Multisensory integration of low-level, non-social information in Autism Spectrum Disorder

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Abstract

In addition to difficulties regarding social communication and interaction, sensory abnormalities are present in the majority of individuals with Autism Spectrum Disorder (ASD), and this characteristic feature is part of the diagnostic criteria for ASD. Given the observed abnormalities in sensory reactivity, processing and perception, it has been suggested that the ability to integrate sensory information may be altered in ASD. Specifically, the ability to integrate information from more than one sensory modality at once, or Multisensory Integration (MSI) has been identified as potentially disrupted in ASD. In fact, altered MSI is thought to contribute to core behavioural features of ASD. Although this area of research in the field of ASD has gained some momentum, much of the evidence for altered MSI comes from studies that use socio-communicative stimuli (i.e., faces and voices). The current dissertation proposed to address this issue by evaluating MSI using 2 tasks void of socio-communicative content in order to remove the confounding effects of social stimuli on interpreting MSI data. Another goal was to broaden the age range investigated by including adults and adolescents in the two studies.

In Study 1, the ability to integrate auditory and visual information was evaluated in adults and adolescents with (n=20) and without ASD (n=20) using the Flash-Beep Illusion task. Both the ASD and the Typically-Developing (TD) groups were shown to have similar susceptibility to the fission illusion. However, the ASD group was significantly more susceptible to the fusion illusion. Results suggest that individuals with ASD show evidence of MSI on the flash-beep illusion task but that their integration of audiovisual sensory information may be more dependent on temporal factors and less selective than for TD individuals. In a second study (Study 2), multisensory facilitation of simple lower-level stimuli was evaluated in adolescents and adults with (n=20) and without ASD (n=19) using a reaction time (RT) paradigm. Reaction time in response to visual-only, auditory-only and multisensory audiovisual trials was compared in both groups. The race model analysis indicated that the race model violation occurred only for the TD group, not the ASD group. In other words, the ASD group did not demonstrate significant multisensory facilitation during the reaction time task whereas the TD group did. These results suggest that MSI is altered in ASD, even for information void of social content or complexity. Individuals with ASD may not benefit from the advantage conferred by multisensory stimulation to the same extent as TD individuals.

These findings, taken together provide support for the hypothesis that MSI is altered in ASD and that this alteration may be, at least in part, driving some of the socio-communicative deficits and restricted or repetitive behaviours and interests in ASD. The results are interpreted within the context of cognitive theories of ASD, and future directions for research and intervention are proposed in light of these findings.

Keywords*: Autism Spectrum Disorder (ASD), Multisensory Integration (MSI), Visual Processing, Auditory Processing, Flash-Beep Illusion, Reaction Time, Development*

Résumé

Outre des difficultés sociales et communicatives, la majorité des individus ayant un trouble du spectre de l'autisme (TSA) font preuve d'anomalies sensorielles. En fait, ces anomalies font partie des critères diagnostic du TSA. Compte tenu des anomalies observées au niveau de la réactivité, de la perception et du traitement de l'information sensorielle, la capacité à intégrer l'information sensorielle a été identifiée comme potentiellement altérée chez les personnes qui présentent un TSA. En particulier, il est supposé que la capacité à intégrer de l'information de plus d'une modalité sensorielle à la fois (i.e., intégration multisensorielle) est perturbée chez les personnes qui présentent un TSA. De plus, il est supposé que l'intégration multisensorielle (IMS) contribue aux caractéristiques comportementales fondamentales du TSA. Quoique la recherche dans ce domaine a pris de l'élan récemment, la majorité des études sur l'IMS chez les personnes qui présentent un TSA porte sur l'intégration des stimuli de nature socio-communicative. La présente thèse avait pour but d'adresser ce problème en évaluant l'IMS à l'aide de deux études qui utilisent des stimuli simples et non-sociaux afin de mieux comprendre l'IMS chez les personnes qui présentent un TSA. De plus, la présente thèse a tenté d'élargir la tranche d'âge en évaluant des adolescents ainsi que des adultes qui présentent un TSA pour les deux études.

Pour l'étude #1, la capacité à intégrer l'information auditive et visuelle a été évaluée à l'aide d'une tâche qui mesure la sensibilité aux illusions visuelles provoquées par l'information auditive chez des adolescents et adultes avec (n=20) et sans TSA (n=20). Les deux groupes (TSA et neurotypiques) démontrent un niveau de sensibilité semblable à l'illusion fission. Par contre, le groupe autiste était significativement plus sensible à l'illusion fusion. Ces résultats suggèrent que les individus autistes font preuve d'IMS, mais que leur intégration d'information

multisensorielle est moins sélective et qu'elle semble dépendre de facteurs temporels plus que chez les neurotypiques.

Pour l'étude #2, nous avons évalué la facilitation multisensorielle à l'aide d'un paradigme de temps de réaction chez des adolescents et des adultes avec (n=20) et sans TSA (n=19). Le temps de réaction aux stimuli visuels, auditifs, et audiovisuels a été comparé pour les deux groupes. Nous avons appliqué le modèle statistique «Race Model» et avons trouvé que seul le groupe neurotypique a violé le «Race Model». Ceci indique que les individus neurotypiques ont fait preuve de facilitation multisensorielle tandis que les individus avec un TSA n'ont pas démontré un tel effet. Les résultats suggèrent que l'IMS est altérée chez les personnes qui présentent un TSA, même lorsque les stimuli sont simples et non-sociaux. Les individus ayant un TSA ne semblent pas bénéficier de l'avantage conféré par la stimulation multisensorielle dans la même mesure que les neurotypiques.

Les résultats des deux études fournissent un soutien à l'hypothèse que l'IMS soit altérée chez les individus avec un TSA. De plus, cette différence semble influencer, au moins partiellement, les caractéristiques comportementales fondamentales du TSA tel les déficits sociaux et communicatifs ainsi que les comportements répétitifs. Les résultats sont interprétés dans le contexte des théories cognitives de l'autisme, et des orientations futures d'intervention et de recherche sont proposées.

Mots clés*: Trouble du spectre de l'autisme (TSA), Intégration multisensorielle (IMS), Traitement visuel, Traitement auditif, Illusion visuelle, Temps de réaction, développement.*

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Preface and Contribution of Authors

Two independent manuscripts are included in this dissertation. Both articles include original contributions to the field.

Manuscript 1 is presented in Chapter 3 and is an exact reproduction of the article *Multisensory integration of low-level information in Autism Spectrum Disorder: Measuring susceptibility to the flash-beep illusion*, published in the Journal of Autism and Developmental Disorders. It is authored by Vanessa A. Bao (VAB), Victoria Doobay (VD), Laurent Mottron (LM), Olivier Collignon (OC), Armando Bertone (AB). VAB planned and developed the experimental methodology with Armando Bertone. VAB recruited participants and collected data along with VD. VAB conducted data analyses. VAB interpreted data along with AB. LM and OC aided in the interpretation of data. VAB wrote the article and edited the paper, with feedback from VD, LM, OC, and AB. All authors read and approved the final manuscript.

Manuscript 2 is presented in Chapter 4 and is an exact reproduction of the article *Reduced multisensory facilitation in adolescents and adults with Autism Spectrum Disorder*, accepted for publication in Scientific Reports. It is authored by Vanessa A. Bao (VAB), Alexia Ostrolenk (AO), Laurent Mottron (LM), Olivier Collignon (OC), and Armando Bertone (AB). VAB planned and developed the experimental methodology with AB. VB recruited participants and collected data. AO and VAB conducted data analyses, and interpreted data. VAB wrote the article, AO participated in drafting the article. VAB edited the paper, with feedback from AO, LM, OC, and AB. All authors read and approved the final manuscript.

Chapter 1

Introduction

The vast majority of individuals with Autism Spectrum Disorder (ASD) experience sensory abnormalities and process sensory stimuli differently than typically developing individuals (Hazen, Stornelli, O'Rourke, Koesterer, & McDougall, 2013; O'Neill & Jones, 1997). In addition to unimodal (i.e., information from one sensory modality) sensory abnormalities, it has been hypothesized that multisensory integration (i.e., the simultaneous integration of sensory information from more than one modality) may be atypical and underlie core features of ASD (Iarocci & McDonald, 2006; Marco, Hinkley, Hill, & Nagarajan, 2011). Although some research findings have lent credence to this hypothesis, many of these studies were conducted using socio-communicative stimuli, which likely confound any results suggesting the existence of impaired MSI in autism.

More recently, research efforts have focused on evaluating MSI using non-social stimuli. Despite this improvement in methodological considerations, MSI processes in ASD remain under-defined. Various studies with similar methodology yield different results, study designs do not typically take into account development, stimulus complexity or temporal factors of sensory processing, and homogenous participant pools make drawing any firm conclusions difficult. Given that MSI may be underlying many of the other features of ASD, it is crucial that this phenomenon be better understood as it may lead to important conclusions about the nature of perceptual, sensory, social, and behavioural characteristics of ASD.

In this thesis, I study MSI of simple lower level info via visual illusions as well as reaction time, and I investigate age related changes in MSI in ASD and typical development by examining adolescents and adults. In the two experiments included in this thesis, I evaluate a) the automaticity of multisensory integration, and b) the presence of multisensory facilitation, in adolescents and adults with and without ASD using lower level simple stimuli. This thesis is presented in 5 chapters. Chapter 2 constitutes a literature review which provides an in-depth review of the research on multisensory integration in ASD.

Chapter 3 presents the first article entitled “Multisensory integration of low-level information in Autism Spectrum Disorder: Measuring susceptibility to the flash-beep illusion”. In this article, we examined multisensory integration of simple, lower-level visual and auditory information in ASD by using the flash-beep illusion paradigm. This paradigm allows for the study of the automatic integration of visual and auditory information by relying on the principle that sensory information is integrated so automatically that it can lead to illusory perception. (Foxe & Molholm, 2009). The objective of our study was to identify whether individuals with ASD were subject to the same illusory perception as typically developing individuals when exposed to the flash-beep illusion task (Shams, Kamitani, & Shimojo, 2000; Shams, Kamitani, & Shimojo, 2002). Additionally, we sought to identify whether there were age-related changes in the automatic integration of auditory and visual information by investigating these processes in adolescents and adults. This article was published in the *Journal of Autism and Developmental Disorders* (Bao, Doobay, Mottron, Collignon & Bertone, 2017).

Chapter 4 presents the second article entitled “Reduced multisensory facilitation in adolescents and adults with Autism Spectrum Disorder”. We sought to further investigate the ability to integrate lower-level auditory and visual stimuli in ASD using a simple reaction time task. Specifically, reaction time in response to simple auditory, simple visual and simultaneously presented audio-visual information was compared in adolescents and adults with and without ASD. The purpose of using this approach was to further reduce the potentially confounding effects of stimulus complexity and task complexity in the evaluation of MSI in ASD. This article was accepted for publication to the journal *Scientific Reports* and is undergoing revisions prior to publication.

Finally, an overall summary of the research presented in this thesis and a discussion highlighting clinical and research implications of the findings, and limitations is expounded in Chapter 5. Future directions in research are also broached in this chapter.

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Chapter 2

Literature Review

Autism Spectrum Disorder

Autism Spectrum Disorder (ASD), a neurodevelopmental disorder with current conservative prevalence estimates of approximately 69/10,000 people, affects many families emotionally and financially, and accounts for a great deal of health research. (Presmanes-Hill, Zuckerman & Fombonne, 2015). The diagnostic criteria for ASD have changed substantially since its recognition as a distinct disorder. It is currently characterized by the presence of impairments in: 1) socio-communicative functioning, as well as, 2) repetitive/restricted patterns of behaviours and interests (American Psychiatric Association, 2013). The repetitive behaviours criterion encompasses: (1) stereotyped/repetitive behaviours or speech, (2) insistence on sameness, strict adherence to routines, or ritualized behaviour, (3) restricted, fixated interests abnormal in intensity or focus, and (4) hyper- or hypo-reactivity to sensory information or unusual interest in sensory information (APA, 2013). With regards to sensory reactivity, individuals with ASD often exhibit an aversion to certain sensory stimuli (e.g., withdrawing from specific noises like the sound of a vacuum cleaner, avoiding certain textures or smells) and/or, seek out sensory experiences through stimulatory behaviours (e.g., peering, echoing, tapping surfaces; Kern et al., 2006; Lovaas, Newsom & Hickman, 1987).

Sensory Abnormalities in ASD

Although sensory abnormalities were referred to in the first descriptions of the disorder (Kanner, 1943), they were only added to the DSM diagnostic criteria for ASD in 2013 (APA, 2013). This addition constituted a significant shift in the conceptualization of ASD and likely came as a result of numerous studies highlighting the ubiquity of sensory abnormalities.

Accounts of altered sensory experiences have been noted in first-hand reports of individuals with ASD as well as via extensive psychological and experimental studies (O'Neill & Jones, 1997). Parental reports have also been heavily relied upon to provide data as to the extent of sensory processing issues in their children. Leekam, Nieto, Libby, Wing, and Gould (2007) looked at parental report of sensory abnormalities in children with high- and low-functioning ASD, which they compared to a typically-developing (TD) comparison group as well as two clinical comparison groups (i.e., a language impairment group and a developmental disability group). Their results indicated that in the TD group, only 33% showed sensory abnormalities, whereas the figures for the clinical comparison group were 65%, and were 94% for the ASD group (Leekam, Nieto, Libby, Wing, & Gould, 2007). What this seems to suggest is that sensory abnormalities in ASD are strikingly common and that they appear to be present regardless of level of functioning (i.e., high-functioning and low-functioning). Hazen, Stornelli, O'Rourke, Koesterer, and McDougall (2014) conducted a literature review and noted that the prevalence of sensory issues in ASD is thought to vary between 69 and 95%. These rates strongly suggest that sensory abnormalities are a concern for the vast majority of individuals with ASD.

Furthermore, sensory abnormalities have been shown to occur across development in ASD (Ben-Sasson et al., 2009; Hazen, et al., 2013), meaning that these issues are not resolved as an individual with ASD gets older. Research has also supported the notion that the sensory issues that exist in ASD are present across sensory modalities (Pellicano, 2013). Individuals with ASD were found to have significantly altered auditory, visual, oral and tactile sensory processing, suggesting there may be a global sensory issue in ASD rather than a modality-specific disturbance (Kern et al., 2006). Overall, these findings indicate that sensory abnormalities are an issue for most individuals with ASD throughout their lifetime, and impact functioning of all senses. This underlines the significance of the DSM-5's inclusion of sensory issues and the need to further investigate perceptual and sensory processes in autism.

In light of the significance of sensory processing abnormalities, it has been suggested that these may actually underlie some of the core social and behavioural characteristics and impairments of ASD (Iarocci & McDonald, 2006; Marco, Hinkley, Hill, & Nagarajan, 2011). The argument is such: if sensory processing is altered or impaired at the lower level, there would be a cascading effect impacting higher-order processes. For instance, disruption in basic visual or auditory processing may contribute to deficits found at the higher level, such as socio-communicative functioning (Marco et al., 2011). Maekawa et al. (2011) studied lower level visual processing in individuals with ASD and found abnormalities at the cortical level. They suggest that atypical visual processes may be related to higher-order functions that have been implicated as altered in ASD (e.g., face-processing). Hilton, Graver, and LaVesser (2007) found a link between socio-communicative impairments and sensory processing impairments. They showed that as the rate and severity of sensory abnormalities increased, ratings of social responsiveness decreased. In yet another study, sensory processing abnormalities were found to be predictive of communicative impairments and maladaptive behaviours (Lane, Young, Baker, & Angley, 2010). Other studies have shown significant relationships between sensory processing issues and behavioural/emotional problems (Baker, Lane, Angley, & Young, 2008; Chen, Rodgers, & McConachie, 2009; Lovaas, Newsom, & Hickman, 1987).

Cognitive Theories of Autism Spectrum Disorder

Given the prevalence of sensory abnormalities, and the extent to which they appear to affect the social, perceptual and behavioural experiences of individuals with ASD, various theories have been proposed in an attempt to explain these abnormalities. The goal in developing these theories was to explain the seemingly disjointed characteristics of ASD within a single unified theory, and attempt to make the link between sensory processing atypicalities and the other core features of ASD (i.e., socio-communicative impairments, repetitive behaviours and interests). A selection of the most influential theories is described in the following section.

Weak central coherence. Weak Central Coherence (WCC) theory, in contrast to previous theories of functioning in ASD (e.g., the Theory of Mind account), attempted to provide an explanation for the socio-communicative deficits, behavioural features, and sensory issues in ASD (Frith & Happé, 1994; Happé, 1994). While the WCC theory took into account areas of impairment in autism, it also attempted to explain areas of relative strength (Happé, 1994).

The concept of “central coherence” is described as the typical approach to information processing, whereby individuals tend to process information to obtain general meaning or a global representation of information; they pull together different pieces of information to understand the larger context (Frith & Happé, 1994; Rajendran & Mitchell, 2007). Instead, individuals with ASD have appeared to focus on parts of objects or of their environment rather than the whole picture (Frith & Happé, 1994; Happé & Frith, 2006). The WCC theory rests on the premise that information is integrated atypically in ASD (Frith & Happé, 1994; Frith, 1997). This account helps to explain the perceptual processing abnormalities in ASD and also speaks to the difference in integrating sensory information from the same sensory modality or from various modalities at once. Since its inception, the Weak Central Coherence theory has changed and adapted itself to new information from empirical research. For instance, the WCC no longer explains the sensory alterations in ASD as a deficit in global information processing, but rather as a superior ability to process local information (Rajendran & Mitchell, 2007). Happé (1999) explains that instead of interpreting weak coherence of information as evidence for an overall deficit in ASD, perhaps it should be seen as a cognitive style. Although the WCC theory has adapted itself to better explain discordant research findings, other theories have also been developed that may in some ways better account for the sensory differences in ASD.

Enhanced Perceptual Functioning. The Enhanced Perceptual Functioning (EFP) model of autism was also developed to help better explain perceptual and sensory differences in ASD (Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert & Burack, 2006). Contrary to the traditional WCC theory, EFP emphasizes areas of superior performance rather than focusing on deficits, and its implications are more wide-ranging than those of other cognitive hypotheses (Mitchell & Ropar, 2004; Mottron & Burack, 2001; Simmons, Robertson, & McKay, 2009).

The EFP theory hypothesizes that the pattern of behaviour, as well as the specific neural and cognitive processes in ASD, are related to a more independent and enhanced functioning of perceptual processes as compared to TD individuals (Mottron et al., 2006). According to the theory, perception in ASD is characterised by a local perceptual bias, as well as enhanced functioning of low-level perceptual mechanisms during both sensory and cognitive tasks (Mottron & Burack, 2001; Mottron et al., 2006).

Temporal binding deficit. The temporal binding deficit hypothesis has been advanced to explain the neural underpinnings of the core and non-core features of ASD (Brock, Brown, Boucher & Rippon, 2002). The authors expanded on the WCC theory by providing a hypothesis for the neural mechanisms that lead to the features of ASD. According to Brock, Brown, Boucher and Rippon (2002): “whereas typical brain development involves the emergence of functionally specialized but nevertheless integrated regions, brain development in autism involves the emergence of functionally specialized brain regions that become increasingly isolated from each other over time" (p. 212). The main implication of the theory is that there may be reduced or altered neural integration across different areas of the brain (Baum, Stevenson & Wallace, 2015; Brock et al., 2002). This is particularly relevant when considering the integration of sensory information from multiple sensory modalities since it requires that different brain regions communicate efficiently to form an integrated percept. Furthermore, this account is considered to help explain not only perceptual processing and sensory integration, but can provide an explanation for behavioural abnormalities, executive functioning deficits and socio-communicative impairments (Brock et al., 2002).

At the behavioural level, temporal binding windows (TBW) have been explored in ASD. The concept of TBW's refers to the window of time during which two stimuli occurring successively will actually be perceived as occurring simultaneously. An adaptive function, it allows for multisensory information to be integrated even when there might be slight temporal asynchronies (Wallace & Stevenson, 2014). In individuals with ASD, it appears that there might be an enlarged or expanded temporal binding window as compared to TD individuals (Foss-Feig et al., 2010; Kwakye, Foss-Feig, Cascio, Stone & Wallace, 2011; Noel, Lytle, Cascio & Wallace, 2017; Stevenson et al., 2014a; Wallace & Stevenson, 2014). An enlarged TBW signifies that individuals with ASD would perceive asynchronous stimuli as simultaneous more so than TD individuals would. In a recent meta-analysis by Zhou et al. (2018), it was found that regardless of the task used to measure TBW's, individuals with ASD showed an enlarged temporal binding window.

Although the above theories differ in some important aspects, a common thread to them all is the implication for sensory integration. Due to the far-reaching implications of an integrative atypicality in ASD, the following section will describe what is currently known about sensory integration in ASD. Particular attention will be paid to the role of stimulus complexity and context (i.e., social vs. non-social) in the ability to integrate multisensory information.

Sensory Integration

Unimodal sensory integration is defined as the process by which different elements of information from one sensory modality become integrated into a whole. An example of such a process would occur when looking at a picture with many details. The visual system needs to integrate all these details in order to be able to perceive the overall scene of the picture. Sensory integration of unimodal information has been implicated as potentially problematic in ASD. Studies have investigated the veracity of these claims by evaluating susceptibility to visual illusions for instance, as well as face processing abilities, auditory integration, etc. (Bedford, Pellicano, Mareschal & Nardini, 2015; Maekawa, et al., 2011; Ropar & Mitchell, 2001).

Although the study of unimodal integration can be helpful to better understand different unisensory experiences, multisensory integration (MSI) may be a more ecological construct in that it more accurately reflects sensory experiences in daily life. Despite this, much of the sensory research in typical development as well as in ASD centers on unimodal sensory processing (Bremner, Lewkowicz, & Spence, 2012; DeGelder & Bertelson, 2003). Thus, most of our understanding of cognitive and sensory development continues to be viewed through a unimodal lens rather than a multimodal one (Bremner et al., 2012). However, a shift toward investigating multisensory processes instead of only focusing on unimodal integration has begun to take hold (Calvert & Thesen, 2004).

Multisensory Integration

The brain is organized in such a way to allow us not only to distinguish information from different modalities but also to integrate this information (Stein & Meredith, 1990). Most of the situations we encounter daily involve stimulation of more than one sensory modality at a time (De Gelder & Bertelson, 2003). For instance, simply taking a drink of coffee targets most of our senses all at once. Our perception is influenced by our visual experience of seeing the coffee and the steam rising from it, holding the cup and feeling its heat, smelling and tasting the coffee, and even hearing the sound made when taking a sip. In any given situation, we must constantly be integrating different pieces of information in order to create a unified percept. Multisensory integration (MSI) is the process by which information from multiple sensory modalities are integrated into a whole (Stein, 2012; Stein & Meredith, 1993). It is through MSI that we perceive and understand that a person's moving mouth and the sound they make when speaking are actually two components of the same event and do not constitute distinct and unrelated occurrences. Without this automatic integration, the perception of our surroundings would be disjointed, confusing and potentially overwhelming.

