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In sync or not in sync? Illusory body ownership in autism spectrum disorder

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ABSTRACT

Background: A fundamental aspect of self-consciousness is body ownership, which refers to the experience that our body and its parts belong to us and it is distinct from those of other persons. Body ownership depends on the integration of different sensory stimulations and it is crucial for the development of functional motor and social abilities, which are compromised in individuals with autism spectrum disorder (ASD). Here we examined the multisensory nature of body ownership in individuals with ASD by using a procedure based on tactile conflicts, namely the numbness illusion (NI).
Method: We induced an illusory feeling of numbness and ownership for another person's finger by asking participants to hold their palm against another person's palm and to stroke the two joined index fingers with the index and thumb of their other hand.
Results: As expected, when the agent self-strokes their finger, healthy participants do not perceive the NI if the stroking is performed asynchronously. Conversely, in individuals with ASD the illusion occurred with both synchronous and asynchronous self-stroking.
Conclusions: We contend that individuals with ASD are more vulnerable than controls to this illusory tactile experience and we discuss the findings in light of impaired perception of the temporal relationships between tactile and proprioceptive inputs.

1. Introduction

The feeling that our body and its parts belong to us and not to other people is a fundamental aspect of self-consciousness, termed body ownership (Gallagher, 2000). Body ownership changes dynamically depending on the nature of the sensory and motor signals experienced (Tajadura-Jiménez & Tsakiris, 2013), as well as on the agent generating those signals (self vs. other; Dijkerman & de Haan, 2007). It originates from the integration of multisensory signals (Van den Bos & Jeannerod, 2002). Therefore, certain incongruent conditions of visual, tactile and proprioceptive stimulation can induce errors or illusions of body ownership for a fake (i.e., rubber) hand (e.g. Botvinick & Cohen, 1998) or for a virtual body (Ehrsson, 2007; Lenggenhager, Tadi, Metzinger, & Blanke, 2007). The integrity of the perception of body ownership has been investigated by manipulating the usual spatial and temporal correlations among sensory inputs using tasks such as the 'rubber hand illusion' (RHI; Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). In this task, the sense of body ownership is altered by delivering regular brush strokes to the participant's visually obscured hand while

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simultaneously administering identical strokes to the same somatic location on a visible rubber hand that the participant is instructed to watch. After a short period of synchronous brushing, participants often report that it begins to feel as if the rubber hand is the participant's own hand. These illusory effects are not reported when the tactile (own hand) and visual (rubber hand) brush strokes are delivered asynchronously, suggesting that such temporally incongruent stimuli are not integrated in a unitary percept.

Given that the development of a sense of body ownership is crucial not only for motor skills such as navigating one's environment (Piaget, 1952), but also for the development of social relations (Chaminade, Meltzoff, & Decety, 2005; Gallese, Keysers, & Rizzolatti, 2004), the study of the RHI illusion has been thought to be of value for the characterization of autism spectrum disorder (ASD). Results from the relatively few studies investigating this issue indicate that children with ASD were initially less susceptible to the illusion than the comparison group, showing a delayed effect of the illusion (Cascio, Foss-Feig, Burnette, Heacock, & Cosby, 2012). Furthermore, they did not show the same overall sensitivity to visuotactile-proprioceptive discrepancy between the rubber hand and the real hand, as for the control group (Paton, Hohwy, & Enticott, 2012). Overall, these findings have been explained in terms of an atypical multisensory temporal integration processing in ASD (Foss-Feig et al., 2010; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011). An additional (and non-mutually exclusive) explanation regarding the RHI in ASD considers an increased difficulty in disembodying the bodily self and embodying the bodily other, suggestive of a steeper and less flexible gradient from self-to-other perception (Noel, Cascio, Wallace, & Park, 2017). Altogether these findings have helped disentangling how typical and atypical recruitment of somatosensory resources modulates the embodied experience (Gallese, 2003), opening to a better understanding of how socio-emotional skills such as imitation and empathy may emerge in ASD.

