interventions that can improve their language skills and social interactions.

Recent research has used brain imaging technology to further investigate the visual processing differences between typically developing children and children with ASD. Keehn, Shih, Brenner, Townsend, and Müller (2013) conducted a study which monitored the brains of children with ASD using functional MRI while the children participated in a visual search task. This study found increased intra-occipital and occipital-frontal connectivity in the participants with ASD as compared to the typically developing participants, which could reflect the mechanism supporting superior visual processing abilities in individuals with ASD. Interestingly, the researchers found a correlation between increased search efficiency and more severe ASD symptomology as measured by the *Autism Diagnostic Observation Schedule*. The researchers acknowledged that the connection between the neural indicators of search efficiency and the degree of social impairment is not fully understood. However, they offered the hypothesis that over-focused attention in individuals with ASD may allow them to excel at visual search tasks, yet may also have the consequence of directing attention away from subtle social cues during communication.

Although the visual processing strengths and auditory processing weaknesses of children with ASD have been researched, no studies have directly investigated whether children with

ASD weight visual information more heavily than auditory information when presented with combined auditory-visual stimuli. Because auditory-visual processing is such a fundamental cognitive component of word learning, an increased understanding of this process in children with ASD will ultimately lead to an increased understanding of their language development. If a difference is revealed between the auditory-visual processing of children with and without ASD, it will be an important component of our knowledge of the cognitive processes contributing to disordered language development in children with ASD.

The present study will further investigate the cognitive processing differences of children with ASD through the administration of a computerized auditory-visual processing task to a typically developing pilot subject who is four years old, and a child with ASD who is three years and five months old. Numerous studies have proven the dominance of auditory input in the auditory-visual processing of typically developing infants and children (Sloutsky and Napolitano, 2003; Robinson and Sloutsky, 2004; Robinson and Sloutsky, 2007; Robinson and Sloutsky, 2008; Robinson and Sloutsky, 2010). To date, none have directly measured this processing in children with ASD. Expanding upon Sloutsky and Napolitano's (2003) study of typically developing four year olds, the current study will investigate how children with ASD process auditory-visual information by training the child to look for a "prize" (a video of clouds moving with musical accompaniment) based on the presentation of auditory, visual, and combined auditory-visual stimuli, then placing components of the trained auditory-visual stimuli in conflict in order to reveal which type of input is weighted in the child's cognitive processing.

Given the evidence of superior visual processing ability in children with ASD, it is predicted that the child with ASD in the present study will rely on the visual component of auditory-visual stimuli presented to them in order to predict the location of the "prize" during each test. The present study should provide additional evidence of the cognitive weighting of visual input in children with ASD, which signals a fundamental difference in a critical process underlying language development in these children as compared to their typically developing peers.

Methods

Participants

Before participants were recruited, the study was approved by The Ohio State University Institutional Review Board (IRB Protocol Number 2011B0517). Participants in this study were one typically developing pilot subject, age four years, and one subject with an autism spectrum disorder diagnosis, age three years and five months. Both were monolingual English speakers. The participants' parents did not receive any monetary compensation for their participation.

Computerized Task

Task Presentation

The computerized task was programmed in E-Prime 2.0. It was presented on a television in a sound proof booth in a lab room in the basement of Pressey Hall. A video camera was placed below the television in order to record the participant's eye gaze as he or she watched the task on the television screen. The task was presented in three modalities: auditory, visual, and combined auditory-visual.

Auditory Task

Stimuli presented were auditory only. During practice trials, the auditory stimuli were the spoken words "cat" and "dog." During training and test trials, the auditory stimuli were the spoken nonsense words "bannow" (/bænau/) and "dayboo" (/deɪbu/).

Visual Task

Stimuli presented were visual only. During practice trials, the visual stimuli were photos of a cat and a dog (see figure 1). During training and test trials, the visual stimuli were two abstract black shapes on white backgrounds. In order to be easily distinguishable, one shape was simple, and the other was more complex (see figure 2).

Auditory-Visual Task

Stimuli presented combined the auditory and visual components from the auditory-only and visual-only tasks. During practice trials, the auditory-visual stimuli were a photo of a cat accompanied by the spoken word "cat" and a photo of a dog accompanied by the spoken word "dog." During training trials, the auditory-visual stimuli were the simple shape accompanied by the spoken word "bannow" and the complex shape accompanied by the spoken word "dayboo." The test trial placed the training stimuli into conflict—in two of the auditory-visual tasks, the simple shape was accompanied by "dayboo," and in the other two auditory-visual tasks, the complex shape was accompanied by "bannow."