The most important advantage of MSI is that it allows us to process incoming information more effectively (Foxe & Molholm, 2009; Hillock, Powers, & Wallace, 2011; Stein & Meredith, 1993). In fact, the advantage conferred by MSI, referred to as multisensory facilitation, goes beyond what would be expected due to the effect of sensory redundancy (Girard, Pelland, Lepore & Collignon, 2013; Stein, Wallace & Stanford, 1999). Although common sense explains why having twice the amount of sensory stimulation (i.e., multi-modal information presented together) would lead to faster responding, the effectiveness and speed of responding to multi-modal information is greater than the sum of its parts (i.e., MSI responding is quicker than what would be expected from summing the response to both unisensory pieces of information; Spence, 2007).

Multisensory integration is also an automatic and largely unconscious process (Foxe & Molholm, 2009). However, despite its automaticity, specific stimulus- and task-related factors dictate whether or not multimodal sensory information becomes integrated (Spence, 2007). Spatial and temporal congruence influences the ability to integrate multisensory information (Hillock et al., 2011; Spence, 2007; Stevenson & Wallace, 2013). As the temporal or spatial gap between sensory information from multiple modalities increases, the ability to integrate the two decreases (Calvert & Thesen, 2004; Hillock, et al., 2011). Semantic congruence is another stimulus-related factor that influences the ability to integrate information. Here, cognitive factors play a role in determining whether two pieces of information actually make sense together (Spence, 2007). For instance, the sound of a bark is more easily integrated with the visual percept of a dog than of a cat (Russo, Mottron, Burack & Jemel, 2012).

Task-related factors also influence the integration of sensory information. The modality appropriateness hypothesis states that the sensory modality that is most relevant to the completion of a particular task will influence the perception of the other modalities (Welch & Warren, 1980). Vision has “higher spatial resolution” so it will dominate and alter the perception of sound on spatial tasks, but sound, which has a “higher temporal resolution”, will alter the perception of other sensory modalities on tasks that are more temporal in nature (Welch & Warren, 1980). However, more recent work suggests that a reliability-based framework of sensory integration may be more appropriate in describing auditory-visual multisensory effects (Alais & Burr, 2004). According to this perspective, the sensory modality that provides the most reliable information in a given situation takes precedence over the other (Andersen, Tiippana & Sams, 2004; Ernst & Banks, 2002).

In sum, MSI is a crucial process that mediates the speed, accuracy, effectiveness and adaptability with which we interact with our environment and make sense of the world around us. Despite its importance, however, MSI is not as well understood in ASD than it is in typical development. Many questions remain regarding the way MSI manifests and develops in ASD.

Multisensory Integration in ASD

As previously described, various cognitive theories have hypothesized that there may exist altered information integration in ASD, and that this alteration may be at the root of the core features of ASD (Brock et al., 2002; Frith & Happé, 1994; Marco et al., 2011; Mottron & Burack, 2001). Foxe and Molholm (2009) explain the reasoning behind the purported link between impaired MSI and the core features of ASD. If individuals with ASD do in fact have difficulty integrating sensory information, "the environment would become a much more complex and confusing space" (Foxe & Molholm, 2009, p.151), and they would be overwhelmed by the amount of incoherent information in their environment. By being unable to make sense of the massive amounts of sensory information they are constantly being bombarded with, individuals with ASD might then withdraw in an attempt to reduce the confusion (Foxe & Molholm, 2009). Some of the sensory aversion and sensory seeking behaviours may also be explained as an effort to cope with the overload of information.

MSI of socio-communicative stimuli in ASD. Due to the wide-ranging implications of a potential multisensory integration deficit in ASD, there has been increasing interest in this area in recent years. Much of the information on MSI in ASD has originated from studies examining the integration of sensory stimuli that are socio-communicative in nature (i.e., speech and faces).

The McGurk effect is a striking example of the automaticity of MSI and has been the paradigm of choice for studying MSI in TD individuals as well as in ASD (Foxe & Molholm, 2009; Iarocci & McDonald, 2006). The McGurk illusion occurs when participants unwittingly integrate discordant auditory and visual stimuli, which results in an illusory percept. When participants see a person mouthing the syllable “ga” while hearing the syllable “ba”, the auditory and visual information is integrated, and results in the erroneous perception of having heard “da” (McGurk & MacDonald, 1976). Susceptibility to the illusion (i.e., presence of the McGurk effect) is thought to be indicative of intact multisensory function. The McGurk illusion is so robust in the typically developing population that conscious awareness of its effect does not help to alter faulty perception. However, the effect is not as clear-cut in individuals with autism.

While some studies have identified a diminished McGurk effect in ASD (Bebko, Schroeder, & Weiss, 2014; Mongillo, et al., 2008; Williams, Massaro, Peel, Bosseler & Suddendorf, 2004), others have found that the effect is contingent on developmental factors (Taylor, Isaac & Milne, 2010), socio-communicative impairments (Iarocci, Rombough, Yager, Weeks & Chua, 2010), or task-related temporal factors (Woynaroski et al., 2013). In typical development, susceptibility to the McGurk illusion is influenced by age effects. Specifically, different maturational patterns for speech vs. non-speech integration were found among TD children and adolescents (Tremblay et al., 2007). Younger children were less susceptible to the McGurk effect than older children, but there was no effect of age on to the non-speech task. This would suggest that the ability to integrate multisensory social information develops at a different rate than for non-social information in typical development. It would follow that developmental factors may impact susceptibility to the McGurk effect in ASD as well.

Taylor, Isaac and Milne (2010) evaluated the developmental trajectory of the McGurk effect in children and adolescents with ASD. They found evidence for an age effect, whereby younger children with ASD had reduced audiovisual integration, but that there appeared to be a rapid catch-up period in the later age groups. Their findings might indicate that although children with ASD initially lag behind their TD counterparts at younger ages, they eventually catch up and perform at similar levels in adolescence (Taylor, Isaac, & Milne, 2010). Another group found very different results to those seen by Taylor et al. (2010); younger children with ASD were shown to have a similar McGurk effect compared to younger TD children, but older children with ASD demonstrated a reduced effect (Stevenson et al., 2014b). The authors hypothesize that methodological differences such as the use of different syllables may be leading to the inconsistency with past research findings. Unfortunately, the developmental trajectory of the McGurk effect is still not well defined. Another study testing the McGurk effect in children with ASD found that while there was evidence for altered multisensory processing as compared to TD children, the effect disappeared once lip-reading ability was controlled for (Iarocci, Rombough, Yager, Weeks, & Chua, 2010). The conclusions drawn from this study suggest that lip-reading and socio-communicative deficits in general may be contributing to a reduced McGurk effect rather than there existing an inherent difficulty integrating sensory information. Although the McGurk illusion has been a helpful tool in defining multisensory functions in typical as well as clinical groups, the results are inconsistent and the use of such an illusion poses a serious problem for interpretation. Specifically, it is very difficult to determine whether poorer performance on the McGurk task is due to altered multisensory integration or whether it simply captures the socio-communicative impairments of ASD due to the social nature of the task.

The speech-in-noise paradigm has also been used to better understand multisensory integration processes in typical development as well as in ASD. Contrary to the McGurk task, which measures MSI by evaluating the illusory perceptions that results from MSI's automaticity, the speech-in-noise paradigm is based on the facilitatory effect of multisensory stimulation. Here, participants hear the sound of a person speaking with various degrees of distracting auditory noise. The idea is that adding a visual stimulus (i.e., video clip of the person who is speaking) should normally provide multisensory facilitation; the perceptual accuracy of what is heard would increase with the addition of facilitatory visual information. The speech-in-noise approach has also been described as more ecologically valid than other MSI tasks (i.e., McGurk), since MSI of socio-communicative information is most relevant in situations where one needs to rely on visual cues to better understand speech in noisy conditions (Smith & Bennetto, 2007).

When comparing adolescents with and without ASD, Smith and Bennetto (2007) found that the facilitation provided by the addition of visual information to the comprehension of speech in a noisy environment was significantly greater in the TD group. Controlling for lip-reading ability only seemed to account for a portion of the MSI impairment seen in the ASD group (Smith & Bennetto, 2007). Since lip-reading cannot account for the entire effect of reduced multisensory facilitation in ASD, it follows that the results might be indicative of a more general impairment in socio-communicative sensory integration. Foxe et al. (2015) expanded upon these results by using a similar experimental method, but paid particular attention to potential developmental differences in MSI in ASD. Whereas younger children showed significant deficits in their audiovisual speech integration ability, older children (i.e., above 13 years of age) did not (Foxe et al., 2015). These results mirror some of the developmental findings of studies using the McGurk task. Although MSI development in ASD may be delayed in comparison to typically developing children, there may be a catch-up period in early adolescence (Foxe et al., 2015).

When speech is difficult to hear, gestures can help to support speech comprehension. Although this is true in typical development, children with ASD have more difficulty processing gestures (Silverman, Bennetto, Campana, & Tanenhaus, 2010). In an MSI task using gestures, adolescents with and without ASD were exposed to the sound of a person describing a complex shape and had to identify the shape that was described (Silverman et al., 2010). One condition was solely auditory (i.e., speech alone), and the other, which included facilitatory gestures to accompany the shape description, was multisensory. The results of the study were such that not only was there no evidence of multisensory facilitation in the ASD group when visual information was added to help process the auditory information, but the addition of gestures actually had a detrimental impact on speech comprehension (Silverman et al., 2010).

Magnée, de Gelder, van Engeland, and Kemner (2008) studied audiovisual speech integration but varied the congruency of the audiovisual stimuli (i.e., whether or not the auditory and visual stimuli matched). They evaluated behavioural responses as well as collected electrophysiological data via EEG (Magnée, de Gelder, van Engeland, & Kemner, 2008). The PDD group showed a similar pattern as the TD group, with reduced amplitudes and increased temporal facilitation during multimodal trials as compared to unimodal trials. This was thought to be indicative that lower-level sensory integration might be intact in ASD. However, whereas a congruency effect was found in the TD group (i.e., delayed responding to incongruent stimuli), this effect was not seen in the PDD group. So, although multisensory audiovisual integration may be occurring normally in ASD, the complexity of the information (e.g., phonological, social) affects integration.

Another study investigated congruency effects in audiovisual speech integration and temporal synchrony in young children with ASD (i.e., 4-6 years old) using a simple preferential looking paradigm for synchronous/asynchronous 1) non-linguistic, 2) simple linguistic, and 3) complex linguistic stimuli (Bebko, Weiss, Demark, Gomez, 2006). Results were such that children with ASD only had preferential looking toward synchronous non-linguistic displays (Bebko, et al., 2006). Moreover, there was a significant correlation between the language abilities of children with ASD and the time spent looking at complex linguistic stimuli, indicating that the higher the language ability, the higher the interest in linguistic stimuli. It can be interpreted that findings of impaired MSI in autism might be driven by the socio-communicative impairments of ASD.

Autism researchers have also investigated MSI using emotional expressions as sensory stimuli. Charbonneau et al. (2013) used a classic multisensory facilitation paradigm (i.e., comparing response time for auditory-alone, visual-alone, and audiovisual conditions) to identify whether there were differences between a group of adolescents and young adults with and without ASD. The premise behind this experimental approach is that performance would be facilitated (i.e., increased accuracy and faster reaction time) by the presence of information from both sensory modalities at once. Although the ASD group did experience multisensory facilitation, the effect was not as large as it was for the TD group (Charbonneau, et al., 2013), suggesting that there is evidence for reduced multisensory facilitation for emotional expression stimuli, but not an inability to integrate multisensory information per se.

The results of studies investigating MSI using socio-communicative stimuli are problematic for a number of reasons. First and foremost, the use of complex, often linguistic, stimuli makes it extremely difficult to draw any firm conclusions about the nature of sensory integration in ASD. Due to socio-communicative impairments, which are a core feature of ASD, one cannot take the above evidence of "impaired or reduced" multisensory functioning at face value due to the confounding use of faces, voices, and gestures as the task stimuli. Moreover, of the limited data available on MSI of social information, there is inconsistency in the results, and disagreement about the nature and developmental trajectory of MSI. Some studies have even found different patterns of results when comparing performance on tasks using simple stimuli to those using socio-communicative stimuli (Bebko et al., 2006; Magnée, et al., 2008). It has been suggested that these discrepancies found between social and non-social MSI abilities are related to exposure and developmental effects (Foxe et al., 2015; Mongillo et al., 2008). Perhaps, due to a preference for non-speech sounds in early childhood, children with ASD may be attending less to speech sounds, thus reducing the exposure to this sensory input. This begs the questions: Is there a fundamental alteration of multisensory integration in ASD when the confounding effects of the use of complex, higher-level stimuli are eliminated?

MSI of non-social stimuli in ASD. The best way to address whether there is a basic alteration in MSI (i.e., a true "weak" coherence of sensory information) is to research MSI using low-level, non-social stimuli. Very few studies have explicitly investigated MSI abilities in ASD using non-social stimuli, and the ones that have, have shown mixed results. Furthermore, only three studies to date have attempted to control for stimulus complexity by testing the same participants on both social and non-social tasks (de Boer-Schellekens, Eussen, & Vroomen, 2013a; Mongillo et al., 2008; Stevenson et al., 2014a). Mongillo et al. (2008) found that while children with ASD performed worse than a TD group on social tasks (e.g., McGurk task, vowel match-mismatch task), there was no difference in performance between groups on non-social tasks. These types of study designs, which intentionally investigate whether there is a difference in sensory integration depending on stimulus complexity or task demands, are rare but crucial if any conclusions are to be made about the nature of MSI in ASD.

Studies that have exclusively looked at MSI of low-level information have yielded mixed results. Some have suggested that MSI may be problematic in ASD, whereas others find no evidence of a disturbance in integration when stimulus and task factors are controlled for. De Boer-Schellekens, Keetels, Eussen, and Vroomen (2013b) used the pip-and-pop paradigm in their study and found a multisensory facilitation effect in ASD (de Boer-Schellekens, Keetels, Eussen, and Vroomen, 2013b). The pip-and-pop paradigm involves a visual search task where participants must identify a target line segment (i.e., horizontal or vertical) among distractor lines (i.e., diagonal). The target line changes colour at random intervals. Visual search is done in two conditions: 1) simple visual search, and 2) presence of a facilitatory sound when the target line changes colour. Collignon et al. (2013) also ran the pip-and-pop test on adults with and without ASD, and found contradictory results. Specifically, it appeared that the ASD group was not experiencing multisensory facilitation (Collignon et al., 2013).

The simplest method used to assess low-level MSI is the reaction time (RT) paradigm. Participants are exposed to 3 conditions: 1) visual only, 2) auditory only, and 3) audiovisual multisensory presentation. The expectation is that typical multisensory function would lead to a facilitatory effect (i.e., faster reaction time) during the audiovisual condition. Children and adolescents (7-16 years old) with ASD were tested using this approach (Brandwein et al., 2013). While the TD comparison group showed evidence for multisensory facilitation, the ASD group, both at the younger and older age groups did not.

Russo, Mottron, Burack, and Jemel (2012) did an MSI task of non-social semantic congruence with adolescents and adults with ASD. The ASD and TD group did not differ in their behavioural performance (i.e., accuracy and reaction time) for audiovisual multisensory information presented either sequentially or simultaneously. However, the researchers also measured event-related potentials (ERP) to detect timing differences in neural processing. They found that while the ASD group processed incongruent sensory information (e.g., seeing a dog, but hearing “meow”) with seemingly no difference at the behavioural level, they did so at different latencies. The ASD group was processing information at a more “perceptual” level (i.e., modulations in the 150-300ms range) whereas the TD group was doing so at a more “cognitive” or higher-order level (i.e., the typical N400 time frame; 300-500ms). Also, the ASD group appeared to be using different areas of the cortex than the TD control group to support this processing. The implication here seems to be that multisensory semantic integration occurs in different brain regions and at different latencies. Non-social semantic priming tasks have also been studied in adult groups. High-functioning adults with Asperger’s were shown to perform with similar levels of speed and accuracy as compared to a TD group when presented with congruent and incongruent non-social stimuli (David, Schneider, Vogeley, Engel, 2011).

Much like the McGurk task, the flash-beep illusion task is a common method used to assess MSI by evaluating the susceptibility to illusions, and it has been identified as fairly robust in the TD population (Shams, Kamitani, & Shimojo, 2000; Shams, Kamitani, & Shimojo, 2002). The flash-beep illusion is a phenomenon that occurs when visual information is misperceived due to the influence of incongruent auditory information. For instance, when a single flash (visual stimulus) is presented with multiple beeps, the flash is actually perceived as being multiple flashes (i.e., fission illusion). The reverse occurs when two flashes are paired with one beep (i.e., the fusion illusion results and the two flashes are perceived as a single one). Van der Smagt, Engeland, and Kemner (2007) were the first to study susceptibility to the flash-beep illusion in individuals with ASD. Using methods similar to those developed by Shams et al. (2000), they found evidence for both the fusion and fission illusion in a group of adolescents and young adults with ASD, and no significant differences with the TD comparison group (van der Smagt, Engeland, and Kemner, 2007).

Children with ASD do not appear to show the same pattern of results on the flash-beep illusion task as adolescents and adults. Foss-Feig et al. (2010) modified the original paradigm by altering the temporal presentation of the beeps in conjunction with the flash. In doing so, they were able to determine whether temporal factors might be at play in integrating visual and auditory information to produce the flash-beep illusion. They found that children with ASD were susceptible to the fission illusion (the fusion illusion was not studied) over a larger temporal window than typically developing children. Whereas the TD group stops perceiving the illusion once the timing between the auditory and visual stimuli becomes too large, the ASD group continue to be impacted by the illusory effect (Foss-Feig, et al., 2010). Another study, which also only examined the fission illusion, was done with slightly younger children and determined that children with ASD had reduced illusory susceptibility (Stevenson et al., 2014b). The authors interpret these findings as indicative of a diminished ability to integrate low-level stimuli in ASD. One major limitation to both the studies of the flash-beep illusion with children with ASD is the sole focus on the fission illusion. Conceptually, the fission illusion results in splitting, or differentiating visual information, but the fusion illusion requires the ability to combine two pieces of visual information into one based on auditory information. Thus, the fusion illusion may be a more useful construct by which to measure multisensory integration. In addition, age effects may well be driving the different results seen in the four studies that have investigated the flash-beep illusion in ASD. Those that have focused on adolescents and adults find no difference between ASD and TD groups, whereas the studies done with children find behavioural and/or temporal differences. Age effects have been shown to play a role in MSI performance in TD and have been hypothesized to influence MSI in ASD (Foxe et al., 2015; Tremblay, et al., 2007).

The concept of an enlarged temporal binding window has driven much of the MSI research in ASD. The temporal order judgement (TOJ) task has been used to assess temporal windows for sensory perception. The TOJ task examines MSI via the ability to dissociate rather than integrate sensory information by varying the stimulus onset asynchronies (Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011). In one study, individuals with ASD needed stimuli to be further apart in time than TD participants did in order to identify them as separate. Similarly to the flash beep illusion findings by Foss-Feig et al. (2010), the ASD group were integrating asynchronous audiovisual information over longer intervals of time than typical participants. However, the authors noted that in the simultaneous tasks, the presentation of an auditory stimulus did provide multisensory facilitation to the ASD group with regards to their reaction time and accuracy (Kwakye et al., 2011). Despite the fact that temporal processing may be altered in ASD, multisensory integration occurs and still confers a facilitatory advantage.

When comparing temporal gaps across tasks of varying stimulus complexity (i.e., flash-beep, hand clap, speech) in another study, no interaction effect of group (i.e., ASD vs. control) by condition were found (de Boer-Schellekens et al., 2013a). Essentially, regardless of the stimulus complexity, the temporal binding gap was enlarged in adolescents and adults with ASD. But, when evaluating temporal binding using different levels of stimulus complexity with young children and adolescents, an ASD group exhibited less temporal accuracy (i.e., a larger temporal binding window) for speech stimuli than for simple or complex non-speech stimuli (Stevenson et al., 2014a). Having also found a reduced McGurk effect in their participants, the authors posited that these results might be supporting the notion of a speech- or social-specific alteration in multisensory integration (Stevenson et al., 2014a).

De Boer-Schellekens et al. (2013b) emphasize that although ASD participants may be showing a larger temporal binding window, this does not necessarily lead to behavioural differences between typically developing individuals and those with ASD. Furthermore, they caution that although temporal processing may be altered in ASD this does not mean that multisensory facilitation is not present. In fact, in a temporal judgment task, they found that the ASD group not only experienced multisensory facilitation (i.e., faster responding when presented with a facilitatory sound), they actually had a larger effect of multisensory facilitation than the control group (de Boer-Schellekens et al., 2013b).

Unfortunately, the state of MSI research in ASD is still in its infancy. Inconsistent findings in the MSI literature in ASD, make it difficult to piece apart socio-communicative deficits from a potential lower-level MSI deficit. Methodological issues have also made it difficult to draw inferences from the performance of individuals with ASD on these tasks. Developmental trajectories are not well defined, most studies have not considered the role of either stimulus complexity or task complexity, the ecological validity of these specific experiments is questionable, and the role of temporal processing alterations in ASD remain unclear.

Rationale, Specific Aims and Hypotheses for the Current Study

Given the gaps in knowledge and inconsistencies in results in the field of MSI research in ASD, more work is needed to clarify what is known about the ability to integrate multisensory information in ASD. Specifically, the goals for the research project are as follows:

1. The primary goal was to determine whether there exists a fundamental difference/impairment in the ability for individuals with ASD to integrate simple, non-social sensory information from multiple sensory modalities. We sought to accomplish this goal by evaluating MSI of lower-level information in individuals with ASD by looking at 1) the illusory perception that results from the automaticity of MSI (i.e., flash-beep illusion in Chapter 3), and 2) multisensory facilitation which results from the integration of two sensory modalities at once (i.e., reaction time task in Chapter 4). Examining MSI functioning using different tasks in the same individuals in order to be able to make stronger conclusions about the nature of MSI in ASD. Comparing performance of the same individuals across different tasks will allow for more generalizability with regards to MSI functioning.
2. The secondary goal was to help address age effects in the study of MSI in ASD by evaluating adolescents and adults with and without ASD. Specifically, does MSI ability change over time in the ASD population? Does a shift in the ability to integrate sensory information occur at a particular point in development?

Hypotheses

Given what is known about MSI in ASD, specific hypotheses were formed in response to the above-mentioned goals and research questions:

1. It is expected that the ASD group's MSI abilities will likely not differ significantly from those of the TD comparison group since non-social stimuli were used in both studies, and individuals with ASD may be more capable of integrating simple non-social stimuli than more complex stimuli. In other words, it is predicted that group differences between the

ASD and typically-developing comparison groups will be smaller than they have been for previous studies using socio-communicative stimuli.