Despite the evidence for atypical body ownership in ASD collected via the RHI (Cascio et al., 2012), empirical evidence on which conditions promote the emergence of abnormal body representations in individuals with ASD is still scarce. To fill this gap, here we empirically explored how tactile and proprioceptive cues modulate the sense of body ownership in ASD, by evaluating the strength of the 'numbness illusion' (NI; Boulware, 1951). The NI arises when one person holds her palm against another person's palm and strokes with the index and thumb of his/her free hand the two joined index fingers. When the stroking occurs synchronously, individuals tend to experience their index finger as bigger or numb and belonging to the confederate (Dieguez, Mercier, Newby, & Blanke, 2009), suggesting an illusory tactile sensation and the disruption of body ownership over one's own finger. In neural terms, the NI has been explained as a result of somatosensory predictions and lack of anticipated somatosensory stimulation (Blakemore, Frith, & Wolpert, 1999). In particular, by inducing the NI while recording somatosensory evoked potentials (SEPs) provoked by median nerve stimulation, Dieguez et al. (2009) showed that illusory finger ownership was associated with a modulation of the earliest cortical component (i.e., the N20 component) of the SEP, which is a marker of the activity in the primary somatosensory cortex (S1). This result has been later confirmed and extended by Martuzzi et al. (2015) in an fMRI study showing that bodily experience modulates the activity within certain subregions of S1, and that the high degree of somatosensory specialization in S1 extends to bodily self-consciousness.

In the present work, we aimed at exploring for the first time the behavioral manifestations of the NI in individuals with ASD, as to assess whether and how their body ownership experience is modulated by synchronous as asynchronous stroking of their fingers as performed by themselves and by another agent. In case of a typical experience of the NI, we would expect individuals with ASD to experience it only when self-synchronous pattern stroking occurs. Variations from this typical pattern would be considered informative in the characterization of body ownership experience in ASD.

2. Methods

2.1. Participants

Eighty-two participants (22 females and 60 males, age range 19–36 years) were included in the study: forty-one individuals with autism spectrum disorder (ASD; 11 females and 30 males, age range 19–31 years, mean age ± 24.78) and forty-one individuals with typical development (11 females and 30 males, age range 19–36 years, mean age ± 24.56). Sample size was estimated by means of the G*Power 3.1 software (Faul, Erdfelder, Buchner, & Lang, 2009) in order to have a high statistical power (> .95) even in the case of a medium-small effect size (.22). Individuals with ASD were recruited via the local Pediatric and Developmental Neuropsychiatric Clinics. Diagnosis of ASD was confirmed with the evaluation of a licensed clinical psychologist based on the Diagnostic and Statistical Manual of Mental Disorder – 5 (DSM-5) and supported with standardized measures as the Autism Diagnosis Observation Schedule (ADOS; Lord, Risi, Lambrecht, Leventhal, & DiLavore, 2000) and the Autism Diagnostic Interview – Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994).

A comparison group of healthy participants was recruited on campus at the University of Padova. Volunteers were included in the control group if they indicated that they did not have a diagnosis of ASD, nor suspect they have ASD, nor have a family member with a diagnosis of ASD. The general cognitive functioning of participants was measured by means of the Wechsler Adults Intelligence Scale – Fourth Edition (WAIS-IV; Wechsler, 2008; Italian language adaptation: Orsini & Pezzuti, 2013) or by Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Both groups did not differ for age, gender and full-scale IQ. All information about the sample description is provided in Table 1.

The experimental procedures were approved by the local ethical committee and the study was carried out in line with the ethical standards of the Declaration of Helsinki (Sixth Revision, 2008). All participants provided written informed consent.

Table 1
Sample description.

	ASD Group	CONTROL Group	t or χ^2	p-value
N°	41	41	–	–
GENDER	Females 27% (n = 11) Males 73% (n = 30)	Females 27% (n = 11) Males 73% (n = 30)	0.00	1.00
AGE	24.78 (3.37; Age range 19–31)	24.56 (4.35; Age range 19–36)	0.25	0.799
Full scale IQ	113.30 (10.90)	107.16 (11.60)	1.64	0.108
ADOS (total)	10.34 (5.25)	–	–	–
ADI-R (Communication)	14.25 (4.3)	–	–	–
ADI-R (Social interaction)	18.35 (6.5)	–	–	–
ADI-R (Repetitive behaviour)	5.2 (2)	–	–	–

Notes. ASD = Autism Spectrum Disorder; IQ = Intelligence Quotient; ADOS = Autism Diagnosis Observation Schedules; ADI–R = Autism Diagnostic Interview-Revised. Age, IQ, ADOS and ADI-R refer to the mean, while standard deviation is given in parentheses.

