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The plasticity of the interpersonal space in Autism Spectrum Disorder

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Abstract

In recent years, there has been a dramatic increase in research examining interpersonal space, i.e., the sector of space immediately around the body in which we interact with other people. These studies have consistently revealed impairments of interpersonal space regulation in psychopathological disorders characterized by social disability, such as autism, schizophrenia and social anxiety. The primary goal of this review is to discuss several key points that have emerged in research on interpersonal space regulation in autism spectrum disorders. Particularly, we review recent behavioral evidence revealing that individuals with autism prefer abnormally larger or shorter interpersonal distance than healthy controls, indicating a deficit in regulating the size of interpersonal space (*permeability)*. Then, we focus on how individuals with autism fail to modify their interpersonal space following a brief cooperative interaction with an unfamiliar adult, suggesting a deficit in adapting interpersonal space to the social context (*plasticity).* Moreover, we discuss evidence indicating that space regulation deficits primarily affect interpersonal (i.e., social), but not peripersonal (i.e., action), space in autism. Finally, we take into consideration the variables influencing interpersonal space plasticity such as person's perspective and severity of social impairment as well as its neural underpinnings.

These findings may provide a critical contribution to understanding of the functional mechanisms underlying interpersonal space regulation and its rehabilitation in autism spectrum disorders.

Keywords: Interpersonal space; peripersonal space; autism spectrum disorders; plasticity.

1. Introduction

Earliest infant-environment interactions, either between child and other individuals, or between child and objects, mainly occur in the space immediately around one's own body. Interactions with other individuals are extremely relevant for the subsequent development of communicative and social abilities, because enhance the infant's possibilities to experience reciprocal social exchanges (Libertus and Violi, 2016). A fundamental social ability which permeates our everyday interactions is the physical distance regulation. Typically, the distance that we choose to maintain between ourselves and others is a behavioral indicator of how close we prefer to stand relative to another person. Thus, interpersonal distance is critical in determining a successful social interaction and reducing the feelings of discomfort due to interpersonal space violations (Kennedy and Adolphs, 2014).

The present review primarily focuses on the functional properties and plasticity of interpersonal (IP) space, in both typical and atypical childhood. Specifically, we focus on different studies on autism spectrum disorders (ASD; DSM-5, APA 2013; Baron-Cohen et al., 1985; Lord et al., 2000; see, for review, Senju, 2013), a clinical population characterized by a profound and persistent impairment in social interaction. Collectively, these studies show that the regulation of IP space is impaired, enlarged or shortened, in individuals with autism. Interestingly, there is recent evidence demonstrating that autism affects IP space regulation, while it seems to leave unaltered peripersonal (PP) space, a functionally, at least partially, distinct representation of the space related to the potentiality to act upon stimuli in the environment (Candini et al., 2019). Finally, we discuss the functional mechanism and the anatomical correlates of impaired interpersonal space in autism.

2. A deficit in interpersonal space regulation in Autism

During social interactions, the interpersonal distance we maintain between ourselves and others indicates how close we prefer to stand relative to an unknown individual. Social psychologists were the first to coin the term interpersonal space referring to the emotionally tinged area around one's own body, and in which another's intrusion may cause a prompt feeling of discomfort and anxiety (Hall, 1966; Hayduk, 1978; Sommer, 1959). When the IP space is violated, individuals may move away in order to reduce the perceived distress and to reinstate the margin of safety.

Recently, a number of studies demonstrated that the regulation of interpersonal space is impaired in individuals affected by disorders of social interaction, such as autism spectrum disorders. For instance, a study by Gessaroli and colleagues (2013) provided an ecological measure of interpersonal space both in typical and atypical developmental populations. In this study, they adopted a Comfort-distance task in which the IP space was measured as the distance at which children felt most comfortable when an unfamiliar and unknown adult (confederate) approached them, or they approached the confederate (see Fig. 1). Then, the distance between the confederate's and the participant's body was recorded with a digital laser measurer and considered as a proxy of interpersonal space extent. This experimental procedure represents one of the most frequently used measures of interpersonal space and allows to reliable estimate preferred interpersonal distance (permeability) under varied conditions (Hayduk, 1983). Interestingly, ASD children chose a larger IP space compared to children with typical development (TD), suggesting that they are less tolerant to closer proximity of an unfamiliar adult. Moreover, despite the described differences, an interesting commonality was found across TD and ASD groups. Indeed, all participants preferred larger interpersonal distance when the confederate approached them (passive approach) compared to when they approached the confederate (active approach) (Candini et al., 2017). This result indicates that if, in social situations, we cannot predict where people stop, we resolve this unpredictability by maintaining others at a larger distance. This apparently subtle difference revealed a fundamental ability which is preserved in autism and might be particularly relevant to assess potentially threatening social situations, such as people that are too close to us (Lloyd and Morrison, 2008).

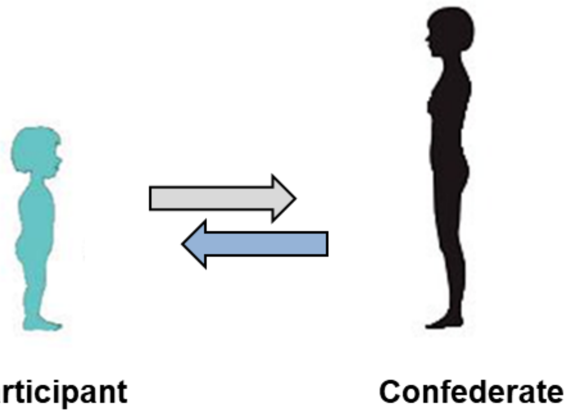

Figure 1 Schematic representation of the Comfort-distance task. The participant (green) and the confederate (black) were depicted. The arrows indicate the approach directions depending on who performed the movement: the participant (active approach) or the confederate (passive approach).

Other studies conducted on adult populations found that ASD individuals prefer closer interpersonal distance, as compared to controls (Asada et al., 2016; Kennedy and Adolphs, 2014; Parsons et al., 2004; Pedersen et al., 1989, 1997). Kennedy and Adolphs (2014) investigated the abnormalities in social distance in individuals with ASD by analysing the Social Responsiveness Scale (SRS; Constantino and Gruber, 2005), a parent-report questionnaire designed to quantify the autistic symptoms severity and the preferred comfort distance from an unfamiliar adult (i.e., Comfort-distance task). Both these measures pointed out that individuals with ASD more frequently tend to invade others' interpersonal space in real-life social contexts (lower scores at SRS compared to their unaffected siblings), and prefer smaller IP space compared to controls, as demonstrated by the Comfort-distance task.

Similarly, Asada and colleagues (2016) adopted a Comfort-distance task to assess preferred IP space in a Japanese sample of adolescent with and without ASD. Two different conditions were adopted: in half of the trials, the confederate walked toward the participants (passive approach) and, in the other half of the trials, the participants walked toward the confederate (active approach). Furthermore, to investigate the role of eye contact in defining the preferred IP space, in half of the trials the experimenter looked toward the participants' eyes, and in the other half of the trials, the experimenter looked down. They found a smaller interpersonal space in ASD participants compared to controls, but no difference emerged between the two groups when the eye contact condition was considered. Indeed, when the confederate approached the participant looking toward the participants' eyes, both ASD and controls preferred larger interpersonal distance, compared to when there was no eye contact. This evidence suggests that ASD individuals can, at least partially, understand and use social cues, such as other people's gaze, during a social interaction in order to choose the preferred interpersonal distance.