2. Given the similarity in stimuli and task complexity used for both studies, it is expected that similar patterns of results will be found for the ASD group across both studies. Specifically, it is expected that the ASD group will demonstrate evidence of multisensory facilitation and multisensory integration both for Study 1 and Study 2, respectively.
3. For both tasks, it is expected that age effects will be found. Specifically, for the flash-beep task in Article 1, it is expected that adolescent participants may be more susceptible to illusory effects than adult participants. This is based on previous research conducted by Innes-Brown et al. (2011) whereby typically-developing children and adolescents (aged 8-17) were significantly more susceptible to fission illusions than adults. It is hypothesized that a similar pattern of results will be found in both the ASD and comparison groups. For the reaction time task in Article 2, it is expected that Brandwein et al.'s (2013) findings, which had indicated that children and adolescents with ASD showed no evidence of multisensory facilitation on a reaction time task, will be replicated. Specifically, it is expected that younger participants will have diminished multisensory facilitation as compared to the older ASD participants.

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Chapter 3 – Manuscript 1

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Multisensory integration of low-level information in Autism Spectrum Disorder: Measuring susceptibility to the flash-beep illusion

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Abstract

Previous studies have suggested atypical audiovisual multisensory integration (MSI) in Autism Spectrum Disorder (ASD). However, much of the research having found an alteration in MSI in ASD involved socio-communicative stimuli. The goal of the current study was to investigate MSI abilities in ASD using lower-level stimuli that are not socio-communicative in nature by testing susceptibility to auditory-guided visual illusions. Adolescents and adults with ASD and Typically-Developing (TD) individuals were shown to have similar susceptibility to a fission illusion. However, the ASD group was significantly more susceptible to the fusion illusion. Results suggest that individuals with ASD demonstrate MSI on the flash-beep illusion task but that their integration of audiovisual sensory information may be more automatic than for TD individuals.

Keywords: Autism Spectrum Disorders, Multisensory Integration, Flash-Beep Illusion, Auditory-Visual Integration

Introduction

Various theories attempt to explain the perceptual and sensory processing differences that make up the specific cognitive architecture of Autism Spectrum Disorder (ASD) and make the link between sensory processing and the core features (i.e., socio-communicative impairments and repetitive/restricted patterns of behaviors and interests) of ASD (Frith & Happé, 1994; Happé & Frith 2006; Brock, Brown, Boucher & Rippon, 2002; Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert & Burack, 2006; Bertone et al 2010). One commonality to these cognitive theories is to hypothesize atypical sensory integration in ASD, both within and across sensory modalities (i.e., sight, hearing, touch, etc.).

While research on Multisensory Integration (MSI) in ASD has expanded, there remain many questions to be answered with regard to the sensory integration capabilities of individuals with ASD. Much of the information on MSI in ASD has originated from studies examining the integration of sensory stimuli that are socio-communicative in nature (i.e., speech and faces; Brandwein et al., 2013; Mongillo et al., 2008). The McGurk effect (i.e., illusory auditory perception influenced by discordant visual information) has been one frontrunner paradigm for studying MSI in TD individuals as well as in ASD (Foxe & Molholm, 2009; Iarocci & McDonald, 2006). While some studies have identified a diminished McGurk effect in ASD (Bebko, Schroeder, & Weiss, 2014; Mongillo, et al., 2008; Williams, Massaro, Peel, Bosseler & Suddendorf, 2004), others have found that the effect is contingent on developmental factors (Taylor, Isaac & Milne, 2010), socio-communicative impairments (Iarocci, Rombough, Yager, Weeks & Chua, 2010), or task-related temporal factors (Woynaroski et al., 2013).

The speech-in-noise paradigm, which is based on the facilitatory effect of multisensory stimulation, has also been used to better understand multisensory integration processes in typical development as well as in ASD. Using the speech-in noise approach to compare adolescents with and without ASD, Smith and Bennetto (2007) found that the facilitation provided by the addition of visual information to better understand speech in a noisy environment was significantly greater in the TD group. Controlling for lip-reading ability only seemed to account for a portion of the MSI impairment seen in the ASD group (Smith & Bennetto, 2007). It follows that the results might be indicative of a more general impairment in socio-communicative sensory integration. Individuals with ASD were also found to be slower than TD individuals at processing speech when gestures accompanied the auditory information (Silverman et al., 2010). Not only was there no evidence of MSI facilitation in ASD, but the addition of visual sensory information (i.e., gestures) actually hindered speech processing.

Charbonneau et al. (2013) sought to evaluate audiovisual integration of emotional sensory information (i.e., visual and auditory representations of fear and disgust) in individuals with ASD. The implications of their results were twofold: the ASD group was less efficient at discriminating emotional information, and they did not benefit as much from the presentation of information from multiple modalities as did TD individuals.

Interpreting the results of studies investigating MSI using solely socio-communicative stimuli can be problematic. First and foremost, the use of complex, often linguistic, stimuli makes it extremely difficult to draw any firm conclusions about the nature of sensory integration in ASD. Due to socio-communicative impairments, which are a core feature of ASD, one cannot take the above evidence of “impaired or reduced” multisensory functioning at face value due to the confounding use of faces, voices, and gestures as the task stimuli. This begs the questions: Is there a fundamental alteration of multisensory integration in ASD when the confounding effects of complex, higher-level stimuli are eliminated?

Few studies to date have attempted to control for stimulus complexity by testing the same participants on both social and non-social tasks. Whereas some of these studies demonstrated unique MSI alteration when socio-communicative stimuli were used (Bebko, Weiss, Demark, Gomez, 2006; Mongillo et al., 2008; Stevenson et al., 2014a), others discovered a more general MSI impairment across both social and non-social tasks (de Boer-Schellekens, Eussen, & Vroomen, 2013).

The flash-beep illusion task is a common method used to assess MSI by evaluating the susceptibility to illusions, and it has been identified as robust in the TD population (Shams, Kamitani, & Shimojo, 2000; Shams, Kamitani, & Shimojo, 2002). By presenting varying numbers of flashes (i.e., visual stimulus) and beeps (i.e., auditory stimulus) sequentially in close temporal proximity, Shams et al., (2000) discovered that when a single flash is presented with multiple beeps, the flash is actually perceived to be multiple flashes (i.e., producing a fission illusion). Andersen, Tiipana and Sams (2004) extended the results with the finding of a fusion illusion (i.e., one beep presented with multiple flashes causes the perception of one flash). The presence of these two illusions is driven by the influence the auditory information has over the visual information.

When the presence of the fusion and fission illusions was examined in a group of high-functioning adults with ASD, it was found that the ASD group was susceptible to both illusions to a similar degree as a TD comparison group, thereby suggesting that the ASD group was showing typical MSI (van der Smagt, van Engeland & Kemner, 2007). In another study using various tasks to evaluate MSI in a sample of high-functioning adults with ASD, the sound-induced flash illusion was tested (Keane, Rosenthal, Chun & Shams, 2010). Similarly, no difference was found between the performance of participants with ASD and TD participants (Keane et al., 2010).

Children with ASD do not appear to show the same pattern of results on the flash-beep illusion task as adolescents and adults. Foss-Feig et al., (2010) modified the original paradigm by altering the temporal presentation of the beeps in conjunction with the flash. In doing so, they were able to determine whether temporal factors might be at play in integrating visual and auditory information to produce the flash-beep illusion. They found that children with ASD were susceptible to the fission illusion (the temporal dependence of the fusion illusion was not studied) over a larger temporal binding window (TBW) than typically developing children. The concept of TBW's refers to the window of time during which two stimuli occurring successively will actually be perceived as occurring simultaneously. Temporal binding windows allow multisensory information to be integrated even when there might be slight temporal asynchronies (Wallace & Stevenson, 2014). In individuals with ASD, it appears that there might be an enlarged or expanded temporal binding window as compared to TD individuals (Baum, Stevenson & Wallace, 2015; Foss-Feig et al., 2010; Kwakye, Foss-Feig, Cascio, Stone & Wallace, 2011; Stevenson et al., 2014a; Wallace & Stevenson, 2014). This would mean that individuals with ASD would perceive asynchronous stimuli as simultaneous more so than TD individuals would.

Another study, examining the fission illusion, was done with slightly younger children and determined that children with ASD had reduced illusory susceptibility (Stevenson et al., 2014b). The authors interpret these findings as indicative of a diminished ability to integrate low-level stimuli in ASD. One limitation to both studies of the flash-beep illusion with children with

ASD is the primary focus on the fission illusion. A study investigating both illusions may be more complete when attempting to determine audiovisual sensory integration.

In sum, results from MSI research in ASD seem to point to two main conclusions: (1) MSI of socio-communicative information is altered in ASD, and (2) individuals with ASD are generally capable of integrating lower-level multisensory information, but that the accuracy of integration may be impacted by factors such as temporal congruence, age, and the specific task used. While some research has been conducted using the flash-beep paradigm in ASD, these studies have either only studied high-functioning individuals with elevated IQ's, examined one of the two flash-beep illusions (i.e., only fission) or have only studied one age group (Foss-Feig, et al., 2010; Keane et al., 2010; Stevenson et al., 2014b; van der Smagt et al., 2007). Furthermore, studies using similar low-level paradigms (e.g., visual search) have yielded inconsistent results (de Boer-Schellekens, Keetels, Eussen, and Vroomen, 2013; Collignon et al., 2013). The present study was conducted to provide more clarity to MSI functioning in ASD for low-level information, and to build upon previous studies that have investigated the flash-beep illusion in ASD by including a wider age and IQ range, examining both the fission and fusion illusions, and simplifying task demands.

Methods

Participants

Participants were recruited through the Clinique d'Évaluation des Troubles Envahissants du Développement (CETED), at the Rivière-des-Prairies Hospital (Montreal, Canada) and through the Perceptual Neuroscience Laboratory for Autism and Development (PNLab). Twenty adolescents and adults with ASD and 20 TD participants took part in the study. Participants were matched as closely as possible on gender, age and Full-Scale IQ (See Table 1). Individuals in the

ASD group met DSM-IV diagnostic criteria for ASD (American Psychiatric Association, 2000) and were diagnosed using the Autism Diagnosis Interview-Revised (Lord, Rutter, & Le Couteur, 1994) and/or the Autism Diagnosis Observation Schedule (Lord, Cook, Leventhal, Amaral, 2000).

Each participant was tested using the Wechsler Intelligence Scale for Children (WISC-IV), or the Wechsler Abbreviated Scale of Intelligence (WASI-II). In order to facilitate matching with the comparison group, and because the task for this study required an ability to sustain attention and follow specific instructions, only participants with a Full-Scale IQ greater than 70 were selected.

Table 1. Participant Demographic Variables by Group

	ASD (n=20)	TD (n=20)	*t*	*p*
Sex				
Male	16	18		
Female	4	2		
Chronological Age			-0.129	0.898
M	18.75	18.95		
SD	4.74	5.06		
Range	13-29	13-28		
Full-Scale IQ			-0.129	0.205
M	102.95	108.10		
SD	13.71	11.46		
Range	79-120	86-125		

Due to the sex ratio that exists in ASD (i.e., approximately 4.3:1 of males to females; Fombonne, 2003), our sample consisted mostly of males, with 16 males (80%) and 4 females (20%). There were 18 males (90%) and 2 females (10%) in the TD group. The ASD group was comprised of adolescents and adults ranging in age from 13 to 29 years old (mean age 18.75; SD 4.74), and TD participants ranged in age from 13 to 28 (mean age 18.95; SD 5.06).

A semi-structured interview conducted during recruitment allowed for the exclusion of participants with: a history of learning disabilities; a familial history (1st degree) of mood disorders, or schizophrenia; and current use of psychiatric medications or recreational drugs. Participants were required to have normal hearing and normal or corrected-to-normal vision, which was assessed using a Lea Runge pocket card for near vision prior to testing. The TD group was also screened for a personal or familial history of ASD during recruitment. Participants in both groups were given financial compensation for their time.

Stimuli

The described stimuli and procedure were similar to those used previously by Shams et al., (2002) and Innes-Brown et al., (2011). The visual stimulus was a white disk subtending 3° of visual angle and positioned 7.5° below a white fixation cross presented on a black background. The fixation cross was constant throughout the trials, and located 2.5° above the center of the screen. The duration of presentation of the disk (i.e., flash) was 12.5 milliseconds. The beep consisted of a 3500 Hz tone presented for the same duration of time as the flash (12.5 ms). The flash-beep task was designed and presented using VPixx™ software and a MACPRO G4 computer, using an 18-inch Viewsonic E90FB 0.25 CRT (1280 × 960 pixels) screen with a refreshing rate of 80 Hz. The mean luminance of the monitor was set at 30.00 cd/m2 (u' = 0.1912, v' = 0.4456 in CIE color space) where minimum and maximum luminance levels were 0.5 and 59.5 cd/m2, respectively. Auditory stimuli were administered via the DataPixx™ data acquisition box. This system allows for the production of sounds at precise frequency and guarantees stability in the quality of auditory stimuli emitted. The auditory stimuli were presented in dichotic listening at 65 db SPL (sound pressure level), with Sennheiser HD280 headphones. Stability of auditory intensity and visual luminance levels was ensured using a sonometer Quest 1100 and a CS-100 Minolta Chromameter, used for luminance/color reading and monitor gamma-correction.

Procedure

Participants were all tested at one of the two satellite locations of the PNLab. To ensure optimal perception of auditory and visual stimuli, the testing rooms are designed to attenuate external sound, and diminish the presence of external light sources. Participants sat in a comfortable armless chair, and viewing distance was set at 57 cm from the eyes of the participants to the center of the screen.

On every trial of the experiment, there were either one (1F) or two (2F) flashes (F) presented with zero (0B), one (1B), or two beeps (2B). There was a total of six possible auditory-visual combinations. The four non-illusion trials are 1F0B, 1F1B, 2F0B, and 2F2B. For the non-illusion trials, the auditory information is either absent or concordant to the visual information, therefore no illusory perception of the visual information can occur. The fission illusion trial is the 1F2B combination, and the fusion illusion trial is the 2F1B combination. On these illusion trials, the auditory information drives the perception of the visual information. While only 1 flash is presented on the fission illusion trial, its pairing with 2 beeps causes the participant to perceive 2 flashes; the auditory information is "fissuring" the perception of the visual information. Similarly, when 2 flashes are paired with only 1 beep, a "fusion" of the visual information occurs; participants perceive only 1 flash. For trials in which there are multiple flashes or beeps (i.e., 1F2B, 2F0B, 2F1B, or 2F2B), the time delay between the first and second stimulus was set at 75 ms. The six trial types were each presented 10 times in random order in a single testing block. Trials were separated into 6 testing blocks, for a total of 360 trials.

Participants were asked to respond as quickly and accurately as possible by pressing the “1” button on the number pad located on the right side of the keyboard when they perceived 1 flash, or the “2” button when they perceived 2 flashes. They were also instructed ahead of time to make their best guess if they were unsure of the number of flashes presented on any given trial. The accuracy of their responses (% correct) as well as their reaction time was measured for each trial.

Results

T-tests indicated that no significant differences existed between the age or FSIQ of the ASD group and the TD control group. Given that age has been shown to affect the flash-beep illusion (Innes-Brown et al., 2011; Stevenson et al., 2014b), a Pearson product-moment correlation coefficient was conducted to assess the relationship between age and performance (accuracy and RT) on the illusion trials for each group (ASD and Control). Results yielded no significant correlations for age by performance on the illusion trials for the ASD group. There were no significant correlations between age and accuracy on either illusion trial for the TD group.

Analysis of Accuracy

A mixed 2-way ANOVA (2×6) was used to determine whether differences in accuracy on each of the six trial types existed between the two groups. A within-subjects factor of trial type (2F2B, 2F1B, 2F0B, 1F0B, 1F1B, 1F2B), and a between-subjects factor of group (ASD, Control) were used. Accuracy was measured as the percentage of correct response (e.g., pressing “2” when two flashes were shown) out of all possible responses for each trial type. Mauchly’s test indicated that the assumption of sphericity had been violated ($\chi 2(14) = 134.64$, $p < .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.543$).

The ANOVA revealed a main effect of trial type, $F(2.717, 103.262) = 92.352$, $p < .001$, $\eta p2 = 0.708$. Specifically, a Post hoc Bonferroni comparison determined that accuracy for both groups was significantly lower for the 2F1B (Fusion) and the 1F2B (Fission) trials than all other trial types, $p < .001$.

The analyses also revealed that there was no main effect of group, $F(1, 38) = 3.803$, $p = .059$, $\eta p2 = 0.091$. The overall accuracy scores of the ASD group (mean overall accuracy of 71.07%) and the Control group (mean overall accuracy of 78.69%), when collapsing across all trial types, did not differ. Importantly, there was a significant interaction effect of group x trial type, $F(2.717, 103.262) = 4.35$, $p = .008$, $\eta p2 = 0.103$ (see Fig. 1). Using a Post hoc Bonferroni comparison, it was found that the ASD group had significantly reduced accuracy on the 2F1B and 2F0B trials (see Table 2) whereas performance did not differ across groups on the other four trial types.

Figure 1. Response accuracy for each trial type by group

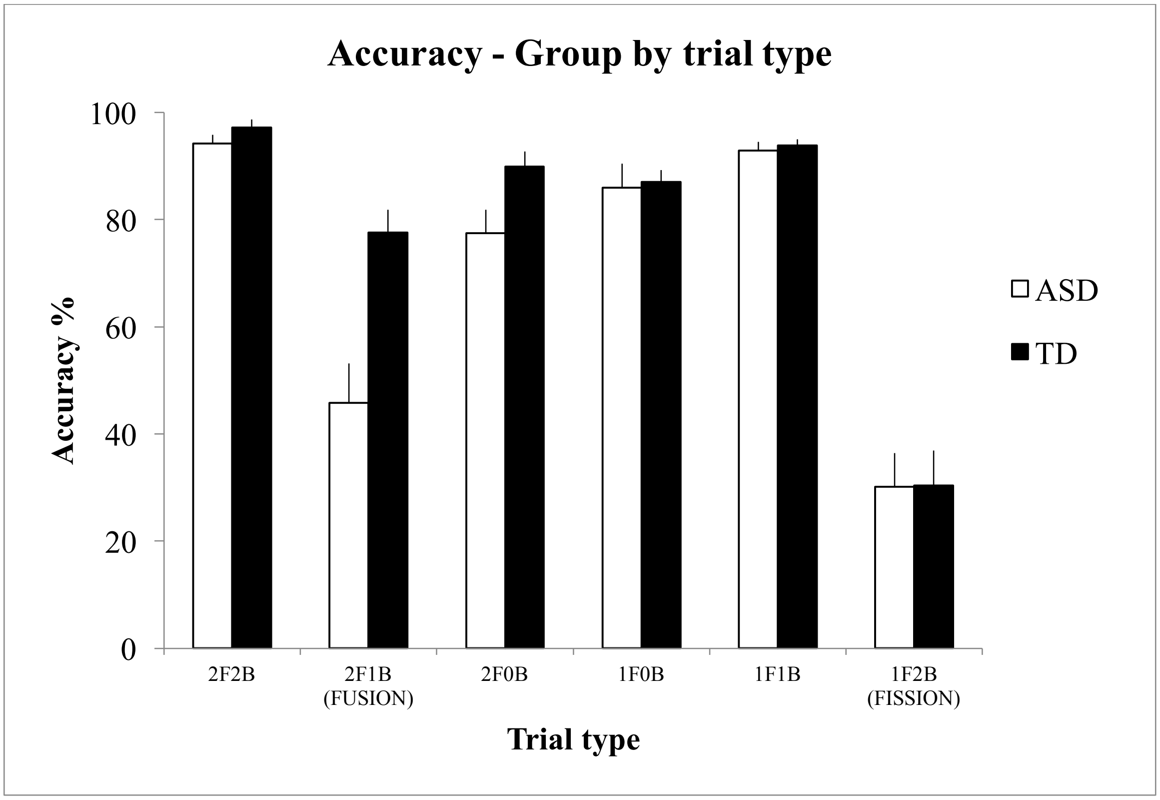

Figure 1. Bar graph representing the difference in accuracy scores on each trial type between the ASD and TD groups.

Table 2. Mean Accuracy Scores and Standard Errors for Each Trial Type Based on Group.

Group	Trial Type	Means	Standard Error
ASD	2F2B	94.16	1.59
	2F1B (Fusion)	**45.75***	6.60
	2F0B	**77.50***	3.69
	1F0B	86.00	3.49
	1F1B	92.91	1.41
	1F2B (Fission)	30.08	6.44
Control	2F2B	97.16	1.59
	2F1B (Fusion)	**73.83***	6.60
	2F0B	**89.91***	3.69
	1F0B	87.08	3.49
	1F1B	93.83	1.41
	1F2B (Fission)	30.33	6.44

Note. Group mean difference, * = p<.05

Analysis of RT

Differences between groups on reaction time (RT) for the different trials were assessed using a mixed 2-way ANOVA (2 × 6). Reaction time (measured in milliseconds) was defined as the time between presentation of the stimulus (i.e., stimulus offset) and participant response (key press). Mauchly's test of sphericity was significant, $\chi2(14) = 80.116$, $p < .001$. Accordingly, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.498$).

Analyses revealed a significant main effect of trial type, $F(2.49, 94.636) = 17.436$, $p < .001$, $\eta_p^2 = 0.32$, and of group, $F(1, 38) = 7.354$, $p = .01$, $\eta_p^2 = 0.162$. The ASD group ($M = 0.69$ ms) had slower RTs than the Control group ($M = 0.57$ ms) when RTs were collapsed across conditions (see Fig. 2). As expected, it was found that the RTs for the 2F2B congruent trials was significantly faster than all other conditions for both ASD and TD groups.