2.2. Procedure

Participants were individually tested in one experimental session. They were requested to press the palm of their right hand against the left-hand palm of an experimenter (Fig. 1).

Keeping this posture, either the participant (self) or the experimenter (other) stroked the dorsal side of the distal phalanges of the joined index fingers with the thumb and the index of the other (free) hand. The stroking was self-paced for 10 s (1 Hz) applied either synchronously (i.e., both fingers stroked simultaneously) or asynchronously (i.e., both fingers alternatively stroked; Video S1). To make sure that the frequency in stroking was similar across participants, a co-experimenter visually inspected by means of a timer whether within 10 s 10 strokes were produced. Synchronous self-stroking was done with the right free hand opened in a repetitive up-to-down movement (both the index finger and the thumbs started from the first phalanx and moved towards the third phalanx of the index finger of the receiver), pressing lightly against the touched index fingers. Asynchronous self-stroking was done with about the same speed and strength, but only one finger was stroked at a time, alternatively. In other words, the index finger of the actor started from the first phalanx whereas the thumb started from the third phalanx of the index finger of the receiver, and they moved in opposite directions. This led to four experimental conditions, namely self-synchronous, self-asynchronous, other-synchronous, and other-asynchronous, expected to differentially affect the strength of the NI. During training, special attention was paid to achieve a consistent stroking frequency and pressure across participants (the participating experimenter was always the same trained

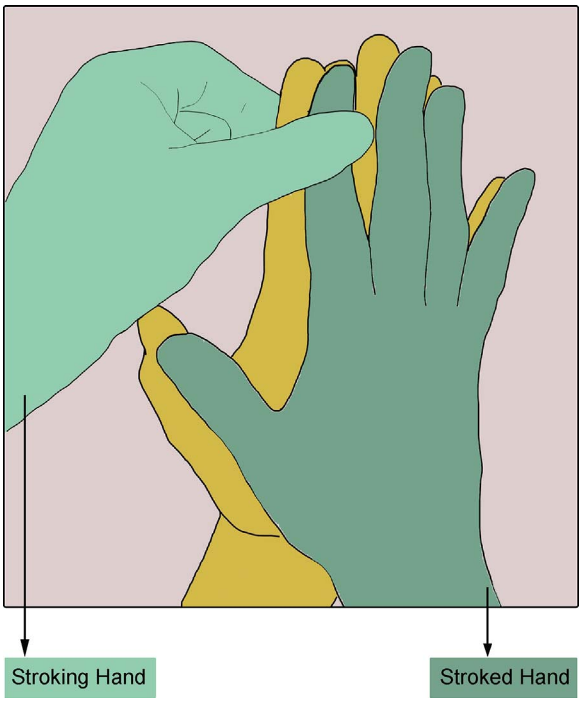

Fig. 1. Procedure to induce the NI: subject's stroked hand (indicated in dark green) is held against another person's palm and the subject strokes with the index and thumb of his other free hand (i.e., stroking hand indicated in light green) the two joined index fingers. The stroking was performed either by the participants (self condition) or by the experimenter (other condition). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Questionnaire administered in the study.

During the stroking of the fingers…				
1. The felt sensation was strange				
2. I felt a sensation of numbness				
3. It seemed like my own stroked finger became wider in size				
4. It seemed like the experimenter's finger became my own finger				
5. It seemed like I felt only big finger was being touched				
Completely disagree 1	Disagree 2	Neutral 3	Agree 4	Completely agree 5

individual). Each of these conditions was repeated four times in a pseudo-randomized sequence for a total of 16 trials. After each trial, the participant was asked to answer 5 questions presented on 5-point Likert scale, ranging from 1 (completely disagree) to 5 (completely agree). To explore the strength of the illusion experienced by the participants during the task, the questions were repeated in a pseudo-randomized order across all trials (Table 2; Dieguez et al., 2009; Martuzzi et al., 2015).