Parsons and colleagues (2004) investigated the use and understanding of *social virtual environments* in a group of adolescents with autism adopting the virtual reality technique. In this study, participants performed a series of tasks in a virtual-café environment simulating real-life social activities (i.e., order a drink from the bar or pay for food and drink). The authors focused on different behavioural parameters such as the social appropriateness of performance, the basic understanding of the virtual environment, the time spent completing the tasks and the number of errors made. When ASD participants were compared to healthy controls, two different results emerged: some ASD participants followed the interpersonal distance rules in virtual environment, whereas other ASD adolescents did not respect the space of virtual characters, walking directly in-between two characters engaged in a conversation, or moving very close to the people at the bar when ordering a drink. These apparently controversial results might be ascribed to the fact that social deficits which characterized the autism spectrum disorders actually fall on a continuum of symptom severity, which may be reflected by different degrees of social space dysfunction in real life. Future research should explore whether individuals with ASD showing deficits in regulating the social distance when assessed in virtual reality environment also manifest difficulty in understanding the expectations and social norms in real-world interactions.

Together these evidence suggests that autism may impact on social distance regulation along two opposite edges: while some studies report that ASD individuals stay too far from other people

(Candini et al., 2017; Freitag, 1970; Gessaroli et al., 2013), other researchers conclude that ASD individuals more often violate the space of others (Asada et al., 2016; Kennedy and Adolphs, 2014; Parsons et al., 2004; Pedersen et al., 1989, 1997). Notably, these findings were not uniform and raises the question of which factors can mediate these differences.

One possible explanation of these contrasting findings could be due to differences in term of age and clinical characteristics of the sample. Accordingly, an enlargement of IP space was found in children (Candini et al., 2017; Gessaroli et al., 2013) whereas a reduction of IP space emerged in adolescents and adults (Asada et al., 2016; Kennedy and Adolphs, 2014; Parsons et al., 2004). Following the clinical classification proposed by Lorna Wing and colleagues (Wing & Attwood, 1987; Wing & Gould, 1979), based on the quality of social interaction three different subgroups of individuals with autism can be identified: i) the *aloof subgroup*, characterized by the tendency to reject unsolicited social or physical contact; ii) the *passive subgroup*, characterized by a lack of spontaneous social approaches to others and by the tendency to engage another person when approached, as long as the other person structures the interaction; and, finally, iii) the *active-but-odd subgroup*, characterized by a willingness to make social approaches to others. In a previous work by Volkmar and colleagues (1989), the aloof children were described as significantly younger than passive or active-but-odd children. Thus it is possible that, in the above mentioned studies, children belong to the aloof subgroup and consequently they chose a larger interpersonal space from others people, whereas adolescents and adults may belong to the passive or active-but-odd subgroups and, therefore, preferred a shorter IP space. However, to verify this hypothesis, an essential first step is an investigation of the developmental time course of the space around the body, as well as how the clinical symptoms characterizing the Wing's classification change according to age. Future studies should address these interesting aspects, which are not fully understood in the literature.

An alternative explanation of these patterns of results is in term of cultural differences, since some studies were conducted in the USA (Kennedy and Adolphs, 2014; Parsons et al., 2004;), while other studies were conducted in Europe (Candini et al., 2017; Gessaroli et al., 2013), and in Japan (Asada et al., 2016). It is well known that cultural factors may deeply affect social behaviour (Hayduk, 1978), and so it is possible that for some cultures being closer to others is normal, while choosing a larger IP distance is deemed inappropriate.

Finally, it is worth to note that the Comfort-distance task is a paradigm developed to *explicitly* measure interpersonal space preferences by stopping another person whenever the participant begin to feel uncomfortable with other's proximity. According to the explicit nature of this task, it is important to consider that the discrepancies observed across studies could be referred to the fact that individuals with ASD may adopt different cognitive strategies when providing an explicit judgment about their preferred interpersonal distance. To overcome this potential confound, and to better clarify which variables induce an enlargement or a reduction of social distance in autism, further investigations adopting an implicit measure of IP space are needed.

3. A deficit in interpersonal space plasticity in Autism

A peculiar feature of interpersonal space concerns its dynamicity: it changes as a function of different social factors, such as age, gender, attachment style, the degree of intimacy and familiarity between individuals, but also the perceived morality of another person (Aiello et al., 1987; Bar-Haim et al., 2002; Dosey & Meisels, 1969; Felipe & Sommer, 1966; Iachini et al., 2015; 2016; Pellencin et al., 2018; Remland et al., 1995). Focusing on maternal attachment style, Bar-Haim and colleagues (2002) demonstrated how these internal representations, mainly developed during infancy, are crucial to explain the variability emerged in interpersonal space regulation in kibbutz children. Interestingly, they found that children with an insecure attachment exhibited a larger interpersonal space, whereas children with an ambivalent attachment allowed more intrusion into their interpersonal space as compared with those characterized by a secure attachment.

Recently, it has been demonstrated, in children with typical development, how following a brief cooperative interaction with a previous unknown person is sufficient to reduce the distance that we maintain from that person and modify interpersonal space (Candini et al., 2017; Candini et al., 2019;

Gessaroli et al., 2013). In this study, the Comfort-distance was measured both in children with typical development and in children with autism, before and after a very brief playtime interval during which the child was invited to read an illustrated book together with the confederate. After only ten minutes of pleasant and cooperative playtime interval with an unfamiliar adult, a subsequent reduction of the interpersonal space was observed, indicating that IP space extent is highly malleable, presumably to facilitate social interactions and communication. Differently, following an uncooperative interaction with the confederate, during which the confederate did not play with the participant and remained silent or provided occasionally criticism, no such a reduction of interpersonal space was observed in TD children (see Fig. 2). Conversely, no changes of IP space emerged in response to a social interaction in ASD children, regardless of whether the nature of interaction was cooperative or uncooperative (Candini et al., 2017; Gessaroli et al., 2013). Overall, these results provide evidence for a deficit of interpersonal space plasticity in ASD children.

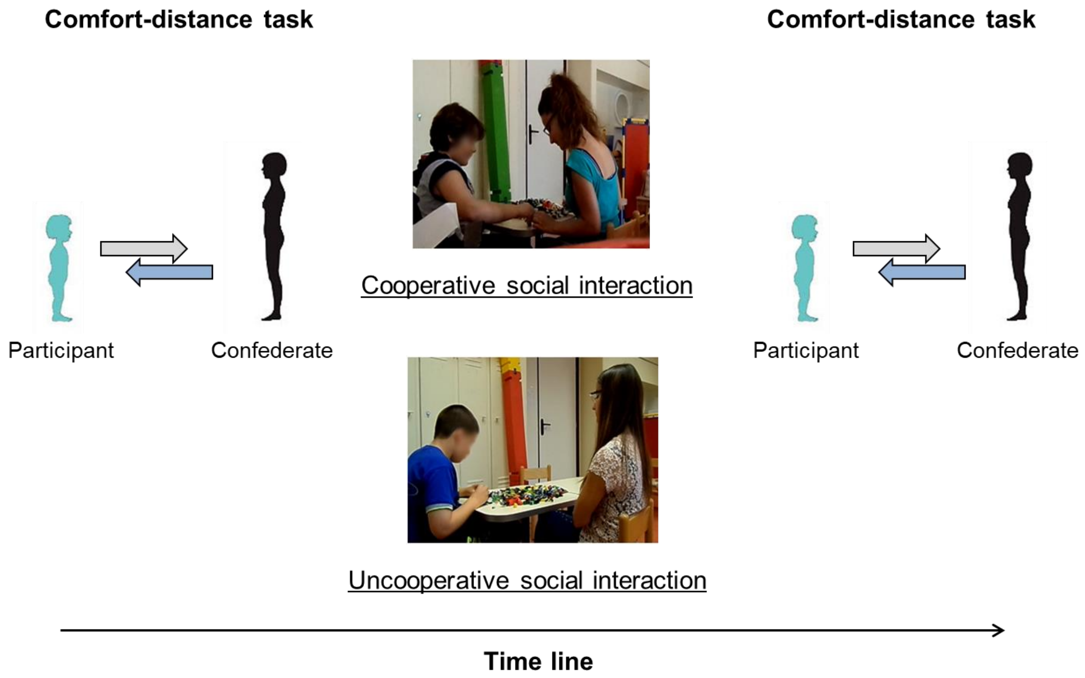

Figure 2 Representation of the Comfort-distance task adopted in Candini et al.'s study (2017). The Comfort-distance task was performed twice, before and after a Cooperative or Uncooperative social interaction. In the Cooperative interaction the confederate played with the participant assembling and building the bricks, encouraged him, provided occasional helpful suggestions, and assumed a smiling face expression

and a relaxing inclined posture (as illustrated in the upper panel). By contrast, in the Uncooperative interaction, the confederate did not play with the participant, remained silent or provided occasional criticisms, and adopted a rigid posture with still face and folded arms (as illustrated in the lower panel). The arrows indicate the approach directions depending on who performed the movement: the participant or the confederate. The participant (green) and the confederate (black) were depicted.