Figure 2. Reaction time in milliseconds for each trial type by group

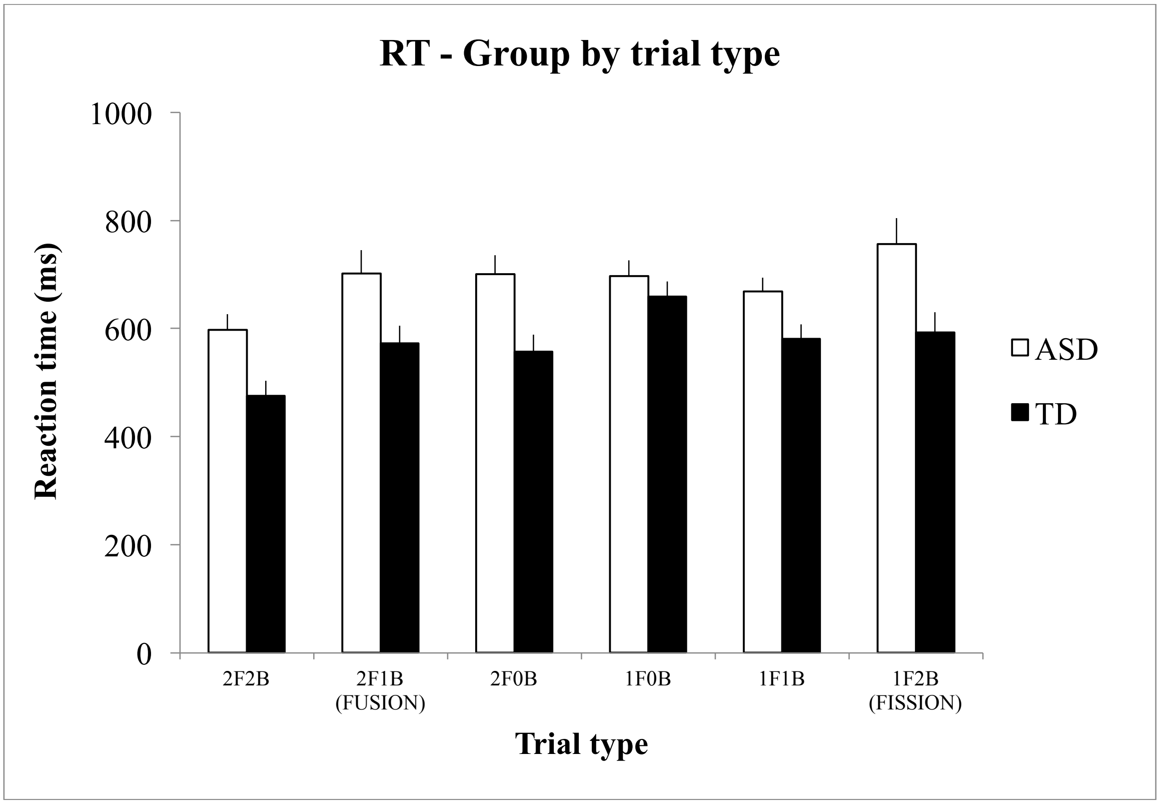

Figure 2. Bar graph representing the difference in reaction times on each trial type between the ASD and TD groups.

Discussion

The goal of the current study was to assess multisensory integration in ASD for low-level information void of socio-communicative context using the flash-beep paradigm. The flash-beep illusion task assesses the susceptibility to auditory-guided visual illusions as a measure of MSI.

In line with our expectations, both groups were found to have significantly diminished accuracy on the fusion (2F1B) and fission (1F2B) trials (i.e., increased susceptibility) than on non-illusion trials. Decreased accuracy on the illusion trials as compared to non-illusion trials is suggestive of audio-visual interactions, with the auditory information influencing the perception of the visual stimulus.

The modality appropriateness hypothesis states that the sensory modality that is most relevant to the completion of a particular task will influence the perception of the other modalities (Welch & Warren, 1980). Vision has "higher spatial resolution" so it will dominate and alter the perception of sound on spatial tasks, but sound, which has a "higher temporal resolution", will alter the perception of other sensory modalities on tasks that are more temporal in nature (Welch & Warren, 1980). However, more recent work suggests that a reliability-based framework of sensory integration may be more appropriate in describing auditory-visual multisensory effects (Alais & Burr, 2004). According to this perspective, the sensory modality that provides the most reliable information in a given situation takes precedence over the other (Andersen, Tiippana & Sams, 2004; Ernst & Banks, 2002). Therefore, the current results may also be partially explained by the auditory stimulus having primacy over the visual one due the auditory system being more appropriate for judging temporal aspects of the current task. There was significantly better accuracy for both the ASD and the TD groups on the 2F2B as compared to the 2F0B and 1F0B trials, significantly better accuracy on the 1F1B trial than the 2F0B, and a difference approaching significance ($p = .057$) between the 1F1B and 1F0B trial. Given the absence of an auditory stimulus for the 1F0B and the 2F0B trials, participants may be having a harder time distinguishing visual information presented in close temporal proximity.

The current study replicated past findings and demonstrated that the TD group was susceptible to the influence of auditory information on the perception of visual information. The TD group had significantly lower accuracy on both the fusion and fission illusion trials as compared to all four other trial types, but their susceptibility to the fission illusion was stronger than to the fusion illusion. The results of the present study also demonstrated that the ASD group, as compared to the TD group, was actually found to be more sensitive to the fusion illusion, but there was no difference between groups on the fission illusion trial. In other words, the fission illusion appears to be as robust in individuals with ASD and TD individuals, but susceptibility to the fusion illusion is more robust in the ASD group. Previous research has shown that in the TD population, the fission illusion is more robust than the fusion illusion (i.e., lower accuracy on fission trials than fusion trials; Andersen, Tiippana, & Sams, 2004; Shams et al., 2002). Shams et al., (2002) found no evidence of the fusion illusion in their original study. Andersen et al., (2004), however, did find evidence for the fusion illusion in a typically-developing participant group, albeit a weaker effect than the fission illusion.

Increased susceptibility to the fusion illusion in ASD may be partially explained by research done on extended temporal windows. Various researchers have determined that there does exist an extended temporal binding window in ASD, meaning that individuals with ASD continue to integrate sensory information over a larger gap in time than do TD individuals (Foss-Feig et al., 2010; Kwakye et al., 2011; Woynaroski et al., 2013). The current results indicating that the ASD group had significantly lower accuracy than the TD group on the 2F1B (i.e., fusion illusion) and 2F0B trials may be explained by the presence of an expanded temporal binding window. Participants with ASD are more likely to integrate 2 flashes into one when they are presented close in time. With regard to the 2F0B trial, the ASD group perceived the two flashes as one even in the absence of the influence of incongruent auditory information. When the auditory information is congruent (i.e., 2F2B), the ASD group does not differ from the TD group.

Foss Feig et al., (2010) studied children with and without ASD on the flash beep task, but specifically looked at temporal binding windows for the fission illusion. They found that children with ASD had approximately a doubly large temporal binding window as compared to the TD group (i.e., they were integrating 2 beeps over a 600 ms window, whereas the TD group was only integrating over 300 ms window.) They found a slight effect of the fusion illusion in the ASD group, but a stronger one in the TD group. Although our findings are in line with theirs with regards to the fission illusion (i.e., it is present in both groups), the finding that the fusion illusion is stronger in our ASD group runs counter to their findings. One potential explanation is that the interstimulus interval between the two flashes in the fusion illusion trial was 50 ms in the study conducted by Foss-Feig et al., (2010) whereas it was 75 ms for the current study. Although this is a relatively small difference, this widening of the interval may have led to the difference between the ASD and TD groups' perception of the fusion illusion. Specifically, the ASD group may have perceived the two flashes as 1 due to their enlarged TBW, but the TD group may have shown less of an effect due to the enlarged interstimulus gap. Similarly, in another study by van der Smagt et al., (2007), an interstimulus interval of 50 ms was also used. Again, the enlarged interval in the current study may have influenced the difference in susceptibility to the fusion illusion between both groups.

Additionally, the differences in results across the current study and those of van der Smagt et al., (2007) may have been due to a number of factors related to our methods and participant sample (e.g., mean FSIQ, diagnostic criteria, age). The participants in the current study spanned adolescence and adulthood, and included greater age variation than had been used in the study by van der Smagt et al., (2007). Given that younger TD children have been found to have greater susceptibility to the flash beep illusion that adults (Innes-Brown et al., 2011), it is possible that the current results of greater susceptibility to the fusion illusion may be related to the larger age variation in the sample. Innes-Brown et al., (2011) found that TD children were more susceptible to both the fusion and fission illusions than adults. They suggested that this difference was due to less selective integration of sensory information in children. It is suggested that children may not yet have “fine-tuned” their ability to integrate sensory information; their visual perception is being altered more automatically and more often by incongruent auditory information than is the case with older individuals. However, it should be noted that a recent study by Stevenson et al., (2014b) found reduced illusory susceptibility to the fission illusion, suggesting that lower-level MSI may not develop in the same way in ASD as in typical development.

It remains possible that the finding that individuals with ASD are significantly more susceptible to the fusion illusion than TD individuals may also be indicating that multisensory integration at the lower-level is somewhat less selective in ASD. This interpretation is consistent with the notion of enlarged temporal binding windows in ASD. The current findings taken together with findings from studies investigating the temporal binding window suggest that individuals with ASD do not appear to have an inability to integrate sensory information from different modalities per se, but that they may simply be integrating the information in a different, possibly less selective manner.

Limitations and Future Directions

It could be suggested that the current results of increased susceptibility to both illusions may be partially accounted for by reduced perceived salience of visual information by the ASD group. However, the ASD and TD groups did not differ significantly on their accuracy ratings of the 1F0B trial, thereby indicating that both groups are able to accurately perceive the visual stimulus. Although reduced visual saliency may influence the interpretability of the performance of individuals with ASD on audiovisual MSI tasks, due to the high level of saliency of the stimuli used in the current study, this factor is not considered to have had a significant impact.

With respect to interpretation of age effects, the lack of a younger child group is a limitation of the current study. The absence of an age effect for the accuracy of illusion trials may be due in part to not having included participants below the age of 13. Increasing sample size and including younger children (e.g., 6–12) to the ASD and TD groups would allow for the further investigation of age-related differences in multisensory processing at the lower level. To our knowledge, no study has yet compared performance on lower level MSI tasks across age groups to investigate developmental trends.

An issue with much of the research done with individuals with ASD is the exclusion of lower functioning individuals on the autism spectrum (i.e., FSIQ of 70 and below). Results of the current study may not be generalizable to all individuals with ASD, a highly variable spectrum of symptom severity. Future studies may include modified task demands and shortened testing time to allow for the testing of lower-functioning individuals with ASD on lower level multisensory tasks such as the flash-beep task used in this study. Due to the fact that lower-functioning individuals with ASD are also affected by sensory abnormalities, there is a need to assess MSI functioning across the spectrum of ASD.

While the current study provides an indication of MSI functioning at the behavioral level, a future direction for studies investigating MSI in ASD should involve looking at the relationship between behavioral manifestations of MSI abilities and the neural networks underlying these processes. Some studies have already begun to investigate MSI in ASD using neuroimaging methods (e.g., EEG, fMRI) but additional research is needed to fully understand the neural mechanisms that underlie multisensory integration in ASD (Brandwein et al., 2013; Maekawa et al., 2011; Magnée et al., 2008).

In conclusion, the findings of the current study continue to shed light on the multisensory integration abilities of individuals with ASD. These findings also lend support to the notion that enlarged temporal binding windows may be a central factor to consider when examining MSI in ASD. Ultimately, future research that considers factors such as age, level of functioning, stimulus complexity, task complexity and temporal factors, can help to better define MSI in ASD and lead to a more thorough understanding of MSI's impact on the core features of ASD.

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Bridge between manuscripts – Article 1 to Article 2

As described in Chapter 2 (Literature Review), multisensory integration is a complex process that can be investigated using a variety of methods, and stimuli. Various experimental designs have been developed to study the integration of different combinations of sensory input (e.g., visual and tactile, auditory and tactile, auditory and visual; Calvert & Thesen, 2004; De Gelder & Bertelson, 2003). Given the relevance for social and communicative processing such as speech perception, the integration of auditory and visual information is often examined in MSI literature. Stimuli used for evaluating MSI has also greatly varied, from simple lower-level stimuli like beeps and flashes, to complex stimuli like speech, and faces (Bebko, Weiss, Demark, Gomez, 2006; Brandwein et al., 2013; Charbonneau, et al., 2013; Magnée, de Gelder, van Engeland, & Kemner, 2008). Finally, the methods used to investigate MSI can also greatly vary. Illusory perception is often used as example of the automaticity of MSI (e.g., McGurk effect, flash-beep illusion), and thus is used to evaluate whether MSI processes are intact (McGurk & MacDonald, 1976; Shams, Kamitani, & Shimojo, 2000; Shams, Kamitani, & Shimojo, 2002). Alternately, the facilitatory effect of MSI can be investigating using visual search tasks, speech in noise tasks, and even simple reaction time tasks (Barutchu, Crewther & Crewther, 2009; Collignon et al., 2013; de Boer-Schellekens, Keetels, Eussen, and Vroomen, 2013; Hershenson, 1962; Smith & Bennetto, 2007).

Article 1 described the use of the flash-beep illusion task to evaluate MSI in ASD. The use of this task is based on the premise that we tend to perceive multiple senses occurring close in time as a single event, which may lead to illusory perception. Specifically, the incongruous pairing of mismatching auditory and visual information leads to either the illusory splitting (i.e., fission illusion) or merging (i.e., fusion illusion) of visual information guided by auditory information. These effects are thought to be a manifestation of MSI's automaticity (Foxe & Molholm, 2009; Soto-Faraco, Navarra & Alsius, 2004). Although illusory effects are often used to evaluate MSI, these paradigms do not directly address the function of multisensory facilitation.

Multisensory facilitation refers to the faster and more efficient processing that occurs when presented with sensory information from multiple senses at once rather than when only presented with information from one sense (Foxe & Molholm, 2009; Hillock, Powers, & Wallace, 2011; Stein & Meredith, 1993). Multisensory facilitation can easily be studied using a simple reaction time paradigm. Reaction time in response to unimodal (visual-only or auditory-only) stimuli is compared to that of multimodal (simultaneous presentation of more than one sensory modality) stimulation. Multisensory facilitation has occurred if the increased speed on multimodal trials goes above and beyond what can be accounted for by sensory redundancy (Stein, Wallace & Stanford, 1999). The study presented in Chapter 4 (Article 2) uses the simple reaction time task to ascertain whether the advantage conferred by MSI (i.e., multisensory facilitation) is present to the same extent in individuals with ASD as for typically-developing individuals.

By using two different approaches for evaluating MSI of lower-level information in ASD, we are able to achieve more precision in our understanding of MSI in ASD. The automaticity of MSI is evaluated using the task of illusory perception, whereas the advantage of increased speed conferred by integrating sensory information from more than one modality is evaluated using the reaction time task.

The aim of Article 2 is help to determine whether there exists an impairment or alteration in the ability for individuals with ASD to integrate sensory information from multiple sensory modalities. Specifically, we aimed to determine whether there is an alteration in MSI abilities for individuals with ASD by using a task that evaluates multisensory facilitation. Article 2, like Article 1, addresses MSI using a simple task design and using simple non-social stimuli, thereby eliminating the confounding effects of task and stimulus complexity. Furthermore, the study helps to address the age-related effects of MSI in ASD.

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Chapter 4 – Manuscript 2

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Reduced multisensory facilitation in adolescents and adults with Autism Spectrum Disorder

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Abstract

Individuals with Autism Spectrum Disorder (ASD) are reported to integrate information from visual and auditory channels in an idiosyncratic way. Multisensory facilitation of simple lower-level stimuli (i.e., flashes and beeps) was evaluated in adolescents and adults with (n=20) and without ASD (n=19) using a reaction time (RT) paradigm. The race model analysis indicated that the race model violation occurred only for the typically-developing (TD) group. While the typically-developing (TD) group showed evidence of multisensory facilitation, the ASD group did not. These results suggest that MSI of even the simplest information, void of social content or complexity, is altered in ASD. Individuals with ASD may not benefit from the advantage conferred by multisensory stimulation to the same extent as TD individuals. Altered MSI for low-level information may have cascading effects on more complex perceptual processes related to language and behaviour in ASD.

Keywords: Autism Spectrum Disorder, Multisensory Integration, Multisensory Facilitation, Reaction Time, Audio-Visual Integration

Introduction

Individuals with Autism Spectrum Disorder (ASD) often avoid certain sensory stimuli (e.g., withdrawing from specific noises like the sound of a vacuum cleaner, avoiding certain textures or smells) and/or, seek out sensory experiences through stimulatory behaviours (e.g., peering, echoing, tapping surfaces; Kern et al., 2006; Lovaas, Newsom & Hickman, 1987). The prevalence of sensory issues in ASD is thought to vary between 69 and 95%, which confirms that sensory abnormalities are a concern for the vast majority of individuals with ASD (Hazen, Stornelli, O'Rourke, Koesterer, and McDougle, 2014). Furthermore, sensory issues have been shown to occur across development in ASD (Ben-Sasson et al., 2009; Hazen, et al., 2014), as well as across sensory modalities (Kern et al., 2006; Pellicano, 2013). Sensory issues are now included among the DSM-5 symptoms for Autism Spectrum Disorder (APA, 2013).

In light of the significance of sensory processing abnormalities, it has been suggested that these may actually contribute to some of the core social and behavioural characteristics of ASD (Iarocci & McDonald, 2006; Marco, Hinkley, Hill, & Nagarajan, 2011). If sensory processing was altered or impaired at the lower level, there would be a subsequent effect on higher-order processes. For instance, disruption in basic visual or auditory processing may contribute to deficits found at the higher level, such as socio-communicative functioning (Marco et al., 2011). In fact, studies have demonstrated a relationship between sensory processing issues and social responsiveness (Hilton, Graver, and LaVesser, 2007), communicative impairments and maladaptive behaviours (Lane, Young, Baker, & Angley, 2010), as well as behavioural/emotional problems (Baker, Lane, Angley, & Young, 2008; Chen, Rodgers, & McConachie, 2009).

The study of unimodal integration (e.g., integrating multiple visual stimuli into a whole) can be helpful to better understand different unisensory experiences. However, multisensory integration (MSI) may be a more ecological construct in that it better reflects naturalistic sensory experiences given that most of the situations that are encountered involve stimulation of more than one sensory modality at a time (Bremner, Lewkowicz, & Spence, 2012; De Gelder & Bertelson, 2003). Multisensory integration is the process by which information from multiple sensory modalities are integrated into a whole (Stein, 2012; Stein & Meredith, 1993). The most important advantage of MSI is that it allows to process incoming information more quickly and effectively (Stein & Meredith, 1993). In fact, the advantage conferred by MSI, referred to as multisensory facilitation, goes beyond what would be expected due to the effect of sensory redundancy (Calvert & Thesen, 2004).

Various cognitive theories have hypothesized that there may exist altered sensory integration in ASD, and that this alteration may be at the root of many diagnostic features of ASD (Brock et al., 2002; Frith & Happé, 1994; Mottron & Burack, 2001). Deficits in sensory integration would potentially lead to a disjointed, confusing, and overwhelming perception of the physical surroundings (Foxe & Molholm, 2009). Sensory aversion and sensory seeking behaviours in ASD, as well as social withdrawal, and communication difficulties may then be partially explained as an effort to cope with the overload of information.

As the wide-ranging implications of MSI alterations in ASD have become more apparent, studies using a variety of different paradigms to evaluate this area of functioning have emerged. Some such approaches have included complex stimuli and task demands, like the ability to integrate audiovisual information to process emotional expressions (Charbonneau, et al., 2013), the speech-in-noise paradigm (Foxe et al., 2015; Smith & Bennetto, 2007), and the McGurk effect task (Bebko, Schroeder, & Weiss, 2014; Iarocci, Rombough, Yager, Weeks & Chua, 2010; Mongillo, et al., 2008; Stevenson et al., 2014a; Taylor, Isaac & Milne, 2010; Williams, Massaro, Peel, Bosseler & Suddendorf, 2004; Woynaroski et al., 2013). Other researchers have investigated the issue using simpler, lower-level approaches like the flash-beep illusion task (Bao, Doobay, Collignon, Mottron, & Bertone, 2017; Foss-Feig et al., 2010; Stevenson et al., 2014b; van der Smagt, Engeland, and Kemner, 2007), and visual search tasks (Collignon et al. 2013; de Boer-Schellekens, Keetels, Eussen, and Vroomen, 2013).

The simple reaction time (RT) task has been frequently used to investigate the ability to integrate basic auditory and visual information in clinical populations (e.g., Schizophrenia: Williams, Light, Braff & Ramachandran, 2010; Wynn, Jahshan & Green, 2014; Developmental Dyslexia: Harrar, et al., 2014; Parkinson's Disease: Fearon, Butler, Newman, Lynch & Reilly, 2015) and non-clinical populations (Barutchu, Crewther & Crewther, 2009; Hershenson, 1962; Mahoney, Li, Oh-Park, Verghese & Holtzer, 2011). During the audiovisual version of the RT task, participants are exposed to 3 conditions: 1) visual only, 2) auditory only, and 3) audiovisual multisensory presentation. The expectation is that typical multisensory function would lead to a facilitatory effect (i.e., significantly faster reaction time) during the audiovisual condition relative to the two unimodal conditions.

Despite the fact that the RT paradigm is arguably the simplest and most straightforward approach to investigate multisensory facilitation, only one study to date has used it to evaluate MSI in children and adolescents (7-16 years old) with ASD using lower-level audiovisual stimuli (Brandwein et al., 2013). While the typically-developing comparison group showed evidence for multisensory facilitation, the ASD group, both at the younger (ages 7-10) and older (ages 11-16) age groups did not. Given the need to evaluate MSI using lower level stimuli in order to better conceptualize this area of functioning in ASD, and the fact that this basic task has never been completed with an older ASD population, the current study aims to fill the gaps in the literature, and help to better define MSI functioning in ASD.

Methods

Participants

This study included a total of 40 participants, of which 20 were individuals with Autism Spectrum Disorder (ASD) and 20 were typically developing (TD). In each diagnostic group, 10 participants were adolescents (age range 13-17) and 10 were adults (age range 18-29). Participants for the ASD group were recruited from the Clinique d'Évaluation des Troubles Envahissants du Développement (CETED) database, at the Rivière-des-Prairies Hospital in Montreal. The typically-developing participants were recruited via the CETED as well as through McGill University. Participants in the ASD group were diagnosed based on DSM-IV criteria as well as the Autism Diagnosis Interview-Revised (Lord, Rutter, & Le Couteur, 1994) and/or the Autism Diagnosis Observation Schedule (Lord, Cook, Leventhal, Amaral, 2000) conducted by trained clinicians. Exclusionary criteria for both groups were assessed via a semi-structured interview and included: diagnosis of schizophrenia, ADHD, epilepsy, history of seizures, head injury, current use of stimulant medication or psychoactive drugs, the use of a hearing aid, and cochlear implants. Inclusionary criteria included: normal or corrected-to-normal vision (as measured by a vision test in the laboratory before beginning testing), and normal hearing (as measured by an auditory acuity test in the laboratory before beginning testing). Furthermore, all participants had to meet the minimum requirement of obtaining a full-scale IQ above 70 using Wechsler intelligence measures (i.e., WISC-IV, WAIS-IV, or WASI-II; Wechsler, 2003; Wechsler, 2008; Wechsler, 2011). Typically developing participants were screened for personal or familial history of ASD. All participants, and their caregivers in the case of minor participants, gave written, informed consent before participating. This study was approved by Rivière-des-Prairies hospital's and McGill University's ethic committees. See Table 1 for participant demographics.