Procedure

Data collection for this study occurred in two separate visits to the lab, each consisting of four short computerized tasks in the booth and the administration of a portion of the *Bayley Scales of Infant and Toddler Development, Third Edition* (Bayley, 2005). At the beginning of the first visit, informed consent was obtained from the parent of the participant and the child assented to participation. The child was then seated in the booth with his or her parent or Dr. Ellawadi—the adult in the booth was instructed not to tell the child where to look; rather, to encourage the child to remain seated and look at the television screen. The experimenter outside of the booth started the task on a computer that was connected to the television inside the booth. Before the presentation of each computerized task, a video was shown of the experimenter giving brief instructions to the child, stating, "Let's play a game. I want you to find all of the clouds. If you find all of the clouds, you get a prize. Ready? Let's go."

Each computerized task consisted of four practice trials and one practice test, ten training trials, and one test. Each task lasted approximately two and half minutes. During the trials, the auditory-visual "prize" (a video of clouds moving with musical accompaniment) appears immediately after the stimulus is presented. The location of the prize (either on the left or right side of the screen) corresponds with the stimulus presented. During the auditory-only and visual-only tests, the presentation of the prize is delayed in order to see if the child has learned the location of the prize and looks for it before it appears. During the auditory-visual tests, no prize appears, because the auditory and visual components on which the child was trained are placed into conflict, which creates a new auditory-visual stimulus. Where the child looks during this test reveals whether he or she weighted the auditory or visual information.

In the first visit, the first task presented was combined auditory-visual (test stimulus: simple visual and "dayboo" auditory). After this task, the child was taken out of the booth and given a sticker to provide a brief break, then he or she was brought back into the booth to be presented with the second task, which was auditory-only (test stimulus: "dayboo"). Following this task, the child was taken to a separate room to be administered the cognitive portion of the *Bayley*. After this testing, the child was taken back to the booth to be presented with an auditory-visual task (test stimulus: simple visual and "dayboo" auditory). Following another brief break and receiving a sticker, the child then watched the final task of the visit, which was visual-only (test stimulus: simple shape). When all of the testing was complete, the child could choose a small prize (such as bubbles, a bouncy ball, or Play-Doh).

The second visit followed the same order of activities as the first visit, with changes to the stimuli presented during the computerized task and the portion of the *Bayley* administered. The first computerized task presented was auditory-only (test stimulus: "bannow") and the second was auditory-visual (test stimulus: complex visual and "bannow" auditory). The language portion of the *Bayley* was then administered (both receptive and expressive). The computerized tasks following the *Bayley* were visual-only (test stimulus: complex shape) and then auditory-visual (test stimulus: complex visual and “bannow” auditory).

Coding

Videos of the participants’ eye gaze during the computerized task were coded frame-by-frame in iCoder. Coding not only revealed the stimulus weighting of the participants, but also allowed monitoring of the participants’ attention throughout the task. Monitoring the participants’ attention throughout training ensures that the results revealed during the tests are based on the participants’ true visual or auditory preference and not simply chance. Thus, in each training trial in the auditory-only, visual-only, and auditory-visual tasks, it was documented whether the participant was attending during stimulus presentation, or looking away.

Results

The cognitive and language (receptive and expressive) scales of the *Bayley Scales of Infant and Toddler Development, Third Edition* (Bayley, 2005) were administered to the participant with ASD to assess general development. Cognitive standard scores are based on a mean of 10 and a standard deviation of 3. The participant had a standard score of 10 on this measure. The language composite standard scores are based on a mean of 100 and a standard deviation of 15. The participant had a standard score of 89 on this measure. Both of these scores fall within one standard deviation of the mean, indicating age appropriate cognitive skills. The *Autism Diagnostic Observation Schedule* (Lord, Rutter, Dilavore, & Risi, 2000) was administered by a trained clinician to confirm the ASD diagnosis. The child did meet criteria for an autism diagnosis.

