A MULTI-METHOD ANALYSIS OF INTERSENSORY PERCEPTION OF SOCIAL INFORMATION IN CHILDREN AND ADOLESCENTS WITH AUTISM SPECTRUM DISORDER

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Abstract

The present study investigated the intersensory processing deficit for social stimuli in individuals with ASD compared to age- and cognitive-ability matched typically developing peers. This deficit was theorized to account (at least partially) for cascading impairments in attention and autism symptomatology across development. The primary goal was to isolate the social and linguistic properties of intersensory (audio-visual) processing using a manipulation of temporal synchrony. In Study One, a multi-method analysis of looking time and proportion of efficient gaze patterns using eye-tracking data from a behavioural task was used. Results provided evidence of a difference in intersensory processing specifically for social stimuli in children with ASD that does not appear to be solely attributable to a deficit in processing faces, language, or body movement.

The secondary goal of the project was to provide a better understanding of variables that impact and are impacted by intersensory processing. In Study Two the strength and direction of the relationship between intersensory processing and developmental, diagnostic, and attention variables was assessed. Results showed that impaired intersensory processing for social information appears to be associated with cascading consequences across development including some of the core impairments in Autism Spectrum Disorder: disrupted sensory processing, social-communication disability, and slower attentional disengagement.

In summary, results of Study One and Study Two are best understood as a specific cognitive-perceptual deficit in social orienting and are consistent with the Intersensory Redundency Hypothesis. The observed intersensory processing differences between groups may be impacted by dysfunctional intersensory integration wherein the most general amodal property, temporal synchrony, is misprocessed at early stages, disrupting selective attention and early social orienting. This impairment impacts the cascading cycle of perception, learning, memory, attention and so on and contributes to core sensory and social-communication impairments associated with Autism Spectrum Disorder.

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Introduction

Autism Spectrum Disorder (ASD) is a neurogenic disorder characterized by significant impairments in social communication as well as a restricted repertoire of activities and interests that cause impairment in daily functioning and are present in childhood and persist through adulthood (DSM-5; American Psychiatric Association [APA], 2013). ASD is thought to exist on a spectrum of symptom severity and level of functioning (from low to high) and individuals with ASD are thought to be quite heterogeneous. Atypical behavioural responses to sensory information are common and the most recent version of the Diagnostic and Statistical Manual of Mental Disorders included these sensory responses into the diagnostic criteria for Autism Spectrum Disorder (DSM5; American Psychiatric Association [APA], 2013). This is an appropriate modification considering that hyper- and hyposensitivities in multiple domains (tactile, auditory, visual, unisensory, low- and high-level multisensory) are reported for more than 96% of children with an ASD and these sensitivities may persist into adulthood (Crane, Goddard, & Pring, 2009; Leekam, Nieto, Libby, Wing & Gould, 2007; Marco, Hinkley, Hill, & Nagarajan, 2011; Tomchek & Dunn, 2007; Waterhouse, Fein, & Modahl, 1996).

Presence of sensory processing symptoms has been shown to predate diagnosis by as much as two years according to retrospective analysis of home videotapes (Adrien et al., 1993). Reports of disordered sensory processing in the research literature are corroborated by clinical reports, parent reports, and neurophysiological data (Baranek, 1999; Kanner, 1943; Marco et al., 2011).

Intersensory Processing In Typically Developing Infants

The development of perception and the capacity to understand and respond to stimuli are based on the fundamental ability to attend to, and spatially and temporally integrate information from multiple sources of input. When this process is successful, the observer is unaware that the information came from different sources and perceives only a coherent event. The appropriate integration of sensory information across multiple modalities is necessary for understanding an event and coordinating and initiating a response (Iarocci & McDonald, 2006). The perceiver must learn to skillfully and economically apply attentional resources to maximize the processing of relevant information and minimize the processing of irrelevant information (Gibson, 1969). These skills are learned through experience and interactions with the environment that produce systematic changes in selective attention across time such that we become expert at attending to meaningful information (Gibson, 1969; Gibson & Pick, 2000).

Information from the environment reaches us over several modalities. For example, a dropped bowl is seen to break into many pieces and also heard to crash, or a stovetop is seen to glow red and also felt to emanate heat. Although information is received over different modalities, we perceive a unitary event. Amodal properties occur when two or more sensory modalities are provided with relevant information. For example, we can identify the temporal characteristics of a rhythm by either watching the hands clap, or by listening to the sound of the hands clapping. Bahrick (2010) proposes that the attentional salience available in multimodal, but not unimodal stimulation commands processing of amodal properties at the expense of others. For example, in multimodal stimulation, attention is focused on amodal properties such as temporal synchrony, rhythm, and intensity and these properties support perception and promote the development of salience hierarchies for amodal over modality-specific elements in the environment. These hierarchies then direct the allocation of attentional resources and sensory processing, and drive interaction with the environment. Due to the inherently social (e.g., mother-infant interaction) nature of the early environment, this action reengages the loop with an early bias towards social orienting.

Intersensory Redundancy Hypothesis (IRH)

The IRH states that selective attention and learning in infancy can be guided by the detection of amodal information (Bahrick, Lickliter, & Flom, 2004). As reviewed in Bahrick and Lickliter (2002), and consistent with Gibson's (1966) ecological view of perception, the detection of amodal information is foundational for perceiving unitary objects and events. Temporal synchrony in particular is described as "the glue" that binds stimulation across the senses and is the most comprehensive type of amodal information (Bahrick, 2010). When several sensory events occur simultaneously, infants are more likely to attend to the multisensory events that share amodal properties than to the unimodal events, particularly if the multimodal events are temporally synchronous (Bahrick & Lickliter, 2002). As infants selectively attend to events with amodal information, the information from amodal properties is recognized prior to information belonging to only one sense (e.g., colour, decibel level, etc.) (Bahrick & Todd, 2012; Bahrick & Lickliter, 2002). Therefore, IR plays an important role in regulating perceptual development as amodal properties are important for drawing attention to global structures rather than more local information.

Newborn infants reliably show intact amodal perception. They turn their heads and eyes in the direction of a sound source, which indicates that the spatial location of the source is given through auditory and visual information (Butterworth, 1983; Muir & Clifton, 1985; Wertheimer, 1961). Lewkowicz (1986) showed that by 4 months of age, infants detect rhythm and duration of tones and flashing lights indicating that they are sensitive to the temporal synchrony that is presented through auditory and visual stimuli. Infants are also sensitive to associations between visual, auditory and tactile information (Gibson & Walker, 1984; Walker-Andrews & Lennon, 1985) and show an enhanced response to stimulation from one modality when it is paired with stimulation from another modality, referred to as intersensory facilitation (Bahrick, Lickliter, & Flom, 2006). Emotional development in infants is also assisted by means of multimodal pairings through face, voice, gesture, posture and touch and leads to the infant's understanding of affect (Walker-Andrews, 1994). Overall, the successful integration of sensory information across modalities is necessary for the development of understanding and interacting with the world.

Intersensory Processing and the Development of Language

A coordinated understanding of sensory input is essential for development of speech and language. During a conversation we receive information over two modalities, the first is the auditory information, or the sound of the person speaking, and the second is the visual information, or the sight of their lips, tongue and jaw moving during speech. Kuhl and Meltzoff (1984) have shown that 18- to 20-week-old infants can detect the correspondence between auditory and visually perceived speech and further report that some infants imitated sounds presented during the experiments, suggesting that infants possess an intermodal representation of speech that would be conducive to vocal learning. Further studies have shown the connection between faces and voices based on lip movements (Dodd, 1979). It is clear that typically developing infants integrate speech information from information provided by auditory and visual modalities.

Intersensory Processing Deficits in Individuals with an Autism Spectrum Disorder

Although the breadth of research regarding intermodal processing of audio-visual information in typically developing infants appears fairly clear and consistent, there is equivocal research regarding children and adults with Autism Spectrum Disorder. There is evidence that individuals with ASD have difficulty with multisensory processing and integrating information across auditory and visual modes (Iarocci & McDonald, 2006). Problems with sensory integration have been seen in several tasks including matching voices to faces (Boucher, Lewis, & Collis, 1998; Loveland, Tunali-Kotoski, Chen, & Brelsford, 1995), forming associations between sound beeps and light flashes (Martineau, Barthelemy, Jouve, Muh, & Lelord, 1992), discriminating temporal synchrony of audiovisual speech (Bebko, Weiss, Demark, & Gomez, 2006), and blending auditory and visual speech (Williams, Massaro, Peel, Bosseler, & Suddendorf, 2004). Smith and Bennetto (2007) found that individuals with autism were significantly worse than a comparison group at identifying spoken words when the sound was paired with the visual image of the face. Compared to individuals with typical development, individuals with ASD overall showed less benefit from the addition of visual information in audiovisual speech perception. For individuals with ASD, the impairment in processing multimodal stimuli is reliably seen within the literature.

Face-to-face communication is one of the most common situations where information is presented over several modalities and sensory integration is imperative for effective understanding. The presence of incongruent visual information can lead to illusory auditory perceptions that inhibit effective communication. This effect has been demonstrated in the laboratory by presenting artificially paired incongruent auditory and visual information. In such a case, people will often report hearing a combination of the presented stimuli. This is known as the McGurk Effect (McGurk & MacDonald, 1976) and it suggests that both modalities of information are contributing to what is heard. Investigation of the McGurk effect has shown that children and adolescents with ASD report fewer fusions of visual and auditory information than typical children, reflecting that children with ASD are less likely to combine the incongruent information during speech perception (Bebko, Schroeder, & Weiss, 2014; de Gelder, Vroomen, & van der Heide, 1991; Williams et al., 2004).

In a study by Ramachandran and Oberman (2006), participants were asked to name nonsense shapes. One object was an amoeboid shape, the other a jagged shape, and participants were instructed to name one object “bouba” and the other “kiki.” Authors report that 99% of the typical population will name the amoeba object “bouba” and the jagged object “kiki.” They hypothesize that this effect is seen because the multisensory system will integrate the visual shape of the object with sound of its name. In the participants with autism, only 20% showed this effect suggesting that they did not integrate the visual information (shape) with the auditory information (name).

Evidence of a Language-specific Deficit in Intersensory Processing in Individuals with an Autism Spectrum Disorder

Multi-disciplinary evidence indicates a deficit in the integration of audio-visual linguistic information in persons with ASD that may be specific to speech (Bebko et al. 2006; Smith & Bennetto, 2007). The Bebko et al. (2006) study identified a speech-specific deficit in discriminating temporal synchrony of audiovisual information in children with ASD. The authors found that the group with ASD did not show this deficit in discriminating temporal synchrony for stimuli that did not contain linguistic information. This suggests that the deficit in intersensory perception is specific to only the linguistic stimuli. The results of this study are consistent with findings from van der Smagt, van Engeland and Kemner (2007). In this study, high-functioning adults with ASD were presented a task to evoke illusory visual percept by presenting sounds concurrently with visual flashes. In this illusion, the sounds are expected to affect the number of flashes perceived. In both groups (ASD and control), this was the observed result and there were no differences between the groups suggesting that the routinely observed autism-specific deficit in integration of auditory and visual stimuli likely occurs in higher order processing stages, consistent with a deficit in a higher order process such as speech intelligibility. Hancock (2009) manipulated the linguistic content of stimuli to show that children with ASD processed non-linguistic information similar to children with TD, but that children with TD showed enhanced processing for linguistic information. Overall, there is consistent evidence that children with ASD process stimuli with linguistic content differently than children with TD. What remains equivocal, however, is whether or not these observed differences in processing are best explained by the linguistic content of the stimuli, or if another variable better explains the difference.

Multimodal (audio-visual) stimuli with linguistic content are inherently social and require processing of body movement and facial features. Atypical face processing in children and adults with ASD has been well documented. Eye-tracking studies have shown that compared to controls, participants with ASD tend to show decreased looking time to the eye region of the face and greater looking time to the mouth region of the face (Pelphrey et al., 2002; Dalton et al., 2005; Spezio, Adolphs, Hurley, & Piven, 2007a; Spezio, Adolphs, Hurley, & Piven, 2007b). Despite increased viewing time to the mouth region of the face, individuals with ASD continue to display speech-specific impairments when processing intersensory information. Studies showing dynamic social scenes have also consistently shown atypical viewing patterns for the ASD group (Boraston & Blakemore, 2007). A recent study by Rice, Moriuchi, Jones, and Klin (2012) identified a distinct difference in the social orienting between the ASD and TD groups.

They also examined a relationship between looking time to social stimuli and standardized measures of social disability, one of the core impairments associated with ASD. As predicted, there was a robust association between looking time to features of the inanimate environment and social disability for the participants with ASD.

Interdisciplinary Evidence of Intersensory Dysfunction in ASD

Evidence of impaired sensory processing in ASD abounds in the neuroscience literature (see Schauder & Bennetto, 2016; and Marco et al., 2011 for reviews). This discussion will be limited to the unisensory and multisensory processing of auditory and visual stimuli at the expense of tactile, gustatory and olfactory processing. The focus will be on the brain's functional response to sensory input with less attention to studies of brain structure and connectivity. Studies of functional response include methodology focused on the timing (electroencephalography, EEG), location (functional magnetic resonance imaging, fMRI), or both timing and location (magnetoencephalography, MEG) of neural responses.

Visual and audio unisensory. Study of auditory processing in ASD provides evidence of early (e.g., primary auditory cortex) atypical neural activity that is thought to reflect activity in the primary and association auditory cortices. These differences may be related to top-down processes that impact early auditory encoding (Whitehouse & Bishop, 2008) and atypical auditory processing may also be related to unusual behaviour responses to auditory stimulation (e.g., covering ears) in children with ASD (Marco et al., 2011). However, the nature, direction, and cause of these atypicalities are equivocal (e.g., Ferri et al., 2003; Oram Cardy, Flagg, Roberts, & Roberts, 2008).

Similar to results of unisensory auditory processing, the evidence of a disturbance in visual processing is equivocal and there is considerable discrepancy in the neurophysiological findings (Marco et al., 2011). Differences between participants with ASD and comparison groups have been identified for detail perception (Bertone, Mottron, Jelenic, & Faubert, 2005), object-boundary detection (Vandenbroucke, Scholte, van Engeland, Lamme, & Kemner, 2008), contrast detection in still and moving stimuli (Sanchez-Marina, & Padilla-Medina, 2008), synchrony of visual areas between the right and left hemisphere (Isler, Martien, Grieve, Stark, & Herbert, 2010), with some studies finding no differences (de Jonge et al., 2007; Koh, Milne, & Dobkins, 2010). The most well-studied area of visual processing in people with ASD is for facial stimuli. Convergent evidence from fMRI and event related potential (ERP) data shows differences in face processing including reduced/altered activation of the fusiform gyrus and the amygdala (Dalton et al., 2005) and absence of the expected increase in the N170 (face processing) wave (Churches, Wheelwright, Baron-Cohen, & Ring, 2010) for participants with ASD compared with controls. For example, using fMRI, Pierce, Müller, Ambrose, Allen and Courchesne (2001) found that adults with ASD process faces outside the fusiform face area (FFA), the region of the brain that supports face processing in typically developing individuals. Discrepancies in the literature for face processing appear to be confounded by differences in the familiarity of the face, attention, gaze direction and visual fixation, and stimulus complexity (Klin, 2008). In general, evidence from neurophysiology studies provides support for deficits in unisensory processing of visual stimuli including reduced/inflexible top-down processing of sensory areas that likely impacts higher order cortical abilities.

Audio-visual multisensory processing in typical development. Multisensory neurons have been identified that have specific properties for perceptual integration. These neurons have the capacity to respond to multisensory stimuli by firing at a rate beyond what would be expected by the summation of the individual unisensory neurons. This “multisensory enhancement” creates what is termed a super-additive response (Stein & Meredith, 1993) and this neuronal feature parallels the behavioural response defined in the IRH as intersensory facilitation. For example, multisensory systems have lower thresholds for activation, reduced reaction times, and the response time to multisensory stimuli is faster (Calvert, Campbell, & Brammer, 2000).

The superior temporal sulcus (STS) is a subcortical brain structure separating the superior temporal gyrus from the middle temporal gyrus on the temporal lobe of the brain. The STS has multisensory capabilities and is implicated in social processing. The STS receives converging auditory and visual inputs (Kaas & Collins, 2004) and contributes to multisensory integration (Cusick, 1997; Beauchamp, Argall, Bodurka, Duyn, & Martin, 2004). Further, the STS is sensitive to the temporal properties of stimuli and shows enhanced response to temporally synchronous audiovisual input (Calvert, Hansen, Iverson, & Brammer, 2001; van Atteveldt, Formisano, Blomert, & Goebel, 2006; Noesselt et al., 2007). In humans, subregions of the STS have been implicated in social perception and cognition (Deen, Koldewyn, Kanwisher, & Saxe, 2015) including the perception of faces (Haxby, Hoffman, & Gobbini, 2000) and biological motion (Grossman et al., 2000). Additionally, the STS is consistently activated in tasks of theory of mind, or, the ability to explain and predict other people's behaviour by attributing to them independent mental states (Saxe & Kanwisher, 2003; Saxe, Xiao, Kovacs, Perrett, & Kanwisher, 2004). Further, the posterior STS may be a particularly important area for audiovisual integration of linguistic stimuli (Nath & Beauchamp, 2012; Scott, Blank, Rosen, & Wise, 2000). Overall, the STS is the brain region most frequently implicated in processing multisensory audiovisual stimuli and it has been shown to have effects on brain regions traditionally considered unisensory (Noesselt et al., 2007). This region is important for social cognition and perception, although it is yet unclear if this region is uniquely involved in multisensory linguistic processing.

Audio-visual multisensory processing in Autism Spectrum Disorder. Many sensory regions identified in multisensory integration have been implicated in Autism Spectrum Disorder including the cerebellum and disrupted connectivity between cortical and sub-cortical regions (Ritvo et al., 1986; Stein & Stanford, 2008). Most significantly, the STS, an area associated with social cognition and perception has been found to respond atypically in individuals with ASD (Castelli, Frith, Happé, Frith, 2002; Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2007; Lavoie, 2016). In summary, there is strong interdisciplinary evidence that individuals with ASD process both social and linguistic stimuli differently than individuals with TD.

Present Study

This study introduces a major extension to the literature by isolating the social and linguistic properties of stimuli that are proposed to contribute to intersensory processing deficits in children with ASD. To this effect, stimuli were presented with varying levels of social and linguistic content using a multi-method approach to analysis of eye-tracking data. The development of intersensory skills is typically examined through the use of the preferential looking paradigm (PLP). In this paradigm, two visual displays are simultaneously presented to infants to examine if they will look more than chance levels (greater than 50%) to one of the two displays, thus displaying a preference for that particular visual display. In intersensory experiments, the integration of audio-visual information has been examined by presenting two visual displays simultaneously with an auditory track that matches only one of the visual displays. The infants' looking behaviour to the two screens is examined for evidence of a preference of one screen over another, as demonstrated through non-random looking patterns. If infants prefer one screen (usually the sound-matched screen), it is interpreted to mean that the infants’ looking behaviour is influenced by the integration of the auditory information with the visual displays (Bebko, Weiss, Demark, & Gomez, 2006). Hancock (2009) used a modified version of the preferential looking paradigm, the PLP-4 where participants view a 4- instead of a 2-screen display to compare intersensory processing of linguistic and non-linguistic stimuli. This methodology has been shown to increase sensitivity to looking patterns and lower chance looking probabilities from 50% to 25% (Oczak, Bebko, Hancock, Brown, & Holden, 2013). In the present study, the PLP-4 was used to investigate intersensory processing of audiovisual information in school-aged children with ASD compared to a typically developing (TD) comparison group. The main objective was to identify what aspect of the stimuli accounts for differences in processing social and non-social information in participants with ASD. This was done by isolating the social and linguistic components of the stimuli and controlling for the effect of biological movement using multi-method analysis of eye-tracking data.

The following terms are used to describe the conditions and are further detailed in the Method section to follow: speech (more formally, the SL trials – social linguistic); oral sounds (SNLO – social non-linguistic oral); clapping (SNLC – social non-linguistic clap) and non-social (NSNL – non-social non-linguistic). Conditions are identified by the number of different types of stimuli that are presented within the same trial and by the number of auditory tracks presented in the trial (see Table 1). Conditions that present two social videos with two non-social videos within the 4-screen display are termed "Mixed." Conditions in which one type of stimulus (speech, oral sounds, clapping, non-social) occupies each quadrant of the four-screen display are termed "Single." There are three different types of conditions, Mixed2, Mixed1, and Single1. In the Mixed2 condition (Appendix A), the two speech videos are identical and the two non-social videos are identical and both the speech and non-social auditory tracks are played simultaneously. Therefore, all videos are temporally synchronous with their respective auditory track. In the Mixed1 condition (Appendix B), the two speech videos are temporally offset from one another (by one second), and the two non-social videos are similarly offset from one another. Only one auditory track is playing (speech or non-social), and this track is temporally synchronous to only one of the video quadrants in a trial. In the Single1 condition (Appendix C), one type of stimulus (e.g., clapping) occupies all four of the quadrants of the screen and the videos are offset from the standard (delayed by one second or advanced by one or three seconds). One auditory track is played and is temporally synchronous to only one of the quadrants.

Table 1.

Title and description of trial combinations presented in Study One

Condition	**# and type of video**	**# and type of auditory track(s) played**	**Videos offset from each other**	**# of videos in synchrony with their respective auditory track(s)**
Mixed2	Four: two speech, two non-social	Two: one speech *and* one non-social	No	All four
Mixed1	Four: two speech, two non-social	One: *either* one speech *or* one non-social	Yes	One
Single1	Four speech	One: speech	Yes	One
Single1	Four oral sounds	One: oral sounds	Yes	One
Single1	Four clapping	One: clapping	Yes	One
Single1	Four non-social	One: non-social	Yes	One

Hypotheses

Part A: Mixed Content.

1. ***Mixed2.*** When both speech (SL) and non-social (NSNL) stimuli are presented within the same trial (i.e., a "Mixed" condition) and both auditory tracks are played in synchrony (a Mixed2 condition),
    a. participants with TD will show longer looking time to the speech stimuli (SL) over the non-social stimuli (NSNL); and
    b. participants with ASD will show no differences in looking time to the speech (SL) and non-social (NSNL) stimuli.
2. ***Mixed1***. When both speech (SL) and non-social (NSNL) stimuli are presented within the same trial and one auditory track is played and is matched to only one of the videos,
    a. participants with TD will show longer looking time to the video that is temporally synchronous with the auditory track; and
    b. participants with ASD will longer looking time to the synchronous screen only when the non-social video is matched to the auditory track.

Part B: Methodology.