Finally, a functional link was provided between IP space plasticity and the severity of social deficit in everyday life in ASD children (Candini et al., 2017). To measure the children's social impairment severity in everyday activities, it has been adopted the Wing Subgroups Questionnaire (Castelloe et al., 1993). Specifically, the rating on one item ("*When the child is with unfamiliar adults or children, he readily approaches others to interact. His manner of interacting is generally appropriate, not awkward or unusual*"*)* was extract and considered as indicator of appropriate IP space regulation. Based on the frequency of inappropriate social responses on this item, we found that the greater was the social impairment severity in social daily interactions, the higher was the impairment observed in interpersonal space plasticity.

4. The selective deficit of interpersonal space versus a preserved peripersonal space

Considering the space surrounding the body, literature distinguishes between the peripersonal space (Farnè et al., 2005; Noel et al., 2019; Serino et al., 2015), and the arm-reaching space. Peripersonal (PP) space represents a multisensory interface between the body and the environment, in which stimuli are coded in motor terms for the purpose of voluntary actions (Brozzoli et al., 2014; Makin et al., 2009; Maravita and Iriki, 2004; Rizzolatti et al., 1981, 1997; see, for review, di Pellegrino and Làdavas, 2015; Makin et al., 2012; Occelli et al., 2011). Reaching space is the space that one's arm can reach without leaning (Coello et al., 2008).

Recently, to directly compare the functional proprieties of the IP and PP spaces, some studies (Iachini et al., 2014; 2015; Patanè et al., 2016; 2017 Ruggiero et al., 2016) adopted the *Reaching-distance* *task*, as a proxy to estimate the PP space extent, and the *Comfort-distance task,* that is a modified version of the stop-distance paradigm, to measure IP space. In the *Reaching-distance task,* participants have to stop when they think they can reach the other person by extending their limb. In the *Comfort-distance task*, participants have to stop at the point where they still feel comfortable with other's proximity (Candini et al., 2017; 2019; Pellencin et al., 2018).

As we have seen before, our interpersonal distance preferences may vary depending on social context. In a similar manner, also peripersonal space is highly flexible. For instance, we can extend our physical action potentialities by using tools (see, for review, Johnson-Frey, 2003, 2004; Maravita and Iriki, 2004; Reynaud et al., 2016), which allows us to reach objects located in a unreachable and far space, thus enlarging the reaching space's boundary (Berti and Frassinetti, 2000; Hunley et al., 2017; Longo and Lourenco, 2006; Taffou and Viaud-Delmon, 2014; see, for review, Brozzoli et al., 2012; Martel et al., 2016).

In literature, the most prominent modulations of peripersonal space has been described as mainly driven by action-related factors. However, there is also evidence demonstrating that peripersonal space extent is influenced by high-order social factors. In this respect, Teneggi and colleagues (2013) provided the first description that the nature of the interaction with another person affects the PP space dimension. The authors measured the participants' PP space boundary adopting an audio-tactile paradigm, both before and after a fair or unfair social interaction. They found that PP space boundary changed according to the relationship with the other person: an extension of the participants' PP space towards the body of the fair (but not of the unfair) other was found. Furthermore, to explore the existence of possible common mechanisms between peripersonal and interpersonal space, Ruggiero and colleagues (2016) investigated whether these spaces are similarly sensitive to the emotional valence of facial expression in a virtual reality environment. In this study, participants performed the reaching- and the comfort-distance tasks while being approached or walking toward a virtual confederate who exhibited happy, angry or neutral facial expressions. An enlargement of peripersonal space when participants were approached by an angry confederate was found. In the same vein, Iachini and colleagues (2015) examined whether a moral or immoral confederate can influence the reaching- and comfort-distance preferred by participants. They observed that preferred distance chosen by participants actually expanded (shortened) with a confederate described as an immoral (moral) person. The same pattern of results was reported in both spaces, although it was particularly strong in the interpersonal space. In sum, this evidence converged to the idea that the plasticity of the space around the body (both the space in which we interact with other as well as the space for act with objects) allows individuals to dynamically and flexibly react to potentially relevant stimuli, placed close the participant's body.

It is worth to note that the social modulations of PP space previously described in literature (Iachini et al., 2015; Ruggiero et al., 2016) emerge especially when the participant's response has a protective valence, thus emphasizing the defensive nature of the action space. According to the interpretation proposed by de Vignemont and Iannetti, (2015), and further discussed by Bufacchi and Iannetti (2018), the space close to the body is a dynamic interface to safely interact with the physical and social environment.

More recently, several empirical findings have been provided to clarify the functional relationship between action and social space (Cartaud et al., 2018; Iachini et al., 2014; 2015; Patanè et al., 2016; 2017; Pellencin et al., 2018). For instance, Patanè and colleagues (2016) directly compared the PP and IP space plasticity measured toward a confederate, by using the reaching- and the comfort-distance, before and after a cooperative tool-use training. In this training, participant and confederate jointly cooperate to reach objects located beyond the arm reaching distance, by using a long tool. Intriguingly, the training evokes opposite effects on PP and IP spaces: the former extends, whereas the latter reduces as compared to before cooperative tool-use training (Patanè et al., 2017). These findings are in accord with the dynamical properties of the space surrounding the body already described (Berti and Frassinetti, 2000; Candini et al., 2017; Gessaroli et al., 2013; Longo and Lourenco, 2006), but also demonstrated that dissociable plastic mechanisms underlying the action and social spaces. Accordingly, PP space is sensitive to tool-use, whereas IP space is sensitive to social cooperation with another person.

A crucial question addressed by a recent study, is whether autism affects the plasticity of both PP and IP space. A group of TD and ASD children performed the Reaching- and Comfort-distance task in two experimental conditions: facing either an inanimate object or a female unfamiliar adult. To explore the plasticity of these spaces both tasks were repeated twice: before and after a cooperative tool-use training in which the child used a tool to cooperate with the confederate (see Fig. 3).

