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1 **The plasticity of the interpersonal space in Autism Spectrum Disorder**

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1 **Abstract**

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

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

19

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

21

1 **1. Introduction**

2 Earliest infant-environment interactions, either between child and other individuals, or between
3 child and objects, mainly occur in the space immediately around one’s own body. Interactions with
4 other individuals are extremely relevant for the subsequent development of communicative and social
5 abilities, because enhance the infant’s possibilities to experience reciprocal social exchanges
6 (Libertus and Violi, 2016). A fundamental social ability which permeates our everyday interactions
7 is the physical distance regulation. Typically, the distance that we choose to maintain between
8 ourselves and others is a behavioral indicator of how close we prefer to stand relative to another
9 person. Thus, interpersonal distance is critical in determining a successful social interaction and
10 reducing the feelings of discomfort due to interpersonal space violations (Kennedy and Adolphs,
11 2014).

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

23 **2. A deficit in interpersonal space regulation in Autism**

24 During social interactions, the interpersonal distance we maintain between ourselves and others
25 indicates how close we prefer to stand relative to an unknown individual. Social psychologists were
26 the first to coin the term interpersonal space referring to the emotionally tinged area around one’s

1 own body, and in which another's intrusion may cause a prompt feeling of discomfort and anxiety
2 (Hall, 1966; Hayduk, 1978; Sommer, 1959). When the IP space is violated, individuals may move
3 away in order to reduce the perceived distress and to reinstate the margin of safety.

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

1 experimenter looked toward the participants' eyes, and in the other half of the trials, the experimenter
2 looked down. They found a smaller interpersonal space in ASD participants compared to controls,
3 but no difference emerged between the two groups when the eye contact condition was considered.
4 Indeed, when the confederate approached the participant looking toward the participants' eyes, both
5 ASD and controls preferred larger interpersonal distance, compared to when there was no eye contact.
6 This evidence suggests that ASD individuals can, at least partially, understand and use social cues,
7 such as other people's gaze, during a social interaction in order to choose the preferred interpersonal
8 distance.

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

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

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

5 One possible explanation of these contrasting findings could be due to differences in term of age and
6 clinical characteristics of the sample. Accordingly, an enlargement of IP space was found in children
7 (Candini et al., 2017; Gessaroli et al., 2013) whereas a reduction of IP space emerged in adolescents
8 and adults (Asada et al., 2016; Kennedy and Adolphs, 2014; Parsons et al., 2004). Following the
9 clinical classification proposed by Lorna Wing and colleagues (Wing & Attwood, 1987; Wing &
10 Gould, 1979), based on the quality of social interaction three different subgroups of individuals with
11 autism can be identified: i) the *aloof subgroup*, characterized by the tendency to reject unsolicited
12 social or physical contact; ii) the *passive subgroup*, characterized by a lack of spontaneous social
13 approaches to others and by the tendency to engage another person when approached, as long as the
14 other person structures the interaction; and, finally, iii) the *active-but-odd subgroup*, characterized by
15 a willingness to make social approaches to others. In a previous work by Volkmar and colleagues
16 (1989), the aloof children were described as significantly younger than passive or active-but-odd
17 children. Thus it is possible that, in the above mentioned studies, children belong to the aloof
18 subgroup and consequently they chose a larger interpersonal space from others people, whereas
19 adolescents and adults may belong to the passive or active-but-odd subgroups and, therefore,
20 preferred a shorter IP space. However, to verify this hypothesis, an essential first step is an
21 investigation of the developmental time course of the space around the body, as well as how the
22 clinical symptoms characterizing the Wing's classification change according to age. Future studies
23 should address these interesting aspects, which are not fully understood in the literature.

24 An alternative explanation of these patterns of results is in term of cultural differences, since some
25 studies were conducted in the USA (Kennedy and Adolphs, 2014; Parsons et al., 2004;), while other
26 studies were conducted in Europe (Candini et al., 2017; Gessaroli et al., 2013), and in Japan (Asada

1 et al., 2016). It is well known that cultural factors may deeply affect social behaviour (Hayduk, 1978),
2 and so it is possible that for some cultures being closer to others is normal, while choosing a larger
3 IP distance is deemed inappropriate.