3. ***Looking Time.***
    a. In the Single1 trials that contain oral sounds (SNLO), clapping (SNLC), or non-social (NSNL) stimuli, participants with TD and those with ASD will show equivalent looking time to the synchronous screen.
    b. In the Single1 trials that contain speech (SL) stimuli, only participants with TD will show longer looking time to the synchronous screen; the group with ASD will show no preference.

4. ***Gaze Patterns.***

    a. During Single1 speech (SL) trials, participants with TD will utilize a higher proportion of efficient gaze patterns (defined below), such that they will look more frequently towards the areas within the video that provide meaningful information about temporal synchrony (e.g., mouth).

    b. During Single1 trials that do not contain any linguistic information (SNLO, SNLC, NSNL), participants with ASD and participants with TD will show equally efficient gaze patterns such that they will look equally as often towards the areas in the video that provide meaningful information about synchrony.

        i. For the Single1 oral sounds (SNLO) trials, participants will look equally as often towards the mouth.

        ii. For the Single1 clapping (SNLC) trials, participants will look equally as often towards the hands.

        iii. For the Single1 non-social (NSNL) trials, participants will look equally as often to the moving marble, finger playing the piano, and nuts and bolts (see Method section for more detail on the stimuli).

Methods

Participants

Two groups of children between ages 6 years, 3 months and 15 years, 4 months (*M* = 10 years, 9 months, *SD* = 2 years, 8 months) participated in this study. The first group included 19 children (17 males, 2 females) with a diagnosis of Autism Spectrum Disorder (ASD). In the current DSM-5, the autism spectrum encompasses the former subgroups of Autism Disorder, ASD, Asperger Syndrome, Pervasive Developmental Disorder, and Pervasive Developmental

Disorder – Not Otherwise Specified. The comparison group included 20 children with typical development (TD) (13 males, 7 females). The participant groups were not evenly distributed by sex. There were more male participants in the group with ASD and more female participants in the group with TD. However, given that ASD affects more males than females (4-5:1, Fombonne, 2003) the sex discrepancy was not unexpected for the group with ASD. An attempt was made to approximate a similar distribution in the group with TD. While not entirely successful, groups in the current study were matched on other variables (age, cognitive ability). Further, there is no evidence in the literature of a clear sex difference in early perceptual-cognitive development for audio-visual tasks (Lewis & Weinraub, 1979). School-aged children were selected for the study, as this is a developmental time period when clinical profiles have become more stable, compared with toddlerhood, and yet the time is closer to the emergence of the syndrome, compared with adulthood (Rice et al., 2012). Diagnosis was confirmed using either the Autism Diagnostic Interview-Revised (ADI-R; Le Couteur, Lord, & Rutter, 2003, n = 13) or the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 2002; n = 1). If families were not available or willing to complete the diagnostic measures, diagnosis was confirmed using diagnostic reports from a pediatrician or a psychologist (n = 5). Participants in both groups reported normal or corrected-to-normal vision and hearing as verified through parent report, as well as no additional neurological impairment. TD participants were included if there was no history or current presentation of intellectual disability (defined as FSIQ ≥ 70) and no history or current presentation of social disability (defined as total score < 15 on the Social Communication Questionnaire). Participants were recruited through local agencies and community resources, or through a previously established multi-site research registry (the Autism Spectrum Disorders - Canadian American Research Consortium; ASD-CARC).

Participants with ASD were matched by group to participants with TD based on their chronological age (CA), verbal ability (VA), nonverbal ability (NVA), and general cognitive ability (GCA) as measured by the Early Years Cognitive Battery or School-Age Cognitive Battery of the Differential Scales, 2nd Edition (DAS-II; Elliott, 2007). Independent samples *t*-tests revealed no significant differences between groups for CA, GCA, VA, and NVA (all *p*s > .131) indicating the participant groups were well-matched on these variables. See Table 2 for a summary of participant demographic information.

Table 2.

Sample demographic information.

	TD (*n* = 20)		**ASD (*n* = 19)**			
	M (SD)	*Range*	*M (SD)*	*Range*	*t (df)*	*p*
Chronological Age (in months)	125.10 (34.45)	75-184	133.68 (28.77)	78-183	-.842 (37)	.405
DAS GCA Standard Score	103.25 (10.35)	81-121	94.72 (22.19)	58-145	1.544 (37)	.131
DAS VA Standard Score	101.85 (10.34)	86-126	94.44 (22.71)	34-133	1.316 (37)	.197
DAS NVA Standard Score	102.60 (10.39)	76-120	98.05 (21.41)	54-128	.851 (37)	.400

Typically Developing (TD); Autism Spectrum Disorder (ASD); Differential Ability Scale, 2nd Edition (DAS-II); general cognitive ability (GCA); verbal ability (VA); and nonverbal ability (NVA).

Measures

Cognitive measure.

Differential Ability Scales-II (DAS-II; Elliott, 2007). The DAS-II is an individually administered test of cognitive ability designed to assess individuals between the ages of 2 years 6 months and 17 years 11 months. It is made up of a core battery of tests measuring verbal reasoning, nonverbal reasoning, and spatial abilities. Together, these provide a full scale measure (GCA). Administration of the core battery takes 45-60 minutes. The DAS-II was selected above one of the Weschler measures (WPPSI, WISC-IV or WASI) first of all because it would not conflict with any previous or subsequent psychoeducational assessment that may be necessary. Secondly, the DAS-II was the most appropriate measure to use with an ASD population due to the broad age range, strength of the differential ability assessment, and reduced verbal loading.

The majority of children with ASD exhibit significant scatter of scores on cognitive profiles, rendering the obtained composite scores non-unitary and potentially invalid. Research suggests that over 50% of children/adolescents with ASD have significant discrepancies between their verbal intelligence quotient (VIQ) and their non-verbal intelligence quotient (NVIQ), a substantially higher rate than in the normative samples on which intellectual measures are standardized. General recommendations regarding test selection include choosing an instrument with reduced verbal loading, opportunities for teaching, decreased demands for social engagement, few timed tasks, and hands-on activities. The *Differential Ability Scale--Second Edition* (DAS-II; Elliott, 2007) is one instrument specifically recommended for use with this population; however, given its relatively recent publication, there is minimal published research on its use in general and special populations. In particular, there are no extant data describing the performance of children/adolescents with ASD on the DAS-II. A study on the first version of the DAS (Joseph, Tager-Flusberg, & Lord, 2002), suggests its strengths include its ability to provide a clear comparison of differential abilities and the relatively brief time required for administration. Overall the authors recommend that the DAS is useful in obtaining valid and reliable distinctions in cognitive abilities in children with developmental disorders. A recent review of the DAS-II suggests that the desirable features described by Joseph et al. (2002) are enhanced in the newer version of the measure.

Autism Spectrum Disorder diagnostic measure.

Autism Diagnostic Interview-Revised (ADI-R; Le Couteur, Lord, & Rutter, 2003). The ADI-R is a semi-structured interview based on the DSM-IV and ICD-10 criteria for autism and pervasive developmental disorders conducted with parents of individuals above the age of 2 years. The ADI-R is composed of 93 items used to assess current and past behaviours related to Autism Spectrum Disorder. The parent responses are coded and scored using an algorithm that provides scores for current and previous behaviours, and a cut-off score for autism.

The ADI-R has demonstrated sound reliability and validity. Inter-rater reliability for the domains, subdomains, and individual items were found to be high (majority with $\kappa > .7$; Lord, Rutter, & Le Couteur, 1994; Poustka et al., 1996). Intraclass correlational tests have indicated strong inter-rater reliability (majority ranging from r = .82-.97; Chakrabarti & Fombonne, 2001; Lord et al., 1994; Poustka et al., 1996). In addition, two studies have demonstrated strong test-retest reliability across 2 to 5 months (r = .77-.97; Hill et al., 2001; Lord et al., 1994). The children in the current study had all received previous diagnoses and all were school-aged, thus the ADI-R is a useful measure to confirm diagnoses.

Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 2002). The ADOS is a standardized, semi-structured, play-based observation instrument that is congruent with the *ICD-10* and *DSM-IV* diagnostic criteria used by professionals for diagnosis of autism. It assesses communication, social interaction, and play or imaginative use of materials for individuals who may have ASD. The ADOS consists of four modules, each based on language and age: I –preverbal/single words; II – phrase speech; III – fluent speech, child/adolescent; IV – fluent speech, adolescent/adult. As reported in the ADOS manual (Lord et al., 2002), intraclass correlations are as follows: interrater reliability ranged from .82 to .93 and test-retest reliability over 1 to 2 weeks ranged from .59 to .73. Cronbach's alphas for internal consistency were consistently highest for the Communication-Social Interaction total score (.91 to .94) and lowest for Stereotyped Behaviors and Restricted Interests scores (.63 to .65 for Modules 2 & 1, and .47 to .56 for Modules 4 and 3).

Only one module is administered to an individual at a given time and the examiner selects the module that is most appropriate for the expressive language skills and chronological age of the child or adult being tested. Each module can be administered in 30 to 45 minutes. In 2004, deBildt examined the interrelationship between the ADOS and the ADI-R, and the *DSM-IV-TR* diagnostic criteria. He found that the agreement between the ADI-R and the ADOS was fair and, when compared with the *DSM-IV-TR* diagnostic criteria, that both instruments measure autism or PDD validly and reliably. He noted that the interrelationship between both instruments and the clinical classification was satisfactory even among low-functioning children.

Stimuli

There were four levels of stimulus type used in this study:

1. speech stimuli (or more formally, SL – social linguistic), consisting of a woman telling a story;
2. oral sounds (SNLO – social non-linguistic oral), consisting of a woman making non-speech sounds with her mouth e.g. kissing sound;
3. clapping (SNLC – social non-linguistic clap) consisting of a woman clapping; and
4. non-social (NSNL – non-social non-linguistic), e.g. hand playing the piano.

Three different versions of each stimulus type were used to retain interest in the videos but for each presentation only one version was used at a time (see Table 3). The speech (SL) trials included three different female actors telling different stories. The oral sounds (SNLO) trials included the same three female actors that appeared in the SL trials, however, in the SNLO trials the actors are making different patterns of non-speech sounds (e.g., kissing, popping, “raspberry” sounds) using their mouth. The clapping (SNLC) trials included the same three female actors as both the SL and SNLO trials clapping their hands. The three different non-social (NSNL) trials included a hand playing a piano, a string of metal nuts and bolts hitting a table, or a ball rolling along a track. Only the speech and non-social stimuli were used in Part A: Mixed content. All four variations of stimuli were used in Part B: Methodology.

All trials were presented using the four-screen preferential looking paradigm (PLP-4) with four videos, one in each quadrant of the display screen. In all conditions, each trial was presented for 12 seconds and preceded by a brief (three second), shrinking cartoon clip intended to attract the participants’ attention so that they were looking in the center of the screen at the onset of the trial presentation.

Part A: Mixed content.

Mixed2. The first condition was presented in a 4-screen design, with two speech (SL) and two non-social (NSNL) videos within the same trial. The two speech videos were synchronised with each other and the two non-social videos were synchronised with each other. Auditory tracks for the speech and non-social videos were played in synchrony with their respective videos at 60 decibels each. A total of three different Mixed2 trials were presented before any of the other test trials (Mixed1 and Single1) so that participants were not influenced by the manipulation of synchrony in the subsequent trials (see Table 3). This design allowed for a measure of visual engagement and a direct comparison of the social and non-social content of stimuli between groups with TD and ASD.

In the current study, several variables in the Mixed2 condition were controlled to allow for direct comparison between conditions. For example, stimuli (speech and non-social) occupied the same amount of physical space on the screen, the auditory tracks played concurrently in synchrony with the corresponding visual stimuli, and the auditory tracks were adjusted to play at the same mean decibel level. On these variables (size, space, synchrony, decibel output) the goal was to equalize the multisensory information. Previous studies have not controlled for these variables in a way that allowed a direct comparison of the social and non-social information. Although these experimental manipulations may have decreased some aspects of the ecological validity of the design, mainly because information in the natural environment is typically more chaotic and variable, these constraints allowed for direct comparison across conditions.

Table 3

Description of condition and presentation order. The quadrant synchronous with the auditory track(s) is in bold.

Condition	**Mixed2 Speech/ Non-social**	**Mixed1 Speech/ Non-social**	**Single1, Speech (SL)**	**Single1, Oral sounds (SNLO)**	**Single1, Clapping (SNLC)**	**Single1, Non-social (NSNL)**
Description	Woman A, Nuts and Bolts **NSNL** **NSNL** **SL** **SL**	Woman B, Mousetrap **SL** NSNL SL NSNL	Woman A SL SL **SL** SL	Woman A SNLO SNLO **SNLO** SNLO	Woman A **SNLC** SNLC SNLC SNLC	Nuts and Bolts NSNL NSNL **NSNL** NSNL
	Woman B, Mousetrap **SL** **NSNL** **SL** **NSNL**	Woman B, Mousetrap **NSNL** SL SL NSNL	Woman A SL SL SL **SL**	Woman B SNLO **SNLO** SNLO SNLO	Woman B **SNLC** SNLC SNLC SNLC	Nuts and Bolts NSNL **NSNL** NSNL NSNL
	Woman C, Piano **NSNL** **SL** **SL** **NSNL**	Woman A, Nuts and Bolts SL NSNL SL **NSNL**	Woman B SL **SL** SL SL	Woman B SNLO SNLO SNLO **SNLO**	Woman C SNLC SNLC **SNLC** SNLC	Mousetrap NSNL NSNL NSNL **NSNL**
		Woman C, Piano NSNL NSNL SL **SL**	Woman C SL SL **SL** SL	Woman C **SNLO** SNLO SNLO SNLO	Woman C SNLC SNLC SNLC **SNLC**	Piano **NSNL** NSNL NSNL NSNL
Order	Played first	Randomized – within and between trial type				
Total = 23	3	4	4	4	4	4

Mixed1. The second condition was also presented in a 4-screen design, and contained both speech (SL) and non-social (NSNL) videos within the same trial. Similar to the condition described above (Mixed2), trials included two speech and two non-social videos; however, the speech videos were offset in time from one another, and the non-social videos were offset in time from one another. Only one of the auditory tracks was played during each trial, either the speech or the non-social. Therefore, only one video was synchronized with the auditory track. For example, if the speech auditory track was played, it matched one of the speech videos while the other speech video was delayed by one second. In this case, the other two non-social videos would not match the auditory track in either content or temporal synchrony and the videos would also be offset from one another by either an advance or delay of one or three seconds. A total of four different Mixed1 trials were presented with half (two) of the trials synchronous to one of the two speech screens and the other half (two) synchronous to one of the two non-social screens. These trials were randomized in presentation with the Single1 trials described below (see Table 3).

Part B: Methodology.

Single1. Four different stimulus types (SL, SNLO, SNLC, NSNL) were presented in the Single1 condition and each presentation used the four-screen preferential looking paradigm (PLP-4). Four identical videos were presented, offset in time from one another (delay of one second, advance of one or three seconds) and the auditory track was synchronous with only one of the videos (Appendix C).

Videos were filmed using a Sony handheld camera, edited using Final Cut Pro, and converted to AVI format as required for presentation in Tobii Studio. The decibel output of the auditory signal for each trial was tested independently with an audiometer and manipulated using Final Cut Pro to ensure that there was no more than a five dB difference between the trials. Trials were then pseudo-randomized using an online list randomizer (Haahr, 2013) and uploaded into Tobii Studio for presentation. Conditions of the randomization ensured that the location of the synchronous screen (upper left, upper right, lower left, lower right) and the stimulus type (SL, SNLO, SNLC, NSNL) were not repeated more than thrice consecutively to avoid looking biases. There were additional trials, similar to those described above, presented for analysis in Study Two of the current project and additional trials for analysis in another project. Altogether, including the trials described above, the trials in the additional studies, and the brief fixation trials, the total presentation time was 20 minutes with a break halfway through the task.

Apparatus

Stimuli were presented to participants on a 27-inch computer monitor set at a resolution of 1280 x 960 pixels that was controlled by a Dell laptop computer and presented using Tobii software. A Tobii X60 eye-tracker was centrally located directly underneath the computer monitor. Participants were seated on a chair and the distance between the eyes to the screen was 55.5-71.0 cm (M = 61.95, SD = 4.40) with their eye-line level with the middle of the screen both horizontally and vertically. A booster seat was used to elevate younger participants. Assuming a fovea visual angle of 2 degrees, on average, this allowed the corresponding size of the fovea on screen to be 2.16cm (Range, 1.94cm – 2.48cm). The eye-tracker recorded eye movements, with a sampling rate of 60Hz. A second, smaller computer monitor was positioned at a 45-degree angle to the participant and was used by the research assistant to observe the status of the eye-tracker throughout the testing session. Overall, the average capture rate for the sample was 76.37% (SD = 24.14), as calculated by Tobii Studio, the eye-tracking software.

General Procedure

Prior to participation, information letters were distributed, informed consent was obtained from the parents (see Appendix D and E); and verbal or written assent (when possible) was obtained from the participants (see Appendix F). Participants were presented with the intersensory (PLP-4) task lasting 20 minutes in total. After a break, children were then assessed using the DAS-II lasting approximately 45-60 minutes.

While the child participated in the intersensory (PLP-4) task, cognitive assessment, and ASD assessment, the parent or caregiver completed questionnaires that were used for analysis in two other studies. This took approximately 60-90 minutes in total. To confirm the diagnosis, parents were asked to provide a copy of the child's diagnostic report. If the parents were willing and there was not enough time to complete the ADOS with the child, the parents were contacted at a later date to complete the ADI-R over the phone.

Upon completion of the study, participants were debriefed and provided with a brief description of the study's objectives, research questions, hypotheses, and potential clinical implications. Parents also had the opportunity to ask any questions regarding the study and to request a summary of the study findings. Families were also thanked and participants were provided with a participation certificate and a token gift (a gift certificate for a book store).

Experimental Procedure

Participants initially viewed a cartoon clip to draw interest to the presentation screen and to increase comfort with the apparatus. Following the cartoon, participants viewed a moving ball in order for the eye-tracker to calibrate their eye movements in preparation for data collection. Calibration was a nine-point, fast-moving calibration. Following successful calibration, participants viewed a familiarization trial, followed by the test trials. The familiarization trial contained a four-screen design with four identical and temporally synchronous video clips matched to one audio track. This was presented to familiarize participants with the 4-screen procedure. Participants then viewed the intersensory task and an attention task. Data from the attention task was used in Study Two of the current project and for another project. All test trials were presented using Tobii Studio.

Data Analysis

Data were analyzed using two distinct methods. The objective of the first set of analyses was to assess differences in looking time between the ASD and TD groups for the Mixed2, Mixed1 and Single1 conditions. The objective for the second set of analyses was to assess differences in the efficiency of gaze patterns between the groups for the Single1 condition.

Method one: Looking time

Tobii software was used to determine location and duration of visual fixations. Data were analyzed per trial based on proportion of time spent looking to the pre-determined Area of Interest (AOI) in each of the four quadrants of the screen; upper right (UR), upper left (UL), lower right (LR) and lower left (LL) as measured using the Tobii Studio presentation program. Proportion of fixation durations was calculated as the total duration of visual fixations to the specified AOI divided by the total duration of visual fixations to the entire presentation (excluding the space between the quadrants). The variable, proportion of fixation durations will be subsequently referred to as "looking time." Participants' data on individual trials were excluded if they did not satisfy these criteria; 1) they were visually fixated within the quadrants for a total of at least three seconds, 2) they fixated within at least two of the quadrants for at least 200 milliseconds each, and 3) they fixated within the synchronous quadrant for at least 200 milliseconds. These stringent criteria were used to ensure that all participants attended to the trial, that they had enough time to change their eye gaze at least twice, and that they visually sampled the synchronous screen as well as at least one comparison screen.

For the mixed content trials, each of the four quadrants was highlighted as an Area of Interest (AOI) to ensure that the areas designated for comparison were identical in size. For the duration of each trial (12s), participants could have been looking either within one of the four AOIs, or not within an AOI (this includes looking elsewhere within the screen, looking between the screens or looking away from the screen). Areas of Interest providing the highest concentration of audio-visual intersensory information were pre-determined by the examiner for the Single1 trials and are as follows: speech (mouth), oral sounds (mouth), clapping (hand), and non-social (moving marble, table where nuts and bolts strike, finger playing piano).

Method two: Gaze patterns

Data were analyzed on a per trial basis to assess the sequence of gaze patterns displayed by each participant for the trials in the Single1 condition. Sequences of looks were coded as either 'efficient' or 'inefficient' based on the pattern of gaze shifts. Looking patterns were categorized as 'efficient' if 1) gaze shifted from an AOI (e.g., mouth) to another AOI, or 2) gaze shifted from an area outside of an AOI (e.g., eye region, off screen) to an AOI. All other gaze patterns were coded as 'inefficient,' for example, if gaze shifted between two areas outside of the AOI or if gaze shifted from an AOI to an area outside of an AOI. Once data was coded, the proportion of 'efficient' transitions was calculated by dividing the number of efficient transitions by the total number of transitions for the trial.

Analyses. To evaluate the hypotheses, the present study used independent samples *t*-tests to test between group effects for single, distinct variables. Mixed factorial ANOVA was used to test between-group differences for repeated measures variables when the relationship between the within-subject variables and the interaction was of interest (e.g., looking time to eye versus mouth region). MANOVA was used to test for group difference along a combination of dependent variables. MANOVA was followed by univariate analysis of variance and discriminant function analysis. Discriminant function analysis was used to determine the effectiveness of the variables in predicting group membership (TD vs ASD). Strength of effect is reported as η_p^2, partial eta squared, or the proportion of variance accounted for by the effect plus the error variance associated with the effect. In these analyses, partial eta squared is a more appropriate measure of strength of effect compared to eta squared because the value of eta squared can depend on the number and strength of other factors in the analysis. Partial eta squared provides an estimate of effect size that is less biased in study designs with substantial independent effects and/or repeated measures; however, this estimate limits comparability across studies with different designs (Lakens, 2013).

Results

Assessing for Response Bias

Looking preferences were evaluated prior to analysis of the hypotheses to ensure that no group differences in inherent looking preferences would skew interpretation of the results. The first test looked at the probability that the TD or ASD participants looked to a quadrant when that quadrant contained the synchronous screen (i.e., upper right, upper left, lower right, lower left, see Figure 1), excluding the black space between quadrants. Approximately equal probabilities would suggest no looking bias. Data were collapsed across experimental trials and stimulus type (speech-SL, oral sounds-SNLO, clapping-SNLC, non-social-NSNL). A Factorial Mixed ANOVA was used to test for differences between participant groups (TD and ASD) for looking time to a quadrant when the video synchronous to the auditory track was in that quadrant (Table

4). The assumption of homogeneity of variance was tested and satisfied using Levene's test (all *ps* > .05). Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of Quadrant, $\chi^2(5) = 11.237, p = .047$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .816). Results of the ANOVA revealed a significant main effect of looking time to the quadrants F (2.448, 93.017) = 4.297, p = .012, η_p^2 = .100. Post hoc tests using the Bonferroni correction revealed that the only significant difference was between the two extremes, that is, between the looking time to the upper right quadrant compared to the lower left quadrant, p = .010, 95% CI [.017, .174]. All other comparisons were not significantly different. Further, the looking time to the synchronous quadrant was greater than .40 for all quadrants (see Table 4). Therefore, participants overall showed a robust visual preference for the synchronous screen at values greater than what would be expected from proportions of chance looking (.25).