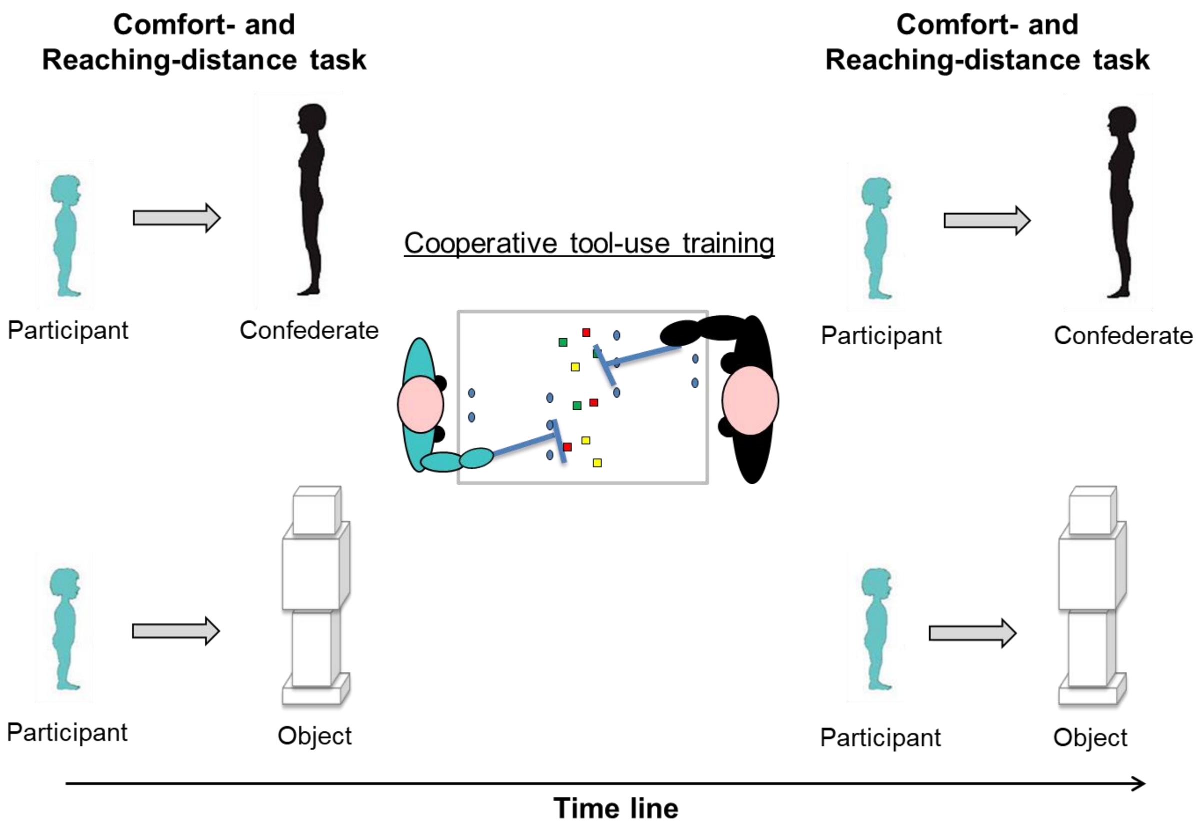

Figure 3 Schematic representation of the experimental procedure adopted in Candini et al.'s study (2019). Participants have to stop at the point *where they still feel comfortable with stimuli's proximity* (Comfort-distance Task) and *when they think they can reach the stimuli by extending their limb* (Reaching-distance Task). Both tasks were performed in two experimental conditions: facing either a female unfamiliar adult (confederate) or an inanimate object, before and after a cooperative tool-use

training session in which the participant (green) and the confederate (black) jointly cooperate to reach colored chips placed in the unreachable space by using a rake.

Authors found that both TD and ASD children preferred larger Comfort- than Reaching-distance. This result could be easily accounted for by the fact that participants were children facing an unfamiliar adult, a situation in which they may have felt distress (Dean et al., 1976; Severy et al., 1979). Supporting this interpretation, the Comfort-distance was modulated by the type of stimulus approached: greater IP space was found when participants moved toward the person compared to the object. A possible explanation is that the inanimate object was perceived as potentially more safe or predictable compared to an unfamiliar adult, thus allowing children to tolerate a closer distance when facing the object than the person. Indeed, when one's own IP space is invaded by an unfamiliar person, a feeling of anxiety can increase resulting in the need to keep other people farther away (Perry et al., 2013; 2015; Strube and Werner, 1984). By contrast, when participants estimated the Reaching-distance toward the person or the object no differences emerged, thereby suggesting that interpersonal, but not peripersonal, space is modulated by the social valence of stimuli. Moreover, a positive correlation between preferred reaching distance and participants' arm length demonstrates that 8 to 13 years old children considered their arm length to evaluate stimulus reachability. This evidence confirms previous developmental studies which suggests that PP space representation is deeply rooted in the action potentialities of their own body (Caçola and Gabbard, 2012; Rochat, 1995) (for similar results in adult population, see Witt et al., 2005; Witt and Proffitt, 2008).

Nevertheless, a critical difference between TD and ASD children emerged when the plastic properties of PP and IP space are considered. Indeed, in TD children, following the cooperative tool use training, PP space extended, both toward the confederate and the object, whereas IP space reduced toward the confederate, but not the object, as compared to before the training. Conversely, in ASD group, both PP and IP spaces extended, regardless of whether they approached the object or confederate. When the effects of cooperative tool-use training were compared in TD and ASD children, similar results emerged in the Reaching- but not in the Comfort-distance task: peripersonal space extended in both groups, whereas interpersonal space reduced in TD but not in ASD children. Thus, in ASD population the tool use is effective in shaping the PP space, whereas the social interaction, during which the tool is used with the confederate, does not contract IP space.

Interestingly, the impairment confined to interpersonal space regulation, correlated with the level of social impairment as measured by the "Social Interaction" ADOS scale subtest (Autism Diagnostic Observation Schedule, Lord et al., 2000): higher is the severity of social interaction deficit, higher is the deficit of IP space plasticity observed in children with autism. This finding is in line with previous evidence (Candini et al., 2017), and suggests that IP space provides a functional and operational measure of social space. Even more intriguingly, having found a preserved peripersonal space regulation in autism is highly relevant because it uncovers an isle of proficiency in reachability estimation, despite the presence of well-documented deficit in planning and executing goal-directed actions in ASD children (Haswell et al., 2009; Linkenauger et al., 2012; Mari et al., 2003; see, for review Moseley and Pulvermuller, 2018). The intact functional properties of *action* space found in ASD children highlight the role of peripersonal space plasticity in order to efficiently adapt our behaviours to a specific context.

A different pattern of results emerged when the *multisensory* component of PP space is considered. Indeed, a couple of studies demonstrates how the multisensory integration within PP space is altered in ASD individuals (Cascio et al., 2012; Paton et al., 2012; Mul et al., 2019). For instance, Cascio and colleagues investigated the multisensory integration within PP space adopting the Rubber Hand Illusion (RHI) in ASD children. They reported that, even if ASD individuals experience the RHI, the susceptibility to this illusion is temporally delayed. In the same direction, in Paton and colleagues' study (2012) the ASD group was less sensitive than controls to visuo-tactile discrepancy between the tactile sensation and the finger seen touching the rubber hand. This is consistent with the idea that individuals with ASD exhibit difficulties in integrating multiple sensorial cues.

More recently, Mul and colleagues' study adopted an audiotactile reaction time task to assess the multisensory component of peripersonal space in ASD adults. They found that multisensory integration of auditory and tactile stimuli in ASD individuals occurs later as compared to controls. A possible explanation which embrace collectively these findings is that ASD individuals are characterized by an altered temporal "windows" within which they bind different stimuli (Stevenson et al., 2014). It could be interesting to explore in autism the functional relationship between the reaching properties and the multisensory integration characterizing the IP space.

5. An impairment in estimating others' interpersonal space preference

Research on social cognition has pointed out that when ASD individuals observe a social interaction they exhibit marked difficulties in adopting the perspective of another person (Frith, 1996). Starting from this evidence, it has been recently examined whether autism also affects the ability to estimate others interpersonal space preference, that is when participants adopted another perspective. In a nutshell, aim of this study was to disentangle if interpersonal space regulation deficit manifests itself only when ASD participants adopted a first-person perspective, or if it affects also the ability to judge interpersonal space between others (see Fig. 4). In this study, the interpersonal space between the participant and an unknown adult was measured in a group of typical developmental children and in two groups of high-functioning ASD children, showing a more and less severe social impairment in daily life, respectively (Candini et al., 2017). The authors found that ASD children preferred larger interpersonal distance compared to TD children, both when they were asked to adopt a first- or a third-person perspective, suggesting that the perspective did not influence the IP space permeability. Notably, perspective and severity of social impairment actually influenced the IP space plasticity: following a cooperative social interaction, ASD children with a less severe social impairment shrink the interpersonal space between themselves and the adult (first-person perspective), whereas no such change was found when they were asked to estimate interpersonal distance between other people (third-person perspective). Conversely, ASD children characterized by a severe social impairment did not show any change of interpersonal space, after compared to before a social interaction, both in first- and in third-person perspective. Taken together, these results suggest that the ability to dynamically adapt and regulate interpersonal space between themselves and others is not sufficient to appropriately estimate interpersonal space between others.

