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Body representation difficulties in children and adolescents with autism may be due to delayed development of visuo-tactile temporal binding

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ABSTRACT

Recent research suggests visuo-tactile binding is temporally extended in autism spectrum disorders (ASD), although it is not clear whether this specifically underlies altered body representation in this population. In the current study children and adolescents with ASD, and typically developing controls, placed their hand into mediated reality system (MIRAGE) and saw two identical live video images of their own right hand. One image was in the proprioceptively correct location (veridical hand) and the other was displaced to either side. While visuo-tactile feedback was applied via brushstroke to the participant's (unseen) right finger, they viewed one hand image receiving synchronous brushstrokes and the other receiving brushstrokes with a temporal delay (60, 180 and 300 ms). After brushing, both images disappeared from view and participants pointed to a target, with direction of movement indicating which hand was embodied. ASD participants, like younger mental aged-matched controls, showed reduced embodiment of the spatially incongruent, but temporally congruent, hand compared to chronologically age-matched controls at shorter temporal delays. This suggests development of visuo-tactile integration may be delayed in ASD. Findings are discussed in relation to atypical body representation in ASD and how this may contribute to social and sensory difficulties within this population.

Although Autism Spectrum Disorders (ASD) have primarily been characterised by difficulties with social communication, interaction, and imagination (Wing and Gould, 1979), atypical sensory processing has recently become a greater focus for identifying and understanding individuals with autism (DSM-V; American Psychological Association, 2013). Clinical reports (e.g. Leekam et al., 2007; Talay-Ongan and Wood, 2000) have documented sensory abnormalities in over 90% of individuals with ASD, highlighting its significance as a defining feature in this population.

Despite the prevalence of atypical sensory processing in autism, many prominent theories of ASD, such as Theory of Mind (Baron-Cohen et al., 1985) and Social Motivation Theory (Chevallier et al., 2012), have focused soley on social interaction difficulties in ASD. Though Weak Central Coherence theory (Happe and Frith, 2006) and Enhanced Perceptual Functioning (Mottron et al., 2006) present a partial explanation for sensory sensitivities, neither theory fully specifies the mechanisms underlying these atypicalities. Furthermore, these theories are unable to account for the heterogeneity of sensory sensitivities seen within and between individuals with ASD, nor can they explain why an individual can exhibit both hyper- and hypo-sensitivities to sensory stimuli (Leekam et al., 2007; Pellicano and Burr, 2012).

Alternatively, it has been suggested that both sensory and socio-communicative features of ASD could be due, at least in part, to atypical multisensory integration (MSI) (Brock et al., 2002; Cascio et al., 2012; Stevenson et al., 2014; Foss-Feig et al., 2010; Kwakye et al., 2011). Evidence from the typical population suggests that MSI develops over a protracted period of time throughout early childhood and becomes more sensitive and specific with age (Gori et al., 2008; Nardini et al., 2008; Cowie et al., 2013; Cowie et al., 2016). As the social world requires one to efficiently integrate sensory information from a range of sources (e.g. auditory, visual, tactile, proprioception), difficulties in binding related inputs could lead to impaired social interaction and sensory overload. For instance, communicating with another person necessitates detecting the temporal synchrony between their speech and lip movements. At the same time one also needs to be able to exclude extraneous sensory information that is unrelated to the event (e.g. the sound of a television in the background). If temporal binding is extended or less precise in ASD then this would lead to problems distinguishing the synchronous sensory information relating to the speaker from sensory inputs that originated from unrelated stimuli (Bahrick and

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Todd, 2012). In support of this argument, Stevenson et al. (2014) demonstrated a relationship between temporally extended audio-visual binding and poor speech processing abilities in children with ASD. Whilst this research explains how communication difficulties in ASD could result from atypical audio-visual binding, there has been a limited amount of research exploring the temporal processing of other sensory modalities in ASD.

One area of sensory integration that merits further research is visuo-tactile-proprioceptive processing. Accurate integration of visual, tactile and proprioceptive inputs underlies our sense of bodily self (i.e. body representation), including body localisation (the ability to locate our limbs) and a sense of body ownership (the awareness and understanding that our body belongs solely to us, and that we can see, feel and move it) (Gallagher, 2000; Nava et al., 2014). Body localisation and body ownership are both important for identifying, distinguishing and comparing ourselves with others (Meltzoff, 2007; Schutz-Bosbach et al., 2006). For instance, many researchers have argued that the ability to detect similarities between someone else's movements and our own is a foundation for perspective taking and empathy for others as it involves 'mentally standing in their shoes' (Husserl, 2012; Smith 2010). Thus, if visuo-tactile-proprioceptive integration is not developing typically, then this could affect the development of one's bodily self, impacting on various higher-order social processes. In support of this, a recent study (Pearson et al., 2016) exploring mechanisms underlying visual perspective taking found performance in typically developing children was predicted by good performance on a body representation task, however this was not the case for those with ASD. Furthermore, there has been evidence of atypical body representation being related to poor empathy in children with autism (Cascio et al., 2012).