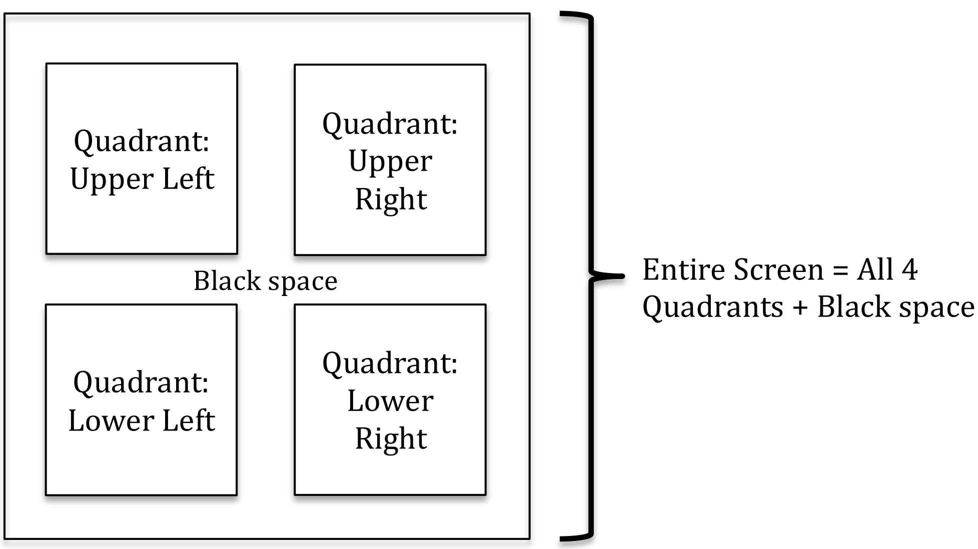

Figure 1. PLP-4. Representative image of the presentation screen divided into four quadrants with remaining blank space. Assessment of response bias to location of the stimuli included only areas identified as quadrants and excluded black space. Assessment of response bias to stimulus type included the entire screen

Table 4

Descriptive statistics for looking time to the four quadrants when that quadrant was synchronous.

	Quadrant			
	Upper Left (UL)	**Upper Right (UR)**	**Lower Left (LL)**	**Lower Right (LR)**
n = 39				
M	.460	.498	.403	.460
SD	.186	.204	.157	.192

Data were then analysed to identify if the groups looked longer (visual engagement) to any one of the stimulus types (speech-SL, oral sounds-SNLO, clapping-SNLC, non-social-NSNL) over another. Engagement was calculated as the total looking time to the entire screen (see Figure 1) for each of the Single1 stimuli, averaged across all presentations of that stimulus (*n*=4 presentations per stimulus type). A Factorial Mixed ANOVA identified a significant main effect for participant group, $F(1,36) = 6.495$, $p = .015$, $\eta_p^2 = .153$; the TD group ($M = 10.893$, $SD = .508$) looked longer to the presentation screen overall than the ASD group ($M = 9.013$, $SD = .535$). Results of Levene's Test indicated no violations to the assumption of homogeneity of variance (all *p*s > .05). Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of stimuli, $\chi^2(5) = 23.985, p < .001$. Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .712). Engagement to the screen among stimulus type (SL, SNLO, SNLC, NSNL) did not differ, $F(2.135,76.873) = .854$, $p = .436$, $\eta_p^2 = .023$ and the interaction between group and stimulus type was also not significant $F(3, 108) = .587$, $p = .625$, $\eta_p^2 = .016$. Results are consistent with previous studies in our lab where, compared to the ASD group, the comparison group showed less time looking away from the presentation screen overall. This difference is dealt with by using the *proportion* of mean looking (total looking time to the Area of Interest across the trial/ total time looking to the screen across the trial) in subsequent analyses in Study One. Overall, group comparisons are unlikely to be biased by the location (quadrant) or by differences in visual engagement to the different stimuli.

Part A. Mixed content

Mixed2. Hypotheses 1a and b. The first hypotheses concerned the Mixed2 trials, which presented two speech (SL) videos and two non-social (NSNL) videos in the same trial with both the speech and non-social auditory tracks playing in synchrony with the matched videos. Hypothesis 1a predicted that participants with TD would prefer the quadrants with speech stimuli whereas hypothesis 1b predicted that participants with ASD would prefer the non-social stimuli. Preference was quantified as the looking time in a predetermined area of interest (AOI). For the mixed content trials, the AOI was identified as the entire quadrant. Identifying more specific AOIs (e.g. mouth, eyes in the speech video and nuts and bolts in the non-social video) would have been problematic for these trials because the size of the AOIs between the speech and non-social videos were not equal, rendering the comparison between stimuli biased. This was resolved by comparing the looking time for the entire quadrant. A one-factor, between-subjects multivariate analysis of variance (MANOVA) was conducted. Looking time to the quadrants (speech, non-social) served as the dependent variables in the analysis and the diagnostic group (TD, ASD) comprised the independent variable. Univariate normality was assessed using standardized skewness and kurtosis and the Shapiro-Wilks test of normality (Appendix G). Normality assumptions underlying MANOVA did not reveal any substantial anomalies. The bivariate correlations for the dependent variables are presented in Appendices H and I respectively. The dependent variables are nearly perfectly correlated and can be assumed to be *singular* at worst; and at best, the variables suffer from multicollinearity. This is problematic because multicollinearity results in high variability in the discriminant function coefficients. As a rule of thumb, correlations in the moderate range are preferable (i.e. .20-.60; Meyers, Gampst & Guarino, 2006), although low correlations are also not considered inappropriate because the only risk is a lack of power (French, Poulson & Yu, 2002). Overlap of 80-90% is considered too high to be tolerated (Grice & Iwasaki, 2007), which ruled out the intended analysis.

As there are only two independent a priori analyses to be conducted, the risk of Type 1 error is low and independent samples t-test was chosen to replace MANOVA. Analyses compared the looking time to the speech and then to the non-social quadrants between diagnostic groups (TD, ASD) in the Mixed2 condition. The assumption of homogeneity of variance was satisfied for both analyses (*p*s $> .05$). Between group differences in looking time were not significant for either the speech quadrants $t(35) = -1.222$, $p = .230$ or the non-social quadrants, $t(36) = .717$, $p = .478$ (see Figure 2). Interestingly, it appeared that both groups preferred the non-social condition. Post hoc analysis using dependent samples *t*-test with Bonferroni correction was used to test if there was an overall greater looking time to the non-social quadrant compared to the speech quadrant (collapsed across diagnostic group). Groups had a significantly longer looking time to the non-social stimuli ($M = .661$, $SD = .126$) compared to the speech stimuli ($M = .315$, $SD = .128$); $t(36) = -8.333$, $p < .001$. Therefore hypotheses 1a and 1b were partially supported. Participants with ASD showed a visual preference for the non-social stimuli during the Mixed2 trials (1a), but the participants with TD also displayed an equally strong preference for the non-social stimuli (1b).

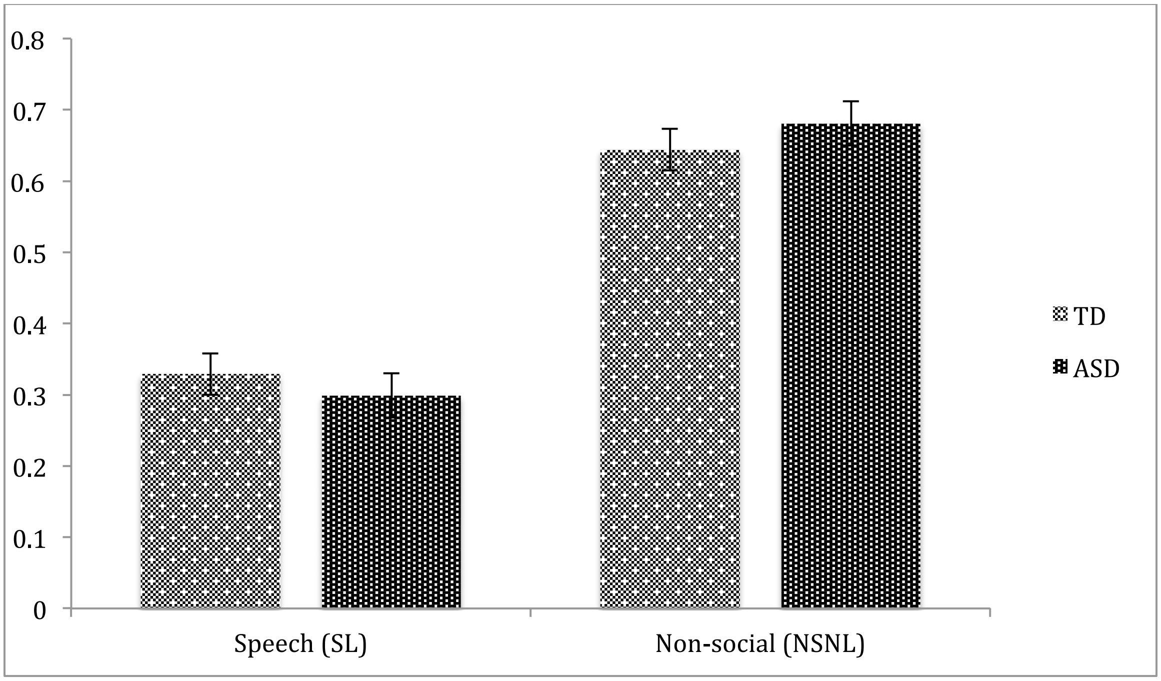

Figure 2. Mixed2, Looking Time. Looking time for the TD and ASD groups to the speech (SL) and non-social (NSNL) quadrants in the Mixed2 trial.

When viewing static or unimodal stimuli, typically developing children prefer to look at the eye region of the face. Less is known about dynamic, multimodal stimuli, although typically developing participants generally also show a preference for the eye region. To assess between-group differences in facial processing of the social stimuli during the task, looking time to the eye and mouth region (of the speech stimuli only) were compared between groups. A Factorial Mixed ANOVA was conducted to compare the main effects of Diagnosis (TD, ASD) and Area of Interest (eyes, mouth) and the interaction effect for the looking time. Results of Levene's Test indicated no violations to the assumption of homogeneity of variance (all *p*s > .05). The only effect that was statistically significant was the Area of Interest factor, $F(1,34) = 18.914$, $p < .001$, $\eta_p^2 = .357$ indicating significantly longer looking time to the eyes ($M = .131$, $SE = .015$) compared with the mouth ($M = .060$, $SE = .007$). The main effect of Diagnosis was not significant $F(1,34) = .218$, $p = .644$, $\eta_p^2 = .006$. The interaction was also not significant $F(1, 34)$

= .857, p = .361, η_p^2 = .025. From the results, it is evident that both groups were visually fixated more to the eyes compared with the mouth region when the speech videos were presented in temporal synchrony with the auditory track.

Mixed1. Hypotheses 2a and b. In the Mixed1 trials, the visual stimuli arrangement was similar to the Mixed2 stimuli, however only one of the auditory tracks was played. In half of the trials, the speech (SL) auditory track was played in synchrony to one of the speech (SL) videos while the other speech video was delayed by one second. In the other half of the trials the non-social auditory track was played in synchrony to one of the non-social videos while the other non-social video was delayed by one second. Hypothesis 2a predicted that the participants with TD would show longer looking time to the video synchronous to the auditory track regardless of whether the video was social or non-social. According to hypothesis 2b, participants with ASD were only expected to show longer looking time when the non-social video was synchronous with the auditory track. No preference was expected when the speech video and auditory track were played in synchrony. A one-factor between-subjects MANOVA was used to examine the association between diagnostic group (TD, ASD), and looking to the synchronous speech or non-social quadrant as DVs. Univariate normality was assessed using standardized skewness and kurtosis and the Shapiro-Wilks test of normality (Appendix J). Tests of skewness and kurtosis revealed a non-normal distribution for the non-social variable for the group with ASD; however, Shapiro-Wilks test of normality did not identify any violations. Considering that sample sizes were relatively equal with no outliers, results suggest that, overall, normality is a reasonable assumption for the MANOVA. A series of Pearson correlations were first performed between the dependent variables in order to test the MANOVA assumption that the dependent variables would be related conceptually and statistically (Appendices K and L). A meaningful pattern of low correlations was observed amongst the dependent variables, suggesting the appropriateness of a MANOVA. Additionally, Box's M value of 2.577 was associated with a *p* value of .492, which was non-significant based on Huberty and Petoskey's (2000) guideline (i.e., $p > .005$). Thus, the covariance matrices between the groups were assumed to be equal for the purposes of the MANOVA.

The multivariate result was significant for diagnostic group, Wilks $\lambda = .673$, $F = 8.008$, $df = (2, 33)$, $p = .0014$, $\eta_p^2 = .327$ indicating that the diagnostic groups can be differentiated along a linear combination of the dependent variables. Prior to conducting a series of follow-up univariate ANOVAs, the assumption of homogeneity of variance was confirmed using Levene's tests (all *p*s > .05). The univariate *F* tests identified a significant difference between groups for the speech condition, $F = 11.409$, $df = (1, 34)$, $p = .0018$, $\eta_p^2 = .251$ but not for the non-social condition, $F = 3.662$, $df = (1, 34)$, $p = .064$, $\eta_p^2 = .097$ (see descriptive statistics in Table 5). Interpretation of these follow-up analyses must be judicious, however, as post hoc ANOVA following MANOVA offers no protection for multiple analyses and inflated Type 1 error rates. Additionally, because the multivariate test indicates that the groups differ along a *combination* of dependent variables, a discriminant function analysis was conducted to better understand how the dependent variables interact to produce the main effect.

Table 5

Descriptive statistics of looking time to the synchronous quadrant in the Mixed1 condition.

	TD		**ASD**	
	Speech (SL)	**Non-social (NSNL)**	**Speech (SL)**	**Non-social (NSNL)**
M	.475	.451	.246	.373
SD	.227	.203	.323	.195

A discriminant analysis was used to test the hypothesis that the participants with TD and participants with ASD differed significantly on a combination of two variables, looking time to the synchronous screen during the Mixed1 trials for the speech and non-social conditions. As expected based on the results of the MANOVA, the function significantly differentiated the groups, Wilks λ= .673, Chi-square (2) = 13.056, Canonical correlation = .572 *p* = .0014. The structure matrix and discriminant function coefficients as well as the group centroids for the function are presented in Tables 6 and 7 respectively. According to the structure matrix, the speech variable was most strongly correlated with the function and the canonical correlation shows that the function is primarily represented by the speech variable. The group centroids suggest that group means, based on the function, are higher in the participants with TD compared to participants with ASD.

Table 6

Structure matrix and Standardized DF Coefficients that emerged from the discriminant function analysis in Mixed1.

	Structure Matrix	**Standardized Canonical Discriminant Function Coefficients**
Speech (SL)	.831	.886
Non-social (NSNL)	.471	.558

Table 7

Group centroids that emerged from the discriminant function analysis in Mixed1.

Diagnostic Group	**Function**
TD	.606
ASD	-.757

Reclassification of cases based on the new canonical variables was highly successful: 77.8% of the cases were correctly reclassified into their original categories. In summary, hypotheses 2a and b were fully supported. Overall, the two groups differed in looking time to the synchronous speech and non-social quadrants. Specifically, when both speech and non-social videos were presented simultaneously, participants with ASD showed weaker looking to the synchronous speech screen compared to the participants with TD, while looking time to the synchronous non-social screen did not differentiate the groups.

Analysis of looking time to the eye versus the mouth region of the face for trials in the Mixed2 condition, presented above, identified a clear preference for the eyes in both groups. In the Mixed1 condition, the auditory track is synchronous with only one video and therefore it is presumed that the mouth, and not the eye region of the face provides the most important information for integration of the auditory and visual information. It was hypothesized that participants would look more to the mouth region in these trials. To assess between-group differences in facial processing of the social stimuli, looking time to the eye and mouth regions (of the speech stimuli only) were compared. A Factorial Mixed ANOVA was conducted to compare the main effects of Diagnosis (TD, ASD) and Area of Interest (eyes, mouth) and the interaction effect. Results of Levene's Test indicated no violations to the assumption of homogeneity of variance (all *p*s > .05). The only effect that was statistically significant was the Area of Interest factor, $F(1,37) = 6.562$, $p < .05$, $\eta_p^2 = .151$ indicating significantly longer looking time to the mouth ($M = .161$, $SE = .019$) compared with the eyes ($M = .094$, $SE = .012$). The main effect of Diagnosis was not significant $F(1,37) = 1.125$, $p = .296$, $\eta_p^2 = .030$. The interaction was also not significant $F(1, 37) = .683$, $p = .414$, $\eta_p^2 = .018$. Both groups had longer looking time to the mouth compared with the eye region. This is opposite to what was found for the trials in the Mixed2 condition, where both groups showed shorter looking time to the mouth compared to the eyes region. Instead, in the Mixed1 condition, when the audio and visual signals were out of synchrony, both groups looked to the critical mouth region to try to resolve the asynchrony.

Part B: Methodology

Looking time. In this section, trials were presented using the four screen design of the preferential looking paradigm as was done in the mixed content trials; however, unlike the trials presented above, all four quadrants displayed the same type of stimuli with the auditory track synchronous with only one of the quadrants (Single1). Trials varied in content to isolate the social and linguistic properties of the stimuli. Areas of Interest included the most pertinent information for intersensory processing, for example, the mouth (speech, SL), the mouth (oral sounds, SNLO), the hands (clapping, SNLC), and the space where the nuts and bolts make contact with the table surface (non-social, NSNL) (see Analysis section for more detail).

Hypotheses 3a and b predicted that participants with TD would show a visual preference (longer looking time) for the identified AOI within the synchronous screen for all stimuli in the Single1 condition (SL, SNLO, SNLC, NSNL). Likewise, participants with ASD were hypothesized to show a visual preference for the identified AOI within the synchronous screen for all but the stimuli with social and linguistic content (that is, for the SNLO, SNLC, and NSNL but not SL). Looking time to the mouth AOI within the synchronous speech trial was expected to differentiate the TD and ASD groups. Prior to conducting the MANOVA, univariate normality was assessed using standardized skewness and kurtosis and the Shapiro-Wilks test of normality (Appendix M). Overall, results suggest that normality is a reasonable assumption. A meaningful pattern of low to moderate correlations was observed (.166-.710, see Appendices N and O) amongst the dependent variables, suggesting the appropriateness of a MANOVA (Meyers et al., 2006). Box's M test was used to evaluate the equality of covariance matrices. The result of the test (Box's M = 9.720, p = .576) was not significant, therefore the covariance matrices between the groups can be assumed to be equal for the purposes of the MANOVA.

A MANOVA was used to compare the participant groups for looking time to the Areas of Interest (AOIs) within the synchronous screen for the four stimulus types (see Table 8 for descriptive statistics). Results of the MANOVA identified a statistically significant difference in looking time to the stimuli based on the participant group, $F(4, 33) = 2.838$, $p = .040$; Wilks λ= .744, $\eta_p^2 = .256$.

Table 8

Descriptive statistics looking time to the AOI's within the synchronous quadrant in Single1.

	TD		**ASD**	
	M	*SD*	*M*	*SD*
Speech (SL)	.177	.085	.099	.091
Oral sounds (SNLO)	.317	.172	.188	.136
Clapping (SNLC)	.264	.182	.213	.182
Non-social (NSNL)	.365	.202	.243	.148

Prior to conducting a series of follow-up ANOVAs, the assumption of homogeneity of variance was considered satisfied (all ps > .05). The univariate F tests identified significant TD-ASD differences between looking time to the synchronous AOI for the speech, $F = 7.376$, $df = (1, 36)$, $p = .010$, $\eta_p^2 = .170$; the oral sounds, $F = 6.407$, $df = (1, 36)$, $p = .016$, $\eta_p^2 = .151$; and the non-social, $F = 4.372$, $df = (1, 36)$, $p = .044$, $\eta_p^2 = .108$ trials, but not for the clapping trials, $F = .754$, $df = (1, 36)$, $p = .391$, $\eta_p^2 = .021$. As described above, post hoc ANOVA does not account for the correlation between the dependent variables and can be susceptible to inflated Type 1 error rates. Therefore, discriminant function analysis was used as an alternative post hoc assessment. The discriminant analysis was used to test the hypothesis that the participants with TD and participants with ASD would differ significantly on a combination of four variables (SL, SNLO, SNLC, NSNL). As expected based on the results of the MANOVA, the function significantly differentiated the groups, Wilks λ= .744, Chi-square (4) = 10.052, Canonical correlation = .506 *p* = .040. The structure matrix and discriminant function coefficients as well as the group centroids for the function are presented in Tables 9 and 10 respectively. According to the canonical coefficients, the function is represented by a combination of the speech and oral sounds variables. The structure matrix shows that the speech and oral sounds variables are most strongly correlated with the function. Review of the group centroids suggests that this function tends to be highest in the participants with TD, with weaker scores in participants with ASD.

Table 9

Structure matrix and Standardized DF Coefficients that emerged from the discriminant function analysis of looking time in Single1.

	Structure Matrix	**Standardized Canonical Discriminant Function Coefficients**
Speech (SL)	.772	.506
Oral sounds (SNLO)	.719	.575
Clapping (SNLC)	.247	-.632
Non-social (NSNL)	.594	.592

Table 10

Group centroids that emerged from the discriminant function analysis of looking time in Single1.

Diagnostic Group	**Function**
TD	.542
ASD	-.602

Reclassification of cases based on the new canonical variables was highly successful: 78.9% of the cases were correctly reclassified into their original categories. Overall, the looking time to the AOIs reliably differentiated the groups. Looking time to the synchronous quadrants in the speech and oral sounds trials, particularly, were the most important variables in differentiating the groups, with longer looking time for the TD group and shorter looking time for the participants with ASD. Looking time to the synchronous non-social stimuli also significantly contributed to the linear model, although the contribution of this variable was not over and above the contribution of the speech and oral sounds variables. Therefore, hypotheses 3a and b were only partially supported: groups differed along the synchronous speech variable as expected and there was no difference identified on the synchronous clapping variable as expected. However, contrary to the hypotheses, the TD group also showed longer looking time to both the synchronous oral sounds and non-social variables compared to the group with ASD.