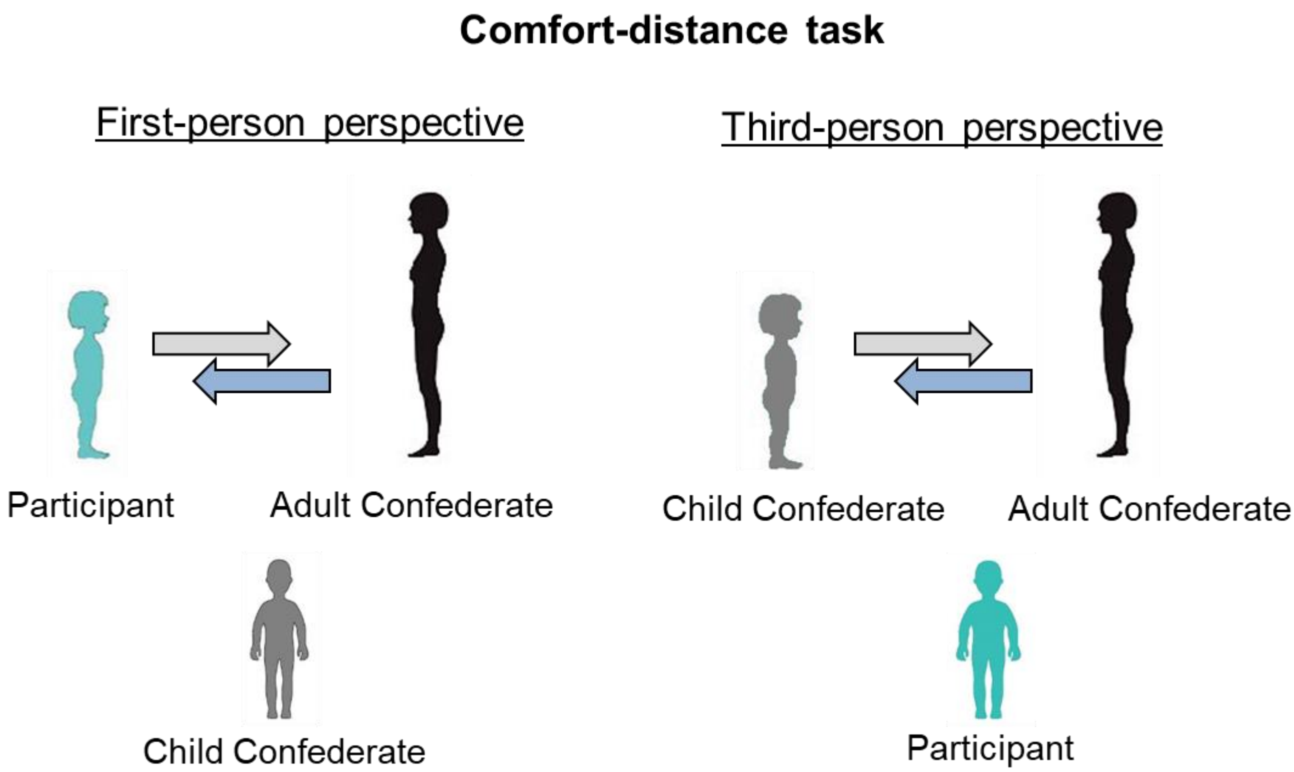

Figure 4 Schematic representation of the Comfort-distance Task in first- and third-person perspective. Participants performed the Comfort-distance Task in two experimental conditions: adopting a first- person perspective (left panel) and a third-person perspective (right panel). The arrows indicate the approach directions depending on who performed the movement. The participant (green), the adult-confederate (black) and the child-confederate (grey) were depicted.

One fascinating point which should be addressed by future studies concerns the relationship between the ability to discriminate between self and other and the ability to regulate the distance between confederate's and participant's body. Since several evidence suggest that integration of body-related multisensory signals within the space around the body participate in the differentiation between self and others, it seems relevant to investigate the link between high-order social cognitive processes and bodily self-representation.

In this respect, Gessaroli and colleagues (2013) investigated one's own body recognition in TD children and in children with ASD. Participants performed a visual task with pictures depicting self and other people's body-parts. Interestingly, both groups showed a facilitation when they visually matched their own, compared to others' body-parts. This result is suggestive of a spared bodily self-recognition in children with ASD. A preserved self-other distinction in ASD adults, even if less plastic than healthy controls, was also found in a subsequent study in which the rubber hand illusion (RHI) was adopted. RHI is an experimental manipulation able to affect the sense of body ownership because induce the illusion to have a rubber hand (Cascio et al., 2012). The authors reported a marked difficulty in disembodying the bodily self and embodying the bodily other (i.e., the rubber hand) in individuals with ASD. This finding indicates that they are less prone to bodily illusions compared to healthy participants. To explain this findings, Noel and colleagues (2017) suggested the presence of a steeper and less flexible self-other boundary in autism.

Along this view, the tendency to choose, in a Comfort-distance task a larger interpersonal space between one's own body and others' body can be a manifestation of the sharp boundary and the inflexible distinction between self and other, which affects both the social and corporeal domains, thus resulting in an impairment of others' emotion recognition, empathy, and theory of mind. Further studies should clarify a possible link between self/other distinction and socio-communicative deficits typically described in ASD individuals.

6. Social anxiety and interpersonal space in Autism

The presence of abnormal interpersonal space in ASD children may reflect overarousal and enhanced fear induced by the presence of other individuals intruding their social space. Supporting this hypothesis, Corbett and colleagues (2010) adopted an ecological paradigm designed to emulate a "real life" playground in order to determine whether such environment would be deemed physiologically stressful in a group of children with and without ASD. They found that, during peer-to-peer social interactions, children with autism have significant higher levels of cortisol than typical developmental children. Thus, it is reasonable to hypothesize that ASD children, due to enhanced fear and hyperarousal following other people approaching and the potential violation of interpersonal space, regulate IP space differently, resulting in an inappropriate distance from other individuals. Coherently to this scenario, several studies suggested that a potential candidate to account for high level of anxiety and abnormal fears in ASD children is an excessively functioning amygdala. Indeed, the amygdala it has been proposed as a key structure implicated in the neuropathology of autism (Juranek et al., 2006; Schumann et al., 2004), and its dysfunction could contribute to impaired social interactions and avoidant behaviours in these individuals (Corbett et al., 2006; 2010; Hirstein et al., 2001; Schulkin et al., 2006; Swartz et al., 2011).

Going further, the level of social anxiety also influences the preferred distance from an unfamiliar person: individuals with high level of social anxiety preferred greater interpersonal distance as compared to those with low social anxiety traits (Rinck et al., 2010; Wieser et al., 2010). In this respect, a recent electrophysiological study revealed a positive correlation between levels of social anxiety, measured by using the LSAS scale (Liebowitz, 1987), and preferred interpersonal distance, as measured by using a modified version of the Comfortable Interpersonal Distance paradigm (CID; Duke & Kiebach, 1974; Duke & Nowicki, 1972). In this paradigm, participants are instructed to imagine themselves in a virtual room visualized on a PC screen and to respond to a virtual person (a friend or a stranger) approaching them by indicating where they would like the person to stop (Perry et al., 2013). At electrophysiological level, attenuated early ERP responses (P1 and N1) for approaching stimuli were found in individuals with high levels of social anxiety. Thus, the more socially anxious an individual was, the smaller was the early ERP amplitude response, suggesting that fewer attentional resources were allocated to social stimuli.

In a recent systematic review, Spain and colleagues (2018) reported that social anxiety commonly co-occurs with autism spectrum disorders and it is associated with poorer social skills, competence and social motivation. Therefore, a possible explanation is that, during social engagement, individuals with high social anxiety levels may feel earlier distress due to poor elaboration of social cues, which would lead them to stand farther away and perpetuate a cycle of less communicative and appropriate social interactions.