2.3. Analysis

Ratings were averaged to produce an individual index of strength of the NI per condition and were analyzed by means of by-subjects and by-group repeated-measures analysis of variance (ANOVA) with Group (ASD and Control) as a between-subject factor and Agent (self, other) and Synchrony (synchronous, asynchronous) as within-subject factors. In the presence of significant interactions, Tukey-corrected comparisons were performed. All statistical analyses were carried out with the R software package (R package version 3.3.9; R Core Team, 2013).

3. Results

Results revealed a significant main effect of Agent [$F(1,80) = 137.72$; $p < 0.001$; partial-$\eta^2 = 0.63$], in line with previous reports (Dieguez et al., 2009; Martuzzi et al., 2015). The NI was stronger for the 'Self' than for the 'Other' conditions, indicating that self-stroking produces greater disruption of tactile sensation and finger's ownership. This pattern holds true for both groups, confirming that the perceptual consequences of touch are in part modulated in ASD in a typical manner (Blakemore et al., 2006), with specific reference to the 'Other' condition. In addition, the investigation of the higher order significant interaction Agent by Synchrony by Group [$F(1,80) = 18.23$; $p < 0.001$; partial-$\eta^2 = 0.19$] revealed that the NI illusion emerged (scores above 3) in both groups when the self-stroking was performed synchronously (ASD group: $t_{40} = 3.83$; $p < 0.001$; control group: $t_{40} = 3.63$; $p < 0.001$). However, when the self-stroking was performed asynchronously, only the ASD group reported the illusion ($t_{40} = 4.10$; $p < 0.001$), whereas the control group failed to experience any numbness ($t_{40} = -0.99$; $p = 0.84$; Fig. 2). No significant differences were observed among 'Other' configurations within- and between-groups. No significant differences were observed among 'Other' configurations within- and between-groups.

4. Discussion

We set out to investigate the perception of body ownership in ASD by using the NI, tactile-proprioceptive illusion. The findings are interesting on several accounts. First, when considering the 'Other' conditions the strength of the illusion is similar for both groups, irrespective of the synchronicity of the stimulation. Instead, with respect to the 'Self' condition, group differences emerge. Temporally incongruent (asynchronous), self-administered stimulations remove the illusory effect of the NI only in the control group, whereas individuals with ASD are still reporting strong NI experiences. If on the one hand the present results suggest that the participants with ASD have the ability to perform the integration of visual, somatosensory and motor signals underlying the NI; on the other hand, the efficiency of such integration seems to be reduced in comparison with the control group. A possible explanation for this may be that the people with ASD tested here did not perceive the asynchronous brushing as asynchronous. This would be in line with previous work demonstrating that in the tactile domain asynchronous stimuli are perceived as synchronous by individuals with ASD (Foss-Feig et al., 2010; Kwakye et al., 2011). This finding contributes to a better characterization of the subtle proprioceptive and sensorimotor differences revealed in ASD, as previously reported with the use of the rubber hand illusion (Paton et al., 2012).

Second, our findings may be interpreted in the context of the over-reliance on proprioception (vs. vision) commonly revealed in ASD (Haswell, Izawa, Dowell, Mostofsky, & Shadmehr, 2009), contributing to non-adaptive behaviors. In agreement with studies of motor coordination and adaptation (Haswell et al., 2009; Masterson and Biederman, 1983), in which ASD individuals are less likely than the control group to integrate proprioceptive information with input from other senses (Minshew, Sung, Jones, & Furman, 2004), we hypothesize that the difference in the strength of the NI across groups in the self-stroking condition might depend on the differential relevance given to proprioceptive information.

