Réseau national d'expertise en troubles du spectre de l'autisme

Article de vulgarisation scientifique

MAKING SENSE OF SENSES: MULTISENSORY INTEGRATION IN AUTISM SENSORY ABNORMALITIES IN AUTISM SPECTRUM DISORDER

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Le RNETSA remercie chaleureusement l'auteure pour sa contribution au développement de l'expertise et des connaissances.

Il est recommandé de citer le document de cette façon :

BAO, Vanessa (2017). *Making Sense of Senses: Multisensory Integration, Autism Sensory Abnormalities in Autism spectrum disorder*. Réseau national d'expertise en troubles du spectre de l'autisme, Trois-Rivières, Québec. Disponible en ligne au [www.rnetsa.ca/http://www.rnetsa.ca/activites-et-productions-du-rne]

Mars 2017

Making Sense of Senses: Multisensory Integration in Autism

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). Specifically, sensory abnormalities (i.e., hypo- or hyper-reactivity to sensory stimulation) were added under the umbrella of restricted and repetitive patterns of behaviour and interests in the DSM-5 ASD diagnostic criteria. For example, individuals with ASD often exhibit an aversion to certain sensory stimuli (e.g., withdrawing from noises like a baby crying or the sound of a lawnmower, avoiding certain textures or smells) or alternatively, seek out sensory experiences through stimulatory behaviours (e.g., peering, echoing, tapping surfaces, twirling items in front of their eyes). 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. Parental reports have also been heavily relied upon to provide data as to the extent of sensory processing issues in their children. Leekam et al. (2007) looked at parental reports 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. 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 et al. (2013) 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.

Sensory abnormalities have also been shown to occur across development in ASD (Hazen, et al., 2013). Research has also supported the notion that the sensory issues that exist in ASD are present across sensory modalities (i.e., sight, sound, smell, taste and touch; 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. 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).

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. (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. Furthermore, while studies of unisensory integration might have found evidence for impaired processes, mechanisms involved in MSI are necessarily different at the neural and perceptual levels (Gingras, Rowland, Stein, & Ebner, 2009). These are some concerns with interpreting MSI research through a unisensory lens. Altered lower level unisensory integration does not automatically imply altered multisensory lower level integration. 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.

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. 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). 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. 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 (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). 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).

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

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. 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. Although some research has begun to develop about the integration of: a) touch and sight, b) smell and taste, c) sight and smell, d) proprioception and touch, etc., the current paper focuses on the research that has been done to investigate the integration of sight and sound. For one, the vast majority of MSI work in ASD has focused on audiovisual integration. Additionally, the integration of sight and sound has far-reaching implications for socio-communicative impairments in ASD.

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 sounds, faces, gestures, etc.). 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. 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, age influences susceptibility to the McGurk illusion. In fact, 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 in ASD is still not well defined.

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 those 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.

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).

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. 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, 2013; 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, 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 the type of stimulus, 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. 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.

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, 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). Evidence for both illusions in ASD was also found in another study that used the flash-beep illusion with adolescents and adults (Bao, 2013).

De Boer-Schellekens, Keetels, Eussen, and Vroomen (2013) used the pip-and-pop paradigm in their study and found a multisensory facilitation effect in ASD (de Boer-Schellekens, Keetels, Eussen, and Vroomen, 2013). 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).

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. Additionally, developmental trajectories are not well defined, most studies have not considered the role of either stimulus complexity or task complexity, and the ecological validity of these specific experiments is questionable. The following sections will serve to provide suggestions for future research as well as to discuss implications for theory and clinical practice.

Future Research 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**

The most contentious issue in MSI research is the role that stimulus complexity plays in obtaining an adequate picture of the way multisensory information is integrated in ASD. 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.

- **Task complexity**

The level of task complexity can also have a significant impact on results. For instance, tasks of semantic priming and simple reaction time tasks have very different task demands. 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. 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 cited above has attempted to study multisensory integration in low functioning individuals with ASD. 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 in research efforts.

- **Developmental trajectories**

As has been discussed, the developmental trajectory of multisensory integration in ASD is not well defined. Truly the only way to understand MSI development across the lifespan is 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.

Clinical Implications

There are important clinical implications to the reinterpretation from a view fundamentally impaired MSI in ASD to the recognition that MSI is influenced by the type of information being processed as well as to the timing of stimulus presentation. In light of the position taken in this paper, the case of sensory integration therapies (SIT) is particularly interesting. These therapies are often expensive, and time-consuming, yet they are routinely implemented with children with ASD despite the lack of evidence for their efficacy (Baranek, 2002; Dawson & Watling, 2000; Lang et al., 2012). 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). More recently, 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 found to be effective.

Furthermore, the literature does not appear to support the hypothesis of a generalized deficit in sensory integration. Not only is there a lack of evidence for sensory integration therapy, SIT's may be attempting to target a problem is not so clear-cut. 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 has 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, reconceptualising 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).

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.

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