Interestingly, this hypothesis has been further explored in a subsequent ERP study in a sample of adults with ASD. The authors found that preferred interpersonal space chosen by ASD participants can be explained by different degree of social anxiety: greater is the social anxiety level, the farther away ASD individuals prefer to stand relative to an unfamiliar adult. In line with the role of attention in social anxiety, the preferred interpersonal space can be predicted by the N1 amplitude, an early ERP component related to attention and discrimination processes. These results suggested that complex social behaviours, such as the ability to properly judge the appropriate interpersonal distance from other individuals, could be influenced by altered early sensory and attentional processes (Perry et al., 2015).

7. Functional anatomy of interpersonal space in Autism

In the last years, the neural bases of interpersonal space are the focus of neuroimaging and neuropsychological studies in healthy subjects and brain damaged patients, respectively.

One of the prominent neuroimaging results coming from a recent fMRI study conducted by Holt and colleagues (2014). The authors found that the activity of a brain network including the dorsal intraparietal sulcus (dIPS) and ventral premotor cortex (vPM) is functionally linked to social behaviours. Indeed, the participants' IP space negatively correlated with the coupling between these two brain regions: the weaker is the dIPS-vPM functional coupling, the larger is the preferred interpersonal space. Interestingly, they suggest a link between areas that respond to virtual approach in the scanner and individual differences in IP space preferences.

Moving to neuropsychological studies, atypical approach-avoidance behaviours are reported in patients with lesion of amygdala (Harrison et al., 2015; Kennedy et al., 2009). For instance, Kennedy and colleagues (2009) reported a single case study in which a patient affected by a bilateral amygdala damage showed a significant reduction of IP space, both in first and in third-person perspective, compared to controls. These findings reveal that a bilateral damage to the amygdala results in an abnormally small interpersonal space, thereby suggesting a key role for this subcortical structure in the neural substrate of social space regulation.

Moreover, in a recent neuropsychological study, Perry and colleagues (2016) made a step forward in understanding the principles mediating IP space preference. Starting from the idea that IP space is related to inhibition of inappropriate social conduct and to social norms, the authors hypothesized that orbitofrontal cortex (OFC) may be a critical brain region implicated in social behavior and interpersonal space regulation. Supporting this view, the authors revealed that patients with OFC damage were impaired in social distancing since they do not keep the expected distance from others. Specifically, OFC patients preferred very close interpersonal distances regardless of whether they were approaching a stranger or a familiar other, compared to both controls and patients with dorsolateral prefrontal damage.

Linking this anatomical evidence to the reduced tolerance of physical closeness with a stranger and the lack of flexibility of interpersonal space emerged in ASD children, it is reasonable to hypothesise that a cortico-subcortical network, involving amygdala and OFC is responsible to mediate the ability to evaluate the relevance of social stimuli in order to choose the appropriate interpersonal distance. This hypothesis is further supported by recent neuroimaging studies indicating that an excessively functioning amygdala may account for the increased anxiety and fear found in population with autism, thereby leading to withdrawal from reciprocal social interaction (Kleinhans et al., 2009; Swartz et al., 2013). Additionally, atypical connectivity between frontal and limbic networks in ASD individuals have also been reported (Cerliani et al., 2015; Glerean et al., 2016; Kleinhans et al., 2016). Collectively, these findings advance our knowledge concerning the neural correlates underlying the space close to the body and provide a starting point for future studies examining the extent to which these representations are flexible both in typical and atypical developmental age.

Concluding remarks

The present review clearly reveals that several factors may have a role in influencing the social space in autism: the social anxiety, the nature of social interaction, the severity of social impairment and the person's perspective. Moreover, these findings highlight a close link between interpersonal space regulation and social behaviors typically observed in everyday life. This suggests that the discrepancy found in IP space plasticity between typical and atypical development may partially reflect the heterogeneity of cognitive underpinnings characterizing autism spectrum disorders.

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References

Aiello, J. R. (1987). Human spatial behavior. In D. Stokols, & I. Altman, (Eds.), *Handbook of Environmental Psychology*. New York: John Wiley and Sons.

American Psychiatric Association, (2013). *Diagnostic and Statistical Manual of Mental Disorders*. 10.1176/appi.books.9780890425596.744053

Asada, K., Tojo, Y., Osanai, H., Saito, A., Hasegawa, T., & Kumagaya, S. (2016). Reduced Personal Space in Individuals with Autism Spectrum Disorder. *PLoS ONE* 11(1): e0146306. https://doi.org/10.1371/journal.pone.0146306

Bar-Haim, Y., Aviezer, O., Berson, Y., & Sagi, A. (2002). Attachment in infancy and personal space regulation in early adolescence, *Attachment & Human Development*, 4:1, 68-83, DOI: 10.1080/14616730210123111

Baron-Cohen, S., Leslie, A., M., & Frith, U. (1985). Does the autistic child have a "theory of mind"? *Cognition*, 21, 37-46.

Berti, A., & Frassinetti, F. (2000). When far becomes near: remapping of space by tool use. *Journal of Cognitive Neuroscience*, 12(3), 415-420. http://dx.doi.org/10.1162/089892900562237

Brozzoli, C. Makin, T. R. Cardinali, L. Holmes, N. P. & Farnè, A. (2012). Peripersonal space: A multisensory interface for body–object interactions. In M. M. Murray, & M. T. Wallace (Eds.), *The neural bases of multisensory processes*. Boca Raton, FL: CRC Press.

Caçola, P., & Gabbard, C., 2012. Modulating peripersonal and extrapersonal reach space via tool use: a comparison between 6- to 12-year-olds and young adults. *Experimental Brain Research*, 218, 321–330. doi 10.1007/s00221-012-3017-8

Candini, M., Giuberti, V., Manattini, A., Grittani, S., di Pellegrino, G., & Frassinetti, F. (2017). Personal space regulation in childhood autism: Effects of social interaction and person's perspective. *Autism Research*, 10(1), 144-154. doi: 10.1002/aur.1637.

Candini, M., Giuberti, V., Santelli, E., di Pellegrino, G., & Frassinetti, F. (2019). When social and action space diverges: a study in children with typical development and autism. *Autism*, 7(23), 1687-1698. doi: 10.1177/1362361318822504

Cartaud, A., Ruggiero, G., Ott, L., Iachini, T., & Coello, Y. (2018). Physiological response to facial expressions in peripersonal space determines interpersonal distance in a social interaction context. *Frontiers in Psycholo*gy, 9, 657. doi: 10.3389/fpsyg.2018.00657

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.

Castelloe, P., & Dawson, G. (1993). Subclassification of children with autism and pervasive developmental disorder: a questionnaire based on Wing's subgrouping scheme. *Journal of Autism Developmental Disorders*, 23, 2, 229-41.

Cerliani, L., Mennes, M., Thomas, R.M., Di Martino, A., Thioux, M., Keysers, C. (2015). Increased functional connectivity between subcortical and cortical resting-State networks in autism spectrum disorder. *JAMA Psychiatry,* 72 (8), 767–777.

Constantino, J., & Gruber, J. (2005). *Social Responsiveness Scale (SRS) Manual*. Los Angeles: Western Psychological Services.

Corbett, B., A., Mendoza, S., Abdullah, M., Wegelin, J., A., Levine, S. (2006). Cortisol circadian rhythms and response to stress in children with autism. *Psychoneuroendocrinology* 31: 59-68. doi:10.1016/j.psyneuen. 2005.05.011.

Corbett, B., A., Schupp, C., W., Simon, D., & Mendoza, S., (2010). Elevated cortisol during play is associated with age and social engagement in children with autism. Molecular Autism, 1:13. doi: https://doi.org/10.1186/2040-2392-1-13

di Pellegrino, G., & Làdavas, E. (2015). Peripersonal space in the brain. *Neuropsychologia*, 66, 126-133. https://doi.org/10.1016/j.neuropsychologia.2014.11.011

Dosey, M.A., & Meisels, M. (1969). Personal space and self-protection. *Journal of personality and social psychology*, 11, 93–97.

