# Multisensory Integration of Low-level Information in Autism Spectrum Disorder: Measuring Susceptibility to the Flash-Beep Illusion

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ORIGINAL PAPER

# 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 audiovisual multisensory integration (MSI) may be atypical 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 less selective than for TD individuals.

**Keywords** Autism spectrum disorder · Multisensory integration · Flash-beep illusion · Auditory-visual integration

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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 and Happé 1994; Happé and Frith 2006; Brock et al. 2002; Mottron and Burack 2001; Mottron et al. 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 and Molholm 2009; Iarocci and McDonald 2006). While some studies have identified a diminished McGurk effect in ASD (Bebko et al. 2014; Mongillo et al. 2008; Williams et al. 2004), others have found that the effect is contingent on developmental factors (Taylor et al. 2010), socio-communicative impairments (Iarocci et al. 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 and 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 et al. 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 et al. 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 et al. 2000, 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, et al. (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 et al. 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 et al. 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 and 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 et al. 2015; Foss-Feig et al. 2010; Kwakye et al. 2011; Stevenson et al. 2014a; Wallace and 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 et al. 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 et al. 2000).

**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 | | |

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.

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/m$^2$ (u' = 0.1912, v' = 0.4456 in CIE color space) where minimum and maximum luminance levels were 0.5 and 59.5 cd/m$^2$, 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 were 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.

## 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, $\chi^2(14) = 80.116$, $p < .001$. Accordingly, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.498$).

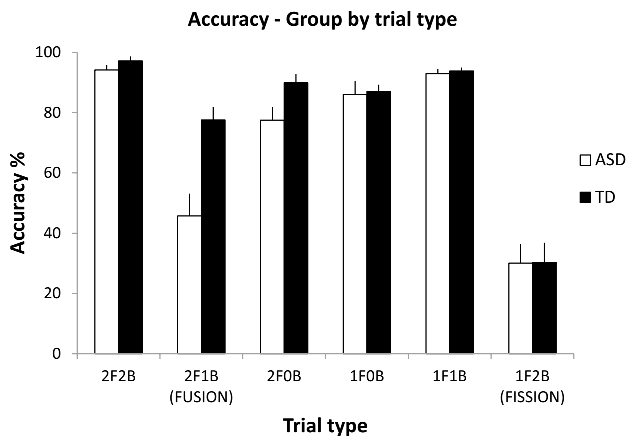


**Fig. 1** *Bar graph* representing the difference in accuracy scores on each trial type between the ASD and control groups

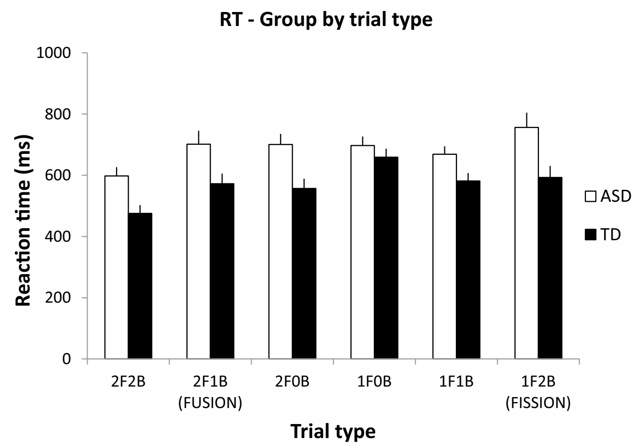


**Fig. 2** *Bar graph* representing the difference in reaction times on each trial type between the ASD and control groups

**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 |

*p < .05

Analyses revealed a significant main effect of trial type, $F(2.49, 94.636) = 17.436$, $p < .001$, ηp2 = 0.32, and of group, $F(1, 38) = 7.354$, $p = .01$, ηp2 = 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.

## 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 and 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 and 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 and 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 et al. 2004; Ernst and 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 et al. 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 & 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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**Author Contributions** VB conceived of the study, participated in the design and data acquisition, performed statistical analyses and interpretation of the data and drafted the manuscript. VD participated in the design and data acquisition and helped to draft the manuscript. LM participated in the interpretation of data and drafting the manuscript. OC participated in data analysis, interpretation of data and drafting the manuscript. AB conceived of the study, participated in the design, acquisition, analysis and interpretation of data, and drafted the manuscript. All authors read and approved the final manuscript.

**Compliance with Ethical Standards**

**Conflict of interest** The authors declare no conflict of interest.

**Ethical Approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed Consent** Informed consent was obtained from all individual participants included in the study.

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