Third, our data may add to the characterization of the disruption of multisensory temporal integration in ASD. The fact that in the ASD group the NI arose independently of the type of stroking, confirms that the NI depends on the temporal synchrony between tactile, proprioceptive, and motor signals (Dieguez et al., 2009). In other words, an aspect of time-varying somatosensory coding (synchronicity) is relevant for this illusion to emerge in controls, but not in ASD. Impaired perception of the temporal relationship

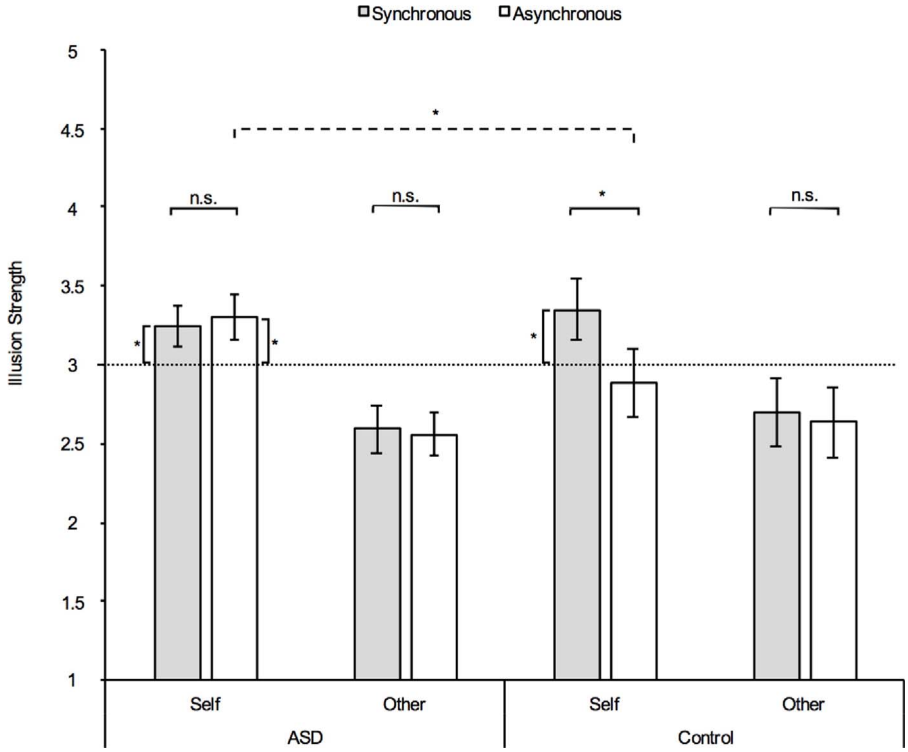

Fig. 2. The illusion strength for the ASD and the control group. Error bars indicate the 95% confidence intervals of the mean. * = $p < 0.05$; n.s. = lack of statistical significance; solid lines = within-group comparison; dashed line = between-group comparison; dot line = threshold for illusion perception. The horizontal dashed line indicates the level above which the NI was experienced.

between cross-modal inputs can be expected in ASD, given for instance the inadequate matching of audiovisual speech information (Stevenson et al., 2014) and, more generally, the difficulties in local/global processing issues widely reported in ASD (Happé & Frith, 2006).

Finally, the high NI ratings for both self-synchronous and self-asynchronous conditions constitute indirect evidence of the dysfunctional neural activity within the primary somatosensory (S1) area in ASD (Khan et al., 2015). Indeed, the NI effect has been previously associated to activity within S1 (Dieguez et al., 2009; Martuzzi et al., 2015). We contend that the degree of somatosensory specialization in S1 can be extended to body ownership in ASD.

Additionally, the present results may be explained taking into account a social perspective, as the embodiment literature suggest (Gallese et al., 2003). As in the case of the RHI, in which individuals with ASD show difficulties in disembodying the bodily self and embodying the bodily other (Noel et al., 2017), disembodiment atypicalities emerge also with the NI. Here, individuals with ASD seem more prone to attribute to the other their somatosensory experience in the self-asynchronous condition, as a result of the illusion.

This atypical recruitment of somatosensory areas, when directly associated with social measures may help us characterize how embodiment phenomena underlie the emergence of socio-emotional skills in ASD (Gallese, 2003). However, before any firm conclusion can be drawn, the very fact that all results are based on the answers to five questions that were asked after each trial may pose some limitations in terms of data interpretation. In particular, a certain degree of caution is needed when considering the neural speculations, despite the fact that they are based on the same paradigm specifications demonstrating such neural underpinnings (Dieguez et al., 2009; Martuzzi et al., 2015).

Collectively, the present results contribute to the discovery and characterization of the atypicalities of tactile and body ownership experiences in ASD, and the NI represents an easy, informative, cost-effective and non-invasive assessment providing fertile ground for understanding body ownership and to probe the link between sensory and social issues in ASD.