To assess between-group differences in facial processing of the social stimuli, looking time to the eye and mouth region (of the speech and oral sounds stimuli only) were compared. Factorial Mixed ANOVAs were conducted to compare the main effects of Diagnosis (TD, ASD) and Area of Interest (eyes, mouth) and the interaction effect on looking time separately to the synchronous speech and oral sounds stimuli. Results of Levene's Test indicated no violations to the assumption of homogeneity of variance (all *p*s > .05) for either analysis. For the speech variable, the main effect for Area of Interest was not significant, $F(1,37) = .033$, $p = .857$, $\eta_p^2 = .001$ while the main effect of Diagnosis $F(1,37) = 3.763$, $p = .060$, $\eta_p^2 = .092$ and the interaction both approached significance, $F(1, 37) = .3.674$, $p = .063$, $\eta_p^2 = .090$ (see Figure 3). Figure 3 illustrates no between group differences in looking time to the eye region but a longer looking time to the mouth region for the group with TD. For the oral sounds variable, the main effect for Area of Interest was significant, $F(1,36) = 48.909$, $p < .001$, $\eta_p^2 = .576$ whereas the main effect of Diagnosis was not significant $F(1, 36) = 3.493$, $p = .070$, $\eta_p^2 = .088$. The interaction was significant, $F(1,36) = 8.150$, $p = .007$, $\eta_p^2 = .185$ and, as the graph illustrates (see Figure 4), there is no overall between-group difference in the looking time to the eye region but significantly longer looking time to the mouth region for the group with TD.

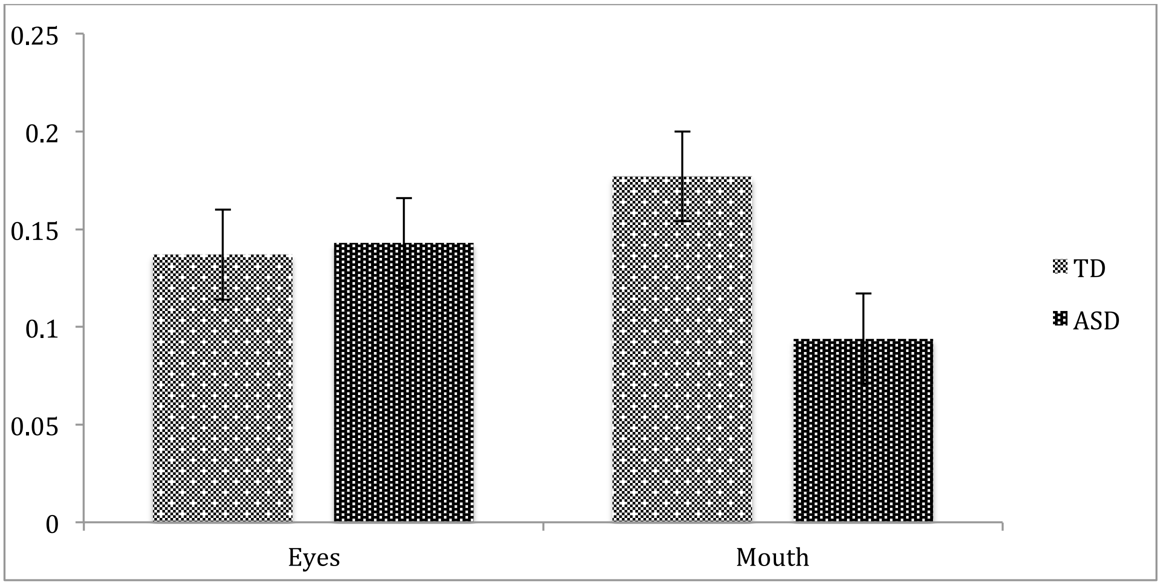

Figure 3. Single1, Eyes versus Mouth in SL. Looking time to the eye and mouth AOI of the synchronous quadrant for the TD and ASD groups in the speech (SL) variable.

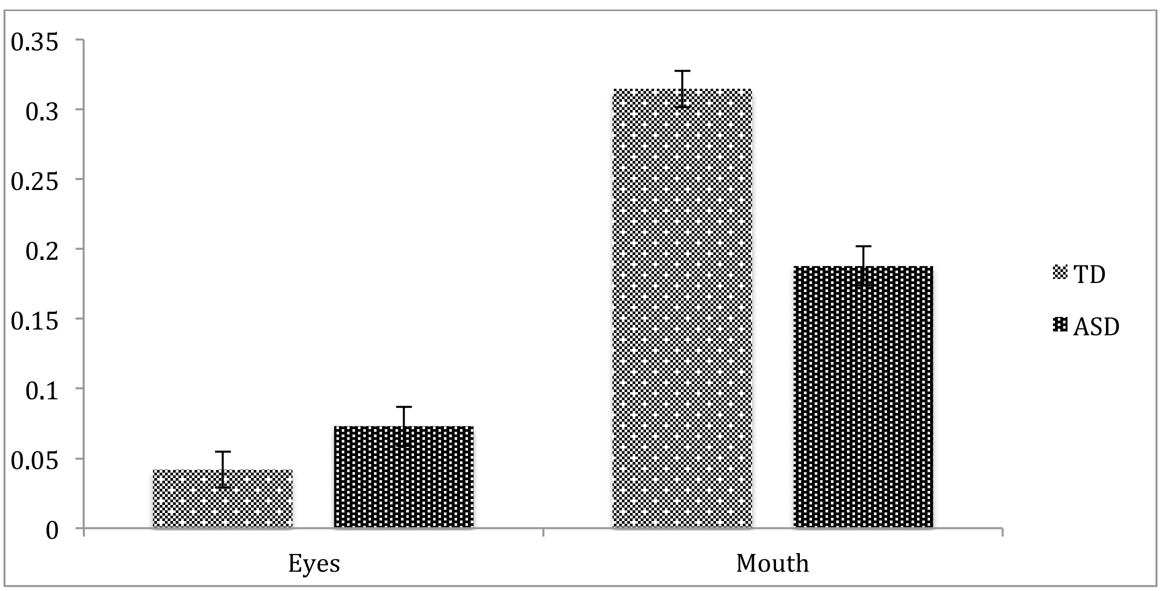

Figure 4. Single1, Eyes versus Mouth in SNLO. Looking time to the eye and mouth AOI of the synchronous quadrant for the TD and ASD groups in oral sounds (SNLO) variable.

Gaze patterns. It was hypothesized (4a) that participants with TD would utilize more efficient gaze patterns than those with ASD (as defined in the analysis section above) during the speech (SL) trials of the intersensory task. It was also hypothesized (4b) that efficiency of gaze patterns would not differ between groups on the other variables (SNLO, SNLC, NSNL). Before analyzing the proportion of efficient transitions, an assessment of the overall gaze patterns was done to determine if there were differences in the average number of times participants shifted gaze during trials across the four conditions. This was necessary to ensure comparable baseline of gaze shifts. To assess overall looking patterns, a series of independent samples t-tests was conducted to assess differences between the diagnostic groups (TD, ASD) in the average number of gaze shifts during trials on each of the stimulus types (SL, SNLO, SNLC, NSNL). None of the effects were significant (see Table 11, all *ps* > .05) suggesting an overall equivalent baseline of looking patterns across group and stimuli.

Table 11

Results of independent t-tests and descriptive statistics for Diagnosis (TD vs. ASD) by average number of gaze shifts within the SL, SNLO, SNLC and NSNL trials.

	TD $n = 20$		**ASD** $n = 19$					
	M	*SD*	*M*	*SD*	*df*	*t*	*p*	**95% CI for Mean Difference**
SL	19.033	5.709	20.487	3.592	37	-.946	.350	-4.568, 1.660
SNLO	17.275	4.952	19.947	6.471	37	-.366	.717	-4.399, 3.054
SNLC	20.000	5.814	19.439	4.835	37	.327	.746	-2.918, 4.041
NSNL	18.025	6.837	19.513	5.407	37	-.751	.457	-5.501, 2.525

Prior to conducting the MANOVA, univariate normality was assessed using standardized skewness and kurtosis and the Shapiro-Wilks test of normality (Appendix P). Overall, results suggest that normality is a reasonable assumption. A meaningful pattern of low to moderate correlations was observed (.053-.755, see Appendices Q and R) amongst the dependent variables, suggesting the appropriateness of a MANOVA (Meyers et al., 2006). Box's M test was used to evaluate the equality of covariance matrices. The result of the test (Box's M = 12.047, p = .387) was not significant, therefore the covariance matrices between the groups can be assumed to be equal for the purposes of the MANOVA.

A MANOVA was used to compare the proportion of efficient gaze patterns (gaze shifts between relevant AOIs) between groups for the four types of stimuli in the Single1 condition (see Table 12 for descriptive statistics). Results of the overall MANOVA identified no statistically significant difference between groups, $F(4, 34) = 1.005$, $p = .419$; Wilks $\lambda = .894$, $\eta_p^2 = .106$. Since there were specific a priori hypotheses, post hoc ANOVA was used to directly test hypotheses 4a and b. Prior to conducting the follow-up ANOVAs, the homogeneity assumption of variance assumption was considered satisfied (all ps > .05). The univariate F tests identified a borderline significant difference between groups in the proportion of efficient gaze patterns for the oral sounds variable, $F = 3.906$, $df = (1, 37)$, $p = .056$, $\eta_p^2 = .095$, 95% CI [-.003, .225] with a trend towards a significant effect for the speech variable, $F = 3.381$, $df = (1, 37)$, $p = .074$, $\eta_p^2 = .084$, 95% CI [-.008, .159]. No group differences were noted for the clapping, $F = .938$, $df = (1, 37)$, $p = .339$, $\eta_p^2 = .025$ or the non-social variables, $F = .679$ $df = (1, 37)$, $p = .415$, $\eta_p^2 = .018$.

Table 12

Descriptive statistics of proportion of efficient gaze patterns for participant groups across the different types of stimuli in the Single1 condition.

	TD		**ASD**	
	M	*SD*	*M*	*SD*
Speech (SL)	.419	.096	.343	.156
Oral sounds (SNLO)	.569	.124	.458	.217
Clapping (SNLC)	.448	.138	.394	.205
Non-social (NSNL)	.739	.189	.689	.188

To summarize, tentative support was demonstrated for hypothesis 4a. The effect for gaze patterns for the speech stimuli trended towards significance. The mean difference between groups is 95% likely to be greater than zero (for the Confidence Interval, -.008 is very close to 0), suggesting a strong likelihood of a true mean population difference between groups. As expected, no difference was observed for the efficiency of gaze shifts on the clapping and non-social stimuli. Contrary to hypothesis 4b, the proportion of efficient gaze shifts observed during the oral sounds trials was significantly different between groups and the mean difference between groups is 95% likely to be greater than zero (-.003 approaches 0), suggesting a true mean population difference between groups. Although this result contradicts the hypothesis, it is in line with results for hypothesis 3a presented above wherein looking time to the synchronous screen of the oral sounds variable was the most important variable in the linear model to differentiate the groups.

Discussion: Study One

Two methodologies (looking time and gaze patterns) were used to analyze eye-tracking data on intersensory perception for dynamic, multimodal stimuli varied in social content with a manipulation of temporal synchrony. The first condition (Mixed2) focused on trials in which speech (SL) and non-social (NSNL) stimuli shared the screen. In the first condition two screens presented identical speech videos and two presented identical non-social videos at the same time. Auditory tracks for both pairs of videos (SL and NSNL) were played in synchrony with the videos. In the second condition (Mixed1), the visual display looked similar to the first trials; however, the two speech videos were offset in time from one another by one second, and the two non-social videos were played offset in time from each other by one second. Only one of either the speech or non-social auditory tracks was played per trial. Therefore temporal synchrony was manipulated and only one of the videos was synchronous with the auditory track per trial. At this time, this is the only known study to concurrently present speech and non-social stimuli with a manipulation of temporal synchrony and, therefore, was the first study to directly compare this amodal property for speech and non-social information within the same trial (Mixed2). Differences in intersensory processing were observed between the ASD and TD groups for only the second condition (Mixed1). In Mixed1, the group with TD showed longer looking time to the synchronous screen when the screen synchronous to the auditory track contained a speech video. No group differences in processing the face region of the speech videos were observed. Both groups preferred to look to the eye region when the videos were presented with two matching sound tracks (Mixed2) and to the mouth region when temporal synchrony was manipulated such that the sound track matched only one quadrant of the screen and was asynchronous and/or inconsistent with the others (Mixed1).

Participants then viewed trials containing four video screens with only one stimulus type (Single1 condition: SL, SNLO, SNLC or NSNL). Videos were offset from one another so that the auditory track was temporally synchronous with only one video screen. Between group differences in looking time to the synchronous screens were identified for all stimuli except for clapping. Compared to the group with ASD, the group with TD showed enhanced looking to the speech, oral sounds, and non-social stimuli. However, discriminant function analysis confirmed that the groups were most reliably differentiated by differences in processing of the intersensory information that was provided by the mouth (i.e. speech and oral sounds). On these (speech and oral sounds) trials, participant groups did not differ in looking time to the eyes, but the group with ASD showed shorter looking time to the mouth region compared to the group with TD. The same data (Single1 condition) were then analyzed according to the efficiency of gaze patterns.

Results generally corroborated the looking time data; compared to the group with ASD, the group with TD showed marginally higher proportions of efficient gaze patterns for both speech and oral sounds trials although no difference was observed for the non-social trials. Intersensory processing (looking time and proportion of efficient gaze patterns) for the clapping trials did not differ between groups.

Intersensory redundancy in typical development

Results generally support the hypothesis that temporal synchrony, the most global amodal property, impacts intersensory processing for audio-visual information. Intersensory redundancy occurs when information from different senses occurs together and in synchrony (Bahrick & Lickliter, 2000) and this phenomenon causes amodal information to stand out with respect to other types of stimulation. Stimuli with redundant properties recruit processing resources such that stimuli are brought to the "foreground" while other properties become "background." Intersensory redundancy promotes perceptual processing in typical development of humans (Bahrick & Lickliter, 2000, 2002; Bahrick et al., 2004) and non-humans (Lickliter, Bahrick, & Honeycutt, 2002; Lickliter, Bahrick, & Honeycutt, 2004). The first prediction of the Intersensory Redundency Hypothesis (Intersensory facilitation) is consistent with results from the group with TD in the current study. Intersensory facilitation occurs when the response to a stimulus from one sensory modality is enhanced by the concurrent stimulation of another modality. This can manifest as 1) faster reaction time, 2) lower threshold of detection, or 3) increase in the rate of recognition, identification, or classification. The non-social stimuli captured attention when the amodal properties of both stimuli were presented, i.e. speech and non-social stimuli were both presented with corresponding, synchronous auditory tracks (Mixed2). In contrast, only the participants with TD showed a preference for the stimuli with amodal (synchronous auditory and visual) properties when these properties were manipulated (Mixed1). In the Mixed1 condition, temporal synchrony was the only element that was manipulated and can be assumed to account for the differences in looking time (evidence of intersensory facilitation) observed for the group with typical development.

Intersensory redundancy for social information in ASD

For the group with ASD, the preference for the non-social stimuli in the mixed content trials is consistent with previous studies (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Hobson, Ouston, & Lee, 1988) and highlights the strong pattern of atypical visual fixation to non-social objects. The majority of previous studies presenting unimodal, static images of social stimuli have consistently identified reduced looking time to the eye region and enhanced looking time to background objects for the ASD group compared to controls (Dalton et al., 2005; Jones, Carr, & Klin, 2008; Klin & Jones, 2008; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002; Rice et al., 2012; Spezio et al., 2007a; Spezio et al., 2007b) with some variable results to fixations in other face regions (Dalton et al., 2005). Differences in viewing social stimuli are even more pronounced in studies using dynamic, social stimuli that are more ecologically valid than static photographs and include multiple social and non-social distractions to approximate a real life situation (Boraston & Blakemore, 2007). In sharp contrast, the current study identified longer looking time to the eyes compared to the mouth of the speech stimuli for both groups when both speech and non-social videos were presented in synchrony with the corresponding auditory track. When temporal synchrony was manipulated, both groups responded to the manipulation and showed longer looking time to the mouth compared to the eyes of the speech stimuli.

The most important difference between the current project and previous research is that, in the current study, neither the speech nor the non-social stimuli were presented as foreground versus background. For example, in a video of two people having a conversation, the people are considered foreground while the rest of the room is considered background. In that example, the intention is to draw attention to the conversation presented in the foreground. This can lead to a biased comparison of visual fixation to the social and non-social information. In the current study, the speech and non-social stimuli were designed to be equally stimulating. This allowed for a true comparison of visual fixation for the social and non-social information between groups.

One explanation for the differences in visual processing observed in this study is that amodal properties of stimuli impact attention for the group with TD as expected, but not for the group with ASD. No group differences were observed when stimuli were presented in synchrony (Mixed2) whereas looking time was impacted by manipulation to the amodal property, temporal synchrony (Mixed1), for the group with TD only. Therefore, it appears that some important properties of intersensory perception remain intact for individuals with ASD. The identified impairment in the integration of auditory and visual information is not attributable to a broad deficit in intersensory processing, but is instead impacted by amodal properties of auditory and visual information.

It is possible that the group with ASD is not benefitting from the intersensory facilitation of the amodal properties as predicted by the IRH. Further, the strongest difference was observed for the social stimuli, suggesting that intersensory facilitation specific to social stimuli may be impaired in individuals with ASD. Results are consistent with research indicating impaired intersensory processing of audiovisual speech (Magnée, de Gelder, Van Engeland, & Kemner, 2008; Bebko et al., 2006) in participants with ASD. To summarize, the difference in audiovisual processing more likely reflects impairment in the super-additive process of multisensory integration for individuals with ASD. Accordingly, the group with ASD is not advantaged by the amodal property (auditory visual temporal synchrony) of the speech stimuli. This hypothesis does not explain why this process appears to be specifically impaired for speech stimuli and it is not possible to discern the exact nature of the breakdown in processing from analysis of the results for the Mixed2 or Mixed1 conditions. It is worthwhile to explore some of the variables that differentiate speech and non-social stimuli to better understand possible factors underlying the mechanism of this impairment and the second part of the present study addresses this question.

In Part B of Study One, stimuli varied by social, linguistic, and body movement content with the goal of isolating the extent to which these properties impact intersensory processing for the TD and ASD participant groups (Single1). Overall, regardless of the linguistic content, groups were most reliably differentiated when the mouth region provided the primary intersensory information.

Intersensory processing in ASD: Language

Sensitivity to intersensory redundancy supports the development of speech and language. Infants are drawn to the face and voice of a speaker and this allows perception of a coordinated, temporally synchronous multimodal event – speech. Results from Study One support research showing enhanced processing of temporally synchronous, multimodal stimuli for children with typical development. In all analyses, the typically developing group displayed longer looking time and more efficient gaze patterns to the synchronous, audio-visual stimuli compared to the asynchronous stimuli. In comparison, the group with ASD showed mixed results based on the content of the stimuli. The group with ASD showed shorter looking time and less efficient gaze patterns to the synchronous, audio-visual stimuli that were social, with linguistic content (speech) and to stimuli that were social, with non-speech content (oral sounds).

When looking at results of the looking time to the mouth region (a point of rich intersensory information), stimuli that were social with non-speech content (oral sounds) actually provided the strongest point of differentiation between the TD and ASD groups. These results are consistent with the notion of an intersensory processing deficit for social information for individuals with ASD. Consistent with Smith and Bennetto (2007) this difference does not appear to result from impaired linguistic strategies. If this were the case, differences between groups would be expected to be greater for the stimuli with speech content. Conversely, some research has identified a relationship between linguistic ability and intersensory processing. Bebko et al. (2006) noted a negative relationship between time looking away from complex social-linguistic stimuli (woman telling a story) and linguistic abilities in children with ASD. The same relationship was not observed for simple social-linguistic stimuli. Overall, the results of the current study suggest that the linguistic content of the stimuli does not differentially impair intersensory processing in participants with ASD; however, the role of language processing, including important variables such as stimulus complexity should be further evaluated.

Intersensory processing in ASD: Human body movement

Results from the current study also do not support a deficit for intersensory processing of audio-visual information produced by the human body (hands clapping) in participants with ASD. Across trials, neither differences between looking time nor efficiency of gaze patterns for temporally synchronous information were observed between the ASD and comparison group. The mere inclusion of the dynamic human face and body in the stimuli did not impede the intersensory task. Rather, intersensory processing was impeded only when the face provided the redundant amodal information; specifically, when the audio-visual information originated from the mouth. These results are somewhat equivocal with previous research. There is evidence of disturbed unimodal visual (Blake, Turner, Smoski, Pozgol, & Stone, 2003) and multimodal audio-visual (Klin et al., 2009) processing of body movement in children with ASD. In the study by Klin et al. (2009), 2-year-old children with ASD preferred the temporally synchronous, non-social point-light displays to the point-light displays of biological motion. Importantly, the results of the current study are not in contrast to the results of Klin et al. (2009). Both studies show intact processing of non-social, temporally synchronous audio-visual stimuli. Klin et al. suggest that audio-visual synchrony for non-social stimuli attracted more processing resources than the stimuli with biological motion for children with ASD, an idea not tested in the current study. Results of this study suggest that intersensory impairments for social stimuli are not better accounted for by impairments in orientation to biological movement.

Intersensory processing in ASD: Human face

Results from Study One demonstrated clear differences in looking time and efficiency of gaze patterns for multimodal synchronous stimuli with social and linguistic content (conditions with speech and oral sounds) for the group with ASD versus the comparison group. Participants in the ASD group failed to show enhanced looking time to the temporally synchronous, audio-visual, social and linguistic information. One of the most intuitive hypotheses is that the deficit in processing intersensory information is better understood as a face-processing deficit. Atypical face processing for individuals with Autism Spectrum Disorders has been well documented (see Dawson, Webb, & McPartland, 2005 for a review). Impairment in memory for faces has included face recognition (e.g., Boucher & Lewis, 1992; Boucher, Lewis & Collins, 1998; Klin et al., 1999) and face discrimination (e.g., Tantam, Monoghan, Nicholson, & Stirling, 1989) in groups of participants with ASD. This does not appear to represent memory impairment per se as the deficit appears specific to facial stimuli (Blair, Frith, Smith, Abell, & Cipolotti, 2002; Boucher & Lewis, 1992). Children with ASD performed comparably well in a memory task for face and nonface stimuli whereas the children in the TD group had enhanced memory for the faces (Serra et al., 2003).