Although there appears to be a clear case for the importance of body representation in social processes, only recently has research demonstrated that extended temporal binding of visuo-tactile inputs may underlie atypical development of the bodily self (Greenfield et al., 2015). Greenfield et al. (2015) developed a task which manipulated visuo-tactile and spatial input in order to induce ownership of a virtual hand. Children and adolescents with ASD and typically developing controls placed their right hand into a multisensory illusion apparatus (MIRAGE, University of Nottingham), which presented two identical live video images of their own hand, immediately above the location of the actual hand and in the same plane as the actual hand. One virtual hand was always aligned proprioceptively with the actual hand (called the veridical hand) and the other was displaced to the left or right of this. While a brush stroke was applied to the participant's actual (hidden) hand, they observed the two virtual images of their hand also being stroked, only one of which had synchronous visuo-tactile inputs while for the other the seen and felt brush strokes were temporally asynchronous. Participants were asked to identify which seen hand was their actual hand subjectively. One approach to performing the task would be to ignore the visuo-tactile input provided by the brush stroking and rely solely on proprioceptive information. However, a wealth of evidence has demonstrated that visuo-tactile synchrony can override proprioceptive information and induce the sense of ownership over a fake limb (see Makin et al., 2008; Tsakiris, 2010). Therefore, detection of temporal synchrony between the felt brush stroke on the participant's actual (unseen) hand and seen brush stroke on either of the virtual hands is essential to body ownership. In order to test for sensitivity to temporal information between visual-tactile inputs, Greenfield et al. (2015) administered a delay of either 60 ms, 180 ms, or 300 ms. Typical, chronologically-matched participants were more consistent than those with ASD i in reporting the synchronous hand to be their real hand at shorter delay lengths (60 ms), even when the image of the synchronous hand was visually displaced from the location of the real hand. These results were interpreted as showing that visual-tactile binding occurs over an extended period of time in autistic children which suggests that the typical integration processes underlying body representation are disrupted. These findings are consistent with other research with individuals with ASD showing reduced susceptibility to the rubber hand illusion which also requires visual-tactile integration (Cascio et al., 2012; Paton et al., 2012).

Whilst the study by Greenfield et al. (2015) demonstrated that participants with ASD had greater difficulties in associating visual-tactile synchrony with their own body at shorter delays, the findings are perhaps limited by the fact that they were based on subjective, forced-choice reports of ownership which only give a categorical measure and cannot tell us the extent to which temporal synchrony affects body ownership in ASD. Furthermore, as individuals with ASD can be overliteral in their interpretation of language (Happe, 1995) it is possible that this could have at least partly contributed to the findings. For instance, when asked "which hand is your actual hand" when viewing the two identical virtual hand images an overliteral interpretation could have resulted in one thinking neither were or both were their real hand.

In addition, the subjective feeling of ownership may not accurately reflect whether the 'owned' body part is incorporated into the body schema (an unconscious representation of the body that is used for action and interaction with the environment) rather than body image (a top-down, perceptual representation of the body) (Haggard and Wolpert, 2005; Kammers et al., 2010, 2006, 2009). In an almost identical task in healthy adults, Newport et al. (2010) demonstrated that the hand stroked in visual-tactile synchrony is incorporated into both body image and body schema. Evidence that body image and schema can be dissociated in this task, however, was later demonstrated in a patient with visuo-spatial neglect who consistently chose different fake hands for subjective ownership (body image) and target pointing (body schema) (Preston and Newport, 2011).

In terms of understanding our own body and actions, in order to understand those of others, an investigation of body schema may be more important and more revealing than body image given the evidence that we understand others' actions through the actions of the self (Chaminade et al., 2005; Gallese, 2003; Gallese et al., 2004). Thus, it might be reasonable to assume that an inability to effectively use temporally synchronous sensory information to construct their own body schema for those with ASD would have a knock-on effect for their ability to understand the social body cues of others. For that reason, the current study retested the same population as in Greenfield et al., 2015, but on a task that directly measured the effect of temporal binding on the body schema. For this task, after seeing two images of their right hand being stroked (one synchronous and one with delay), participants were required to point to a target with their real, unseen hand. The degree to which the synchronously stroked hand had been incorporated into body schema can be inferred from the direction and magnitude of pointing errors. If participants with ASD do not integrate visual and tactile sensory input across the same temporal delays as typically developing individuals then this will result in a pointing trajectory that reflects embodiment of the spatially congruent hand across all conditions. In typically developing children and adolescents it is expected that temporal synchrony will provide the basis for updating the body schema and will be tightly bound to the image of the hand with visual-tactile synchrony, even when their actual hand is in a different spatial location. Therefore, control participants should show pointing trajectories indicating they have incorporated the virtual hand with synchronous visuo-tactile input regardless of its spatial congruency.

1. Method

1.1. Participants

All participants in this study had also taken part in a previous published study carried out by the same authors (Greenfield et al., 2015). Participants included 31 children and adolescents with ASD, aged 8–15 years (two female, one left-handed), 28 chronological age-matched (CA) typically developing controls (8 female, 5 left-handed), and 27 verbal mental age-matched (MA) typically developing controls,