Declaration of conflicting interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Author contributions

U. Castiello developed the study concept. U. Castiello and S. Guerra contributed to the study design. Testing and data collection were performed by S. Guerra and E. Straulino. A. Spoto, S. Guerra, V. Parma performed the data analysis and interpretation. U.

Castiello, S. Guerra and V. Parma drafted the manuscript. All authors approved the final version of the manuscript for submission.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.rasd.2017.07.003.

References

Blakemore, S.-J., Frith, C. D., & Wolpert, D. M. (1999). Spatio-temporal prediction modulates the perception of self-produced stimuli. *Journal of Cognitive Neuroscience*, *11*(5), 551–559. http://dx.doi.org/10.1162/089892999563607.

Blakemore, S.-J., Tavassoli, T., Calò, S., Thomas, R. M., Catmur, C., Frith, U., et al. (2006). Tactile sensitive in Asperger syndrome. *Brain and Cognition*, *61*(1), 5–13. http://dx.doi.org/10.1016/j.bandc.2005.12.013.

Botvinick, M., & Cohen, J. (1998). Rubber hands feel touch that the eyes see. *Nature*, *391*, 756.

Boulware, J. T. (1951). Numbness, body-image, and the Japanese illusion. *Science*, *114*(2970), 584–585.

Cascio, C. J., Foss-Feig, J. H., Burnette, C. P., Heacock, J. L., & Cosby, A. A. (2012). The rubber hand illusion in children with autism spectrum disorders: Delayed influence of combined tactile and visual input on proprioception. *Autism*, *16*(4), 406–419. http://dx.doi.org/10.1177/1362361311430404.

Chaminade, T., Meltzoff, A. N., & Decety, J. (2005). An fMRI study of imitation: Action representation and body schema. *Neuropsychologia*, *43*(1), 115–127. http://dx.doi.org/10.1016/j.neuropsychologia.2004.04.026.

Dieguez, S., Mercier, M. R., Newby, N., & Blanke, O. (2009). Feeling numbness for someone else's finger. *Current Biology*, *19*(24), R1108–R1109. http://dx.doi.org/10.1016/j.cub.2009.10.055.

Dijkerman, H. C., & de Haan, E. H. (2007). Somatosensory processes subserving perception and action. *The Behavioral and Brain Sciences*, *30*, 189–201. http://dx.doi.org/10.1017/S0140525x07001392.

Ehrsson, H. H. (2007). The experimental induction of out-of-body experiences. *Science*, *317*(5841), 1048. http://dx.doi.org/10.1126/science.1142175.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*, 1149–1160. http://dx.doi.org/10.3758/BRM.41.4.1149.

Foss-Feig, J. H., Kwakye, L. D., Cascio, C. J., Burnette, C. P., Kadivar, H., Stone, W. L., et al. (2010). An extended multisensory temporal binding window in autism spectrum disorders. *Experimental Brain Research*, *203*(2), 381–389. http://dx.doi.org/10.1007/s00221-010-2240-4.

Gallagher, S. (2000). Philosophical conceptions of the self: Implication for cognitive science. *Trends in Cognitive Sciences*, *4*(1), 14–21. http://dx.doi.org/10.1016/S1364-6613(99)01417-5.

Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences*, *8*(9), 396–403. http://dx.doi.org/10.1016/j.tics.2004.07.002.

Gallese, V. (2003). The roots of empathy: The shared manifold hypothesis and the neural basis of intersubjectivity. *Psychopathology*, *36*, 171–180. http://dx.doi.org/10.1159/000072786.

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5–25. http://dx.doi.org/10.1007/s10803-005-0039-0.

Haswell, C. C., Izawa, J., Dowell, L. R., Mostofsky, S. H., & Shadmehr, R. (2009). Representation of internal models of action in the autistic brain. *Nature Neuroscience*, *12*(8), 970–972. http://dx.doi.org/10.1038/nn.2356.

Khan, S., Michmizos, K., Tommerdahl, M., Ganesan, S., Kitzbichler, M. G., Zetino, M., et al. (2015). Somatosensory cortex functional connectivity abnormalities in autism show opposite trends, depending on direction and spatial scale. *Brain*, *138*(5), 1394–1409. http://dx.doi.org/10.1093/brain/awv043.