The majority of the published studies on facial processing assess unimodal visual face perception for either static or dynamic stimuli. Consistent with the Intersensory Redundancy Hypothesis, unimodal processing is enhanced in unimodal conditions (Bahrick, 2010). Accordingly, unimodal processing observed in most experimental research likely presents an enhanced and ecologically *in*valid representation of the salience of faces compared to what would be observed in a real world, multimodal environment where individuals speak in synchrony with facial movements. Overall, within the literature, differences in face processing between ASD and comparison groups may represent an inflated illustration of real-world impairments and may not be comparable to results of the current study. For example, compared to the group with TD, participants with ASD in the present study showed no differences in looking time to the eye region of the face for any of the dynamic multimodal stimuli. In fact, when speech and non-social stimuli were presented together with both auditory tracks playing in synchrony with the videos, both groups preferred the eye region compared to the mouth region. These results contradict the majority of studies that found decreased looking to the eye region for participants with ASD. In the current study, fixations to the face region were impacted only when the stimuli were presented with the visual and auditory properties out of sync. Notably, this shows that the general face processing deficit described in the literature is likely a much more complex phenomenon than previously assumed. The discrepancy in results across studies is likely due to differences in the type of stimuli (dynamic versus static, unimodal versus multimodal) or the task used in studies and, further, perhaps the magnitude of the identified face processing deficit is better understood as an experimental artifact.

Animal models may also offer an innovative approach to understanding face processing in humans, including the coordination of facial cues with speech processing. Rhesus monkeys focus predominantly on the eye region of the face as opposed to the mouth when viewing vocalizations while fixations to the mouth are closely correlated to the onset of mouth movements (Ghazanfar, Nielsen, & Logothetis, 2006). Future studies would benefit from an analysis of the coordination of the timing of visual fixations with the onset of mouth movements to better understand multimodal, dynamic processing of the face during speech.

The current study presented a complex task that required visual search of the mouth region to resolve an intersensory challenge. Participants with TD modified their visual fixations to the face region (increased looking time to the mouth) in accordance with this task whereas the search strategies for the ASD group were inconsistent. Overall, it appears that group differences in facial processing alone do not account for the differences in intersensory processing of dynamic speech stimuli. This is not to say that a deficit in face processing does not exist and/or that the two processes are unrelated. Rather, that for children with ASD, there may be multiple downstream consequences to an early impairment in intersensory facilitation for social events; namely, difficulties with both facial processing and intersensory processing.

Stimuli with redundant properties draw attention and enhance processing. In the current study (Single1), the stimuli were manipulated so that only the video synchronous with the auditory track retained a redundant property, namely, temporal synchrony. According to the IRH, this manipulation should enhance the processing for this video at the expense of videos that are offset in time, and result in increased looking time to the matched video. This phenomenon was observed for both groups for the non-social and clapping videos. This underscores the notion that participants with ASD do not experience a global deficit in intersensory processing. However, for the speech and oral sounds stimuli, this phenomenon was observed only for the group with TD. The group with ASD did not show this enhanced processing to the speech or oral sounds conditions. Therefore, differences in looking time to the face regions in the current task are best understood as a specific deficit in intersensory processing for social stimuli with amodal properties.

Benefits of a multi-method approach to the analysis of eye-tracking data

Eye-tracking studies have become an increasingly popular method to examine looking patterns of participants with ASD. Typically, hypotheses are evaluated by quantifying the looking time within predefined regions (AOIs). This approach has been widely used in eye-tracking research because it enables a reliable and stable estimate of an observer's fixation points within AOIs (Yi et al., 2014). One limitation of this approach is that it treats all fixations within the identified region homogenously and fails to identify any differences with respect to fixation patterns within and between these areas (Yi et al., 2014). This limitation was addressed in the current study by including a complementary approach to the data analysis, an examination of looking patterns between and within the identified AOIs.

Compared to the group with TD, participants with ASD used marginally less efficient gaze patterns in conditions where the mouth provided the audio-visual information (speech and oral sounds). Participants with ASD made proportionally more gaze shifts to areas of the stimuli that did not provide critical information about temporal synchrony (e.g. off the screen, other face regions). Some other recent studies have also identified differences in visual search strategies between groups with ASD and control groups (Mercadante, Macedo, Baptista, Paula, & Schwartzman, 2006; Guillon et al., 2015; Liu, Li, & Yi, 2016; Yi et al., 2014). Guillon et al. (2015) used fixation duration analysis and analyzed saccades made between AOIs to reveal that the left eye might anchor visual scanning strategies for children with TD, but not for children with ASD. This use of multi-method analysis of eye-tracking data demonstrates how this approach can provide information that is both complementary and clarifying.

Examples of differences in results based on methodology have been observed in other studies of sensory processing as well. For example, Yi at al. (2014) failed to find differences in mean fixation duration to the face for ASD and comparison groups whereas they identified differences in face-scanning patterns between core facial features (e.g. eyes and nose). Differences in results are also noted between behavioural data and visual event-related potentials (ERP) (Key & Stone, 2012). In this study, nine-month-old infants at either average or high risk for autism spectrum disorder viewed static images of faces. Results of the eye-tracking data revealed no group differences in the number, duration, or distributions of fixations with equal looking to the mouth and eyes. The ERP data for the same task revealed that although all infants detected eye and mouth changes in the stimuli, they did so using different brain regions.

Multi-method analysis is especially important when the results using looking time only are somewhat equivocal. For example, in the current study, analysis of looking time identified group differences in looking to the speech, oral sounds, and the non-social conditions. Post hoc analysis of looking time showed that the non-social variable did not differentiate groups over and above the contribution of the speech and oral sounds variables. Unfortunately, no further interpretation was possible using only the results of the analysis of looking time. In this case, interpretation of results using both methodologies (looking time and efficiency of gaze patterns) is advantageous. Overall, it appeared that although the group with ASD spent less time looking to the synchronous non-social condition, they utilized an equally efficient proportion of gaze patterns to search the stimuli. In summary, the use of multi-method analysis can clarify and consolidate the interpretation of data in many cases. In the current study, analysis of participant gaze patterns narrowed the interpretation of a deficit in intersensory perception for children with ASD for social stimuli with and without speech; namely, when the coordination of voice and lips provided the amodal information.

The methodology of using scan paths to identify differences in processing stimuli between groups of participants with ASD and controls is relatively new and has thus far focused on identifying differences in scanning of static images, as noted above. No studies (to the knowledge of the author at the present time) have analyzed scan paths (compared to overall looking time) while viewing dynamic, multimodal stimuli in participants with ASD. The current study presents the first use of a multi-method approach to the analysis of eye-tracking data in a study with social and non-social, dynamic multimodal stimuli with a manipulation of temporal synchrony.

Conclusions of Study One

This study provides evidence of a difference in intersensory processing specifically for social stimuli in school-age children with ASD. This deficit does not appear to be solely attributable to a deficit in processing language or body movement nor is it attributable to a deficit in face processing. Rather, the sensory processing deficit appears specific to the integration of audio-visual stimuli with the significant amodal property, temporal synchrony, during social processing. The implications of this deficit will be explored in Study Two, including the relationship between intersensory processing, social orienting and ASD symptoms.

Study Two: Variables Associated with Intersensory Processing in Children with and without ASD

Introduction

Social Orienting

For typically developing infants, social events (faces, voices) provide essential information for guiding perceptual, cognitive, social, and linguistic development. These events are highly prevalent in early life; they are salient to infants and easily capture attention. Infants show a visual preference and recognition for faces and they recognize upright faces better than inverted faces at age four months (Goren, Sarty, & Wu, 1975; Walton & Bower, 1993; Fagan, 1972). Newborns are particularly attuned to stimulation and interactions with the mother that start in utero. Newborns can discriminate their mother's face (Bushnell, 2001), her voice (DeCasper & Fifer, 1980), and the prosody of speech (DeCasper & Spence, 1986). Social events and reciprocal social interactions in particular provide essential, ongoing, amodal stimulation. Social exchanges between mother and infant are characterized by frequent amodal temporal and intensity shifts with infants across auditory, visual and tactile stimulation. These frequent exchanges help the infant to organize and filter information in a chaotic world. How is this done? In line with the Intersensory Redundancy Hypothesis, these ongoing presentations of redundant multimodal information help infants to attend and focus on relevant information. This attunement provides the basis for what is generally referred to as "social orienting." In early development, social orienting attracts and maintains selective attention to faces, voices, and audiovisual speech and supports further perceptual processing of social events. Therefore, in multimodal dynamic social situations, infants are able to allocate their limited attentional resources to meaningful properties of social events (Bahrick, 2010).

Social Orienting and Attention Disengagement in Autism Spectrum Disorder

Children and adults with Autism Spectrum Disorder experience atypicalities in early-developing attentional control mechanisms. Orienting, a component of attentional control, involves the ability to disengage from an existing point of focus, make a saccade to a new stimulus, and engage with that stimulus (Johnson, Posner, & Rothbart, 1991). Some of the identified attention difficulties in young children with ASD include orienting to social and non-social stimuli (Baranek et al., 2013; Dawson et al., 2004; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Osterling & Dawson, 1994) and disengaging attention from salient stimuli (Landry & Bryson, 2004). Further, attention disengagement deficits are amongst the earliest markers in at-risk siblings of children with ASD (Bryson et al., 2007; Elsabbagh et al., 2009, 2013) and are predictive of a later diagnosis (Zwaigenbaum et al., 2005). Nonetheless, some discrepancy continues to exist within the literature concerning the nature of the impairment in attention in children with ASD. For example, a recent study (Fischer et al., 2014) found no differences in speed of disengagement for participants with ASD and controls. McMorris (2015) suggested that impaired attention disengagement in children with ASD is dependent on the child's engagement in the task and properties of the stimuli including type (social, non-social), modality (unimodal, multimodal), motion (dynamic, static) and synchrony between auditory and visual information (temporally synchronous, temporally asynchronous). Overall, despite the behavioural evidence that some important attentional processes are impaired in children with ASD, little is known about the cause, mechanism, or downstream effects of this impairment, or how this impairment is related to the core behavioural symptoms associated with ASD.

Attention Disengagement and Sensory Processing in Autism Spectrum Disorder

Impaired intersensory processing is hypothesized to underlie some of the core attention impairments in children with ASD (Bahrick & Todd, 2012) although some have suggested that poor attention disengagement may impact sensory systems (Sabatos-DeVito, Schipul, Bullock, Belger, & Baranek, 2016; Sanz-Cervera et al., 2015) or that intersensory processing is modulated by attention mechanisms (Magnée, de Gelder, van Engeland, & Kemner, 2011). While the causal pathways of the relationship between attention disengagement and sensory processing are equivocal, these processes appear to be significantly intertwined in early development and likely impact domains of impairment associated with ASD.

Atypical sensory responses have also been associated with impaired attention in children with ASD. Sensory hyporesponsiveness to both social and non-social stimuli was found to be a significant predictor of poor joint attention using a behavioural orienting task (Baranek et al., 2013) and sensory hyperresponsiveness co-occurred with overfocused attention in a sample of participants with ASD (Liss, Saulnier, Fein, & Kinsbourne, 2006). Using a gap-overlap task, Sabatos-DeVito et al., (2016) found that the ASD group showed impaired ability to disengage (decreased accuracy) from the central fixation relative to the comparison groups. The effect of impaired disengagement was strongest for dynamic and dynamic multimodal stimuli although performance was also impacted by age and developmental variables. Children who were older and with higher IQ performed better in the disengagement task. Importantly, participants with ASD showed a significant effect of sensory response patterns with attentional disengagement and orienting abilities. Generally, higher sensory seeking behaviors and more hyporesponsiveness were associated with poorer attentional disengagement, whereas higher levels of hyperresponsiveness facilitated attentional disengagement. Overall, evidence from a combination of questionnaire and laboratory-based behavioral data suggest a relationship between atypical sensory processing and impairments in attention disengagement in children and adults with ASD.

Interdisciplinary Evidence for Impaired Attention Disengagement in ASD

Interdisciplinary evidence also supports the hypothesized linkage between disrupted sensory processing and attention impairments in ASD. For example, neural responses to auditory stimuli were found to be associated with sensory seeking behaviour in participants with ASD through complex interactions of sensory and attentional processing indices (Donkers et al., 2015). Atypical neural response have also been identified in neurophysiological studies with complex task demands and are thought to indicate a potential deficit in selective inhibition and attention (Townsend et al., 2001; Ciesielski, Knight, Prince, Harris, & Handmaker, 1995), especially when stimuli reach the capacity of already overloaded attention and/or working memory based systems.

Multisensory integration and attention interact atypically in high-functioning adults with ASD (Magnée et al., 2011). Magnée et al. looked at event-related potentials (ERPs) following a presentation of emotionally congruent and incongruent face-voice stimuli. Findings from the study showed multisensory processing for emotional signals was shown to be intact in some conditions and disturbed only when attention was divided between the visual and auditory components of the stimulus. This suggests that sensory processing is impacted by the ability to divide attention over information from different modalities (auditory and visual).

Further, the Superior Temporal Sulcus (STS) is the primary brain region implicated in processing, modulating, and integrating multimodal sensory information. The STS has also been implicated in the control of visual attention (Corbetta & Shulman, 2002) highlighting a potential mechanism for the relationship between sensory processing and attention. Marco et al. (2011)

suggest that there is an important disruption in the flow of multidirectional information in individuals with ASD and that this disruption in cortical communication underlies the difficulties in attending and flexibly responding to the environment. Schauder and Bennetto (2016) propose that different attention mechanisms may impact different sensory systems. For example, attention engagement may impact auditory change detection and attention switching may regulate visual change detection. Overall authors suggest that disruption in attention networks can result in a lack of flexible top-down regulation of sensory processing.

Cascading Effects of Impairments to the Attention and Perceptual System

In general, early deficits in intersensory processing and attention are considered primary deficits in ASD and have cascading effects on the development of subsequent skills, including arousal regulation, joint attention, and other social-cognitive skills (Bahrick & Todd, 2012; Keehn, Müller, & Townsend 2013). Using eye-tracking technology in a lab-based paradigm, a study by Rice, Moriuchi, Jones, and Klin (2012) identified a difference in the orientation to multimodal social stimuli between ASD and TD groups. They also examined a relationship between the variability in fixation for social stimuli and standardized parent-report measures of social disability. As predicted, there was a robust association between fixation on features of the inanimate environment and social disability. Thus far, studies of the association between parent-report ASD symptoms, developmental level, attention, and sensory processing have been limited by an over-reliance on parent-report questionnaire data as a measure of sensory processing and/or attention.

Present Study

The present study investigated the relationship between intersensory processing, attention disengagement, and developmental impairments associated with Autism Spectrum Disorder.

Results of Study One study identified atypical intersensory processing specific to social stimuli in children with ASD. There were two parts of Study Two. In Part A: Participant Variables, the goal was to quantify the relationship between intersensory processing and 1) age and cognitive ability, 2) social-communication disability, 3) repetitive behaviors, and sensory auditory filtering, and 4) executive functioning using data from diagnostic assessment and parent report questionnaires. In Part B: Attention Disengagement, the goal was to quantify the relationship between atypical intersensory processing and attention disengagement using data collected from lab-based eye tracking tasks. The overall goal of Study Two was to expand on the results of Study One to provide a better understanding of the intersensory processing deficit of social stimuli in individuals with ASD and cascading impairments in attention and autism symptomatology across development.

Hypotheses

Part A: Participant variables.

1. For both the ASD and TD groups, exploratory analyses of the relationship between intersensory processing and chronological age and cognitive ability were done.
2. For the ASD group, social-communication disability was expected to be negatively associated with performance on the intersensory task: as social-communication disability increases, performance on the intersensory task (looking time to the synchronous stimuli, proportion of efficient gaze patterns) would decrease. For the TD group, no relationship was predicted because variability on the social-communication variable was expected to be too low to assess a linear relationship.
3. For the ASD group, exploratory analysis of the relationship between intersensory processing and repetitive behaviors and auditory filtering was done. For the TD group, no

relationship was predicted because variability on the repetitive behaviors variable and auditory filtering variable were expected to be too low to assess a linear relationship.

4. For the ASD group, executive functioning was expected to be negatively associated with performance on the intersensory task: as executive functioning deficits increase, performance on the intersensory task (looking time to the synchronous stimuli, proportion of efficient gaze patterns) would decrease. For the TD group, no relationship was predicted because variability on the executive functioning variable was expected to be too low to assess a linear relationship.

Part B: Attention disengagement.

1. For the ASD group, the time from fixation on the stimulus to fixation on the peripheral stimulus (disengagement) in the attention task was expected to be negatively associated with performance on the intersensory task: as time to fixation increases, performance on the intersensory task (looking time to the synchronous stimuli, proportion of efficient gaze patterns) would decrease.

Methods

Participants

Participants were the same matched groups of children from Study One except for one participant from the group with ASD who was excluded from analyses using the attention task due to a recent change in medication that could impact performance on the attention task. Refer to Study One for information regarding participant inclusion and exclusion criteria. Due to the exclusion of one participant, independent samples t-tests were recalculated to test for group differences in age and cognitive ability. Results revealed no significant differences between groups for chronological age (CA), general cognitive ability (GCA), verbal ability (VA), and non-verbal ability (NVA) (all *p*s > .225). Participant groups were well-matched based on chronological age and cognitive ability. See Table 13 for a summary of participant demographic information.

Table 13

Sample demographic information.

	TD (*n* = 20)		ASD (*n* = 18)			
	M (*SD*)	*Range*	*M* (*SD*)	*Range*	*t* *df*	*p*
Chronological Age (in months)	125.10 (34.45)	75-184	134.78 (29.19)	78-183	-.929 36	.359
DAS GCA Standard Score	103.25 (10.35)	81-121	96.59 (21.36)	58-145	1.236 36	.225
DAS VA Standard Score	101.85 (10.34)	86-126	96.18 (22.15)	34-133	1.023 36	.313
DAS NVA Standard Score	102.60 (10.39)	76-120	100.5 (19.10)	64-128	.851 37	.672

Typically Developing (TD); Autism Spectrum Disorder (ASD); Differential Ability Scale, 2nd Edition (DAS-II); general cognitive ability (GCA); verbal ability (VA); and nonverbal ability (NVA).

Measures

Child Measures. The Child Measures in the current study are identical to the Child Measures described in Study One.

Parent-Report Measures.

Social Communication Questionnaire, Lifetime Form (SC; Rutter, Bailey, & Lord, 2003). The SCQ is a 40-item, parent-report questionnaire used to evaluate communication skills and social functioning in children who may have ASD. The questionnaire is completed in less than ten minutes and can be used to evaluate anyone over the age of four years, with a mental age of at least two years. The Lifetime form focuses on the child's entire developmental history and provides a total score that can be interpreted in relation to specific cutoff points or used to compare symptom levels. Using a threshold score of 15 results in a sensitivity value of .96 and a specificity value of .80 in a large population of children with autism and other developmental disabilities (Chandler et al., 2007).

Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000). The BRIEF is a parent-report questionnaire, completed in 10-15 minutes, used to assess impairment of executive function in children 5 to 18 years. The questionnaire provides information on eight clinical scales (Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, Monitor), which form two broader indexes (Behavioral Regulation and Metacognition) as well as an overall score (Global Executive Composite). Authors report high internal consistency (alphas = .80-.98) and test-retest reliability for parents (r=.82) (Gioia, Isquith, Guy, & Kenworthy, 2000).

Short Sensory Profile- Auditory Filtering subscale (SSP; McIntosh, Miller, & Shyu, 1999). The SSP is a 38-item caregiver report measure comprising the items that demonstrated the highest discriminative power of atypical sensory processing among all the items from the long version, the Sensory Profile (SP; Dunn, 1999). Caregivers rate the frequency with which the child responds to various sensory experiences in everyday situations along a 5-point likert scale with a lower score indicating more impairment. Seven subscales are identified: tactile sensitivity, taste/smell sensitivity, movement sensitivity, visual/auditory sensitivity, underresponsive/seeks sensation, auditory filtering, and low energy/weak. Administration of the SSP takes approximately 10 minutes and is recommended for research protocols. The SSP is one of the most frequently used methods for studying atypical sensory responsivity in ASD (Rogers, Hepburn & Wehner, 2003) and this is likely because items overlapping with the diagnostic features of ASD (social-communication and motor items) were removed in the early phase of development. The SSP total score has an internal consistency of α = .95 and has been shown to discriminate children with ASD from typically developing children (Tomchek & Dunn, 2007). For the current study, the auditory filtering subscale of the SSP was used for comparison. Auditory filtering is the ability to filter out salient sound from background noise, such as when "tuning in" to a conversation in a noisy social environment (i.e. the cocktail party phenomenon, Cherry, 1953). Auditory filtering impairments have been identified in individuals with ASD using the SSP (Rogers et al., 2003) and impairments may be specifically related to deficits in intersensory processing of audio-visual information (Alcantara, Weisblatt, Moore, & Boltone, 2004; Groen et al., 2009).

Repetitive Behavior Scale-Revised (RBS-R; Bodfish, Symons, Parker, & Lewis, 2000). The RBS-R is a 43-item parent-report measure to assess repetitive and restrictive behaviors in children. Items are rated for the presence and severity of specific behaviors over the last months along a 4-point Likert scale. Authors report high internal consistency (.78-.91) and good inter-rater reliability (67%) across the six subscales: stereotyped behaviour, self-injurious behaviour, compulsive behaviour, ritualistic behaviour, sameness behaviour, and restricted behaviour. The RBS-R has been found to be reliable for use with children with ASD (Bishop et al., 2013; Mirenda et al., 2010; Schertz, Odom, Baggett, & Sideris, 2016).

Stimuli

Intersensory task. The stimuli in the current study are identical to the stimuli used in the Single1 condition described in Study One.

Attention task. The stimuli in the attention task were presented using a similar design to the four screen preferential looking paradigm (PLP-4) used in Study One, and all trials lasted for

12 seconds. Unlike the stimuli in Study One, only one video was presented in one of the four quadrants of the screen at a time and changed quadrants during the trial (See below). The matching auditory track was always played but it was synchronous with the video in half the trials and offset in the other half (auditory information was delayed by three seconds). Stimuli contained either speech (SL -woman telling a story) or non-social (NSNL - mousetrap, nuts and bolts, piano) dynamic, multimodal content and videos were identical to the speech and non-social videos used in the intersensory task in Study One. No trials in the attention task presented oral sounds (SNLO) or clapping (SNLC) videos. A total of eight trials were presented (2 audio-visual synchronous speech, 2 audio-visual asynchronous speech, 2 audio-visual synchronous non-social, 2 audio-visual asynchronous non-social). As in Study One, videos were filmed using a Sony handheld camera, edited using Final Cut Pro, and converted to AVI format as required for presentation in Tobii Studio.