Duke, M.P., & Kiebach, C. (1974). A brief note on the validity of the comfortable interpersonal distance scale. *Journal of Social. Psycholo*gy, 94 (2), 297–298.

Duke, M.P., & Nowicki, S. (1972). A new measure and social-learning model for interpersonal distance. *Journal of Experimental Research in Personality* 6, 119–132.

Felipe, N., J., & Sommer, R. (1966). Invasions of Personal Space. *Social Problems*, 14, 2, 1. https://doi.org/10.2307/798618

Freitag, G. (1970). An experimental study of the social responsiveness of children with autistic behaviors. *Journal of Experimental Child Psychology*, 9, 436–453.

Frith, U. (1996). Cognitive explanations of autism. Acta Paediatrica Suppl, 85, S416, 63-68.

Gessaroli, E., Santelli, E., di Pellegrino, G., & Frassinetti, F. (2013). Personal space regulation in childhood autism spectrum disorders. *PLOS ONE*, 8: e74959.

Gessaroli, E., Andreini, V., Pellegri, E., & Frassinetti, F. (2013). Self-face and self-body recognition in autism. Research in Autism Spectrum Disorders, 7(6), 793-800. https://doi.org/10.1016/j.rasd.2013.02.014

Glerean, E., Pan, R.K., Salmi, J., Kujala, R., Lahnakoski, J.M., Roine, U., & Jääskeläinen, I.P. (2016). Reorganization of functionally connected brain subnetworks in high-functioning autism. *Human Brain Mapping*, 37 (3), 1066–1079.

Hall, E. (1966). *Distances in man: The hidden dimension*. New York: Garden City, Double Day.

Harrison, L.A., Hurlemann R., & Adolphs, R. (2015). An Enhanced Default Approach Bias Following Amygdala Lesions in Humans. *Psychological Science*, 26, 10, 1543-55. doi: 10.1177/0956797615583804

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

Hayduk, L., A. (1978). Personal space: An evaluative and orienting overview. *Psychological Bulletin*, 85, 117-134.

Hayduk, L., A. (1983). Personal space: Where we now stand. *Psychological Bulletin*, 94, 293–335.

Hirstein, W., Iversen, P., & Ramachandran, V., S. (2001). Autonomic responses of autistic children to people and objects. *Proc Bioogical Science*, 268: 1883-88. doi: 10.1098/rspb.2001.1724.

Holt, D. J., Cassidy, B. S., Yue, X., Rauch, S. L., Boeke, E. A., Nasr, S., Tootell, R. B., Coombs, G. (2014). Neural correlates of personal space intrusion. *Journal of Neuroscience*, 34(12), 4123-34.

Hunley, S., B., Marker, A., M., & Lourenco, S., F. (2017). Individual Differences in the Flexibility of Peripersonal Space. *Experimental Psychology*, 64(1), 49-55. doi: 10.1027/1618-3169/a000350.

Iachini, T., Coello, Y., Frassinetti, F., & Ruggiero, G. (2014). Body space in social interactions: A comparison of reaching and comfort distance in Immersive Virtual Reality. *PLOS ONE*, 9(11), e111511. doi:10.1371/journal.pone.0111511

Iachini, T., Coello, Y., Frassinetti, F., Senese, V. P., Galante, F., & Ruggiero, G. (2016). Peripersonal and interpersonal space in virtual and real environments: effects of gender and age. *Journal of Environnemental Psychology*, 45, 154–164. doi: 10.1016/j.jenvp.2016.01.004

Iachini, T., Pagliaro, S., & Ruggiero, G. (2015). Near or far? It depends on my impression: moral information and spatial behavior in virtual interactions. *Acta Psychologica*, 161, 131-136. http://dx.doi.org/10.1016/j.actpsy.2015.09.003

Johnson-Frey, H. S. (2003). *Cortical mechanisms of human tool use. Taking action: cognitive neuroscience perspectives on the problem of intentional acts*, MIT Press.

Johnson-Frey, H., S. (2004). The neural bases of complex tool use in humans. *Trends in Cognitive Science*, 8(2), 71-78.

Juranek, J., Filipek, P. A., Berenji, G. R., Modahl, C., Osann, K., & Spence, M. A. (2006). Association between amygdala volume and anxiety level: magnetic resonance imaging (MRI) study in autistic children. *Journal of Child Neurology*, 21(12):1051-8. doi: 10.1177/7010.2006.00237

Kennedy, D. P., & Adolphs, R. (2014). Violations of personal space by individuals with autism spectrum disorder. *PLoS One* 6, 9, 8, e103369.

Kennedy, D. P., Gläscher, J., Tyszka, J. M., & Adolphs, R. (2009). Personal space regulation by the human amygdala. *Nature Neuroscience*, 12, 1226–1227.

Kleinhans, N., M., Johnson, L., C., Richards, T., Mahurin, R., Greenson, J. Dawson, G., Alward, E. (2009). Reduced neural habituation in the amygdala and social impairments in autism spectrum disorders. *Americal Journal of Psychiatry*, 166:467-475. doi:10.1176/appi.ajp.2008.07101681.

Kleinhans, N.M., Reiter, M.A., Neuhaus, E., Pauley, G., Martin, N., Dager, S., Estes, A. (2016). Subregional differences in intrinsic amygdala hyperconnectivity and hypoconnectivity in autism spectrum disorder. *Autism Research*, 9 (7), 760–772.

Libertus, K., & Violi, D. A. (2016). Sit to talk: relation between motor skills and language development in infancy. *Frontiers Psychology*, 7:475.

Liebowitz, M. R. (1987). *Social phobia*. Modern Problems of Pharmacopsychiatry, 22, 141–173.

Linkenauger, S., A., Lerner, M., D., Ramenzoni, V., C., & Proffitt, D., R. (2012). A perceptual-motor deficit predicts social and communicative impairments in individuals with autism spectrum disorders. *Autism Research*, 5(5), 352-62. doi: 10.1002/aur.1248

Lloyd, D., M., and Morrison, C., I. (2008). ‘Eavesdropping’ on social interactions biases threat perception in visuospatial pathways. *Neuropsychologia*, 46, 95-101.

Longo, M., R., & Lourenco, S., F. (2006). On the nature of near space: effects of tool use and the transition to far space. *Neuropsychologia*, 44(6), 977-81.

Lord, C., Risi, S., Lambrecht, L., Cook, E., H., Jr, Leventhal, B., L., Di Lavore, 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), 205-23.

Makin, R., Holmes, N., P., Brozzoli, C., Rossetti, Y., & Farnè, A. (2009). Coding of visual space during motor preparation: approaching objects rapidly modulate corti-cospinal excitability in hand-centered coordinates. *Journal of Neuroscience*, 29, 11841–11851.

Makin, T., R., Holmes, N., P., Brozzoli, C., & Farnè, A. (2012). *Experimental Brain Research*, 219, 421. https://doi.org/10.1007/s00221-012-3089-5

Maravita, A., & Iriki, A. (2004). Tools for the body (schema). *Trends in Cognitive Science*, 8, 79–86.

Mari, M., Castiello, U., Marks, D., Marraffa, C., Prior, M. (2003). The reach-to-grasp movement in children with autism spectrum disorder. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 358(1430), 393-403.

Martel, M., Cardinali, L., Roy, A., C., & Farnè, A. (2016). Tool use: an open window into body representation and its plasticity. *Cognitive Neuropsychology*, 33(1-2), 82-101. doi: 10.1080/02643294.2016.1167678

Moseley, R., L. & Pulvermuller, F. (2018). What can autism teach us about the role of sensorimotor systems in higher cognition? New clues from studies on language, action semantics, and abstract emotional concept processing. *Cortex*, 100, 149-190. doi: 10.1016/j.cortex.2017.11.019.