Kwakye, L. D., Foss-Feig, J. H., Cascio, C. J., Stone, W. L., & Wallace, M. T. (2011). Altered auditory and multisensory temporal processing in autism spectrum disorders. *Frontiers in Integrative Neuroscience*, *4*, 129. http://dx.doi.org/10.3389/fnint.2010.00129.

Lenggenhager, B., Tadi, T., Metzinger, T., & Blanke, O. (2007). Video ergo sum: Manipulating bodily self-consciousness. *Science*, *317*(5841), 1096–1099. http://dx.doi.org/10.1126/science.1143439.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview – Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, *24*(5), 659–685. http://dx.doi.org/10.1007/BF02172145.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Jr, Leventhal, B. L., DiLavore, P. C., et al. (2000). The Autism Diagnostic Observation Schedule – Generic: A standard measure of social and communication deficits associated with the spectrum of Autism. *Journal of Autism and Developmental Disorders*, *30*(3), 205–223. http://dx.doi.org/10.1023/A:1005592401947.

Martuzzi, R., van der Zwaag, W., Dieguez, S., Serino, A., Gruetter, R., & Blanke, O. (2015). Distinct contributions of Brodmann areas 1 and 2 to body ownership. *Social Cognitive and Affective Neuroscience*, *10*(11), 1449–1459. http://dx.doi.org/10.1093/scan/nsv031.

Masterson, B. A., & Biederman, G. B. (1983). Proprioceptive versus visual control in autistic children. *Journal of Autism and Developmental Disorders*, *13*(2), 141–152. http://dx.doi.org/10.1007/BF01531815.

Minshew, N. J., Sung, K. B., Jones, B. L., & Furman, J. M. (2004). Underdevelopment of the postural control system in autism. *Neurology*, *63*(11), 2056–2061. http://dx.doi.org/10.1212/01.WNL.0000145771.98657.62.

Noel, J. P., Cascio, C. J., Wallace, M. T., & Park, S. (2017). The spatial self in schizophrenia and autism spectrum disorder. *Schizophrenia Research*, *179*, 8–12. http://dx.doi.org/10.1016/j.schres.2016.09.021.

Orsini, A. & Pezzuti, L. (2013). WAIS-IV. Contributo alla taratura italiana (16–69 anni). Giunti OS. Firenze.

Paton, B., Hohwy, J., & Enticott, P. E. (2012). The rubber hand illusion reveals proprioceptive and sensorimotor differences in autistic spectrum disorder. *Journal of Autism and Developmental Disorders*, *42*(9), 1870–1883. http://dx.doi.org/10.1007/s10803-011-1430-7.

Piaget, J. (1952). *The origins of intelligence in children.* New York: Norton, 357–419.

R Core Team (2013). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing.

Stevenson, R. A., Siemann, J. K., Woynarosky, T. G., Schneider, B. C., Eberly, H. E., Camarata, S. M., et al. (2014). Brief report: Arrested development of audiovisual speech perception in autistic spectrum disorder. *Journal of Autism and Developmental Disorders*, *44*(6), 1470–1477. http://dx.doi.org/10.1007/s10803-013-1992-7.

Tajadura-Jiménez, A., & Tsakiris, M. (2013). Balancing the éInner“ and the éOuter“ self: Interoceptive sensitivity modulates self?other boundaries. *Journal of Experimental Psychology: General*, *143*(2), 736–744. http://dx.doi.org/10.1037/a0033171.

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology and Human Perceptual Performance*, *31*(1), 80–91. http://dx.doi.org/10.1037/0096-1523.31.1.80.

Van den Bos, E., & Jeannerod, M. (2002). Sense of body and sense of action both contribute to self-recognition. *Cognition*, *85*(2), 177–187. http://dx.doi.org/10.1016/S0010-0277(02)00100-2.

Wechsler, D. (1999). *WASI: Wechsler abbreviated scale of intelligence*. San Antonio, TX: Psychological Corporation.

Wechsler, D. (2008). *Wechsler adult intelligence scale* (4th ed.). San Antonio, TX: Pearson.