Attention task design. Each trial began with a cartoon picture or video (central fixation) presented in the middle of the screen, which remained for three seconds. Following the presentation of the central fixation, the participants were presented with a video in one quadrant of the screen for three seconds. After three seconds, a second video appeared in another quadrant. The first video remained and then disappeared 500ms after the onset of the second video, thus requiring attention to be disengaged from the previous video to shift to the new one. This sequence was repeated four times. The order of the quadrants in which the video was presented was randomized. Within each trial, the participants were presented with the same type of stimulus (e.g. speech); however, the second stimulus was always discontinuous from the first. For example, if the participants were first presented with a speech stimulus (woman telling a story), the second stimulus included the same story and actor; however, it would be at a different part of the story. The order in which the trials were presented was randomized and the total presentation lasted approximately three minutes.

The attention disengagement stimuli were selected from a larger set of stimuli in a project that compared attention processing in children with ASD to children with TD (McMorris, 2015). The larger attention project was presented alongside the intersensory task described in Study One. Altogether, including the trials described above, the remaining trials from the larger attention task, and the trials from the intersensory task (Study One), the total presentation time was 20 minutes with a break halfway through the task.

Apparatus

The apparatus used in Study Two is identical to the apparatus described in Study One.

General Procedure

The general procedure used in Study Two is identical to the general procedure described in Study One.

Experimental Procedure

The experimental procedure used in Study Two is identical to the experimental procedure described in Study One.

Data Analysis

Variables.

Intersensory task variables. Variables from the intersensory task included looking time and the proportion of efficient gaze patterns for all of the trials in the Single1 condition (SL, SNLO, SNLC, NSNL) from Study One.

Attention disengagement variable – time to fixation. Tobii software was used to determine location and duration of fixations. Dynamic Areas of Interest (AOIs) were created for each stimulus within a trial. Dynamic AOIs are used for trials in which stimuli may appear or disappear within the same trials and are set up to collect data only when the stimuli are present. Tobii software calculated the *time to fixation* based on the time it took participants to fixate attention from one video to the next video after it appeared on the screen. Time to fixation was then averaged across the four opportunities to disengage attention per trial.

SCQ. The total score on the Social-Communication questionnaire was calculated. Higher scores indicate more impairment.

BRIEF. Scores on the Metacognition Index (MI), Behavioral Regulation Index (BRI) and the overall Global Executive Composite were calculated. Higher scores indicate more impairment.

RBS-R. The total score on the revised repetitive behavior scale was calculated. Higher scores indicate more impairment.

Auditory Filtering. The auditory filtering subscale of the SSP was calculated. Lower scores indicate more atypical sensory response.

Analyses. Hypotheses were tested by calculating Pearson's correlation coefficient (r), to measure the strength of the association between the intersensory task variables (looking time and proportion of efficient gaze patterns) and 1) the participant variables and 2) the attention disengagement variable. Cohen's standard was used to evaluate the strength of the relationship where a correlation coefficient (r) between .10 and .29 represent a small association; coefficients between .30 and .49 represent a moderate association; and coefficients above .50 represent a large association (Cohen, 1988).

Results

Part A: Participant Variables

Participant variables (parent-reported characteristics and results of the cognitive assessment) are presented for the whole sample and by diagnostic group in Table 14. The participants with ASD differed from the participants with TD on all parent-report clinical measures ($p < .01$). Groups did not differ on the measures of cognitive ability (see Participant Characteristics section). Descriptive statistics for the intersensory test variables are presented in Table 15. See Study One for a complete between-group analysis of the intersensory test variables.

Table 14

Descriptive statistics of participant variables.

	Whole Group *n* = 39	ASD Group *n* = 19	TD Group *n* = 20
Variable	**Mean *(SD)* Range**	**Mean *(SD)* Range**	**Mean *(SD)* Range**
DAS-II: Verbal Cognition Ability (VCA)	98.34 *(17.492)* 34-133	94.44 *(22.714)* 34-133	101.85 *(10.338)* 86-126
DAS-II: Nonverbal Cognition Ability (NVCA)	100.38 *(16.627)* 54-128	98.05 *(21.40)* 54-128	102.60 *(10.394)* 76-120
DAS-II: General Cognitive Ability (GCA)	99.21 *(17.315)* 58-145	94.72 *(22.186)* 58-145	103.25 *(10.351)* 81-121
SCQ: Total Score	9.78 *(9.274)* 0-30	16.16 *(8.739)* 3-30	3.06 *(2.187)* 0-8
SSP: Auditory Filtering Score	22.69 *(5.841)* 12-30	18.84 *(4.574)* 14-27	26.35 *(4.416)* 12-30
RBS-R: Total Score	9.33 *(12.606)* 0-54	17.26 *(14.071)* 1-54	1.80 *(2.764)* 0-11
BRIEF: Behavior Regulation (BRI) Index	53.38 *(12.436)* 36-84	62.42 *(9.737)* 46-84	44.80 *(7.764)* 36-63
BRIEF: Metacognition (MI) Index	54.05 *(14.807)* 3-80	63.89 *(8.333)* 47-80	44.70 *(13.557)* 3-77
BRIEF: Global Executive Composite (GEC)	55.26 *(12.519)* 36-80	64.63 *(8.757)* 46-80	46.35 *(8.331)* 36-64

Table 15

Descriptive statistics of intersensory test variables

		Whole Group	ASD Group	TD Group
Variable		**Mean *(SD)* Range *n***	**Mean *(SD)* Range *n***	**Mean *(SD)* Range *n***
Looking Time	**SL**	.137 *(.096)* .01-37 39	.094*(.091)* .01-.37 19	.177 *(.085)* .07-.35 20
	SNLO	.256 *(.167)* .02-.63 38	.188 *(.136)* .02-.46 18	.317 *(.172)* .08-.63 20
	SNLC	.234 *(.182)* .01-.64 39	.203 *(.182)* .01-.64 19	.264 *(.182)* .02-.55 20
	NSNL	.306 *(.185)* .01-.87 39	.244 *(.144)* .01-.57 19	.365 *(.202)* .04-.87 20
Gaze Patterns	**SL**	.382 *(.133)* .06-.65 39	.343 *(.156)* .06-.65 19	.419 *(.096)* .27-.57 20
	SNLO	.515 *(.182)* .07-.80 39	.458 *(.217)* .07-.80 19	.569 *(.124)* .28-.72 20
	SNLC	.421 (*.174*) .10-.79 39	.394 (*.205*) .10-.79 19	.448 (*.138*) .25-.70 20
	NSNL	.7147 *(.188)* .28-.96 39	.689 *(.188)* .32-.94 19	.739 *(.189)* .28-.96 20

Correlations between participant variables and the Study One intersensory dependent variables (looking time and gaze patterns) are presented in Tables 16 and 17 respectively for the group with TD. For the group with ASD, correlations between participant variables and intersensory test variables (looking time and gaze patterns) are presented in Tables 18 and 19 respectively. The following abbreviations are used for all participant variables in the TD and ASD groups: Chronological age in months (CA); Differential Ability Scale, 2nd Edition verbal ability (DAS VA); Differential Ability Scale, 2nd Edition nonverbal ability (DAS NVA); Differential Ability Scale, 2nd Edition general cognitive ability (DAS GCA); Social-Communication Questionnaire – Lifetime Version (SCQ); Repetitive Behavior Scale – Revised (RBS-R); Auditory filtering subscale- Short Sensory Profile – (AF-SSP); Behavior Inventory of Executive Functioning, Behavior Regulation Index (BRIEF BRI); Behavior Inventory of Executive Functioning, Metacognition Index (BRIEF MI); Behavior Inventory of Executive Functioning, Global Executive Composite (BRIEF GEC).

Table 16

TD group: correlations between participant variables and looking time to synchronous AOI of the intersensory test variables.

	Intersensory Test Variables				Participant Variables									
	Looking Time													
	SL	**NSNL**	**SNLO**	**SNLC**	**CA**	**DAS VA**	**DAS NVA**	**DAS GCA**	**SCQ**	**RBS-R**	**AF-SSP**	**BRIEF BRI**	**BRIEF MI**	**BRIEF GEC**
SL														
NSNL	.35													
SNLO	.48*	.59*												
SNLC	.44*	.71**	.62**											
CA	.00	.53	.45*	.70**										
DAS VA	.00	-.24	.12	-.33	-.17									
DAS NVA	.03	-.18	.22	-.08	-1.6	.54*								
DAS GCA	.27	-.21	.28	.08	-.25	.78**	.84**							
SCQ	-.43	.24	.12	.02	.07	-.01	.17	-.06						
RBS-R	-.11	.36	.32	.23	.31	-.37	.14	-.26	.54*					
AF-SSP	.13	-.07	-.01	.00	-.01	.20	.47*	.30	-.24	.01				
BRIEF BRI	-.25	.12	-.18	-.21	-.04	-.24	-.23	-.49*	.46	.64**	.00			
BRIEF MI	-.32	-.39	-.40	-.37	-.36	.24	-.17	.12	.10	-.56**	-.52*	-.27		
BRIEF GEC	-.31	.24	-.05	-.11	-.11	-.17	-.27	-.34	.65**	.48*	-.44	.70**	.19	

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

Intersensory Test Variables: Looking time to the synchronous AOI in the Single1 condition (SL, NSNL, SNLO, SNLC).

Table 17

TD group: Correlations between participant variables and proportion of efficient transitions (gaze patterns) to the synchronous AOI of the intersensory test variables.

	Intersensory Test Variables				Participant Variables									
	Gaze Patterns				CA	DAS VA	DAS NVA	DAS GCA	SCQ	RBS-R	AF-SSP	BRIEF BRI	BRIEF MI	BRIEF GEC
	SL	NSNL	SNLO	SNLC										
SL														
NSNL	.05													
SNLO	.59**	.43												
SNLC	.25	.45*	.39											
CA	-.14	.56**	.13	.54*										
DAS VA	.10	.21	.32	-.21	-.17									
DAS NVA	.27	.20	.21	-.17	-.16	.54*								
DAS GCA	.34	.31	.37	-.03	-.25	.78**	.84**							
SCQ	-.20	.03	-.09	-.40	.07	-.01	.17	-.06						
RBS-R	.09	.01	.14	-.00	.31	-.37	.14	-.26	.54*					
AF-SSP	.23	-.12	.17	.00	-.01	.20	.47*	.30	-.24	.01				
BRIEF BRI	-.10	-.17	-.02	-.32	-.04	-.24	-.23	-.49*	.46	.64**	.00			
BRIEF MI	-.17	.09	-.31	-.30	-.36	.24	-.17	.12	.10	-.56**	-.52*	-.27		
BRIEF GEC	-.21	-.07	-.07	-.29	-.11	-.17	-.27	-.34	.65**	.48*	-.44	.70**	.19	

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

Intersensory Test Variables: Proportion of efficient transitions (Gaze Pattern) to the synchronous AOI in the Single1 condition (SL, NSNL, SNLO, SNLC).

Table 18

ASD group: correlations between participant variables and looking time to synchronous AOI of the intersensory test variables.

	Intersensory Test Variables				Participant Variables									
	Looking Time													
	SL	NSNL	SNLO	SNLC	CA	DAS VA	DAS NVA	DAS GCA	SCQ	RBS-R	AF-SSP	BRIEF BRI	BRIEF MI	BRIEF GEC
SL														
NSNL	.17													
SNLO	.58*	.19												
SNLC	.20	.51	.61**											
CA	-.01	.14	.37	.54*										
DAS VA	.19	.18	.20	.47*	.41									
DAS NVA	.18	.01	.08	.17	.24	.70**								
DAS GCA	.39	.19	.23	.39	.45	.90**	.81**							
SCQ	-.44*	.27	-.21	.10	.04	-.38	-.41	-.44						
RBS-R	-.07	.28	.03	-.06	-.24	-.67**	-.60**	-.64**	.56*					
AF-SSP	.59**	.30	.38	.29	.04	.48*	.45	.51*	-.44	-.41				
BRIEF BRI	.19	.32	.16	.07	-.11	-.34	-.25	-.21	.34	.69**	-.13			
BRIEF MI	.15	-.02	.27	.10	.16	-.04	.07	.08	.01	.41	-.21	.65**		
BRIEF GEC	.20	.12	.25	.11	.08	-.16	-.04	-.02	.14	.55*	-.19	.86**	.95**	

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

Intersensory Test Variables: Looking time to the synchronous AOI in the Single1 condition (SL, NSNL, SNLO, SNLC).

Table 19

ASD group: correlations between participant variables and proportion of efficient transitions (gaze patterns) to the synchronous AOI of the intersensory test variables.

	Intersensory Test Variables				**Participant Variables**									
	Gaze Patterns				**CA**	**DAS VA**	**DAS NVA**	**DAS GCA**	**SCQ**	**RBS-R**	**AF-SSP**	**BRIEF BRI**	**BRIEF MI**	**BRIEF GEC**
	SL	**NSNL**	**SNLO**	**SNLC**										
SL														
NSNL	.31													
SNLO	.75**	.33												
SNLC	.58**	.32	.57*											
CA	.43	.37	.52*	.55*										
DAS VA	.35	.25	.46	.65**	.41									
DAS NVA	.29	.18	.35	.40	.24	.70**								
DAS GCA	.63**	.23	.64**	.69**	.45*	.90**	.81**							
SCQ	-.23	.08	-.44	-.11	.04	-.38	-.41	-.44						
RBS-R	-.09	-.24	-.25	-.34	-.24	-.67**	-.60**	-.64**	.56*					
AF-SSP	.30	.39	.34	.39	.04	.48*	.45	.51*	-.44	-.41				
BRIEF BRI	.29	.06	.01	.05	-.11	-.34	-.25	-.21	.34	.69**	-.13			
BRIEF MI	.25	-.26	.10	.18	.16	-.04	.07	.08	.01	.41	-.21	.65**		
BRIEF GEC	.31	-.14	.09	.15	.08	-.16	-.04	-.02	.14	.55*	-.19	.86**	.95**	

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

Intersensory Test Variables: Proportion of efficient transitions (Gaze Pattern) to the synchronous AOI in the Single1 condition (SL, NSNL, SNLO, SNLC).

TD Group.

Chronological Age. For the group with TD, chronological age is significantly positively associated with looking time to the synchronous screen for the oral sounds (SNLO), $r(18) = .45$, $p = .047$; clapping (SNLC), $r(18) = .70$, $p = .001$; and non-social (NSNL), $r(18) = .53$, $p = .017$ variables. Also for the group with TD, chronological age is significantly positively associated with the proportion of efficient gaze patterns to the synchronous screen for the clapping, $r(18) = .54$, $p = .014$ and non-social variables, $r(18) = .56$, $p = .009$. Chronological age is the only participant variable associated with performance using either methodology (looking time or gaze pattern) for the group with TD and this association represents a moderate to large effect.

ASD Group.

***Chronological Age*.** Within the ASD group, chronological age was significantly positively associated with looking time to the synchronous screen for the clapping (SNLC) variable, $r(18) = .54$, $p = .018$ only. Analysis of the relationship between chronological age and the second methodology, gaze patterns, revealed a significant positive associated for the clapping, $r(18) = .55$, $p = .015$, and the oral sounds (SNLO) variables, $r(18) = .46$, $p = .053$ and marginal significance for the speech (SL), $r(18) = .43$, $p = .065$ variable.

Cognitive Ability. The Verbal Ability subscale on the DAS-II, 2nd Edition was significantly positively associated with looking time to the synchronous screen for the clapping (SNLC) $r(18) = .47$, $p = .050$ variable for the ASD group only. A positive association was also found with the proportion of efficient gaze patterns for the clapping, $r(18) = .65$, $p = .003$ variable, and a marginally significant association for the oral sounds (SNLO), $r(18) = .46$, $p = .053$ variable. The relationship between Non-verbal Ability (DAS-II, 2nd Edition) and both methodologies (looking time and gaze patterns) was not significant for all stimuli (SL, NSNL, SNLO, SNLC; all *p*s > .05). A positive association was noted between DAS-II General Cognitive Ability and the efficiency of gaze patterns for the speech (SL), $r(18) = .63$, $p = .005$; the oral sounds, $r(18) = .64$, $p = .004$; and the clapping, $r(18) = .69$, $p = .002$ variables. No association between General Cognitive Ability and looking time was identified for any stimuli in the group with ASD (all *p*s > .05).

Social-Communication. The association between scores on the Social Communication Questionnaire (SCQ) and intersensory task performance approached significance for two of the variables: looking time to the synchronous AOI in the speech (SL) variable $r(18) = -.439$, $p = .060$, and efficiency of gaze patterns for the oral sounds (SNLO) variable, $r(18) = -.445$, $p = .056$. Of particular interest, although the relationships did not reach statistical significance, scores on the SCQ were negatively associated with looking time and efficiency of gaze patterns for all of the speech and oral sounds variables. These negative associations are likely clinically significant because they demonstrate the relationship between performance on a lab-based assessment of intersensory processing and a parent-report measure of symptom severity for participants with ASD. It is therefore meaningful to try to understand the strength of this effect more broadly. The value of *r* ranges from -.21 to -.44 for the association between scores on the SCQ and measures of looking time and efficiency of gaze patterns for the speech and oral sounds variables. This represents a moderate to strong negative relationship: as social disability increases, intersensory processing decreases. Importantly, this relationship is not seen for the clapping (SNLC) and non-social (NSNL) variables. The range of values for *r* crosses zero (-.11 to .27) for the clapping and non-social stimuli and likely represents no relationship between these variables and scores on the SCQ. These results provide partial support for the second hypothesis in Part A; social-communication disability was associated with some, but not all of the intersensory task variables.

Repetitive Behaviors. The measure of repetitive behaviors (RBS-R) was not associated with intersensory processing for the ASD group.

Auditory Filtering. Scores on the Auditory Filtering subscale of the Short Sensory Profile were significantly associated with looking time to the synchronous screen in the speech (SL) variable, $r(18) = .590$, $p = .008$. A significant relationship was not observed for any other variable. However, the pattern of correlations between the AF-SSP and the measures of intersensory processing (looking time and efficiency of gaze patterns) suggests an overall moderate to strong relationship (the value of *r* ranges from .29 to .59) across all variables (SL, SNLO, SNLC, NSNL) for the participants with ASD. Overall, it appears that intersensory processing (for social *and* non-social stimuli) is related to auditory filtering in the ASD group only in that deficits in auditory filtering are related to weaker intersensory processing.

Executive Functioning. Contrary to the fourth hypothesis in Part A, for the group with ASD executive functioning was not associated with intersensory processing for either of the methodologies (looking time or efficiency of gaze patterns).

Part B: Attention disengagement

Impaired attention disengagement has been considered one of the hallmark impairments in children with ASD, although the impact of attention disengagement on dynamic, multimodal stimuli is equivocal (McMorris, 2015). The focus of Study Two, Part B was to assess the relationship between intersensory processing and disengagement for dynamic, multimodal stimuli. The same participants with TD and ASD completed two independent lab-based paradigms using eye-tracking technology to assess intersensory processing (looking time and proportion of efficient gaze patterns) on the one hand and disengagement (time to fixation) on the other, for stimuli varied in social and linguistic content. Table 20 presents descriptive statistics for the attention disengagement variable for the entire sample and by diagnostic group. Correlations between the intersensory test variables (looking time and proportion of efficient gaze patterns) and attention disengagement (time to fixation) are presented in Tables 21 and 22 for the participants with TD and ASD respectively.

Table 20

Descriptive statistics of attention disengagement (time to fixation, in seconds) for all groups

	Whole Group *n* **= 38**	**ASD Group** *n* **= 18**	**TD Group** *n* **= 20**
	Mean ***(SD)*** **Range**	**Mean** ***(SD)*** **Range**	**Mean** ***(SD)*** **Range**
Disengage	.591 *(.197)* .34-1.10	.672 *(.232)* .37-1.10	.519 *(.124)* .34-.73

Table 21

TD group: correlations between Intersensory test variables (looking time and proportion of efficient gaze patterns) and attention test variable (disengage).

		Looking Time				**Gaze Patterns**				**Attention**
		SL	**NSNL**	**SNLO**	**SNLC**	**SL**	**NSNL**	**SNLO**	**SNLC**	**Disengage**
Looking Time	**SL**									
	NSNL	.35								
	SNLO	.48*	.59**							
	SNLC	.44*	.71**	.62**						
Gaze Patterns	**SL**	.66**	.20	.33	.12					
	NSNL	.22	.25	.45*	.52*	.05				
	SNLO	.63**	.44*	.68**	.33	.59**	.43			
	SNLC	.59**	.46**	.46*	.82**	.25	.45**	.39		
Attention	**Disengage**	-.32	.01	-.63**	-.31	-.33	-.58**	-.46*	-.28	

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

Intersensory Test Variables: Looking time to the synchronous AOI in the Single1 condition (SL, NSNL, SNLO, SNLC). Proportion of efficient transitions (Gaze Pattern) to the synchronous AOI in the Single1 condition (SL, NSNL, SNLO, SNLC).

Attention Test Variables: Time to fixation per trial on average (Disengage).

Table 22

ASD group: correlations between Intersensory test variables (looking time and proportion of efficient gaze patterns) and attention test variable (disengage).

		Looking Time				Gaze Patterns				Attention
		SL	**NSNL**	**SNLO**	**SNLC**	**SL**	**NSNL**	**SNLO**	**SNLC**	**Disengage**
Looking Time	**SL**									
	NSNL	.17								
	SNLO	.58*	.19							
	SNLC	.20	.51*	.61**						
Gaze Patterns	**SL**	.69**	.42	.57*	.47*					
	NSNL	.20	.46*	.28	.43	.31				
	SNLO	.59**	.06	.66**	.44	.75***	.33			
	SNLC	.25	.26	.46	.80**	.58**	.32	.57*		
Attention	**Disengage**	-.31	-.34	-.42	-.54*	-.40	-.61**	-.59**	-.63**	

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

Intersensory Test Variables: Looking time to the synchronous AOI in the Single1 condition (SL, NSNL, SNLO, SNLC). Proportion of efficient transitions (Gaze Pattern) to the synchronous AOI in the Single1 condition (SL, NSNL, SNLO, SNLC).

Attention Test Variables: Time to fixation per trial on average (Disengage).

In the group with TD, time to fixation on a newly presented stimulus (attention disengagement), was negatively associated with the measure of intersensory processing for all variables, at least to a degree, except for looking time to the synchronous screen for the non-social (NSNL) stimuli ($r=.01$). A *significant* negative relationship was observed between disengagement and looking time to the synchronous screen in the oral sounds (SNLO) variable, $r(18) = -.63$, $p = .003$. A significant relationship was also observed between disengagement and the proportion of efficient gaze patterns to the oral sounds, $r(18) = -.46$, $p = .041$ and non-social variables, $r(18) = -.58$, $p = .007$. On average, TD participants who took a longer time to disengage showed shorter looking time to the synchronous stimuli and lower proportion of efficient gaze patterns.