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

Occelli, V., Spence, C., & Zampini, M. (2011). Audiotactile interactions in front and rear space. *Neuroscience & Biobehavioral Reviews*, 35(3), 589-598. http://dx.doi.org/10.1016/j.neubiorev.2010.07.004

Parsons, S., Mitchell, P., & Leonard, A. (2004). The use and understanding of virtual environments by adolescents with autistic spectrum disorders. *Journal of Autism Developmental Disorders*, 34, 449–66.

Patanè, I., Farnè, A., & Frassinetti, F. (2017). Cooperative tool-use reveals peripersonal and interpersonal spaces are dissociable. *Cognition*, 166, 13-22. https://doi.org/10.1016/j.cognition.2017.04.013

Patanè, I., Iachini, T., Farnè, A., & Frassinetti, F. 2016. Disentangling action from social space: tool-use differently shapes the space around us. *PLOS ONE* 11(5): e0154247.

Pedersen, J., & Schelde, J., T. (1997). Behavioral aspects of infantile autism: an ethological description. *European Child & Adolescent Psychiatry*, 6, 2, 96-106.

Pedersen, J., Livoir-Petersen, M., F., & Schelde, J., T. (1989). An ethological approach to autism: an analysis of visual behaviour and interpersonal contact in a child versus adult interaction. *Acta Psychiatrica Scandinavica* 80, 4, 346-55.

Pellencin, E., Paladino, M., P., Herbelin, B., & Serino, A. (2018). Social perception of others shapes one's own multisensory peripersonal space. *Cortex*, 104, 163-179. doi: 10.1016/j.cortex.2017.08.033

Perry, A., Levy-Gigi, E., Richter-Levin, G., & Shamay-Tsoory, S., G. (2015). Interpersonal distance and social anxiety in autistic spectrum disorders: A behavioral and ERP study. *Social Neuroscience*, 10, 354-65.

Perry, A., Rubinstenb, O., Peled, L., & Shamay-Tsoory, S., G. (2013). Don't stand so close to me: A behavioral and ERP study of preferred interpersonal distance. *Neuroimage*, 83, 761-9.

Perry, A., Lwi, S. J., Verstaen, A., Dewar, C., Levenson, R. W., & Knight, R. T. (2016. The role of the orbitofrontal cortex in regulation of interpersonal space: evidence from frontal lesion and frontotemporal dementia patients. *Social Cognitive and Affective Neuroscience*, , 1894–1901

Quesque, F., Ruggiero, G., Mouta, S., Santos, J., Iachini, T., and Coello, Y. (2017). Keeping you at arm's length: modifying peripersonal space influences interpersonal distance. *Psychol. Res*. 81, 709–720. doi: 10.1007/s00426-016-0782-1

Remland, M., S., Jones, T., S., & Brinkman, H. (1995). Interpersonal distance, body orientation, and touch: effects of culture, gender, and age. *Journal of Social Psychology*, 135, 3, 281-97.

Reynaud, E., Lesourd, M., Navarro, J., & Osiurak, F. (2016). On the neurocognitive origins of human tool use: A critical review of neuroimaging data. *Neuroscience Biobehavioural Review*, 64, 421-37. doi: 10.1016/j.neubiorev.2016.03.009.

Rinck, M., Rörtgen, T., Lange, W., G., Dotsch, R. Wigboldus, D. H. J., Becker, E.S. (2010). Social anxiety predicts avoidance behaviour in virtual encounters. *Cognition and. Emotion*, 24 (7), 1269–1276

Rizzolatti, G., Fadiga, L., Fogassi, L., & Gallese, V. (1997). The space around us. *Science*, 277, 190–191.

Rizzolatti, G., Scandolara, C., Matelli, M., & Gentilucci, M. (1981). Afferent properties of periarcuate neurons in macaque monkeys. II. Visual responses. *Behavioural Brain Research,* 2(2), 147-163. http://dx.doi.org/10.1016/0166-4328(81)90053-x

Rochat, P. (1995). Early objectification of the self. In: P. Rochat, *The self in infancy.* Advances in psychology book series. Amsterdam: Elsevier.

Ruggiero, G., Frassinetti, F., Coello, Y., Rapuano, M., Di Cola, A. S., & Iachini, T. (2016). The effect of facial expressions on peripersonal and interpersonal spaces. *Psychol. Res*. 81, 1232–1240. doi: 10.1007/s00426-016-0806-x

Schulkin, J. (2006). Autism and the amygdala: An endocrine hypothesis. *Brain and Cognition*, 65: 87-99.

Senju, A. (2013). Atypical development of spontaneous social cognition in autism spectrum disorders. *Brain Development*, 35(2), 96-101. doi: 10.1016/j.braindev.2012.08.002.

Severy, L. J., Forsyth, D. R., & Wagner, P. J. (1979). A multimethod assessment of personal space development in female and male, Black and White children. *Journal of Nonverbal Behaviour*, 4(2), 68-86. http://dx.doi.org/10.1007/BF01006352

Schumann, C., M., Hamstra, J., Goodlin-Jones, B., L., Lotspeich, L., J., Kwon, H., Buonocore, M., H., Lammers, C., R., Reiss, A., L., & Amaral, D., G. (2004). The amygdala is enlarged in children but not adolescents with autism; the hippocampus is enlarged at all ages. *Journal of Neuroscience*, 24(28) 6392-6401; doi: 10.1523/JNEUROSCI.1297-04.200

Sommer, R. (1959). Studies in personal space. *Sociometry*, 22, 247-260

Spain, D., Sin, J., Linder, K., B., McMahon, J., & Happé, F. (2018). Social anxiety in autism spectrum disorder: A systematic review. *Research in Autism Spectrum Disorders*, 52, 51-68

Strube, M. J., & Werner, C. (1982). Interpersonal distance and personal space: A conceptual and methodological note. *Journal of Nonverbal Behaviour*, 6, 163-170.

Swartz, J., R., Wiggins, J., L., Carrasco, M., Lord, C., & Monk, C., S. (2011). Amygdala habituation and prefrontal functional connectivity in youth with autism spectrum disorders. *J Am Acad Child Adolesc Psychiatry* 52: 84-93.

Swartz, J.R, Wiggins, J.L., Carrasco, M., Lord, C., Monk, C., S. (2013). Amygdala habituation and prefrontal functional connectivity in youth with autism spectrum disorders. *Journal American Academic Child Adolescence Psychiatry* 52: 84-93.

Taffou, M., & Viaud-Delmon, I. (2014). Cynophobic fear adaptively extends peri-personal space. *Frontiers in Psychiatry*, 5, 122. doi: 10.3389/fpsyt.2014.00122

Volkmar, F. R., Cohen, D. J., Bregman, J. D., Hooks, M. Y., & Stevenson, J. M. (1989). An examination of social subtypologies in autism. *Journal of the American Academy of Child and Adolescent Psychology*, 28, 82-86.

Wieser, M. J., Pauli, P., Grosseibl, M., Molzow, I., & Mühlberger, A. (2010). Virtual social interactions in social anxiety—the impact of sex, gaze, and interpersonal distance. *Cyberpsychol. Behav. Soc. Netw*. 13 (5), 547–554.

Wing, L., & Attwood, A. (1987). *Syndromes of autism and atypical development*. In D. J. Cohen & A. Donnelan (Eds.), Handbook of autism. New York: Wiley.

Wing, L., & Gould, J. (1979). Severe impairments of social interaction and associated abnormalities in children: Epidemiology and classification. *Journal of Autism and Developmental Disorders*, 9, 11-29.

Witt, J. K., & Proffitt, D. R. (2008). Action-specific influences on distance perception: A role for motor simulation. *Journal of Experimental Psychology. Human Perception and Performance*, 34, 1479–1492.

Witt, J. K., Proffitt, D. R., & Epstein,W. (2005). Tool use affects perceived distance, but only when you intend to use it. *Journal of Experimental Psychology. Human Perception and Performance*, 31, 880–888.