Table 1. Participant Demographic Variables by Group.

	ASD (n=20)	TD (n=19)	*t*	*p*
Sex				
Male	16	17		
Female	4	2		
Chronological Age			-0.252	0.802
M	19.21	19.61		
SD	4.71	5.15		
Range	13-29	13-28		
Wechsler Full-Scale IQ			-1.189	0.242
M	102.95	107.79		
SD	13.71	11.55		
Range	79-120	86-125		

Apparatus

The stimuli were designed and presented using VPixx™ software and a MACPRO G4 computer, using an 18-inch Viewsonic E90FB .25 CRT (1280 X 1024 pixels) screen with a refreshing rate of 80 Hz. The mean luminance of the monitor was set at 30.00 cd/m2 (u' = 0.1912, v' = 0.4456 in CIE color space) where minimum and maximum luminance levels were 0.5 and 59.5 cd/m2, respectively. Viewing distance was set at 57cm from the eyes of the participants to the center of the screen. Auditory stimuli were administered via the DataPixx™ data acquisition box. The auditory stimuli were presented in dichotic listening at 65 db SPL, with Sennheiser HD280 headphones. Stability of auditory intensity and visual luminance levels was ensured using a sonometer Quest 1100 and a CS-100 Minolta Chromameter, used for luminance/color reading and monitor gamma-correction.

Stimuli and Procedure

Multisensory integration (MSI) was assessed using a target detection task. Participants were either presented with the auditory stimulus alone (A trials; beep), the visual stimulus alone (V trials; flash) or both stimuli at the same time for the bimodal trials (AV trials). Participants were instructed to use the index finger of their dominant hand to press a button on a response pad as quickly and accurately as possible when a visual and/or and auditory target was detected. Participants began each new trial by pressing the space bar on a keyboard. Their reaction time (RT), defined by the time elapsed between the onset of the stimulus and the response button press, was recorded and used to measure performance. Unimodal and bimodal trials were interspersed randomly with blank catch trials (i.e., no visual or auditory stimulus presented) in order to reduce the likelihood of anticipatory responses.

Each participant completed a total of 4 trial blocks of 64 trials each, for a total of 256 trials, with short breaks between trial blocks. The first 4 trials of every block were practice trials to ensure that participants understood the process; these trials were not included in the analyses. The remaining 60 trials were presented in random order and included 15 blank catch trials, 15 auditory-only trials, 15 visual-only trials and 15 bimodal trials (audiovisual). Each trial began with a fixation cross-presented in the center of the screen for 1500ms. For the active trials, the presentation of the fixation cross was followed by a visual stimulus, an auditory stimulus, or the simultaneous presentation of both stimuli after a variable random time delay of either 500, 750, 1000, 1250 or 1500ms. The auditory stimulus consisted of a 3500 Hz tone presented binaurally through noise-cancelling headphones for a duration of 12.5ms. The visual stimulus was a white disk subtending 3° of visual angle and positioned 7.5° below a white fixation cross presented for a duration of 12.5ms on a black background.

Analysis

Outlier rejection process. The goal of data cleaning was to eliminate trials in which the participant was distracted (Gondan & Minakata, 2016). Responses with a reaction time inferior to 100 ms or superior to 1500 ms were excluded from analysis. The following rule was used to exclude any participant who was not paying attention to the task for an extended length of time: if 5 trials on any modality in a block were either unanswered or over/under the outlier threshold, then the whole block was removed from analysis. If 2 blocks out of 4 were invalidated in this process, then the participant was excluded. The outlier rejection process led to the exclusion of one TD participant who failed to answer 11 visual trials in the last two blocks. For the other participants, a total of 6 trials were excluded from the TD group data, and 31 from the ASD group data (either because the participant missed them, or because they fell out of the 100-1500ms window). In total, 20 participants with ASD and 19 TD participants were included in the analysis.

ANCOVA. The effect of two independent variables (i.e., diagnostic group and trial type) on reaction time (dependent variable), controlling for age (covariate) were assessed using a 2-way mixed-factorial ANCOVA [2 (ASD vs. TD) x 3 (auditory trials vs. visual trials vs. audiovisual trials)]. Greenhouse-Geisser corrections were applied when the Mauchly's test of sphericity was significant in order to correct for the heterogeneity of variance. Bonferroni adjustments for multiple comparisons were used. Statistical significance was set at $p<0.05$.

Race model analysis. The data was analyzed using Matlab (The Mathworks, Inc.) and a program called RMItest, written by Jeff Miller and described in Ulrich et al. (2007). Given that the bimodal stimuli provide two cues rather than one, the effects of multiple, redundant stimulation cannot be distinguished from the effects of multisensory facilitation by comparing the raw RTs for unimodal and bimodal stimuli. Subsequently, the race model analysis was used to determine whether any effect of quicker reaction time of AV trials went above and beyond the effect of redundant stimulation to indicate true multisensory facilitation.

The race model predicts that the reaction time to multimodal stimuli will be equal to the RT of the fastest individual stimulus (i.e. the RT to an audiovisual stimulus should be equal to the fastest RT observed for unimodal stimulation; Miller, 1982). If, however, reaction time to detect multimodal stimuli is significantly faster than for a unimodal signal, the race model prediction is violated, and this facilitation can be attributable to multisensory integration. The coactivation model stipulates that neural activations for both stimuli are combined and result in shorter reaction times (Miller, 1982; Ulrich et al., 2007).

In the race model analysis, cumulative density functions (CDFs) of the RT distributions are generated for every participant and each experimental condition (i.e., visual alone, auditory alone, and bimodal condition). The CDFs obtained from the two unimodal conditions are then summed in order to compute the race model prediction for each participant. This measure provides an estimate of the boundary at which the race model inequality is violated. Percentile points are then determined for every distribution of RT, including the estimated bound for each participant. In the current study, the race model inequality was evaluated at 10 different points of the RT distributions (the 5th, 15th, 25th… 95th percentile points). In other words, for each participant, the percentiles are computed taking the 5%, 10%, etc. trials with the shortest RT. The percentile values are then aggregated across participants in each group (ASD vs. TD). For each percentile, the mean RTs for the bimodal condition are compared to the bound using a two-tail one-sample t test. A Bonferroni correction for multiple comparisons is used to reduce Type 1 error. For example, if the race inequality is violated at the 5th percentile, it means that the 5% fastest RTs for each participant in the bimodal condition, when aggregated, were significantly faster than the race model predicts, i.e. shorter than the estimated race model inequality bound. If any percentile shows significantly faster RTs in the bimodal condition relative to the bound, it can be concluded that the race model cannot account for the redundancy gain observed in the bimodal condition, supporting the existence of a multisensory integrative process. This analysis was computed for each group as a whole, and for adolescents and adults separately in each group.

Results

ANCOVA results

A 2-way mixed-factorial ANCOVA [2 (ASD vs. TD) x 3 (auditory trials vs. visual trials vs. audiovisual trials)] was used to determine differences between groups and trial type, controlling for age. There was no main effect of group, $F(1, 36) = .106$, $p = .747$, $\eta_p^2 = .003$, and no significant group x trial type interaction, $F(1.36, 48.97) = 1.076$, $p = .326$, $\eta_p^2 = .029$. Although pairwise comparisons indicate that there are significant differences between all trial conditions, after controlling for age, no main effect of condition was found, $F(1.36, 48.97) = 1.056$, $p = .331$, $\eta_p^2 =.029$.

Figure 1. Mean RTs for the ASD and TD groups on A, V, and AV trials

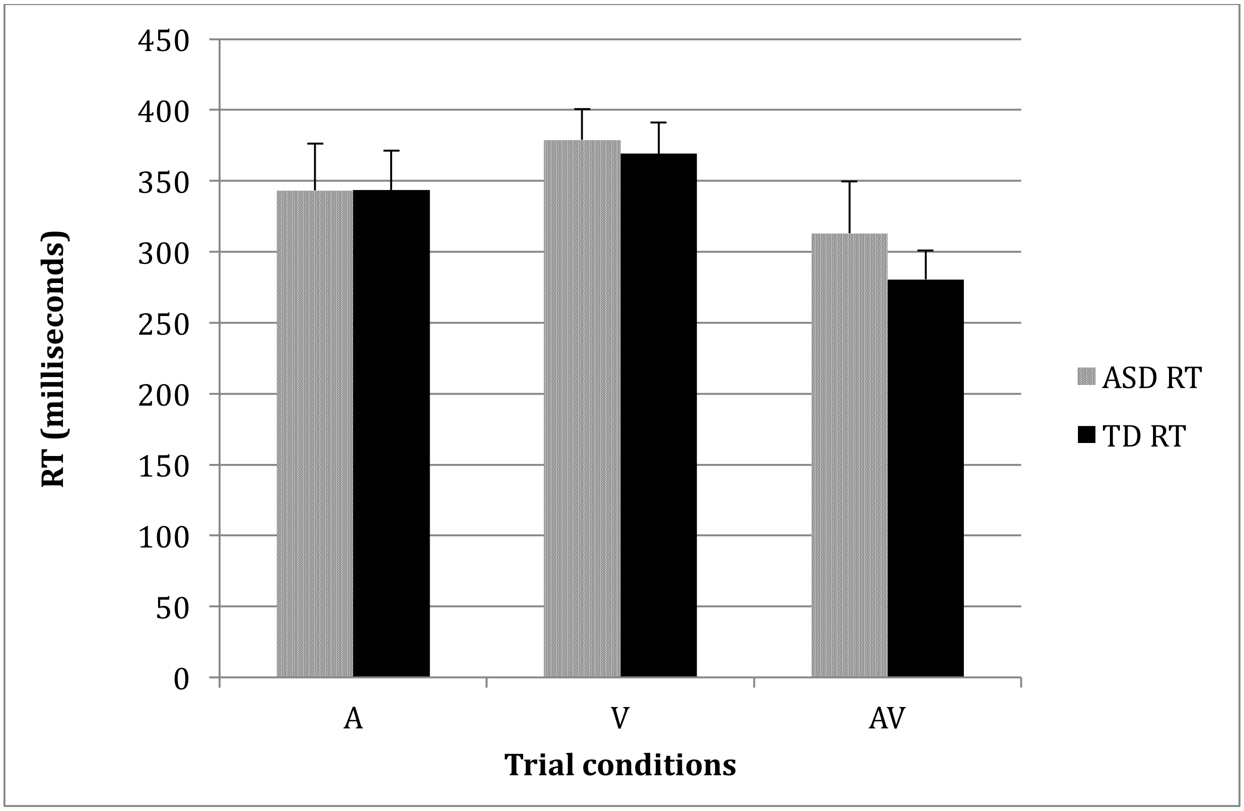

Figure 1. Mean reaction times (ms) for the ASD and TD group across the trial conditions (audio (A), visual (V) and audiovisual (AV)). RTs for the AV conditions were significantly shorter than RTs for the V condition. Error bars are indicated by the Standard Error.

Race model analysis results

The race model analysis showed different results according to the diagnostic groups (see Table 2 for detailed results). For the TD group, the bimodal stimuli violated the race model assumption through the 65th percentile of the reaction time distribution, suggesting that the redundancy gain could be explained by multisensory facilitation. However, in ASD, there was no significant violation of the race model, showing no evidence for multisensory facilitation (Figure 2). Similar results were found when the same analysis was run according to age group (See

Figures A & B in Appendix I). In TD adults, the same violation of the race model through the 65th percentile was found. The violation was reduced to the 45th percentile in TD adolescents. There was no significant violation of the race model for either adults or adolescents with ASD. Although both groups show similar reaction times in response to the three conditions, the race model analysis was able to identify a difference in the facilitation that can be specifically attributed to the bimodal nature of the trials.

Table 2. Race Model Inequality Analysis Results by Group

	ASD group			TD group		
Quantile	Mean RT (in ms) for AV trial	Bound	t-value	Mean RT (in ms) for AV trial	Bound	t-value
0.05	214.83	224.21	1.560	204.84	225.09	3.930*
0.15	242.64	248.82	0.767	224.78	248.91	4.046*
0.25	262.23	267.59	0.589	238.88	263.90	4.905*
0.35	276.83	283.86	0.847	251.58	276.87	4.628*
0.45	289.62	296.41	0.780	263.83	288.86	4.919*
0.55	307.87	307.45	-0.040	278.23	299.10	3.528*
0.65	324.80	317.84	-0.558	290.54	309.50	2.793*
0.75	345.91	329.02	-1.240	309.22	320.46	1.303
0.85	388.12	338.96	-2.110	334.00	329.50	-0.431
0.95	460.15	350.44	-3.429	392.93	338.26	-3.399

* indicates significant $p<.05$

Figure 2. *Test for violation of the race model inequality for the ASD and TD groups*

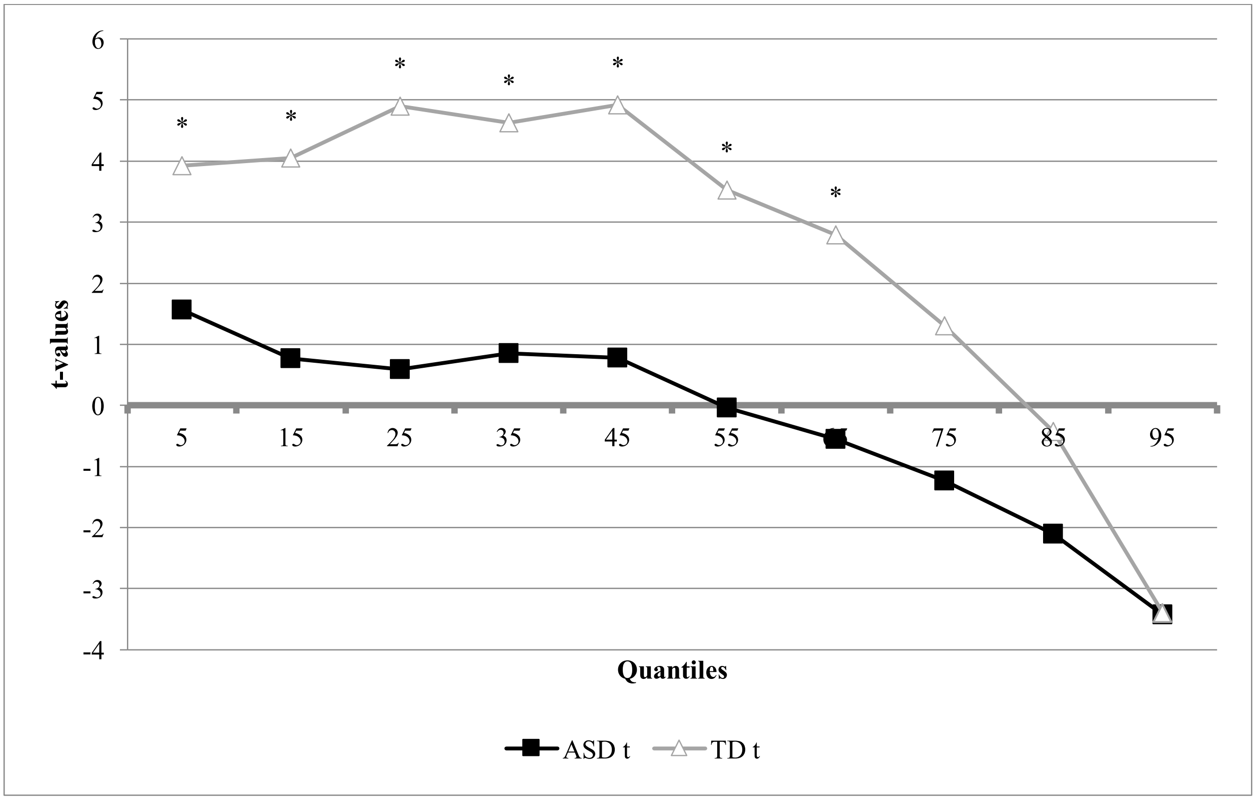

Figure 2. The graph represents the difference in milliseconds (Y axis) between the model prediction based on the auditory and visual conditions, and the RTs obtained in the audiovisual conditions for each group (ASD and TD). Positive values represent RTs that were faster than the race model prediction. The difference between the bound (represented as 0 on the Y axis) and the RTs of the bimodal condition are computed for each percentile of the RT distribution (X axis). * indicates significant violation of the race model ($p<.05$).

Discussion

Research investigating multisensory integration in ASD has expanded, and a burgeoning body of literature exists specifically on the integration of auditory and visual information. However, one of the simplest and most straightforward approaches to investigating audiovisual MSI (i.e., the RT paradigm) has been underutilized to address the question of whether MSI is altered in ASD. Only one study to date has used the simple RT task using lower-level stimuli (i.e., flashes and beeps) to investigate MSI in children with ASD (Brandwein et al., 2013). The current study aimed to expand on this work by using the RT task to evaluate MSI of audiovisual information in adolescents and adults with ASD. Results indicate that only the TD group demonstrated multisensory facilitation, while the ASD group showed no evidence of multisensory facilitation. The race model analysis determined that the TD group violated the race model assumption through the 65th percentile (i.e., violation at any percentile is sufficient to provide evidence of multisensory facilitation). On the other hand, the ASD group RTs did not violate the race model at any of the percentiles. These findings clearly indicate that TD individuals benefit significantly (i.e., faster reaction times) from the concurrent presentation of multiple sensory stimuli, whereas individuals with ASD did not. Overall, these results suggest that MSI is altered in ASD for the most basic type of audio-visual information, using the simplest (RT) task.

These results are also consistent with many of the findings from tasks that have used socio-communicative stimuli and have supported a hypothesis of altered or reduced multisensory integration in ASD (Bebko et al., 2014; Charbonneau, et al., 2013; Mongillo, et al., 2008; Silverman et al., 2010; Smith & Bennetto, 2007; Williams et al., 2004). In fact, the current results go beyond those conclusions to support the idea that MSI is altered in ASD regardless of the complexity of the task or stimuli used to assess this area of functioning. Despite the fact that these results are consistent with the findings of many other studies investigating MSI in ASD, there remains inconsistency in the field. Specifically, some other studies have not shown differences between ASD and TD individuals during tasks designed to assess MSI, or have found that differences may be stimulus- or task-dependent (de Boer-Schellekens et al., 2013; Iarocci et al., 2010; Magnée et al., 2008; van der Smagt et al., 2007; Woynaroski et al., 2013). For instance, some work done using the flash-beep illusion as a method of investigation has shown that individuals with ASD demonstrate susceptibility to one or both of the flash-beep illusions (Bao et al. 2017; Foss-Feig et al., 2010; van der Smagt, et al., 2007). The potential difference between those results and the results from RT tasks, may lie in the use of different paradigms to assess MSI. In the RT task, MSI is measured within the context of multisensory facilitation: How can the presentation of two concurrent stimuli aid in the speed and efficiency with which sensory information is processed? However, with tasks like the flash-beep illusion or the McGurk effect, it is the automaticity and generalizability of MSI that can lead to faulty or illusory perception that is measured: How can perception be impacted by the tendency to integrate sensory information into one coherent percept? Essentially, individuals with ASD may not be benefitting from multisensory facilitation, and instead rely more consistently on information from one modality at a time when performing speeded tasks, but may be susceptible to the same illusory perception as typically developing individuals when the addition of sensory stimuli serves to impede perception, rather than aid it.

This suggestion is consistent with the results of Collignon et al. (2013) in their evaluation of multisensory facilitation using a visual search paradigm. Both ASD and TD participants performed two variations of a visual search task. In the simple visual search condition, participants had to find a visual target amongst distractor items, where the target as well as the distractors changed colour at random intervals. In the multisensory facilitation condition, participants were “aided” by a facilitatory sound that coincided with the target’s colour change. While the TD participants exhibited signs of multisensory facilitation (i.e., their search time was improved on the multisensory condition), the ASD participants showed no such evidence of facilitation. Individuals with ASD may be showing evidence of a local processing bias, which is consistent with accounts from the Weak Central Coherence theory (Frith & Happé, 1994;) as well as the Enhanced Perceptual Functioning hypothesis (Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006).

Comparing the effect of multisensory facilitation across age groups using the race model, yielded no further differences within the ASD group, and only a slight difference within the TD group. Specifically, the race model was not violated at any of the percentiles neither for the adolescent nor the adult participants with ASD, but was violated through the 45th percentile for the TD adolescents and the 65th percentile for the TD adults. Although the TD adolescents still exhibit the presence of multisensory facilitation, it may be argued that the effect is not as strong as it is for older participants. These results are in line with those of Brandwein et al. (2013) who demonstrated that the younger (7-10) and older (11-16) children with ASD exhibited no significant race model violations, but that the younger TD participants exhibited fewer race model violations than the older TD children. Taking these results together, it may be the case that in typical development, the ability to integrate multiple sensory stimuli and perform with more speed and efficiency due to multisensory facilitation is an ability that fully develops in later adolescence and adulthood. On the other hand, the results from both studies may support that individuals with ASD continue to integrate sensory information atypically (i.e., benefit less from multisensory facilitation) throughout development. However, such a conclusion may not be able to be fully drawn without longitudinal analyses of multisensory integration. Only by examining how this area of functioning progresses throughout development will the developmental trajectory of MSI be fully understood. Furthermore, as the population of individuals with ASD continues to age, the MSI ability of older individuals should be taken into consideration to better understand the developmental trajectory of MSI in ASD.

Although the current study addresses some of the gaps in the literature, it does present some limitations. For instance, the sample size is small and does limit the ability to generalize findings to the overall ASD population. In the future, recruiting larger samples to facilitate interpretation of reaction time data as well as perform age analyses allowing for better understanding of age effects on MSI in ASD.

Overall, the results of the current study help to support a growing body of literature that indicates that individuals with ASD do not integrate sensory stimuli in an entirely typical fashion. Most importantly, MSI in ASD appears to be atypical using the RT paradigm which may be considered one of the most simple and elementary indices of MSI. This may suggest that the core features of ASD have an early origin in the lower level of sensory processing. If individuals with ASD have difficulty integrating even lower-level information like simple flashes and beeps, then it follows that this altered processing has cascading effects on more complex perceptual processes like communication, social interaction, and interacting with the environment effectively (Foxe & Molholm, 2009; Stevenson et al., 2017). Given the importance of this area of functioning, further research should continue to help disentangle the effects of multisensory integration difficulties from methodological differences across studies. In addition, future research focusing on bridging the gap between the neural mechanisms and the behavioural manifestations of MSI would allow for better understanding of the ways in which MSI differs in ASD and the far-reaching consequences of such an alteration.