In the group with ASD, disengagement was also negatively associated with looking time and the proportion of efficient gaze patterns for all variables, to a degree. The strength of those relationships was significant for disengagement and looking time to the synchronous screen for the clapping (SNLC) variable, $r(18) = -.54$, $p = .019$ as well as disengagement and efficiency of gaze patterns to the oral sounds, $r(18) = -.59$ $p = .009$; clapping, $r(18) = -.63$, $p = .005$; and non-social, $r(18) = -.61$, $p = .007$ variables. Overall, the strength of the relationships between disengagement (time to fixation) and intersensory processing (looking time and proportion of efficient gaze patterns) represents medium to large effects (Cohen, 1988) for both participant groups.

Discussion: Study Two

The overall goal of the current project was to provide a better understanding of the intersensory processing deficit for social stimuli in individuals with ASD. This deficit was theorized to account (at least partially) for cascading impairments in attention and autism symptomatology across development. The primary goal was to isolate the social and linguistic properties of intersensory (audio-visual) processing using a manipulation of temporal synchrony, one of the most global amodal properties. In Study One, a multi-method analysis of looking time and gaze patterns using eye-tracking data from a behavioural task was used to isolate differences in processing between the ASD and comparison group across dynamic, multimodal stimuli varied for social and linguistic content. The secondary goal of the project was to provide a better understanding of variables that impact and are impacted by intersensory processing. This was addressed in Study Two by assessing the strength and direction of the relationship between intersensory processing and developmental, diagnostic, and attention variables.

Chronological Age

For both the TD and ASD groups, chronological age was positively associated with intersensory perception (looking time and proportion of efficient gaze patterns) for some of the stimuli and not others. In the TD group, a positive association was found between chronological age and the non-social and clapping stimuli using both methodologies as well as looking time to the oral sounds stimuli. In the ASD group, chronological age was associated with the clapping trials using both methodologies as was the efficiency of gaze patterns to the speech and oral sounds stimuli. The relationship between chronological age and intersensory processing is not well understood in the literature. Some studies have found an association between audio-visual intersensory processing of complex stimuli and chronological age in typical development

(Hancock, 2009). Bahrick (2010) theorizes that patterns of unimodal and intersensory facilitation are less evident across development as perception capabilities improve and complex events become more familiar to the observer. Intersensory perception is a function of familiarity and task difficulty in relation to the expertise of the perceiver. For example, by the age of 5 months, performance on a task of discrimination of simple tempo changes was at ceiling – infants no longer showed intersensory facilitation. The authors were able to reinstate the effect of intersensory facilitation by increasing task difficulty (Bahrick & Lickliter, 2004). Therefore, the skill level of the perceiver, rather than age, is the more important variable. Even older perceivers should experience intersensory and unimodal facilitation when encountering new or complex information. For both groups in Study Two, as age increased, participants showed enhanced intersensory perception in the oral sounds condition suggesting that this condition in particular may have been either novel or more complex compared to other stimuli. This result has face validity as encountering this type of information (person making non-speech sounds with the mouth) during every day interactions would be much less common than, for example, observing speech. However, in this study, chronological age is only a loose approximation for experience or skill level. If expertise of the perceiver is important, future studies should assess experience or skill in a more direct way because this has important implications for individuals with ASD. When an infant fails to integrate and perceive important multisensory cues, such as the pairing of lips and voice, they are less likely to respond to the stimulation. Failed response decreases the opportunity for future cues. For example, the parent may be less responsive and engaging if there is no reciprocal response over time, decreasing the multisensory learning opportunities for the child. As a result, the child fails to receive opportunities to practice these skills and develop the expertise necessary to navigate the complicated social environment, likely impacting language development. It would be valuable to also understand if there are possible points of intervention to improve skill level and build expertise in intersensory processing either in infants vulnerable to developing ASD or across the lifespan in individuals with ASD.

Cognitive Ability

For the ASD group in Study Two, verbal ability was associated with looking time for the clapping trial and efficiency of gaze patterns for the oral sounds stimuli. General cognitive ability was associated with efficiency of gaze patterns in the speech, oral sounds, and the clapping trials. No association was found for the TD group. It is possible that this result was not observed for the group with TD because, although the average scores of cognitive ability did not differ between groups, the range of scores for the cognitive variable was smaller in the group with TD (DAS-II GCA, Range 81-121) than in the group with ASD (DAS-II GCA, Range 58-145). The variability for the TD group may have been too low to identify a significant linear relationship. For the group with ASD, this result is consistent with the hypothesis that cognitive level can impact intersensory processing when stimuli are of a certain level of novelty or complexity relative to the experience of the perceiver (Bahrick, 2010) although the relationship between cognitive ability and intersensory processing remains equivocal.

Social-Communication

In the ASD group, scores on a measure of social-communication impairment increased (i.e, greater impairment) as intersensory processing for the social variables decreased (speech and oral sounds). No relationship was found for this measure of autism symptomatology and intersensory processing for the other stimuli (non-social and clapping). The relationship between social-communication disability and atypical processing of social information is consistent within the literature (Rice et al., 2012; Jones, Carr & Klin, 2008; Klin et al., 2002). The results from Study Two provide experimental evidence from an integration of behavioural data and a parent report questionnaire to support the hypothesis that sensory processing differences are central to the social deficits in ASD (Cascio, Woynaroski, Baranek, & Wallace, 2016; Bahrick & Todd, 2012, Schauder & Bennetto, 2016). Further, by manipulating the social and linguistic content of the intersensory stimuli, this study isolated the specific relationship between sensory processing of social information (with and without speech) and the social-communication deficits in ASD. Although it is not possible to determine a causal relationship between the variables, these results are consistent with the hypothesis that early deficits in intersensory processing for social stimuli impede the development of attention hierarchies that serve to orient attention to meaningful social information (Bahrick & Todd, 2012). Individuals with ASD experience particular difficulty with attending to meaningful social information, such as, responding to their name, interpreting facial expressions, asking socially inappropriate questions, and sharing interests or engaging attention from others. Atypical development of the social sensory processing system may underlie the development of this cluster of symptoms.

Auditory Filtering

In the group with ASD, although only statistically significant for the speech variable, a moderate to strong association was observed between atypical auditory filtering and impaired intersensory processing for all variables, social and non-social. Atypical sensitivity to sensory information for individuals with ASD is well-documented, particularly for auditory and visual modalities (Ramachandran & Oberman, 2006; Talay-Ongan & Wood, 2000; Iarocci & McDonald, 2006). Further, auditory filtering impairments in particular have been identified for individuals with ASD; for example, abnormalities in auditory filtering may be part of an atypical sensory profile that represents a distinctive symptom profile of children with ASD (Rogers et al., 2003; Wiggins, Robins, Bakeman, & Adamson, 2009). Auditory filtering impairments have also been found in behavioural and biological studies (Russo, Zecker, Trommer, Chen & Kraus, 2009). For example, children with ASD have been found to require a higher signal-to-noise ratio compared to a comparison group in order to perceive speech (Alacantara et al., 2004; Groen et al., 2009). The current study adds complementary evidence from an audio-visual eye-tracking task that auditory filtering is related to the intersensory processing deficit in ASD.

Repetitive Behaviors

For the ASD group, no relationship was observed between the repetitive behaviors scale and looking time or proportion of efficient gaze patterns. Restricted, repetitive, and stereotyped behaviors represent one of the core symptoms in the diagnosis of ASD and these behaviors are theorized to be related to intersensory processing deficits (Lewis & Bodfish, 1998; Richler, Huerta, Bishop, & Lord, 2010). Bahrick and Todd (2012) suggest that repeated stimulation and self-stimulation may facilitate coupling of the multimodal system and serve to integrate sensory and motor systems. Repetitive behaviors may provide predictable and well-integrated multisensory stimulation in what is otherwise experienced as a chaotic multi-sensory world. This study did not provide support for this theory; however, repetitive behaviors were measured using parent-report questionnaires rather than behavioural assessment. It is possible that standardized behavioural assessment of repetitive behaviors would provide a more accurate assessment and should be considered in future studies.

Executive Functioning

For the ASD group, no relationship was observed between executive functioning and either looking time or proportion of efficient gaze patterns. The executive control system has been theorized as a higher-order attention system responsible for a variety of cognitive processes such as inhibition, planning, and cognitive flexibility. Although executive functions are impaired in children with ASD (Hill, 2004), the impact of differences in executive functioning abilities is equivocal. Using the Attention Network Task (Fan, McCandliss, Sommer, Raz, & Posner, 2002), Keehn, Lincoln, Müller, & Townsend (2010) found that the visual orienting system (i.e., disengaging and shifting) and not executive control skills are impaired in children and adolescents with ASD. It is possible then that disruption in specific attention abilities, and not a general measure of executive functioning may be related to autism symptomology, including disrupted sensory processing (see below for a discussion of attention disengagement). Additionally, executive functioning was measured using parent-report questionnaires rather than behavioural assessment. It is possible that behavioural assessment of executive functioning would provide a more specific assessment of executive dysfunction and should be considered in future studies.

Attention Disengagement

Attention disengagement was associated with both measures of intersensory processing for the group with ASD. As time to fixation, defined as the time to disengage from one stimulus and visually fixate on a peripheral stimulus increased, looking time and the proportion of efficient gaze patterns decreased. That is, for participants with ASD, the slower their disengagement from the stimulus, the shorter their looking time to the synchronous stimuli tended to be and the less efficient were their gaze patterns. A similar, but less consistent relationship was observed for the comparison group. These results are consistent with evidence of impaired disengagement in children with ASD (Landry & Bryson, 2004; Bryson et al., 2007; Elsabbagh et al., 2009, 2013) particularly for multimodal stimuli (Sabatos-De Vito et al., 2016) and further support the hypothesis that the development of impaired attentional disengagement is intertwined with atypical sensory processing (Bahrick & Todd, 2012; Sabatos-De Vito et al., 2016). The causal nature of this relationship is as yet unclear.

Impaired disengagement may be related to differences in the audiovisual temporal integration window identified in children with ASD. Studies of the temporal integration window have used the flash-beep task to assess the impact of auditory stimuliation (beeps) on the perception of visual stimuliation (flashes of light). In typical development, the number of beeps presented influences the number of flashes perceived. Van der Smagt, van Engeland, and Kemner (2007) reported no differences in processing the task for a group with ASD compared to a group with TD. However, the perception of the illusion is dependent on the SOA, the stimulis onset asynchrony between the presentation of the flash and the beeps. In a study by Foss-Feig et al. (2010), participants with ASD reported the flash beep illusion at greater SOAs compared to the group with TD suggesting that the children with ASD were able to successfully integrate the audio-visual information, albeit across a larger temporal processing window. A larger, less precise temporal binding window may have implications for attentional selectivity in noisy, social, multimodal environments. For example, noisy environments may increase confusion and "accidental synchrony" between concurrent but unrelated auditory and visual streams (Bahrick & Todd, 2012) and disturbances in attentional selectivity as a result may be more likely to occur in social environments where the environment is typically more fast-paced and complex.

Visual disengagement and atypical sensory response were recently compared for participants with ASD and comparison groups using a gap-overlap paradigm and caregiver-report questionnaires (Sabatos-DeVito et al., 2016). While impaired disengagement and orienting for dynamic versus static stimuli were identified in all groups, only the group with ASD had slower times to disengage from multimodal versus unimodal stimuli. Further, in the ASD group, elevated scores on measures of hyporesponsiveness and sensory seeking were associated with slowed disengagement. In contrast, more accurate and faster disengagement scores were associated with elevated hyperresponsive scores. Sabatos-DeVito et al. (2016) propose that children with higher sensory-seeking behaviors may process local stimulus features at the expense of global features.

The current study is the first to use a multi-method experimental design to identify a relationship between attention disengagement and intersensory processing in children with ASD and to present evidence that attentional control and sensory processing systems are intertwined. It is not possible to determine the causal direction of the association between intersensory processing and attention from the results of Studies One and Two. One possibility is that early attentional disengagement abilities contribute to different sensory response patterns. Alternatively, it is more likely that deficits in early integration of sensory information disrupt the allocation of attentional resources and the development of attentional hierarchies that support the ability to disengage and orient attention in individuals with ASD. The mechanism of this is unclear although it is possible that, for individuals with ASD, the deficit in integrating multisensory information interferes with the cue to attend to novel stimuli and slows the process of disengaging and orienting attention.

Conclusion

Across the lifespan, intersensory processing is likely impacted by the expertise of the perceiver. It is possible that complex and novel social stimuli are processed more slowly, less efficiently, or otherwise atypically in children with ASD compared to children who are typically developing. Impaired intersensory processing for social information appears to be associated with cascading consequences across development including some of the core impairments in

Autism Spectrum Disorder: disrupted sensory processing and social-communication disability. In addition, impaired intersensory processing is associated with slower attentional disengagement in children with ASD. In summary, results support the hypothesis that impaired intersensory processing impacts the attentional salience of social events leading to deficits in social orienting and disengagement in dynamic, multimodal stimuli in children with ASD.

Integration of Findings

Study One and Study Two offered contributions to the understanding of intersensory processing in children with ASD in four distinct ways. First, Study One was effective in isolating the social and speech elements of the stimuli and results demonstrated a deficit in intersensory processing for information provided by the mouth region of the stimuli. Therefore, intersensory processing of social stimuli appears to be impaired in children with ASD, whether the mouth is providing linguistic information or simply making non-linguistic sounds. Second, this is the first study to use a multi-method approach to the analysis of dynamic, multimodal eye-tracking data in children with ASD. Eye-tracking has become a common approach in experimental studies with children with ASD and Study One demonstrated how the multi-method approach to analysis can offer corroborating evidence and clarification in understanding data. Third, results from the mixed content trials in Study One challenged the notion of a broad deficit in face processing in children with ASD. Properties of the stimuli and task demands are important factors in predicting how individuals will view social stimuli, including faces. Fourth, laboratory-based behavioural tasks were used to identify a relationship between attention and intersensory processing. At the present time, this is the first study to test the relationship between these two important processes without relying on the use of parent-report measures for at least one of the variables.

In summary, the observed differences between the ASD and control group in looking time and efficiency of gaze patterns for multimodal, social information are not likely accounted for by a) a general deficit in intersensory perception (equivalent intersensory results were observed in the Mixed2 condition and Single1, clapping trials), b) a language-specific intersensory impairment (impaired intersensory processing was observed for the ASD group for both the speech *and* oral sounds conditions), c) a deficit in processing body movement (equivalent intersensory results were observed in the Single1, clapping trials), or d) a deficit in face processing (equivalent looking to face regions was observed between groups in the Mixed1 and Mixed2 conditions). Results are likely best understood as a specific cognitive-perceptual deficit in social orienting and are consistent with the Intersensory Redundency Hypothesis. The observed intersensory processing differences between groups may be impacted by dysfunctional intersensory integration wherein the most general amodal property, temporal synchrony, is misprocessed at early stages, disrupting selective attention and early social orienting. This impairment impacts the cascading cycle of perception, learning, memory, attention and so on and contributes to core sensory and social-communication impairments associated with Autism Spectrum Disorder.

Limitations

Participants. Despite the many strengths of the current study, there are a number of limitations to note. First, the participant groups were not evenly distributed by sex. There were more male participants in the group with ASD and more female participants in the group with TD. Given that ASD affects more males than females (4-5:1, Fombonne, 2003) the sex discrepancy was not unexpected for the group with ASD and groups in the current study were matched on other variables (age, cognitive ability) and not sex. Although there is no evidence in the literature of a clear sex difference on these tasks, future studies should attempt to match groups on sex to account for any differences in this variable. In addition, participant groups included school-aged children between 6 and 16 years old and results should not be presumed generalizable to young children, older adolescents, or adults.

Methodology. Information about ASD symptoms and executive functioning was obtained via parent report. The data is thus limited to behaviors that are observable to parents. This is less problematic when the behaviour relates to interaction and communication but more problematic when trying to quantify internal experiences (e.g. sensory discomfort and attention). It is possible that some of the null findings are a result of a lack of sensitivity in the parent-report measures. Future studies should attempt to corroborate results using self-report measures in capable participants and laboratory-based assessments where available.

Areas of Interest for the eye-tracking analyses were pre-determined by the experimenter. This creates a potential bias because, although the decisions are theoretically driven and evidence-based, it limits the data set and creates the possibility of missing unexpected outcomes. For example, Guillon et al. (2015) unexpectedly identified differences in processing for left and right eyes between ASD and comparison groups and this result was only identified because experimenters used data-driven areas of interest.

Future studies should continue to utilize new and complementary analyses to interpret the copious amounts of data provided by the eye-tracking technique. Future studies would also benefit from integrating the findings from behavioural studies with studies investigating the neural pathways and mechanisms of sensory processing. This shift towards an interdisciplinary approach will support an appreciation for the biological basis of these processes and ultimately a better understanding of sensory processing.

Clinical Implications

Our ability to understand impairments in intersensory processing in Autism Spectrum Disorder is fundamentally limited by our current understanding of intersensory processing in typical development. So much is yet to be understood about early social orienting in typical development, and atypical development may serve as a window to better understand early processes. Nonetheless, the dynamic process of development should not be ignored. Subtle differences in developmental timing, neuronal processes, and environmental interactions can lead to significant divergence in phenotypical outcome, thus limiting the appropriateness of synthesis of typical and atypical perspectives.

Understanding atypical face scanning patterns may aid in early detection and classification of children with Autism Spectrum Disorder. Efforts are already underway to apply a machine learning method to analyze eye movement from a face processing task to classify children with ASD (Liu, Li & Yi, 2016). A better understanding of differences in processing social and non-social information will help to improve the specificity and sensitivity of these developing models.

If attention problems are found to be secondary to sensory problems in children with ASD, it would seem reasonable to suggest that reducing sensory problems may improve attention and this would have several important implications for intervention in the classroom. This might include application of recommended procedures already being used for children with ADHD, such as minimizing competing auditory input, which may be helpful, as well as presenting visual information at a reduced pace. Special attention should be paid to the timing of presentation of the visual and auditory information.

The multi-method approach to analysis of eye-tracking data helps to provide comprehensive assessment of the specific differences in processing social information, including the face, that have been identified in children with ASD. These data can inform the development of more specific, effective, and evidence-based training programs (e.g., computer programs) to support enhanced social communication. Additionally, training programs can be created to help children focus attention to multimodal, synchronous events such as the coordination of lips and voice. Over time and with repetition, this training will help children attend to relevant intersensory information and ignore irrelevant, competing information.

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Appendices

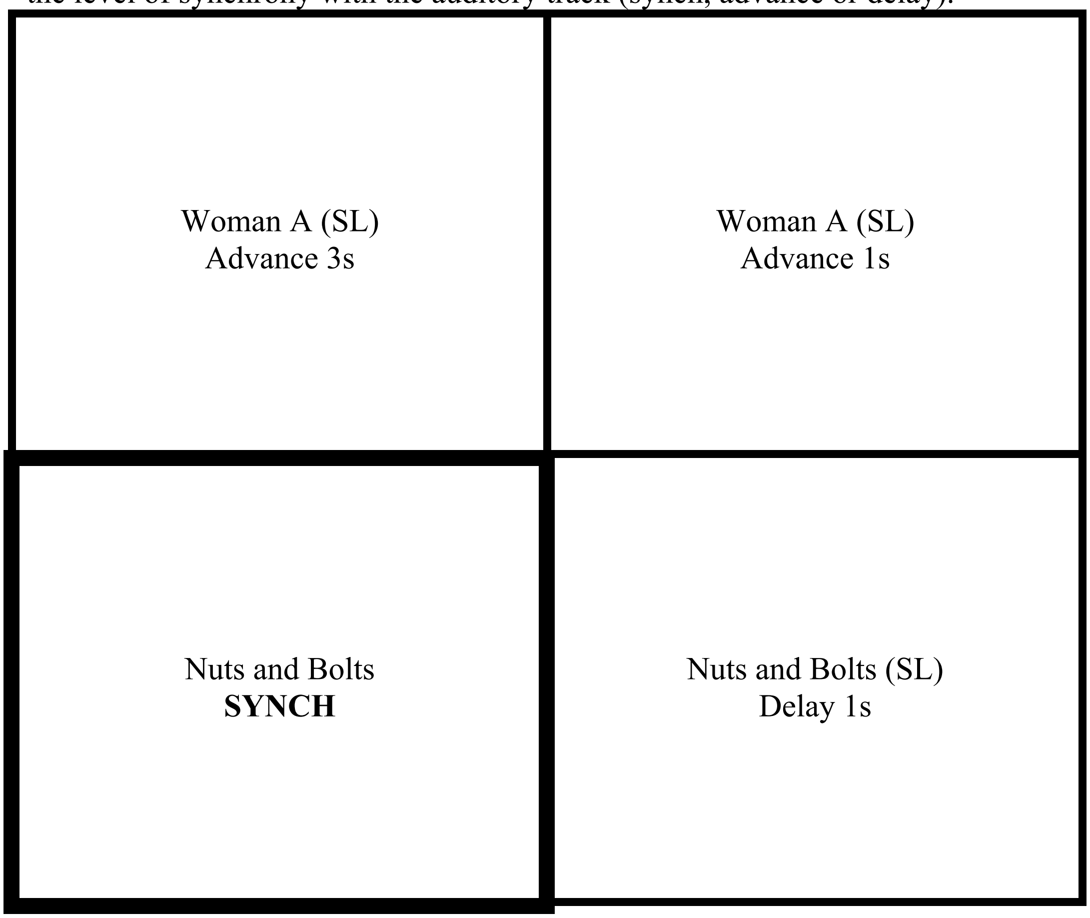
Appendix A

Mixed2. This figure shows an example of a Mixed2 trial, with both the SL and NSNL auditory tracks playing. The videos are all synchronous with the auditory track that matches the content of the video.