Training

Results indicate that both the typically developing pilot participant and the participant with ASD attended to the majority of all training trials across modalities. During visual-only training, the pilot participant attended for 100% of trials, and the participant with ASD attended for 90% of trials (see figure 3). During auditory-only training, the pilot participant attended for 80% of trials, and the participant with ASD attended for 65% of trials (see figure 4). Finally, during auditory-visual training, the pilot participant attended for 92.5% of trials, and the participant with ASD attended for 85% of trials (see figure 5). These results illustrate the success of the substantial piloting period in ultimately creating an experiment that keeps the attention of the participants.

The purpose of the auditory-only and visual-only tests was to give the participant greater experience with the task outside of the auditory-visual test, which is what was actually used to reveal an auditory or visual preference. Both the typically developing pilot participant and the participant with ASD successfully anticipated the appearance of the clouds 50% of the time during the auditory-only and visual-only tests (see figures 6 and 7). It is important to note that in the other 50% of these tests, both participants did look in the correct direction, but it was after the clouds appeared—the participants never looked in the incorrect direction after the auditory-only or visual-only stimuli were presented.

Test

After revealing that the participants did in fact attend throughout training, frame-by-frame coding was used to determine the auditory or visual preference of the typically developing pilot participant and the participant with ASD during the auditory-visual test. Coding indicated that the typically developing pilot participant weighted visual information in 75% of auditory-visual test trials, and auditory information in 25% of trials. The participant with ASD weighted visual information in 50% of trials, auditory information in 25% of trials, and was looking away from the screen in 25% of trials. These results are summarized in figure 6.

Discussion

The results of the auditory-visual test do not support the initial hypothesis that typically developing children will display a preference for auditory input when processing auditory-visual stimuli, while children with ASD will display a visual preference. The participant with ASD did display a visual preference, but the typically developing pilot participant did not display the anticipated auditory preference. Extensive evidence has proven the auditory preference of typically developing children (Sloutsky and Napolitano, 2003; Robinson and Sloutsky, 2004; Robinson and Sloutsky, 2007; Robinson and Sloutsky, 2008; Robinson and Sloutsky, 2010), so the visual preference exhibited by the typically developing pilot participant was unexpected. However, upon further review of the literature, some evidence was found of a visual preference in typically developing four-year-olds. Robinson and Sloutsky (2004) found that when the complexity of the visual stimulus used in their experiment decreased (from three geometric shapes to one), a visual preference emerged in the participants. The current study also used only one geometric shape as the visual stimulus, which may be one explanation for the pilot participant's visual preference.

Although the results from the participant with ASD did support the hypothesis, fewer trials were coded for him than the typically developing participant because he attended to less of the stimuli across all modalities. This is consistent with his ASD diagnosis, and is a limitation that a larger sample size will lessen. Interestingly, both participants had the lowest percentage of attention during auditory-only training. This is most likely reflective of the fact that the participants had nothing to look at on screen during stimulus presentation, unlike during the presentation of the visual and combined auditory-visual stimuli. Overall, however, both participants paid attention during the majority of training (see figures 3-5), proving that the participants were capable of attending during the task.

The results of the current study thus far provide an interesting foundation for further data collection. With data collected from only one typically developing pilot participant and one participant with ASD, the conclusions that can be drawn from the current study thus far are very limited. As participant recruitment and data collection continues, an increased sample size should reveal patterns of visual or auditory weighting in both groups of participants with greater certainty. The impact of limitations that naturally exist when testing children is exacerbated by the current small sample size of the study—for example, the participant with ASD looked away during one entire auditory-visual test trial, which constitutes 25% of his test data. Ultimately, data from the first participant with ASD does reveal the anticipated visual preference, but data collection from more participants with ASD is necessary before any definitive conclusions can be reached. Additionally, data from more typically developing participants will improve our general understanding of changes in auditory-visual processing throughout development—existing literature shows that the strong auditory preference of infants becomes more variable in childhood and eventually leads to a visual preference in adulthood, and more data from the current study may provide greater insight into how this preference changes throughout early childhood.

References

Bayley, N. (2005). Bayley scales of infant and toddler development: Third edition. Upper Saddle River, NJ: Pearson Education, Inc.

Blumberg, S.J., Bramlett, M.D., Kogan, M.D., Schieve, L.A., Jones, J.R., & Lu, M.C. (2013). Changes in prevalence of parent-reported autism spectrum disorder in school-aged U.S. children: 2007 to 2011-2012. *National Health Statistics Reports, 65.*

Dettmer, S., Simpson, R.L., Myles, B.S., & Ganz, J.B. (2000). The use of visual supports to facilitate transitions of students with autism. *Focus on Autism and Other Developmental Disabilities, 15,* 163-169.