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Chapter 5 – Discussion

Summary of Main Findings & Contributions to the Field

The purpose of this dissertation was to help fill in some gaps in the literature as it pertains to Multisensory Integration in ASD. Specifically, two approaches to evaluating MSI were undertaken in an attempt to better define the MSI abilities of individuals with ASD. Much of the previous research in the field has examined MSI using socio-communicative stimuli. Given the socio-communicative deficits in ASD this approach can be highly informative and provide some insight into the way speech and faces are processed and integrated in ASD. However, this approach also brings forth a potential confound in that it becomes difficult to determine whether impairments found in the integration of socio-communicative stimuli is due to difficulty integrating sensory information vs. difficulty processing socio-communicative stimuli. Although more recent research has shifted focus in an attempt to better understand MSI in ASD, as a burgeoning field, there are many gaps in the literature. Some such areas needing expansion include: better defining age effects/developmental trajectories in MSI for individuals with ASD, better controlling for the effect of stimulus and task complexity in measuring MSI, better defining population characteristics, etc. The two studies conducted as part of this thesis were designed to address some of these gaps in the literature. The following sections provide a summary of the findings for each study as well as a summary of the overall findings taken together. Theoretical and clinical implications are explored. Finally, limitations and future research directions are described.

Study 1 – Summary and Contributions

Objectives and contributions. The goal of Study 1 was to use the Flash-Beep paradigm to better define MSI of lower-level, non-social information in ASD. The Flash-Beep paradigm, developed by Shams, Kamitani, and Shimojo (2000, 2002), is based on the premise that MSI can lead to illusory perception. Presenting an incongruent number of flashes and beeps in close temporal proximity can lead to an auditory-guided visual illusion. Some research with an ASD population has previously been done using the flash-beep paradigm. However, some criticism of this research relates to the restrictiveness of the participant pools as well as the sole focus on the fission illusion.

For instance, van der Smagt, van Engeland, and Kemner (2007) were the first to study the flash-beep illusion in ASD. They specifically studied very high-functioning (i.e., average FSIQ of 122) young adults. Although they reportedly had participants complete a variety of stimulus combinations, including those with multiple flashes and 1 beep which would be the basis for evaluating the fusion illusion, they only reported on the presence of a fission illusion. Keane, Rosenthal, Chun and Shams (2010) evaluated the flash-beep illusion in adults with ASD. However, some criticism of their methods includes the small sample size (only 6 ASD/TD pairs were included in analyses), the sole focus on adults, selection of higher functioning individuals (i.e., IQ above 80, with some participants in the Superior range of functioning), and the apparent sole focus on the fission illusion.

Foss-Feig et al. (2010) used the basic flash-beep paradigm but modified temporal factors of the task (i.e., interstimulus interval) to determine whether children (8-17) had an enlarged temporal binding window. In addition to modified task demands and a restricted age range, the researchers chose to evaluate solely the fission illusion (i.e., the illusory perception of multiple flashes created by the incongruent pairing of multiple beeps with one flash). The fourth investigation of the flash-beep illusion in ASD was conducted by Stevenson et al. (2014b). This research team had a very well-defined population, matching across ASD/TD groups. However, they restricted their study to only children (6-18) and most importantly, only examined the fission illusion.

Overall, although the flash-beep paradigm had been investigated in ASD, methodological issues existed in the literature, not least of which was the absence of any true data on the presence of a fusion illusion in ASD. Given these limitations, specific goals were outlined in order to fill in gaps in the literature as it pertained to MSI in ASD and more specifically the presence of the flash-beep illusion. Study 1 was designed to build upon previous studies that have investigated the flash-beep illusion in ASD in order to better define MSI functioning in ASD by including a wider age, examining both the fission and fusion illusions, and simplifying task demands to increase ease of interpretability.

Summary of results & interpretation. The results of Study 1 indicated that both the ASD and the TD groups had significantly decreased accuracy on the fusion and fission illusion trials as compared to non-illusion trials. In other words, both group were susceptible to both illusions. Susceptibility to the auditory-guided visual illusions within the flash-beep paradigm indicates that auditory information is integrated with that of visual information, thereby suggesting that the illusory perception that occurs during this task is a result of MSI.

Given that previous research on the flash-beep illusion had focused almost entirely on the presence of the fission illusion, one of the most interesting findings brought forth by this study related to the difference in susceptibility to the fission and fusion illusion. The ASD group was significantly more sensitive to the fusion illusion than the TD group, whereas there was no such group difference in susceptibility to the fission illusion. Typically-developing individuals had been found to have more consistent and robust susceptibility to the fission illusion rather than the fusion illusion (Andersen, Tiippana, & Sams, 2004; Shams et al., 2002). Although the mechanism behind this difference in susceptibility to both illusions across groups remains unclear, different interpretations were suggested in Manuscript 1. One possible explanation relates to temporal windows. Individuals with ASD have been shown to have a larger temporal binding window than TD individuals (de Boer-Schellekens, Eussen, & Vroomen, 2013a; Foss-Feig, et al., 2010; Kwakye et al., 2011; Stevenson et al., 2014a; Woynaroski et al., 2013; Zhou et al., 2018). In other words, individuals with ASD tend to perceive as congruent (i.e., occurring at the same time) sensory stimulation that is incongruent over a larger interstimulus interval than do TD individuals. This enlarged temporal binding window is suggestive of less selective integration of multisensory cues. Therefore, whereas the TD group in Study 1 were showing susceptibility to the fusion illusion and integrating incongruent sensory stimuli, the ASD group was doing so more consistently. A predisposition to "over-integration" over a temporal gap may have played a role in the ASD group's increased susceptibility to the fusion illusion. Overall, the results of Study 1 indicate that while multisensory integration is present in ASD when using a simple task, and non-social stimuli, the way in which sensory information is integrated is not entirely typical and may be less selective than in typical development.

Study 2 – Summary and Contributions

Objectives and contributions. Much like Study 1, the goal of Study 2 was to address stimulus complexity, task complexity and age effects to better understand the integration of lower-level, non-social auditory and visual information in ASD. Despite its simplicity and straightforwardness in identifying discrepancies between unisensory and multisensory responses, this task design has only been used in one study of children with ASD (Brandwein, 2013). In their study, Brandwein et al. (2013) obtained EEG data for children (7-16) with and without ASD during a simple reaction time task. Their behavioral findings were such that the TD participants showed multisensory facilitation (i.e., violation of the race model) at both the younger (7-10) and older age groups (11-16), with significantly greater multisensory facilitation in the older group. However, neither the younger nor the older ASD group demonstrated any multisensory facilitation. The primary objective of Study 2 was to utilize a reaction time task, one of the simplest and most elegant methods for assessing audiovisual MSI, to evaluate MSI in adolescents and adults with ASD.

Summary of results & interpretation. The simple RT task completed for Study 2 consisted of comparing the reaction time between stimulus onset and button press in response to either 1-a simple auditory stimulus, 2-a simple visual stimulus or 3-the simultaneous multisensory presentation of both auditory and visual stimuli. In order to accurately identify whether multisensory facilitation has occurred, the race model is used for data analysis. The race model is based on the premise that the facilitatory effect of multisensory integration accounts for a greater reduction in RT than would be expected due to sensory redundancy (i.e., summation of the facilitatory effect of unisensory stimulation).

First, the results collected from Study 2 indicated that, as expected, a significant effect of multisensory facilitation occurred in the TD group (i.e., there was a significant violation of the race model assumption). In fact, both the TD adolescent and TD adult participants saw a significant multisensory facilitation effect. These results are consistent with intact multisensory integration abilities.

Second, the ASD group showed no evidence of multisensory facilitation whatsoever at either the younger or older age group. These findings suggest that individuals with ASD, regardless of their age, do not benefit from the same facilitatory effect of multimodal sensory stimulation as do TD individuals. Furthermore, the findings support the notion that MSI is altered in ASD regardless of the complexity of the task or stimuli used to assess this area of functioning.

Overall Summary and Contributions

While both studies included within this dissertation address different aspects of MSI, overall conclusions can be made about their implications. On the surface, the results from both studies appear inconsistent with one another. Study 1 concludes that susceptibility to auditory-guided visual illusions is present in ASD, thereby suggesting that multisensory integration is occurring in ASD, whereas Study 2 found no sign of multisensory facilitation in the ASD group. This discrepancy is explained by a few distinct factors.

Although both study designs use 1-simple non-social stimuli, and 2-simple computerized tasks that do not require higher-order cognitive processes, the paradigms differ in their approach to measuring and conceptualizing MSI. Multisensory integration can be perceived as advantageous or detrimental to perception depending on the context. On the one hand, it allows us to process multisensory information more quickly and accurately and facilitates our everyday interactions with our environment. On the other hand, it can become so automatic that it can lead to our integration of information that does not constitute the same perceptual event. In Study 1, the flash-beep illusion task takes advantage of the automaticity of MSI that can lead to illusory perception. So, MSI is not measured according to the advantage it confers but instead it is MSI is measured as a function of the outcome of overly automatic integration. The opposite is true for

Study 2, where MSI was evaluated by measuring the facilitatory effect of simultaneous multisensory stimulation. The discrepancy between the results of both studies can be partially explained by the different in perspective for evaluating MSI used in both tasks. Individuals with ASD may not be experiencing multisensory facilitation, instead relying more consistently on information from one modality at a time. Relying more heavily on one modality serves equally well to explain the strong susceptibility to auditory-guided visual illusions during the flash-beep task of Study 1. According to a reliability-based perspective of MSI, the sensory modality providing the most accurate and reliable information for a given situation (Alais & Burr, 2004, Andersen, Tiippana & Sams, 2004; Ernst & Banks, 2002). Given that auditory information is considered more "reliable" for gauging temporal information, participants may have been relying more so or even entirely on the auditory information of the flash-beep task, thereby explaining why they were so strongly susceptible to both auditory-guided visual illusions (Welch & Warren, 1980).

Therefore, although seemingly inconsistent, the pattern of results from both studies can be reconciled when considering that the same mechanisms may be underlying the way in which individuals with ASD process sensory information. Both studies do, in fact, point towards altered MSI in individuals with ASD across lower-level, non-social tasks. The key conclusion is that the current studies appear to confirm that there exists an alteration in MSI in ASD and that this alteration may be influenced by various task and stimulus-related factors (i.e., timing, illusory perception vs. multisensory facilitation).

Clinical Implications

The current results provide a more nuanced view of MSI in ASD than has been described in the past (e.g., Weak Central Coherence, Enhanced Perceptual Functioning). Specifically, the results indicate that individuals with ASD do not have a fundamental inability to integrate information from multiple sensory inputs, but instead do so in an atypical manner. Given the situation, individuals with ASD demonstrate diminished selectivity for integrating information (i.e., enlarged temporal binding windows), or may be over-relying on unisensory information to guide their perception, which diminishes the impact of multisensory facilitation.

There are important clinical implications to the reinterpretation from an entirely impairment-view of MSI in ASD to one that recognizes the influence of stimulus, timing and task-related factors in MSI. The case of sensory integration therapies (SIT) is particularly interesting. These therapies are expensive, and time-consuming, yet they are routinely implemented with children with ASD despite the lack of evidence for their efficacy (Baranek, 2002; Barton, Reichow, Schnitz, Smith, & Sherlock, 2015; Dawson & Watling, 2000; Lang et al., 2012; Leong, Carter, & Stephenson, 2015; Lydon, Healy, & Grey, 2015). These therapeutic approaches were developed on the premise that addressing sensory integration deficits could improve overall functioning and lead to the reduction of stereotyped and repetitive behaviours (Baranek, 2002). Reviews of these therapies have determined that there is not much empirical support for these therapies, but that the lack of empirical research made it difficult to evaluate them (Baranek, 2002; Dawson & Watling, 2000). A review by Lang et al. (2012) determined that, while more research could help to better understand their efficacy, these forms of therapy were not effective. Weitlauf, Sathe, McPheeters, & Warren (2017) conducted a review whose goal was to evaluate the effectiveness of sensory-based interventions for individuals with ASD.

While they concluded that some studies yielded modest, short-term effects, the evidence for effectiveness of sensory-based treatments is minimal, and increased methodological rigor is needed to draw conclusions about these therapies. A similar conclusion was drawn by Barton, Reichow, Schnitz, Smith and Sherlock (2015) in their systematic review of the effectiveness of sensory treatment for children with disabilities. Although they did not solely focus on individuals with ASD, they found a lack of support for sensory-based therapies for children with disabilities in general (Barton et al., 2015).

Furthermore, the results of the current dissertation provide support for altered MSI rather than a complete absence of the ability to integrate sensory information. Not only is there a lack of evidence for sensory integration therapy, SIT's may be attempting to target a problem that does not exist. Instead, early intervention may do better to target the integration of socio-communicative information. There may be preferential attention for attending to non-social stimuli instead of social stimuli early in life, thus creating less exposure to this type of information (Foxe et al., 2015; Mongillo et al., 2008). Increased exposure to speech and non-verbal communication may be a more useful intervention target.

Emphasis on remedying socio-communicative integration impairments could influence targeted approaches later in life as well. Research has shown that in the case of audiovisual speech integration, the addition of gestures or faces either have no effect on information processing or even may have a detrimental effect on speech comprehension (Silverman et al., 2010). Knowing that the addition of gestures to speech may hinder processing could help professionals to develop more appropriate approaches in clinical treatment and in the classroom. Accommodating students with ASD so that wherever possible, they be exposed to one socio-communicative sensory modality at once, could help to reduce overload and support learning.

Teachers, parents and therapists may also be encouraged to reduce gestures that do not explicitly aid in instruction given that children with ASD do not use or understand gestures in the same way as TD children (Sowden, Clegg, & Perkins, 2013). Furthermore, reconceptualizing the MSI profile of individuals with ASD could also change our perspective on the need for eye contact training. There is difficulty modulating and tolerating eye contact in ASD, which may be related to audiovisual speech integration (O'Handley, Radley, & Whipple, 2015). Behavioural approaches often focus on increasing eye contact to improve social skills and communication, but if avoidance of a person's eyes is serving the purpose of reducing overload to aid speech processing, it might be counterproductive to be focusing on modifying eye contact to such a great extent. In fact, research has shown that whereas for TD children, eye contact helps to support cognitive performance, the same effect is not found in ASD (Falck-Ytter, Carlström & Johansson, 2015).

Another core issue with the rationale for using SIT's is that these therapies rest on the notion that MSI is a behavioral construct that can be modified using behavioral approaches. Contrary to some of the other cognitive theories of ASD (i.e., Weak Central Coherence, Enhanced Perceptual Functioning), the temporal binding deficit hypothesis is the only cognitive theory that has developed out of neurophysiological evidence of altered processing (Brock et al., 2002). It is also the only theory that comes close to adequately explaining the inconsistent findings in MSI in ASD. Temporal alteration in ASD exists at both the behavioural and neural level (Brock et al., 2002; Foss-Feig et al., 2010). Many of the studies investigating MSI using temporal binding have found that individuals with ASD may actually be over-integrating multisensory information. If asynchronous, unrelated information is integrated due to the expanded temporal binding window, it follows that the environment would be confusing, and perceptual errors might result. The overload of sensory information and perceptual errors might then contribute to the speech integration difficulties, sensory seeking and aversion, withdrawal, repetitive behaviours, etc. Attempting to influence neurological phenomena based on sensory integration therapies that have evolved from behavioural observation and self-report may be counter-productive. A more useful approach would be to examine neurophysiology in an attempt to work from a bottom-up perspective (i.e., develop possible interventions strategies stemming from principles uncovered in neurophysiological research) rather than a top-down approach (i.e., creating interventions to target behavioral characteristics of ASD that may be related to MSI without consideration for the neural underpinnings of MSI functioning). The lack of evidence for SIT's may be related in part to the tenuous connection between intervention targets and the mechanisms driving MSI. Some research into the neural underpinnings of behavioral treatments (i.e., Pivotal Response Treatment) is beginning to emerge in an attempt to better conceptualize the neural mechanisms implicated in these therapies (Venkataraman et al., 2016). Although no such research has been conducted for sensory integration therapies, movement in that direction would likely bring more clarity to the mechanisms implicated in SIT's and whether or not neurophysiological change is occurring in response to these therapies.

A main problem with bridging the gap between research into MSI and developing interventions to target alterations or deficits in this area is the lack of communication between the research and clinical worlds. Cascio, Woynaroski, Baranek and Wallace (2016), highlight the commonalities as well as gaps that exist between the world of MSI research in ASD, which is often conducted by researchers with little clinical exposure, and the clinical world of MSI intervention, usually by professional Occupational Therapists. Both fields share many of the same perspectives and assumptions: 1-behavioral responses to sensory input is related to neural processing of sensory input, 2-sensory abnormalities may underlie higher-level deficits in ASD, and 3- sensory integration may be responsive to treatment (Cascio, Woynaroski, Baranek, & Wallace, 2016). However, lack of consistency in terminology used by researchers and clinicians, differing methods for evaluating MSI, and general lack of communication between both fields are factors that are identified as needing improvement in order to improve MSI intervention research. In a review by Beker, Foxe & Molholm (2018), identify some potential intervention targets and procedures that may have a more neurological basis for intervention than some of the typical SIT's. For instance, they describe the possibility for neurofeedback repetitive transcranial magnetic stimulation in improving MSI abilities (Beker et al., 2018). Although there is no firm research base for these methods being implemented to directly target MSI in ASD, the prospect of approaching MSI intervention from the neural level is a promising and exciting shift in the field.

Moving forward, there is a need for MSI research to better help inform clinical practice to ensure that effective treatments tailored to the needs of the individual with ASD can target the most appropriate areas of functioning. Multisensory integration research in individuals with ASD is only just beginning. Although neither the development nor the nature of MSI in ASD are still entirely clear, current efforts to uncover the multisensory mechanisms that contribute to the core behaviours and impairments of ASD have valuable implications.

Limitations and Future Directions

Multisensory integration research in ASD has begun to yield interesting results, but there are many ways in which the methodological approaches could be improved. Due to inconsistent results across studies, and the fact that the breadth of research is still limited, moving forward, researchers addressing MSI in ASD could help to better define MSI functioning in ASD by making some of the following improvements.

Stimulus Complexity

Possibly one of the most contentious issues in MSI research, is the role that stimulus complexity plays in obtaining an adequate picture of the way multisensory information is integrated in ASD. Since much of the previous research had implemented stimuli that were complex and socio-communicative, a goal of the present dissertation was to eliminate this factor entirely to reduce noise in the data. However, this was arguably one of the main limitations of the current research. Given the differences in findings between socio-communicative MSI tasks and non-social MSI tasks, it is clear that the nature of the information that needs to be integrated influences, at least to a certain extent, the ability of individuals with ASD to efficiently and accurately integrate sensory information. Studies need to be designed in a way that systematically addresses the issue of stimulus complexity. At the research level, doing so will help to better define MSI functions in ASD. Even more importantly, however, distinguishing between impaired socio-communicative processing versus impaired integration of any type of information would have huge implications on treatment approaches and how the ASD phenotype is conceptualized. So far, only three studies have looked at MSI using different levels of stimuli (i.e., non-social and social) in the same participants (de Boer-Schellekens, Eussen, & Vroomen, 2013a; Mongillo et al., 2008; Stevenson et al., 2014a). However, even within this limited body of data, developmental differences and task complexity issues have not been controlled for. Moving forward, increased methodological considerations will need to be made to truly be able to piece apart the role of stimulus complexity in driving some of the results of MSI research in ASD.

Task complexity

The level of task complexity can have a significant impact on results of studies investigating MSI in ASD. One limitation of both studies included in this thesis is that they both have relatively low task complexity. Although this was helpful in the interpretation of results because it eliminated a potentially confounding factor, limited conclusions can be drawn about the effect of task complexity on MSI. For instance, although they both use non-social stimuli, tasks of semantic priming and simple reaction time tasks have different task demands (Brandwein et al., 2013; Russo et al., 2012). The semantic priming task requires participants to tap into prior knowledge about animals, make judgments about whether two stimuli match or not, and be able to understand verbal instructions. A simple reaction time task, on the other hand, does not require the use of higher-order cognitive functions like decision-making or conceptual knowledge. Therefore, the ability to generalize findings across these tasks is limited. The influence of task complexity is even greater when comparing speech-based tasks to lower-level tasks. By ensuring that task complexity can be controlled for as well as stimulus complexity, MSI functioning in ASD may eventually be better understood.

Homogeneous samples within a heterogeneous population

Following from the issue of task complexity, homogenous samples of high-functioning participants have been researched in MSI studies due to the more complex task requirements. One of the limitations of the current dissertation relates to the exclusive inclusion of individuals with and without ASD that are considering “high-functioning”. Individuals with ASD who are lower functioning (i.e., usually defined as those with an IQ below 70 or 80, and/or delays in adaptive functioning) are often forgotten in autism research in general. In fact, not a single one of the studies investigating MSI described in the literature review of Chapter 2 has attempted to study multisensory integration in low functioning individuals with ASD. This is not entirely surprising given the need for sustained attention, comprehension of verbal instructions, and other factors necessary for the completion of experimental tasks. However, it is possible that MSI ability may manifest differently in low functioning as compared to higher functioning individuals with ASD. Moving forward, the field of MSI research in ASD could benefit from some increased creativity regarding how to modify task designs to make them appropriate for low functioning participants. For instance, tasks could be designed to have fewer trials, more frequent breaks, and reduced or non-existent verbal instructions. When irrelevant to the task at hand, allowing participants to respond non-verbally would be preferable over verbal responses. It may also be necessary to limit MSI investigations in low functioning groups to simple reaction time tasks, or to develop alternative methods of assessment entirely (e.g., modifying the preferential looking paradigm used with children in order to adapt it to adults). Unfortunately, the exclusion of low functioning individuals with ASD in research has been the norm so far, but researchers should begin to consider ways of involving the entire spectrum of autism.

Developmental trajectories

Unfortunately, the developmental trajectory of multisensory integration in ASD is not adequately defined. Developmental trajectories have begun to be evaluated in ASD for a variety of abilities, including theory of mind and executive functions (Pellicano, 2010), cognitive control (Solomon, Ozonoff, Cummings, & Carter, 2007), daily living skills (Smith, Maenner, & Seltzer, 2012), and well as for characteristics of ASD symptomatology (Lord, Bishop & Anderson, 2015; Richler, Huerta, Bishop, & Lord, 2010). As of yet, collecting longitudinal data to identify the developmental trajectory of multisensory integration has not been attempted. The ideal approach to understand MSI development across the lifespan would be to conduct a longitudinal study.

Longitudinal data, being extremely difficult to collect, may not be the most feasible option for most researchers. However, a step in the right direction would be to start by testing children, adolescents and adults within the same study using tasks and stimuli of varying complexity. In doing so, it would be easier to control for methodological variance, and thus ensure that clearer conclusions could be drawn. A limitation of the current two studies was the sole inclusion of adolescents and adults. A move toward having all MSI research take a developmental approach (i.e., include all age groups), would hopefully begin to provide more clarity to the field. In their review, Beker, Foxe and Molholm (2018), suggest that the overall picture of development in MSI research in ASD is that there exists a delay in MSI abilities, with some studies asserting a catch-up phase in adulthood, while others contend MSI continues be delayed in adults with ASD. This possibility suggests that MSI may be a relevant target for early intervention in children with ASD, and that well-designed interventions may help to close the gap between TD and ASD individuals.