Woman A (SL) **SYNCH (with SL audio)**	Nuts and Bolts (NSNL) **SYNCH (with NSNL audio)**
Woman A (SL) **SYNCH (with SL audio)**	Nuts and Bolts (NSNL) **SYNCH (with NSNL audio)**

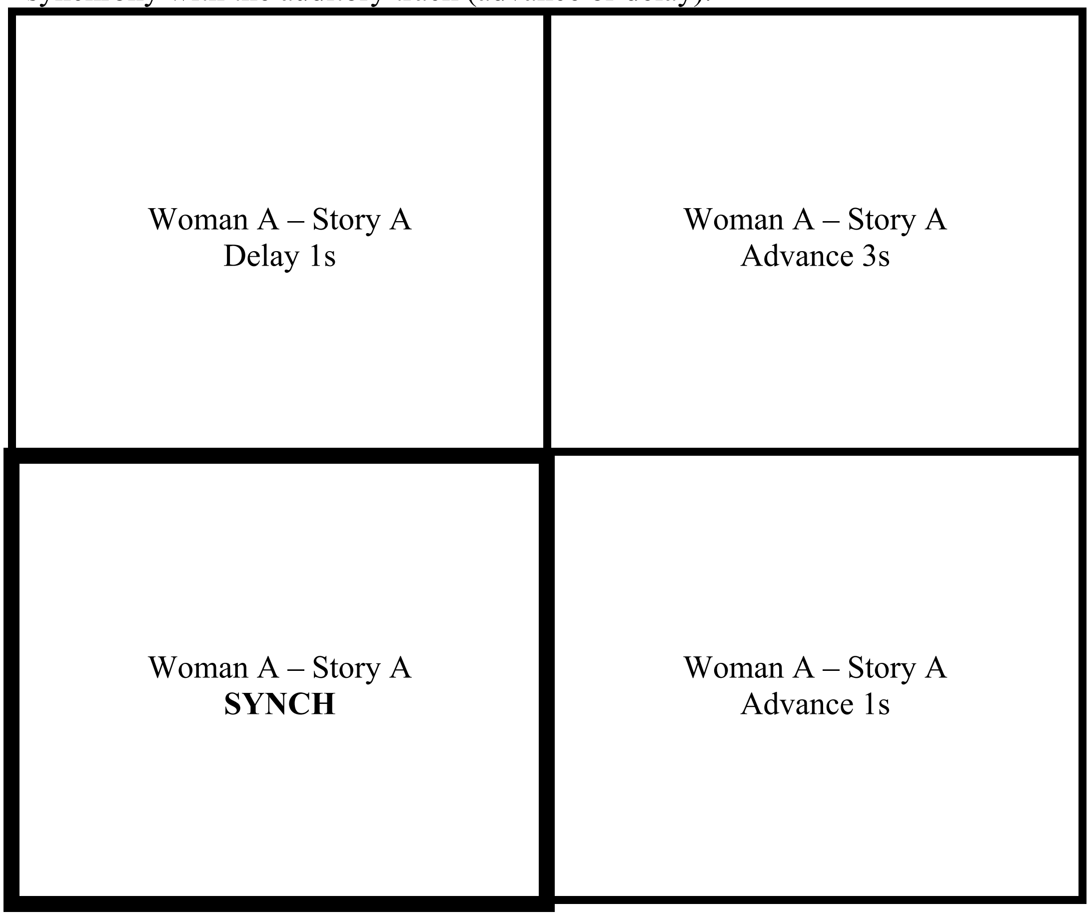
Appendix B

Mixed1. This figure shows an example of a Mixed1 trial, synchronous to the NSNL video in the lower left quadrant. The video in each quadrant is identified by the trial type (SL or NSNL) and the level of synchrony with the auditory track (synch, advance or delay).



Appendix C

Single1 (SL). This figure shows an example of a Single1 SL trial, synchronous to the video in the lower left quadrant. The videos in each of the other quadrants are identified by the level of synchrony with the auditory track (advance or delay).



Appendix D

Informed consent for parents of participants with TD.

INFORMATION LETTER

Information Processing in Autism Spectrum Disorders: Understanding Attention and Intersensory Processing as Core Deficits

Dear Parent,

Purpose of the Study

Two abilities are thought to help people interact socially: 1) attention (shifting your attention from one person or object to another); and 2) combining together what we see with what we hear (intersensory processing). Both attention shifting and intersensory processing are impaired in many children and adolescents with Autism Spectrum Disorders (ASD). Although these difficulties together could lead to other impairments in making sense of the world around us, there has only been limited research on how they work together. We are asking for your and your child's assistance in a research study to look at how they work together and how they impact on social understanding and communication in ASDs.

A better understanding of the nature of information processing abilities, specifically attention and intersensory processing, will help us better understand the normal course of development in children and adolescents.

What will Participation Involve?

This study will involve children between the ages of 6 and 16 years of age who have been diagnosed with an Autism Spectrum Disorder (ASD). In order to participate, individuals must: a) have at least a 2-year-old verbal ability in English; b) normal or corrected-to-normal hearing and vision; and c) no known neurological issues (epilepsy, brain injury, etc.). Children will be asked to watch a short video and some pictures that have been created specifically to understand how children attend to and understand what they see and what they hear. The images and video that children will see include a woman telling a story, a woman making voice sounds, a piano being played, and some animated cartoons. During the session, the child's eye movements will be video recorded and tracked using eye-tracking equipment.

Along with this, there will one cognitive (thinking) activity examining children's problem solving skills (e.g., working with puzzles) and one language activity (e.g., looking at pictures). Additionally, the Autism Diagnostic Observation Scale (ADOS), a structured observation scale children and adults with ASD will be administered. Overall, the experiment should take no longer than one and a half hours for your child.

Parents will also be asked to complete several questionnaires about a range of skills and characteristics of your child. These include thinking skills, self-control, communication and social skills, repetitive and sensory-type behaviors. An additional questionnaire will ask about your experiences obtaining a diagnosis for your child and any previous diagnoses that may have been given. We will also ask you to provide a copy of the diagnostic report for clarification. Parent involvement should take approximately 60 to 90 minutes.

Are there any Risks Involved?

All of the parts of this study have been reviewed and there are no risks involved. All information that is collected will be kept strictly confidential to the fullest extent possible by law. To ensure confidentiality, paper data will be stored in a locked cabinet, and other data will be stored on an external hard drive in an encrypted file that will be kept at the Child Learning Projects Lab at York University. The lab is also locked and only accessible by project personnel. All children will be given a participant number by which they will be identified. Data and audio-video recordings will be stored for an extended period after the study to enable comparison and combination with data in future studies. Once all projects in this line of research have been completed, all data and recordings will be destroyed (paper materials will be shredded and video will be destroyed). In the event that the results are published or presented, only grouped data will be used to guarantee anonymity. Any individual or personal information will be kept confidential. You will be provided with a small gift in appreciation for your participation. In addition, we will offer modest compensation for your travel, parking or transit, if you choose. This study is being conducted under the supervision of Dr. James Bebko, a professor at York University and a Clinical Psychologist.

Withdrawal from the Study: Participation is completely voluntary, *you or your child can withdraw from the study at any time* and it will not affect any of the services that you may currently be receiving. If you decide to stop participating, you will still be eligible to receive the promised compensation for agreeing to be in this project. Your decision to stop participating, or to refuse to answer particular questions, will not affect your relationship with the researchers, York University, or any other group associated with this project. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible.

Please read and sign the attached consent form indicating whether your child may or may not participate. Please feel free to ask me any questions or if you would like more information. Thank you for your interest and participation in this study, it is greatly appreciated!

Sincerely,

Carly McMorris
Doctoral Candidate

Lisa Hancock
Doctoral Candidate

INFORMED CONSENT FORM

Information Processing in Autism Spectrum Disorders: Understanding Attention and Intersensory Processing as Core Deficits

By signing this form, I agree that I have read and understood the description of the study, and that I allow my child to participate. I understand that the information collected about my child during this study will remain completely confidential within the limits of the law and that we may choose to stop participating at any time. I understand that participation in this study will in no way affect any services that we are receiving now or in the future. I agree to have my child's participation and eye-movements video-recorded for purposes of later analyzing looking patterns.

Parent/Guardian Name (please print) ___________________________________

Parent/Guardian Signature _________________________ Date________________________

Relationship to the minor who is participating in this study:
____

Child's Name (please print): ____________________________________

Child's Date of Birth (d/m/y): ____________________________________

Child's current age (in years): _______________

Principal Investigator Signature_______________________ Date
____

Questions about the Research? If you have questions about the research in general or about your role in the study, please feel free to contact us using the contact information below. You may also contact my Graduate Program – the Psychology Department Graduate office at (416) 736-5290. This research has been reviewed and approved by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Sr. Manager & Policy Advisor for the Office of Research Ethics, 309 York Lanes, York University (telephone 416-736-5914 or e-mail ore@yorku.ca).

Carly McMorris
Doctoral Student
York University

Lisa Hancock
Doctoral Student
York University

Dr. James Bebko
Supervising Professor
York University

Additional Information ***(please complete the following information)***

Child's first language_________________ Child's most frequently used language____________

By the age of **3**, was your child's language the same as typically developing children? ☐ YES ☐ NO

My child's hearing: Estimated test date____________________

☐ has not been tested
☐ has been tested and no problems were found
☐ has been tested and the following difficulties were found:
____

My child's vision: Estimated test date_____________________
☐ has not been tested
☐ has been tested and no problems were found
☐ has been tested and the following difficulties were found:
____

Has your child **ever** received Intensive Behavioral Therapy (IBI: at least 20 hours of behavioral therapy a week)? (Please note: This question is only to help us understand your child's previous experiences)
☐ YES ☐ NO

* Limited compensation for your travel, parking or transit is available, if you wish; would you like to receive $10.00 to partially cover these costs? ☐ YES ☐ NO

1. Do you wish to receive a brief summary of the grouped findings of this study? (*Please note that it may be 12 months after completion of the study before all the results have been analyzed*)
☐ YES ☐ NO

2. Are you willing to be contacted for participation in future studies (no obligation)? ☐ YES ☐ NO

If you answered **YES** to either of the two above questions, please provide:

Name: ____

Mailing Address:
____

Telephone: ___________________________ Email Address:______________________

Appendix E

Informed consent for parents of participants with ASD.

INFORMATION LETTER

Information Processing in Autism Spectrum Disorders: Understanding Attention and Intersensory Processing as Core Deficits

Dear Parent,

Purpose of the Study

Two abilities are thought to help people interact socially: 1) attention (shifting your attention from one person or object to another); and 2) combining together what we see with what we hear (intersensory processing). Both attention shifting and intersensory processing are impaired in many children and adolescents with Autism Spectrum Disorders (ASD). Although these difficulties together could lead to other impairments in making sense of the world around us, there has only been limited research on how they work together. We are asking for your and your child's assistance in a research study to look at how they work together and how they impact on social understanding and communication in ASDs.

A better understanding of attention and intersensory abilities will help us identify central difficulties in ASD that may aid in the earlier detection of ASD. It may also provide insight into other characteristics of ASD, such as repetitive and rigid behaviours (for example, over selectivity/'narrow' focus), and social difficulties (e.g., joint attention, face-processing).

What will Participation Involve?

This study will involve children between the ages of 6 and 16 years of age who have been diagnosed with an Autism Spectrum Disorder (ASD). In order to participate, individuals must: a) have at least a 2-year-old verbal ability in English; b) normal or corrected-to-normal hearing and vision; c) no known neurological issues (epilepsy, brain injury, etc.), and d) a previous diagnosis of an ASD by a psychologist or psychiatrist according to DSM-IV-TR criteria. Children will be asked to watch a short video and some pictures that have been created specifically to understand how children attend to and understand what they see and what they hear. The images and video that children will see include a woman telling a story, a woman making voice sounds, a piano being played, and some animated cartoons. During the session, the child's eye movements will be video recorded and tracked using eye-tracking equipment.

Along with this there will one cognitive (thinking) activity examining children's problem solving skills (e.g., working with puzzles) and one language activity (e.g., looking at pictures). Additionally, the Autism Diagnostic Observation Scale (ADOS), a structured observation scale children and adults with ASD will be administered. Overall, the experiment should take no longer than one and a half hours for your child.

Parents will also be asked to complete several questionnaires about a range of skills and characteristics of your child. These include thinking skills, self-control, communication and social skills, repetitive and sensory-type behaviors. An additional questionnaire will ask about your experiences obtaining a diagnosis for your child and any previous diagnoses that may have been given. We will also ask you to provide a copy of the diagnostic report for clarification. Parent involvement should take approximately 60 to 90 minutes.

Are there any Risks Involved?

All of the parts of this study have been reviewed and there are no risks involved. All information that is collected will be kept strictly confidential to the fullest extent possible by law. To ensure confidentiality, paper data will be stored in a locked cabinet, and other data will be stored on an external hard drive in an encrypted file that will be kept at the Child Learning Projects Lab at York University. The lab is also locked and only accessible by project personnel. All children will be given a participant number by which they will be identified. Data and audio-video recordings will be stored for an extended period after the study to enable comparison and combination with data in future studies. Once all projects in this line of research have been completed, all data and recordings will be destroyed (paper materials will be shredded and video will be destroyed). In the event that the results are published or presented, only grouped data will be used to guarantee anonymity. Any individual or personal information will be kept confidential. You will be provided with a small gift in appreciation for your participation. In addition, we will offer modest compensation for your travel, parking or transit, if you choose. This study is being conducted under the supervision of Dr. James Bebko, a professor at York University and a Clinical Psychologist.

Withdrawal from the Study: Participation is completely voluntary, *you or your child can withdraw from the study at any time* and it will not affect any of the services that you may currently be receiving. If you decide to stop participating, you will still be eligible to receive the promised compensation for agreeing to be in this project. Your decision to stop participating, or to refuse to answer particular questions, will not affect your relationship with the researchers, York University, or any other group associated with this project. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible.

Please read and sign the attached consent form indicating whether your child may or may not participate. Please feel free to ask me any questions or if you would like more information. Thank you for your interest and participation in this study, it is greatly appreciated!

Sincerely,

Carly McMorris
Doctoral Candidate

Lisa Hancock
Doctoral Candidate

INFORMED CONSENT FORM

Information Processing in Autism Spectrum Disorders: Understanding Attention and Intersensory Processing as Core Deficits

By signing this form, I agree that I have read and understood the description of the study, and that I allow my child to participate. I understand that the information collected about my child during this study will remain completely confidential within the limits of the law and that we may choose to stop participating at any time. I understand that participation in this study will in no way affect any services that we are receiving now or in the future. I agree to have my child's participation and eye-movements video-recorded for purposes of later analyzing looking patterns.

Parent/Guardian Name (please print) ____________________________________

Parent/Guardian Signature __________________________ Date_________________________

Relationship to the minor who is participating in this study:

____

Child's Name (please print): _____________________________________

Child's Date of Birth (d/m/y): _____________________________________

Child's current age (in years): _______________

Principal Investigator Signature________________________ Date

____

Questions about the Research? If you have questions about the research in general or about your role in the study, please feel free to contact us using the contact information below. You may also contact my Graduate Program – the Psychology Department Graduate office at (416) 736-5290. This research has been reviewed and approved by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Sr. Manager & Policy Advisor for the Office of Research Ethics, 309 York Lanes, York University (telephone 416-736-5914 or e-mail ore@yorku.ca).

Carly McMorris
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York University

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Additional Information ***(please complete the following information)***

Child's first language__________________ Child's most frequently used language_____________

By the age of **3**, was your child's language the same as typically developing children? ☐ YES ☐ NO

My child's hearing: Estimated test date_____________________

☐ has not been tested
☐ has been tested and no problems were found
☐ has been tested and the following difficulties were found:
____

My child's vision: Estimated test date______________________
☐ has not been tested
☐ has been tested and no problems were found
☐ has been tested and the following difficulties were found:
____

Has your child **ever** received Intensive Behavioral Therapy (IBI: at least 20 hours of behavioral therapy a week)? (Please note: This question is only to help us understand your child's previous experiences)
☐ YES ☐ NO

* Limited compensation for your travel, parking or transit is available, if you wish; would you like to receive $10.00 to partially cover these costs? ☐ YES ☐ NO

1. Do you wish to receive a brief summary of the grouped findings of this study? (*Please note that it may be* <u>*12 months*</u> *after completion of the study before all the results have been analyzed*)
☐ YES ☐ NO

2. Are you willing to be contacted for participation in future studies (no obligation)? ☐ YES ☐ NO

If you answered **YES** to either of the two above questions, please provide:

Name: ____

Mailing Address:
____

Telephone: _____________________________ Email Address:_______________________

Appendix F

Assent Form.

ASSENT FORM

Information Processing in Autism Spectrum Disorders: Understanding Attention and Intersensory Processing as Core Deficits

Why are we doing this study?
We would like to learn more about how people think about information and how they pay attention to and understand the things they see and hear.

What will happen during the study?
You will see some pictures and some special videos of people talking and some cartoons. We will use a computer to show us where you were looking and we will make a video recording of you while you are watching so we can see what you are looking at. After that we will do some activities where we will ask you to build things, tell us about some words, look at some books, make a puzzle, and play with some toys. When we are finished you will be given a small gift.

Are there good or bad things about the study?
Most kids like to watch this video and think the study is fun. We don't think that there are any bad things about the study.

Who will know about what I said or did in the study?
If you are part of this study, your name will not be given to anyone. We won't tell anyone about what you said or did. We will not show the videotape of you to anyone and will erase the video once the results are of no more use for us. Also, we will destroy any papers that we used in the study.

Can I decide if I want to be in the study?
You can decide if you want to be in the study. It is O.K. if you do not want to be part of the study. It is O.K. if you say yes now and change your mind later. Your parents know about the study and have said that you can be in it. Please ask questions that you have at any time.

Assent:
The study has been explained to me. I know that I can ask questions about the study at any time. I know that I can decide to stop at any time. I have been told that all of the videos and other information collected will not be given to anyone. It will only be seen by the research team.

____________________________	____________________________
NAME	SIGNATURE
____________________________	____________________________
Carly McMorris (Researcher) or Lisa Hancock (Researcher)	DATE

Appendix G

Results of normality tests for the Mixed2 dependent variables (SL, NSNL) in the MANOVA comparing the groups with TD and ASD.

		Skewness	**SE $_{Skewness}$**	**$z_{skewness}$**	**Kurtosis**	**SE $_{Kurtosis}$**	**$Z_{Kurtosis}$**	**Shapiro-Wilk Test**		
								Statistic	**df**	***p* value**
TD	**SL**	.169	.524	.322	-.445	1.104	.403	.984	19	.979
	NSNL	-.042	.524	.080	-.525	1.104	.475	.987	19	.991
ASD	**SL**	-.134	.550	.244	-.969	1.063	.911	.962	17	.679
	NSNL	.224	.550	.407	-.438	1.063	.412	.983	17	.979

Appendix H

Correlations among the Mixed2 dependent variables (SL, NSNL) for the group with TD.

	SL	**NSNL**
SL		-.989**
NSNL	-.989**	

**p < .01

Appendix I

Correlations among Mixed2 dependent variables (SL, NSNL) for the group with ASD.

	SL	**NSNL**
SL		-.957**
NSNL	-.957**	

**p <. 01

Appendix J

Results of normality tests for the Mixed1 dependent variables (SL, NSNL) in the MANOVA comparing the groups with TD and ASD.

		Skewness	SE $_{Skewness}$	$z_{skewness}$	Kurtosis	SE $_{Kurtosis}$	$Z_{Kurtosis}$	Shapiro-Wilk Test		
								Statistic	df	*p* value
TD	**SL**	.366	.512	.715	-.223	.992	.225	.969	20	.729
	NSNL	.124	.512	.242	-.403	.992	.406	.959	20	.525
ASD	**SL**	.718	.580	.1.238	.166	1.121	.892	.937	15	.342
	NSNL	1.361	.580	2.346	3.219	1.121	2.871	.890	15	.067

Appendix K

Correlations among the Mixed1 dependent variables (SL, NSNL) for the group with TD.

	SL	NSNL
SL		-.219
NSNL	-.219	

Appendix L

Correlations among Mixed1 dependent variables (SL, NSNL) for the group with ASD.

	SL	NSNL
SL		.121
NSNL	.121	

Appendix M

Results of normality tests for the dependent variables (SL, SNLO, SNLC, NSNL) in the MANOVA comparing looking time for the groups with TD and ASD.

		Skewness	**SE $_{Skewness}$**	**$z_{skewness}$**	**Kurtosis**	**SE $_{Kurtosis}$**	**$Z_{Kurtosis}$**	**Shapiro-Wilk Test**		
								Statistic	**df**	***p* value**
TD	**SL**	.649	.512	1.268	-.711	.992	.717	.920	20	.097
	SNLO	.228	.512	.445	-1.038	.992	1.046	.950	20	.362
	SNLC	-.051	.512	.996	-1.467	.992	1.48	.904	20	.050
	NSNL	.613	.512	1.197	.942	.992	.949	.955	20	.443
ASD	**SL**	1.484	.580	2.558	3.726	1.121	3.323	.868	15	.032
	SNLO	.384	.580	.662	-.928	1.121	.827	.943	15	.419
	SNLC	.964	.580	1.662	.555	1.121	.495	.907	15	.121
	NSNL	.622	.580	1.072	.274	1.121	.244	.963	15	.747

Appendix N

Correlations among dependent variables (SL, SNLO, SNLC, NSNL) in the MANOVA comparing looking time for the group with TD.

	SL	**SNLO**	**SNLC**	**NSNL**
SL		.477*	.444*	.352
SNLO	.477*		.622**	.592**
SNLC	.444*	.622**		.710**
NSNL	.352	.592**	.710**	

*p < .05, **p < .01

Appendix O

Correlations among dependent variables (SL, SNLO, SNLC, NSNL) in the MANOVA comparing looking time for the group with ASD.

	SL	**SNLO**	**SNLC**	**NSNL**
SL		.583*	.205	..166
SNLO	.583*		..607**	..193
SNLC	.205	.607**		.510*
NSNL	.166	.193	.510*	

*p < .05, **p < .01

Appendix P

Results of normality tests for the dependent variables (SL, SNLO, SNLC, NSNL) in the MANOVA comparing efficiency of gaze patterns for the groups with TD and ASD.

		Skewness	$SE_{Skewness}$	$z_{skewness}$	Kurtosis	$SE_{Kurtosis}$	$Z_{Kurtosis}$	Shapiro-Wilk Test		
								Statistic	df	*p* value
TD	**SL**	-.032	.512	.0625	-1.081	.992	1.090	.952	20	.403
	SNLO	-.623	.512	1.217	-.350	.992	.353	.925	20	.121
	SNLC	.068	.512	.133	-.746	.992	.752	.920	20	.097
	NSNL	-.934	.512	1.824	.222	.992	.224	.910	20	.065
ASD	**SL**	.077	.524	.147	-.071	1.014	.070	.970	19	.784
	SNLO	-.416	.524	.794	-.667	1.014	.658	.943	19	.300
	SNLC	.459	.524	.876	-.735	1.014	.725	.950	19	.391
	NSNL	-.540	.524	1.030	-.699	1.014	.689	.939	19	.254

Appendix Q

Correlations among dependent variables (SL, SNLO, SNLC, NSNL) in the MANOVA comparing efficiency of gaze patterns for the group with TD.

	SL	**SNLO**	**SNLC**	**NSNL**
SL		.593**	.252	.053
SNLO	.593**		.386	.429
SNLC	.252	.386		.449*
NSNL	.053	.429	.449*	

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

Appendix R

Correlations among dependent variables (SL, SNLO, SNLC, NSNL) in the MANOVA comparing efficiency of gaze patterns for the group with ASD.

	SL	**SNLO**	**SNLC**	**NSNL**
SL		.755**	.585**	.315
SNLO	.755**		.571*	.328
SNLC	.585**	.571*		.323
NSNL	.315	.328	.323	

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