Ellis Weismer, S., Lord, C., & Esler, A. (2010). Early language patterns of toddlers on the autism spectrum compared to toddlers with developmental delay. *Journal of Autism and Developmental Disorders, 40*, 1259-1273.

Keehn, B., Shih, P., Brenner, L. A., Townsend, J., & Müller, R. (2013). Functional connectivity for an 'Island of sparing' in autism spectrum disorder: An fMRI study of visual search. *Human Brain Mapping*, *34*, 2524-2537.

Lord, C., Rutter, M., Dilavore, P.C., & Risi, S. (2000). Autism diagnostic observation schedule. Torrance, CA: WPS.

O'Connor, K. (2012). Auditory processing in autism spectrum disorder: A review. *Neuroscience and Biobehavioral Reviews, 36,* 836-854.

Paul, R., Chawarska, K., Cicchetti, D., & Volkmar, F. (2008). Language outcomes of toddlers with autism spectrum disorders: A two year follow-up. *Autism, 1*, 97-107.

Quill, K.A. (1995). Visually cued instruction for children with autism and pervasive developmental disorders. *Focus on Autistic Behavior, 10,* 10-21.

Robinson, C.W., & Sloutsky, V.M. (2004). Auditory dominance and its change in the course of development. *Child Development, 75,* 1387-1401.

Robinson, C.W., & Sloutsky, V.M. (2007). Visual processing speed: Effects of auditory input on visual processing. *Developmental Science, 10,* 734-740.

Robinson, C.W., & Sloutksy, V.M. (2008). Effects of auditory input in individuation tasks. *Developmental Science, 11,* 869-881.

Robinson, C.W., & Sloutsky, V.M. (2010). Effects of multimodal presentation and stimulus familiarity on auditory and visual processing. *Journal of Experimental Child Psychology, 107,* 351-358.

Sloutsky, V.M., & Napolitano, A.C. (2003). Is a picture worth a thousand words? Preference for auditory modality in young children. *Child Development, 74,* 822-833.

List of Figures

Figure 1: Practice visual stimuli

Cat Dog

Figure 2: Training visual stimuli

Simple Complex

Figure 3: Percentage of training during which the child paid attention, visual-only

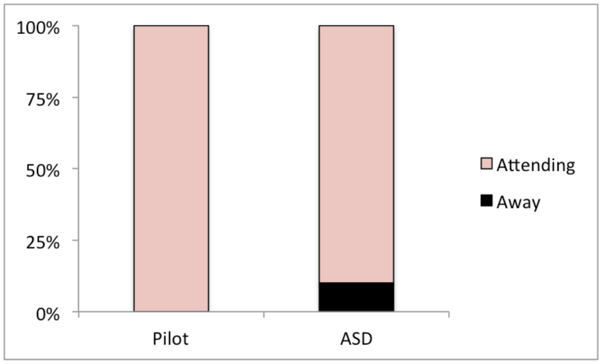

Figure 4: Percentage of training during which the child paid attention, auditory-only

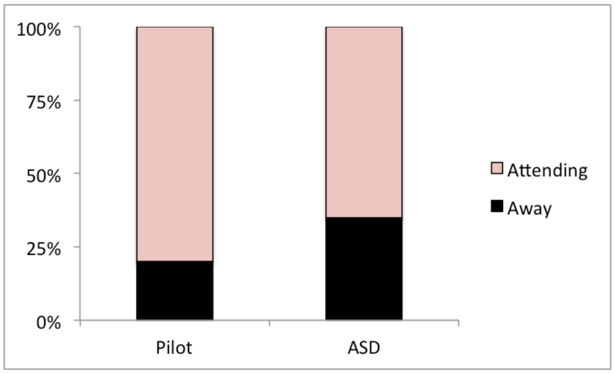

Figure 5: Percentage of training during which the child paid attention, auditory-visual