Beyond the focus on conducting developmental research, there is also a severe lack of information on MSI processes in older adults with ASD. In fact, the vast majority of ASD research in general appears to exclude older adults. Some research in TD populations have investigated differences in MSI throughout development, including older adults, and have found that differences throughout aging occur (Bedard & Barnett-Cowan, 2016; Chan, Connolly, & Setti, 2018; Couth, Gowen, & Poliakoff, 2018; Laurienti, Burdette, Maldjian, & Wallace, 2006; Peiffer, Mozolic, Hugenschmidt, & Laurienti, 2007). Given these aging differences in the TD population, it might be expected that similar age-related differences exist in the ASD population. Moving forward, including participants from across the lifespan in ASD research would be beneficial to better define the developmental trajectory of MSI in ASD.

Next steps in MSI research in ASD

Beyond creating research protocols that address the methodological limitations of MSI research in ASD, there are current new frontiers being explored in MSI research. As described above, the temporal binding hypothesis has gained momentum as one of the most accurate ways of conceptualizing MSI functioning in ASD. Some of the recent research into temporal factors of MSI and specifically, temporal binding windows, as continued to shape our understanding of MSI in ASD (Stevenson et al., 2015). Chan, Langer and Kaiser (2016) review some of the research in ASD that has implemented temporal order judgments (TOJ) and other methods (i.e., sound-induced flash-illusion) to examine temporal binding windows in ASD. They also suggest that the predictive coding theory (i.e., a difference in the ability for individuals with ASD to consolidate bottom-up sensory input with top-down predictive inferences) may be helpful in explaining the presence of enlarged temporal binding windows in ASD (Chan, Langer, & Kaiser, 2016).

Research on MSI in the TD population has yielded interesting results that will hopefully eventually be investigated in ASD in order to better understand this area of functioning in ASD. For instance, a recent study by Dean et al. (2017) has gone beyond looking at cross-modal temporal acuity in multisensory perception, and has studied whether attentional load influences temporal binding in MSI. They found that increasing attentional load has detrimental effects on the ability to engage in multisensory temporal processing (Dean et al., 2017). They take their interpretation further by suggesting that these findings may have implications for our understanding of the way in which individuals with ASD process multisensory information. Specifically, they suggest that the enlarged temporal binding window in ASD may be partially attributable to difference in the ability to manage attention in ASD.

Although the main focus in the field of MSI research has largely been on gathering behavioral data, considering how the sensory symptoms of individuals with ASD correlates with their ability to integrate sensory information could provide valuable additional information. This may include collecting qualitative as well as quantitative data on the sensory symptoms experienced by individuals with ASD. Gathering information from self-report, parent questionnaires, and clinical interviewing in addition to collecting behavioral data from psychophysical experiments could help to provide more depth to our understanding of the subjective experience of sensory processing and multisensory integration in individuals with ASD.

Another shift in MSI research in ASD has been to move toward solely behavioural studies to those that also investigate the neural underpinnings of MSI. Increasing interest has been taken in attempting to define neural models for MSI in ASD (Baum, Stevenson, & Wallace, 2015; Martinez-Sanchis, 2015; Noriega, 2015), collecting neurophysiological data during behavioural tasks of MSI (Brandwein et al., 2013; Chmielewski, Wolff, Mückschel, & Roessner, 2016; Magnee et al., 2008; Mueller et al., 2013; Russo et al., 2010), inferring phenotypic differences by investigating brain-based differences (Chang et al., 2014), and even investigating multisensory alterations in autism by using animal models of ASD (Siemann et al., 2017). Overall, there appears to have been a shift in the literature towards better defining the brain-based alterations in ASD that may be contributing to the behavioural differences observed in research.

Concluding remarks

The studies included in this dissertation constitute an original contribution to the literature. Both studies bring about some much-needed clarity to the way in which lower-level sensory information is integrated in ASD. Multisensory integration was assessed using two different but complementary paradigms: 1- the auditory guided visual illusion in the flash-beep paradigm, and 2- multisensory facilitation via the simple reaction time task. Taken together, the results of these studies support the notion that MSI is altered in ASD even when the stimuli used is simple and non-social, and that specifically, temporal factors and stimulus-related factors may have some influence on the way in which audiovisual sensory information is integrated in ASD. Despite the contribution of these studies, more research addressing developmental factors, heterogeneous samples, stimulus and task complexity, as well as neurobiological foundations of MSI is necessary to better understand MSI in ASD. Continued research in this area has implications for theoretical perspectives as well as intervention for individuals with ASD.

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Appendix A

Telephone Recruitment Script - French

Canevas téléphonique pour le recrutement des sujets

« Bonjour, je m'appelle … … , je suis assistant(e) de recherche au laboratoire de recherche du Dr Bertone à l'hôpital Rivière-des-Prairies. Je vous appelle afin de vous demander si vous seriez intéressé et disponible pour participer à une étude. Le titre de l'étude est : *L'Évaluation de l'intégration multisensorielle et de la sensibilité aux illusions visuelles chez les individus qui ont un TSA*.

« Votre participation consistera à effectuer diverses tâches dans lesquelles vous aurez à détecter différents types de stimuli auditifs et visuels qui vous seront présentés. Vous devrez participer à une session d'environ 1.5 à 2.5 heures afin de compléter les tâches. Des stimuli visuels seront présentés à l'écran d'ordinateur et des stimulis auditifs seront présentés à travers des écouteurs.

Vous n'avez aucun avantage direct à participer à cette étude à part le fait de faire avancer les connaissances scientifiques sur l'autisme. Il n'existe pas de risques prévisibles liés à votre participation, mis à part le temps que cela vous prendra pour effectuer les tâches et votre déplacement.

La compensation pour l'étude est de 15$. Il vous est possible d'abandonner l'étude à tout moment.»

Si la personne est intéressée, vérifier si elle répond aux critères d'inclusion :
« J'aurais quelques questions à vous poser avant de confirmer votre participation à l'étude. Avez-vous des problèmes de vision? Portez-vous des lunettes ou des verres de contact qui corrigent ces problèmes de vision? Avez-vous des problèmes d'ouïe? Portez-vous un appareil auditif? Avez vous un diagnostic de TSA? Est-ce qu'un membre de votre famille immédiate à un diagnostic de TSA? Prenez-vous actuellement des médicaments présentement? Si oui, quel type? Avez-vous un diagnostic de TDAH? Faites-vous de l'épilepsie?»

Si la personne répond aux critères :
« Quand seriez-vous disponibles pour participer à l'étude? »

Fixer le rendez-vous.
« Parfait, je viendrai vous chercher à l'accueil de l'Hôpital Rivière des Prairies, à l'heure et au jour fixé, je vous laisse le numéro où me joindre d'ici là. Le formulaire de consentement sera expliqué et signé sur place.

S'il vous plaît, il est important de ne consommer ni alcool ni drogues dans les jours qui précèdent le rendez-vous. Avez-vous des questions? Si vous souhaitez me rejoindre, vous pouvez me contacter au (numéro téléphone). Merci beaucoup.»

Appendix B

Consent Form – French, Minor Participants

FORMULAIRE D'INFORMATION ET D'ASSENTIMENT

(Participants mineurs 6-17)

1. **Titre du projet, nom des chercheurs et affiliation**
L'évaluation de l'origine et du développement de l'intégration multisensorielle en autisme.

Chercheurs principaux
Armando Bertone, Ph.D., Professeur adjoint, Université McGill

Co-chercheurs
Vanessa Bao, M.A., Candidate au doctorat, Université McGill

Quel est le but de ces tâches?
Le but des tâches est de nous aider à comprendre comment les enfants et les adolescents avec et sans autisme (TSA) sont capables de mettre ensemble l'information qu'ils voient et qu'ils entendent. Les participants complètent 3 tâches à l'ordinateur. Nous voulons savoir s'il y a une différence entre les enfants avec un TSA et les enfants sans TSA dans la façon qu'il perçoivent de l'information simple et de l'information plus complexe.

Qu'est-ce que je vais faire au laboratoire?
Je vais te demander de faire quelques différentes activités aujourd'hui. Tu trouveras peut-être quelques-unes des activités très faciles, tandis que d'autres seront peut-être plus difficiles – c'est complètement normal! Je veux juste que tu fasses de ton mieux. Certains enfants (ça dépend de chaque personne) commencent leur participation avec quelques activités (casse-têtes, questions) qui nous aident à savoir comment tu penses et comment tu comprends les choses autours de toi.

Puis, il va y avoir 3 tâches à compléter, et chacune se fera devant un écran d'ordinateur. Tu devras porter des écouteurs pour compléter ces tâches. Pour la tâche 1, tu vas faire une activité ou tu devras peser un bouton aussi vite que tu peux lorsque tu vois et/ou tu entends quelque chose. Pour la tâche 2, tu vas essayer de trouver une image cible sur l'écran aussi vite que tu peux. Pour la tâche 3, tu vas voir et/ou entendre des visages et des voix, et tu vas essayer de deviner c'est quelle émotion qu'on t'a montrée.

Une fois terminé, tu vas recevoir $15 pour ta participation.

Est-ce que je suis obligé de faire ces tâches?
Tes parents nous ont donné leur permission pour que tu puisses participer au projet de recherche au laboratoire. Mais, tu n'es pas obligé de participer si tu ne veux pas. Si tu ne veux pas participer, tu n'as pas besoin de répondre à aucune question et tu n'as qu'à me dire ou dire à tes parents que tu veux arrêter. Même si on a déjà commencé les activités tu as toujours le droit de changer d'idée

et de décider de ne pas participer.

Qui saura ce que je fais durant ces activités?
Toutes les réponses que tu donnes durant les activités sont confidentielles. Ça veut dire que c'est seulement moi et les autres chercheurs qui travaillent avec moi sur ce projet qui peuvent voir tes réponses. Les réponses de tous les enfants et les adolescents qui ont participé peuvent être présentées à des rencontres ou dans des articles, mais ton nom ne sera jamais utilisé, et personne ne saura que tu as fait partie de cette étude.

As-tu des questions?

Veux-tu participer à cette étude?

Assentiment du Participant [Mineur]

Nom du participant (en majuscules): ____________________________________

J'ai lu et compris le contenu du présent formulaire. Je certifie qu'on me l'a expliqué verbalement. J'ai eu l'occasion de poser toutes mes questions et on y a répondu à ma satisfaction. Je sais que je suis libre de participer au projet et que je demeure libre de m'en retirer en tout temps, par avis verbal, sans que cela n'affecte <u>la qualité des traitements, des soins futurs et des rapports avec mon médecin ou l'hôpital (à adapter selon le contexte)</u>. Je certifie qu'on m'a laissé le temps voulu pour prendre ma décision. Je comprends que je recevrai une copie signée du présent formulaire. Je consens à participer à ce projet.

Signature du participant__________________________ Date __________________

Accord verbal de l'enfant / majeur inapte incapable de signer mais capable de comprendre la nature de la participation au projet

Oui ( ) Non ( )

____
Nom du chercheur | Signature du chercheur | Date

Appendix C

Consent Form – French, Adult Participants

FORMULAIRE D'INFORMATION ET DE CONSENTEMENT
(Participants majeurs)

1. **Titre du projet, nom des chercheurs et affiliation**
   L'évaluation de l'origine et du développement de l'intégration multisensorielle en autisme.

   Chercheurs principaux
   Armando Bertone, PhD., Professeur adjoint, Université McGill

   Co-chercheurs
   Vanessa Bao, M.A., Candidate au doctorat, Université McGill

2. **Description du projet**
Ce projet de recherche vise à investiguer l'intégration multisensorielle (le processus permettant à un individu d'intégrer de l'information provenant de plus qu'une modalité sensorielle à la fois) chez les individus atteints d'un trouble du spectre autistique (TSA). La capacité à intégrer de l'information visuelle et auditive simple et complexe sera évaluée à l'aide de trois tâches informatisées. Nous évaluerons s'il existe des différences entre les individus autistes et les individus neurotypiques dans leur capacité d'intégrer de l'information multisensorielle.

3. **Procédures de l'étude**
Je participerai à une session de 1.5 à 2.5 heures, dépendamment du besoin ou non de compléter une évaluation cognitive. Pour la première tâche, ma participation consiste à détecter un son, une image présentée sur un écran d'ordinateur ou parfois les deux en même temps. Pour la deuxième tâche, ma participation consiste à chercher un objet cible sur un écran lorsqu'il y aura parfois la présence d'un son (un bip). Finalement, durant la troisième tâche, je devrai faire un choix afin d'indiquer quelle émotion est transmise visuellement sur l'écran et/ou de façon auditive à travers des écouteurs. Je complèterai ces tâches au Laboratoire de Neuroscience de la Perception pour l'autisme et les troubles du développement de l'Hôpital Rivière-des-Prairies.

4. **Avantages et bénéfices pour le sujet**
Il n'y a aucun avantage découlant de ma participation à cette étude, outre le fait de contribuer à l'avancement des connaissances scientifiques dans ce domaine de recherche.

5. **Indemnité compensatoire**
Suite à cette expérience, une indemnité compensatoire de 15$ me sera remise.

6. **Inconvénients et risques**
Un inconvénient est le temps pris pour me rendre à l'Hôpital Rivière des Prairies, où l'étude s'effectue, ainsi que le temps que je vais mettre pour compléter les tâches. Aucun risque connu n'est relié aux expériences auxquelles je vais participer. Des mesures seront prises afin de pallier

aux éventuels inconvénients qui peuvent être entrainés par la répétition de stimuli soit la fatigue, l'inconfort relié à l'immobilité et à l'attention soutenue. En effet, la présentation des stimuli sera régulièrement interrompue, me permettant ainsi de relaxer légèrement.

7. **Modalités prévues en matière de confidentialité**
Les informations qui me concernent dans le cadre de ce projet demeureront confidentielles. Un code chiffré sera utilisé pour remplacer mon nom de sorte qu'aucun membre de l'équipe autre que les chercheurs impliqués dans l'étude (mentionnés plus haut), ne puisse m'identifier. Les données obtenues au cours de ce projet seront donc codées, mais non anonymes. Un code sera utilisé lors de la publication de l'étude et dans aucun cas mon nom ne sera divulgué. Les données nominatives ne seront pas conservées. Seules les données brutes le seront. Ces données seront conservées pour une période de dix ans, car elles sont nécessaires aux vérifications suite à la publication. Mes informations personnelles contenues dans la base de données de la Clinique de l'autisme de l'Hôpital Rivière-des-Prairies pourront être consultés dans le cadre de cette recherche, et les résultats de la présente recherche pourront y être transférés. Il est possible que les chercheurs doivent permettre l'accès aux dossiers de recherche au comité d'éthique de la recherche de HRDP et aux organismes subventionnaires de la recherche à des fins de vérification ou de gestion de la recherche. Tous adhèrent à une politique de stricte confidentialité.

8. **Clause de responsabilité**
S'il survient un incident suite à ma participation à cette étude, je pourrai faire valoir tous les recours légaux garantis par les lois en vigueur au Québec, sans que cela n'affecte les soins qui me sont prodigués. Ma participation ne libère ni les chercheurs ni l'établissement de leurs responsabilités civiles et professionnelles.

9. **Liberté de participation et droit de retrait**
Ma participation à cette étude est tout à fait volontaire. Ainsi, je suis libre d'accepter ou de refuser d'y participer. Mon refus ne va pas nuire à mes relations avec mon médecin ou avec les autres intervenants si je suis un patient à l'Hôpital Rivière des Prairies. Je suis également libre de me retirer de cette étude en tout temps. Toute nouvelle connaissance acquise au cours du processus d'expérimentation pouvant affecter ma décision d'y participer me sera communiquée dans les plus brefs délais. Mes données seront détruites au cas où je déciderais de ne pas compléter les tâches.

10. **Nom des personnes-ressources**
Pour de plus amples renseignements au sujet de ce projet de recherche ou pour aviser de mon retrait, je pourrai contacter le chercheur principal, Armando Bertone, au 514-323-7260, poste 4571. Si vous avez des plaintes, des commentaires à formuler ou si vous avez des questions concernant vos droits en tant que participant de recherche, vous pouvez communiquer avec la commissaire locale aux plaintes et à la qualité des services de l'Hôpital Rivière-des-Prairies, Mme Hélène Bousquet, au 514-323-7260, poste 2154.

11. **Formule d'adhésion et signatures**
J'ai lu et compris le contenu du présent formulaire. Je certifie qu'on me l'a expliqué verbalement. J'ai eu l'occasion de poser toutes mes questions et on y a répondu à ma satisfaction. Je sais que je suis libre de participer au projet et que je demeure libre de m'en retirer en tout temps, par avis verbal, sans que cela n'affecte la qualité des traitements, des

soins futurs et des rapports avec mon médecin ou l'hôpital (à adapter selon le contexte). Je certifie qu'on m'a laissé le temps voulu pour prendre ma décision. Je comprends que je recevrai une copie signée du présent formulaire. Je consens à participer à ce projet.

Nom du sujet en majuscules	Signature du sujet	Date

12. **Formule d'engagement du chercheur**
Je certifie avoir expliqué au(x) signataire(s) les termes du présent formulaire de consentement, avoir répondu aux questions qu'il(s) m'a(ont) posées à cet égard, lui(leur) avoir clairement indiqué qu'il(s) reste(nt) à tout moment libre de mettre un terme à sa(leur) participation et que je lui(leur) remettrai une copie signée et datée du présent formulaire de consentement

Nom du chercheur en majuscules	Signature du chercheur	Date

13. **Informations de type administratif**
Le formulaire original sera inséré à mon dossier médical (s'il y a lieu). Une copie sera insérée dans le dossier de recherche et une autre copie me sera remise. Le projet de recherche et le présent formulaire de consentement ont été approuvés par le comité d'éthique de la recherche de l'Hôpital Rivière-des-Prairies.

Appendix D

Consent Form – French, Parents of Minor Participants

FORMULAIRE D'INFORMATION ET DE CONSENTEMENT (Parents)

1. **Titre du projet, nom des chercheurs et affiliation**
L'évaluation de l'origine et du développement de l'intégration multisensorielle en autisme.

Chercheurs principaux
Armando Bertone, PhD., Professeur adjoint, Université McGill

Co-chercheurs
Vanessa Bao, M.A., Candidate au doctorat, Université McGill

2. **Description du projet**
Ce projet de recherche vise à investiguer l'intégration multisensorielle (le processus permettant à un individu d'intégrer de l'information provenant de plus qu'une modalité sensorielle à la fois) chez les individus atteints d'un trouble du spectre autistique (TSA). La capacité à intégrer de l'information visuelle et auditive simple et complexe sera évaluée à l'aide de trois tâches informatisées. Nous évaluerons s'il existe des différences entre les individus autistes et les individus neurotypiques dans leur capacité d'intégrer de l'information multisensorielle.

3. **Procédures de l'étude**
Votre enfant participera à une session de 1.5 à 2.5 heures, dépendamment du besoin ou non de compléter une évaluation cognitive. Pour la première tâche, la participation de votre enfant consiste à détecter un son, une image présentée sur un écran d'ordinateur ou parfois les deux en même temps. Pour la deuxième tâche, la participation de votre enfant consiste à chercher un objet cible sur un écran lorsqu'il y aura parfois la présence d'un son (un bip). Finalement, durant la troisième tâche, votre enfant devra faire un choix afin d'indiquer quelle émotion est transmise visuellement sur l'écran et/ou de façon auditive à travers des écouteurs. Votre enfant complètera ces tâches au Laboratoire de Neuroscience de la Perception pour l'autisme et les troubles du développement de l'Hôpital Rivière-des-Prairies.

4. **Avantages et bénéfices pour le sujet**
Il n'y a aucun avantage découlant de la participation de mon enfant à cette étude, outre le fait de contribuer à l'avancement des connaissances scientifiques dans ce domaine de recherche.

5. **Indemnité compensatoire**
Suite à cette expérience, une indemnité compensatoire de 15$ sera remise à mon enfant.

6. **Inconvénients et risques**
Un inconvénient est le temps pris pour se rendre à l'Hôpital Rivière des Prairies, où l'étude s'effectue, ainsi que le temps mis pour compléter les tâches. Aucun risque connu n'est relié aux expériences auxquelles mon enfant va participer. Des mesures seront prises afin de pallier aux

éventuels inconvénients qui peuvent être entrainés par la répétition de stimuli soit la fatigue, l'inconfort relié à l'immobilité et à l'attention soutenue. En effet, la présentation des stimuli sera régulièrement interrompue, permettant à votre enfant ainsi de relaxer légèrement.

7. **Modalités prévues en matière de confidentialité**
Les informations qui concernent mon enfant dans le cadre de ce projet demeureront confidentielles. Un code chiffré sera utilisé pour remplacer le nom de mon enfant de sorte qu'aucun membre de l'équipe autre que les chercheurs impliqués dans l'étude (mentionnés plus haut), ne puisse m'identifier. Les données obtenues au cours de ce projet seront donc codées, mais non anonymes. Un code sera utilisé lors de la publication de l'étude et dans aucun cas le nom de mon enfant ne sera divulgué. Les données nominatives ne seront pas conservées. Seules les données brutes le seront. Ces données seront conservées pour une période de dix ans, car elles sont nécessaires aux vérifications suite à la publication. Les informations personnelles de mon enfant contenues dans la base de données de la Clinique de l'autisme de l'Hôpital Rivière-des-Prairies pourront être consultés dans le cadre de cette recherche, et les résultats de la présente recherche pourront y être transférés. Il est possible que les chercheurs doivent permettre l'accès aux dossiers de recherche au comité d'éthique de la recherche de HRDP et aux organismes subventionnaires de la recherche à des fins de vérification ou de gestion de la recherche. Tous adhèrent à une politique de stricte confidentialité.

8. **Clause de responsabilité**
S'il survient un incident suite à la participation de mon enfant à cette étude, je pourrai faire valoir tous les recours légaux garantis par les lois en vigueur au Québec, sans que cela n'affecte les soins qui sont prodigués à moi ou mon enfant. Ma participation ne libère ni les chercheurs ni l'établissement de leurs responsabilités civiles et professionnelles.

9. **Liberté de participation et droit de retrait**
La participation de mon enfant à cette étude est tout à fait volontaire. Ainsi, mon enfant et moi sommes libres d'accepter ou de refuser d'y participer. Un refus ne va pas nuire à nos relations avec notre médecin ou avec les autres intervenants si mon enfant est un patient à l'Hôpital Rivière des Prairies. Mon enfant et moi sommes également libres de se retirer de cette étude en tout temps. Toute nouvelle connaissance acquise au cours du processus d'expérimentation pouvant affecter notre décision d'y participer nous sera communiquée dans les plus brefs délais. Les données de mon enfant seront détruites au cas où nous déciderions de ne pas compléter les tâches.

10. **Nom des personnes-ressources**

Pour de plus amples renseignements au sujet de ce projet de recherche ou pour aviser de notre retrait, je pourrai contacter le chercheur principal, Armando Bertone, au 514-323-7260, poste 4571. Si vous avez des plaintes, des commentaires à formuler ou si vous avez des questions concernant vos droits en tant que participant de recherche, vous pouvez communiquer avec la commissaire locale aux plaintes et à la qualité des services de l'Hôpital Rivière-des-Prairies, Mme Hélène Bousquet, au 514-323-7260, poste 2154

11. **Formule d'adhésion et signatures**

J'ai lu et compris le contenu du présent formulaire pour le projet qui requiert la participation de mon enfant. Je certifie qu'on me l'a expliqué verbalement. J'ai eu l'occasion

de poser toutes mes questions et on y a répondu à ma satisfaction. Je sais que mon enfant est libre de participer au projet et qu'il demeure libre de s'en retirer en tout temps, par avis verbal, sans que cela n'affecte la qualité des traitements, des soins futurs et des rapports avec son médecin ou l'Hôpital (à adapter selon le contexte). Je demeure aussi libre de l'en retirer à tout moment aux mêmes conditions. Je certifie qu'on m'a laissé le temps voulu pour prendre ma décision. Je certifie que le projet a été expliqué à mon enfant dans la mesure du possible et qu'il accepte d'y participer sans contrainte ou pression de qui que ce soit. Je comprends que je recevrai une copie signée du présent formulaire. Je consens à ce que mon enfant participe à ce projet.

Nom du représentant légal	Signature du représentant légal	Date

12. **Formule d'engagement du chercheur**
Je certifie avoir expliqué au(x) signataire(s) les termes du présent formulaire de consentement, avoir répondu aux questions qu'il(s) m'a(ont) posées à cet égard, lui(leur) avoir clairement indiqué qu'il(s) reste(nt) à tout moment libre de mettre un terme à sa(leur) participation et que je lui(leur) remettrai une copie signée et datée du présent formulaire de consentement.

Nom du chercheur	Signature du chercheur	Date

13. **Informations de type administratif**
Le formulaire original sera inséré au dossier médical de mon enfant (s'il y a lieu). Une copie sera insérée dans le dossier de recherche et une autre copie me sera remise. Le projet de recherche et le présent formulaire de consentement ont été approuvés par le comité d'éthique de la recherche de l'Hôpital Rivière-des-Prairies.

Appendix E

Telephone Recruitment Script – English

Recruitment - Oral Script

Institution: Faculty of Education, McGill University

Title of Project: The nature and development of Multisensory Integration in ASD

Project Leader: Vanessa Bao, M.A., Ph.D. student
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Oral Script:
"Hello, my name is RECRUITMENT RESEARCH ASSISTANT'S NAME calling from the McGill University's Perceptual Neuroscience Laboratory for Autism and Development, led by Dr. Armando Bertone. You were previously contacted for studies with Dr. Bertone and you agreed to be contacted about new studies. I am calling to find out if you/your child is available and interested to participate in a new study entitled, "The nature and development of Multisensory Integration in ASD".

Response: "*No*". **Recruiter**: I am sorry to hear that, but thank you for your time. Hopefully, we will speak to you again in the future. Take care."

Response: "*Yes*". **Recruiter**: "Excellent! The aim of this study is to better assess how individuals with and without autism combine visual and auditory information through computer tasks. This study will take place over one session, which will last between 1.5 and 2.5 hours depending on whether you/your child would need to complete a short cognitive assessment. During the session, [you/your child] will be asked to sit in front of a computer screen and complete 3 different tasks. On all the tasks, you/your child will see images and/or hear sounds from headphones and have to provide an answer based on what you/your child perceive by pressing a button. Dr. Armando Bertone will be supervising all of the testing, which will take place in Duggan House laboratory of the PNLab, on the McGill University downtown campus.

"There is no direct benefit from participating in this study, other than contributing to the scientific advancement of knowledge with respect to the development of visual and auditory perception in ASD and typical development. Furthermore, there are no foreseeable risks or harm associated with [you/your child's] participation in this study. To reduce the effects of fatigue, each testing session will include as many breaks as [you/your child] require(s)."

"It is important for you to know that you are free to abandon this study at any time. Are you still interested in participating?"

“You/your child will receive $15 for participating in this study, which will be handed out upon its completion.”

If the participant (and their parent(s), when applicable) is/are interested, verify that the participant meets certain inclusion criteria: “I will have to ask you a few questions before confirming [your/your child’s] participation in the study.

[Do you/does your child] have any problems with vision? If so, do [you/they] wear glasses or contact lenses to correct these problems? If so, they will need to bring their glasses to the testing session.

[Do you/does your child] have any problems with hearing? [Do you/does your child] have a cochlear implant or use a hearing aid?

[Are you/is your child] currently taking medication? If yes, what kind of medication?

[Do you/does your child] have a diagnosed disorder of attention (ADHD) or seizures?”

Do you/does your child have a diagnosis of Autism Spectrum Disorder? Do you/does your child have a family member in their immediate family with a diagnosis of ASD?

If the participant conforms to the inclusion criteria:
“When are you available to participate in the study?”

Please fill out and print a participant form once the family has committed to participate. Please record the appointment date and time, and any other pertinent notes on the participant form. Record all appointments in the online calendar (only accessed by the applicants).

Additional Information
“Participants will be assessed individually under the supervision of Dr. Armando Bertone (Assistant Professor) at the Perceptual Neuroscience Laboratory for Autism and Development. (Education Building, 3700 McTavish Street). I will come to meet you in the foyer of the Education building at the arranged date and time. “At the laboratory, I will explain and issue a consent form before testing begins.”
“It is important to refrain from taking alcohol or non-prescription drugs before participating in the study as this can affect your/your child’s performance”

[For parents of child participants] “Once started, you will wait in the waiting room, adjacent to the child-friendly testing room, while your child participates in the study.”

“Do you have any questions? If you require any additional information or need to withdraw [your child] from the study, please contact, Armando Bertone, at 514-398-3448. Thank you.”

Appendix F

Consent Form – English, Minor Participants

Assent Form (6- to 17-year-olds)

Institution: Faculty of Education, McGill University
Title of Project: The nature and development of Multisensory Integration in ASD

Project Leader: Vanessa Bao M.A., Ph.D. student
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University
514-398-6655
pnlab.mcgill@gmail.com

Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Why are we doing these tests on the computer?
We are doing these tasks to better understand how well kids and teenagers with and without Autism Spectrum Disorder (ASD) can put together information that they see and that they hear. Our goal is to have participants do 3 computer tasks to see if there is any difference between how both groups (ASD and not-ASD) make sense of simpler and more complex information.

What will happen during your time here at the lab?
You will be asked to do a few of activities with our team at the lab today. You might find some of the activities very easy, and some of them hard – that's completely normal! We just want you to always try your best. We might start off (it depends on each person) with some activities (puzzles, questions) to see how you think and make sense of things.

Then there will be 3 main tasks, and for each of these you will be sitting in front of a computer and need to wear headphones. In task 1, you will do a computer activity where you need to press a button as quickly as you can when you see and/or hear something. For task 2, you will have to try to find a target on the screen as fast as you can. For task 3, you will see and/or hear faces and voices, and you will have to try to figure out which emotion is being shown/heard.

Once we're done, you will receive $15 for your participation.

Can you decide if you want to do these tests?
Your parents gave their permission to have you participate in this research project. But, you do not

have to participate if you do not want to. If you do want to participate, you do not have to answer any of the questions and we can stop at any time.

Who will know what I did during these activities?
All of the responses given during these activities are kept confidential. This means that only myself and other researchers that work with me on this project will see your answers. The answers from all of the kids and teenagers who participated in this project may be presented at meetings or written in articles, but your name will never be used and no one will know that you participated in this study. The reason we will be keeping all your information confidential, which means not sharing your name, personal information or your answers, is to make sure we protect your privacy.

Do you have any questions?

Do you want to take part in the study?

Verbal assent was obtained: ☐

Participant's name: ___________________________________

Participant's signature ________________________________ Date ______________________________

____ _________

Name of Examiner Signature of Examiner Date

Appendix G

Consent Form – English, Adult Participants

Adult (18+) Consent Form

Institution: Faculty of Education, McGill University

Title of Project: The nature and course of Multisensory Integration in Autism Spectrum

Project Leader: Vanessa Bao M.A., Ph.D. student
School & Applied Child Psychology
Department of Educational and Counselling Psychology
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514-398-6655
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Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Introduction: We are interested in investigating the nature of multisensory integration (i.e., the process by which an individual integrates information from more than one sense at the same time) in individuals with an Autism Spectrum Disorder (ASD). The ability to integrate simple and complex visual and auditory information will be assessed using three computerized tasks. We will evaluate whether individuals with ASD and typically developing individuals perform differently on tasks that measure multisensory integration.

Procedures: The study will take between 1.5 and 2.5 hours to complete, depending on whether or not you need to complete a brief cognitive assessment. For all three tasks, you will be sitting at a desk in front of a computer and will be required to wear headphones. For the first task, you will need to quickly press a button when you detect a sound (i.e., beep) and/or an image (i.e., flash). For the second task, you will need to search for a target object on the screen while occasionally hearing a sound (beep). Finally, in the third task, you will need to make a choice between two options to indicate which emotion you saw and/or heard. You will be completing these tasks at the Perceptual Neuroscience Laboratory for Autism and Development (PNLab) in the Faculty of Education at McGill University.

Advantages of the proposed study: There is no other direct advantage from your participation in the present study other than your contribution to the advancement of scientific knowledge regarding how multisensory integration functions and develops in ASD and typical development.

Disadvantages of the proposed study: There are no known side effects associated with the previously described visual and/or behavioural tasks. Steps will be taken to reduce any potential discomfort or inconvenience related to having to sustain attention on a task and be exposed to repetitive stimuli. For instance, frequent breaks will be taken throughout your participation in order to minimize fatigue.

Confidentiality: All the information will be kept confidential, except as required or permitted by law. You will be assigned a study number and the information will be filed using this unique identifier code. Only this code will link the participant to the sample. The principal researcher can only perform the decoding of the data or an individual authorized by the former. Therefore, apart from Dr. Bertone and the principal investigator, only members of regulatory agencies or members of the Research Ethics Board may have access to the data. If data from this study is published or presented at scientific meetings, personal identity will never be revealed. All of the information will be kept confidential, except as required or permitted by law. Data obtained from this study will be stored until the completion of the principal investigator's thesis defense, after which it will be rendered completely anonymous through the deletion of any identifiers that would allow for the participant to be retraced.

Participation: Participation is voluntary. You may refuse to participate or withdraw from the study at any time without any prejudice to your future involvement with McGill University. In the case that you do withdraw from the study, all previous data collected will be destroyed.

Incidental Findings: Although your cognitive and behavioural findings are clinically non-interpretable (i.e., not used for diagnosis), any questions regarding your performance will be explained to you, upon your request.

Compensation: You will be compensated $15 for your participation upon completion of the study.

Contact Numbers: If you have any questions about the research, please contact Vanessa Bao at (514) 398-6655 or pnlab.mcgill@gmail.com, or Dr. Armando Bertone at the Faculty of Education at (514) 398-3448 or armando.bertone@mcgill.ca. If you have any ethical concerns or complaints about your participation in this study, and want to speak to someone not on the research team, please contact the McGill Ethics Manager at 514-398-6831 or lynda.mcneil@mcgill.ca.

Declaration of the participant:
Please sign below if you have read the above information and consent to your participation in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. A copy of this consent form will be given to you and the researcher will keep a copy.

Name of Participant Signature of Participant Date

Appendix H

Consent Form – English, Parents of Minor Participants

Parent Consent Form

Institution: Faculty of Education, McGill University

Title of Project: The nature and development of Multisensory Integration in ASD

Project Leader: Vanessa Bao M.A., Ph.D. student
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Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Introduction: We are interested in investigating the nature of multisensory integration (i.e., the process by which an individual integrates information from more than one sense at the same time) in individuals with an Autism Spectrum Disorder (ASD). The ability to integrate simple and complex visual and auditory information will be assessed using three computerized tasks. We will evaluate whether individuals with ASD and typically developing individuals perform differently on tasks that measure multisensory integration. We are asking for your permission to include your child as a participant in this study.

Procedures: The study will take between 1.5 and 2.5 hours to complete, depending on whether or not your child needs to complete a brief cognitive assessment. For all three tasks your child will be sitting at a desk in front of a computer and will be required to wear headphones. For the first task, your child will need to quickly press a button when they detect a sound (i.e., beep) and/or an image (i.e., flash). For the second task, your child will need to search for a target object on the screen while occasionally hearing a sound (beep). Finally, in the third task, your child will need to make a choice between two options to indicate which emotion they saw and/or heard. Your child will be completing these tasks at the Perceptual Neuroscience Laboratory for Autism and Development (PNLab) in the Faculty of Education at McGill University.

Advantages of the proposed study: There is no other direct advantage from your and your child's participation in the present study other than your contribution to the advancement of scientific knowledge regarding how multisensory integration functions and develops in ASD and typical development.

Disadvantages of the proposed study: There are no known side effects associated with the previously described visual and/or behavioural tasks. Steps will be taken to reduce any potential discomfort or inconvenience related to having to sustain attention on a task and be exposed to repetitive stimuli. For instance, frequent breaks will be taken throughout your child's participation in order to minimize fatigue.

Confidentiality: All the information will be kept confidential, except as required or permitted by law. Your child will be assigned a study number and the information will be filed using this unique identifier code. Only this code will link the participant to the sample. The principal researcher can only perform the decoding of the data or an individual authorized by the former. Therefore, apart from Dr. Bertone and the principal investigator, only members of regulatory agencies or members of the Research Ethics Board may have access to the data. If data from this study is published or presented at scientific meetings, personal identity will never be revealed. All of the information will be kept confidential, except as required or permitted by law. Data obtained from this study will be stored until the completion of the principal investigator's thesis defense, after which it will be rendered completely anonymous through the deletion of any identifiers that would allow for the participant to be retraced.

Participation: Participation is voluntary. You or your child may refuse to participate or withdraw from the study at any time without any prejudice to your future involvement with McGill University. In the case that you do withdraw from the study, all previous data collected will be destroyed.

Incidental Findings: Although your child's cognitive and behavioural findings are clinically non-interpretable (i.e., not used for diagnosis), any questions regarding their performance will be explained to you, upon your request.

Compensation: Your child will be compensated $15 for their participation upon completion of the study.

Contact Numbers: If you have any questions about the research, please contact Dr. Armando Bertone at the Faculty of Education at (514) 398-3448 or armando.bertone@mcgill.ca. If you have any ethical concerns or complaints about your participation in this study, and want to speak to someone not on the research team, please contact the McGill Ethics Manager at 514-398-6831 or lynda.mcneil@mcgill.ca.

Declaration of the participant:
Please sign below if you have read the above information and consent to your child's participation in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. A copy of this consent form will be given to you and the researcher will keep a copy.

____
Name of Child

____
Name of Parent/Legal tutor   Signature of Parent/Legal tutor   Date

Appendix I

Age Analysis Figures for Manuscript 2

Figure A. Test for violation of the race model inequality for the adolescent ASD and TD groups

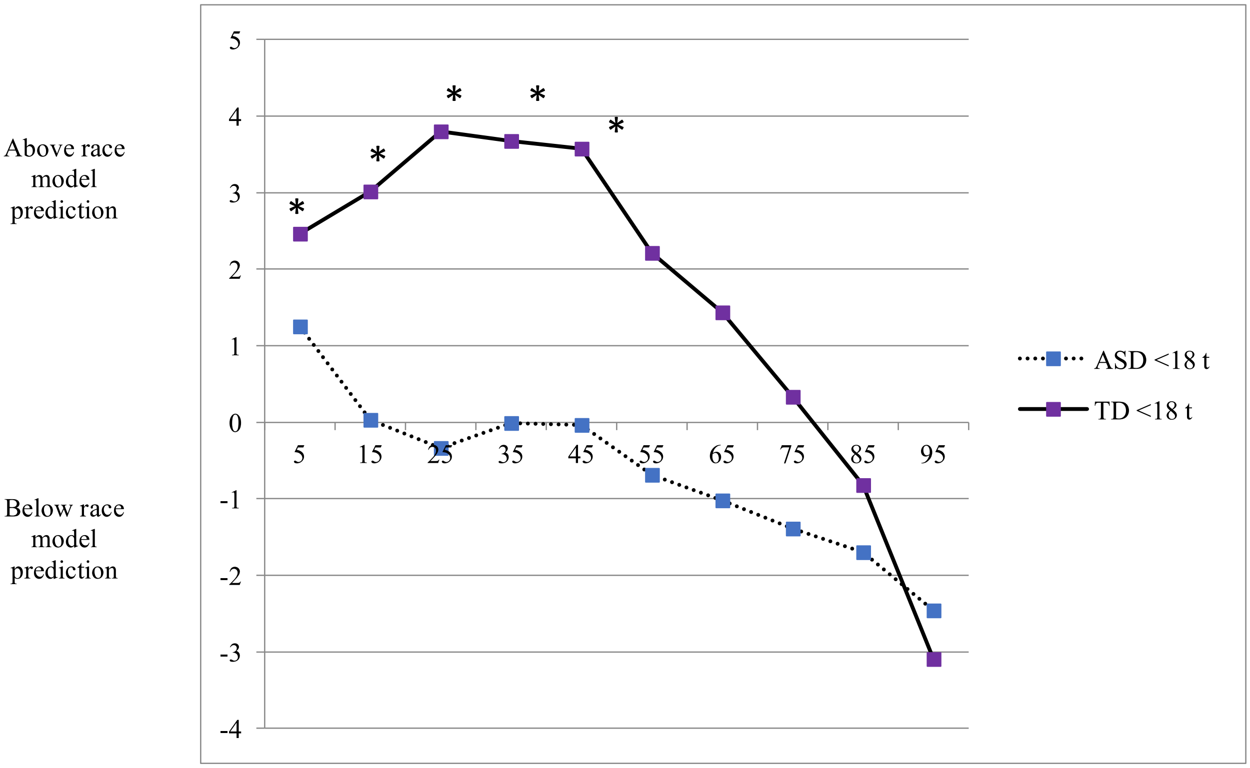

Figure A. The graph represents the difference in milliseconds (Y axis) between the model prediction based on the auditory and visual conditions, and the RTs obtained in the audiovisual conditions for adolescents in each group (ASD and TD). Positive values represent RTs that were faster than the race model prediction. The difference between the bound (represented as 0 on the Y axis) and the RTs of the bimodal condition are computed for each percentile of the RT distribution (X axis). * indicates significant violation of the race model (p<.05).

Figure B. Test for violation of the race model inequality for the adult ASD and TD groups

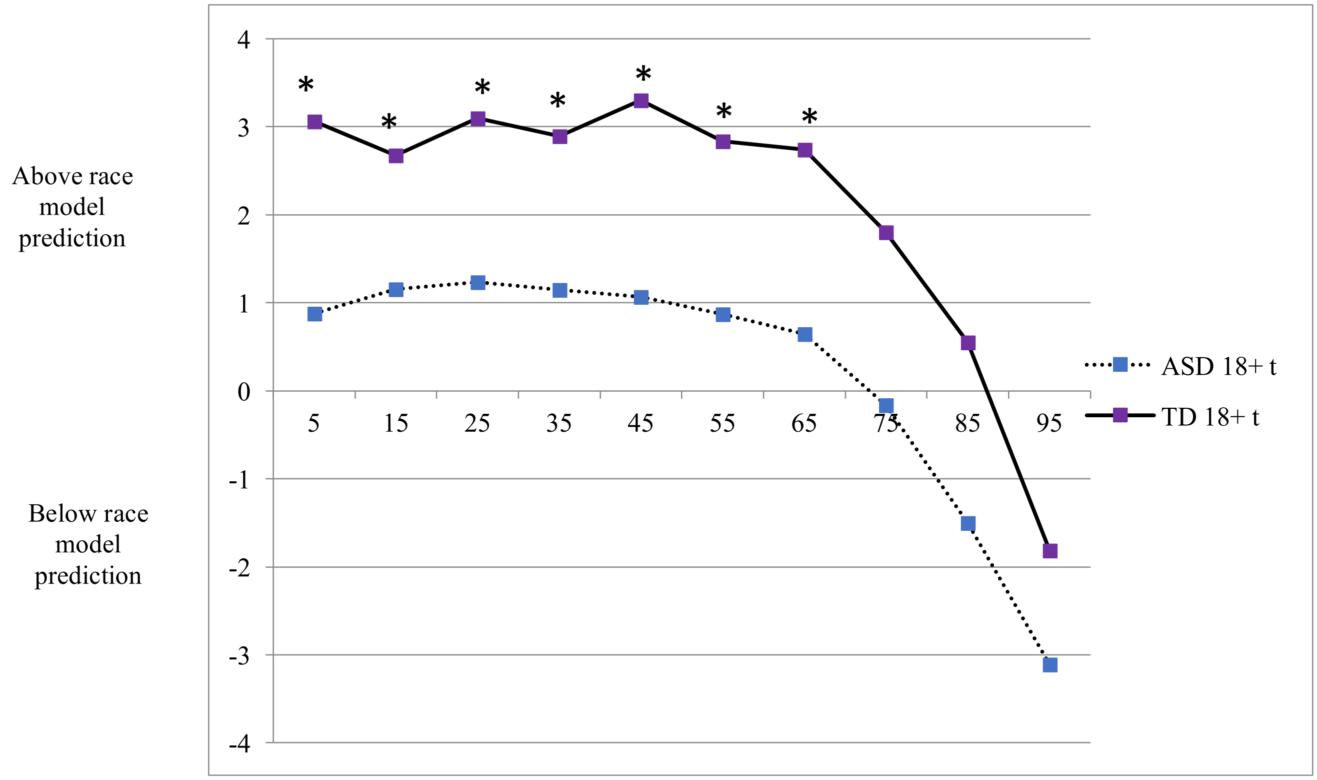

Figure B. The graph represents the difference in milliseconds (Y axis) between the model prediction based on the auditory and visual conditions, and the RTs obtained in the audiovisual conditions for adults in each group (ASD and TD). Positive values represent RTs that were faster than the race model prediction. The difference between the bound (represented as 0 on the Y axis) and the RTs of the bimodal condition are computed for each percentile of the RT distribution (X axis). * indicates significant violation of the race model (p<.05).