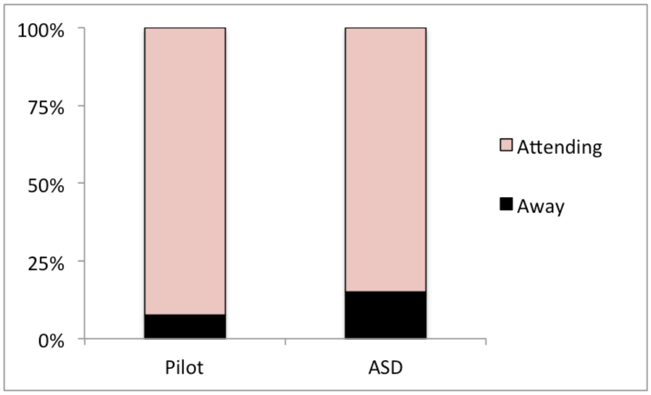

Figure 6: Looking during visual-only test

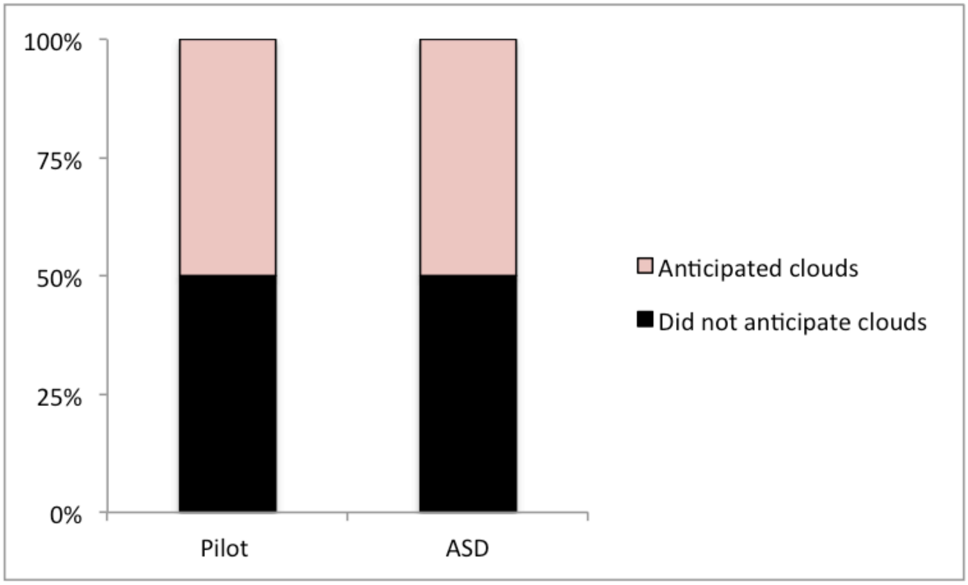

Figure 7: Looking during auditory-only test

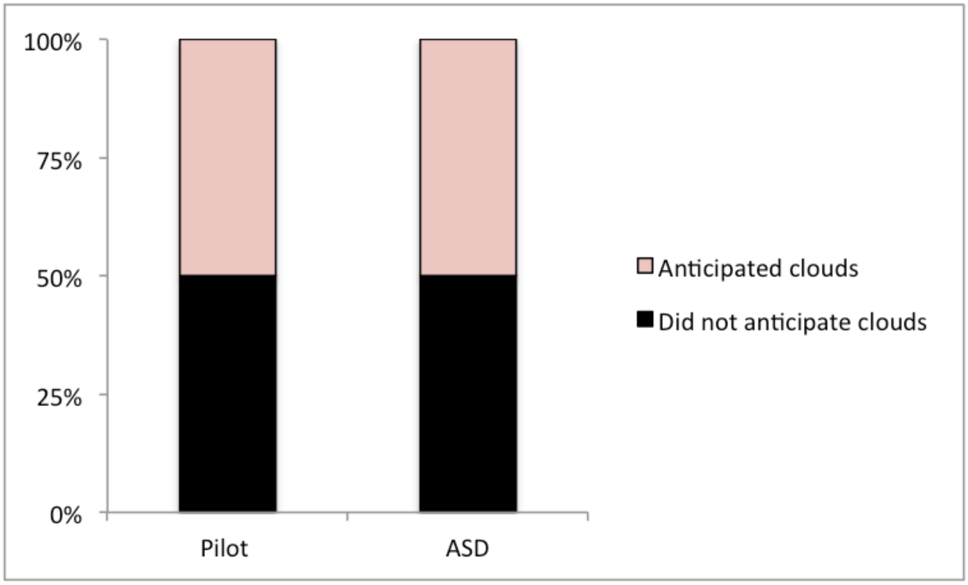

Figure 8: Stimulus weighting during auditory-visual test