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

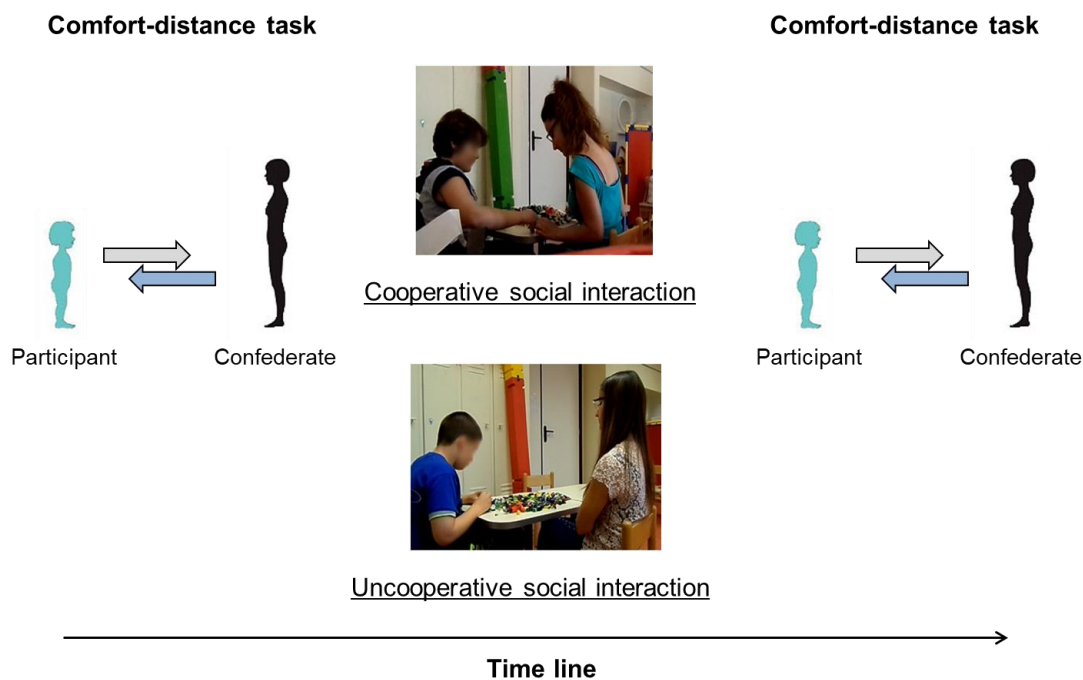
12

13 **3. A deficit in interpersonal space plasticity in Autism**

14 A peculiar feature of interpersonal space concerns its dynamicity: it changes as a function of different
15 social factors, such as age, gender, attachment style, the degree of intimacy and familiarity between
16 individuals, but also the perceived morality of another person (Aiello et al., 1987; Bar-Haim et al.,
17 2002; Dosey & Meisels, 1969; Felipe & Sommer, 1966; Iachini et al., 2015; 2016; Pellencin et al.,
18 2018; Remland et al., 1995). Focusing on maternal attachment style, Bar-Haim and colleagues (2002)
19 demonstrated how these internal representations, mainly developed during infancy, are crucial to
20 explain the variability emerged in interpersonal space regulation in kibbutz children. Interestingly,
21 they found that children with an insecure attachment exhibited a larger interpersonal space, whereas
22 children with an ambivalent attachment allowed more intrusion into their interpersonal space as
23 compared with those characterized by a secure attachment.

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

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



13
 14 **Figure 2** Representation of the Comfort-distance task adopted in Candini et al.'s study (2017). The
 15 Comfort-distance task was performed twice, before and after a Cooperative or Uncooperative social
 16 interaction. In the Cooperative interaction the confederate played with the participant assembling and building
 17 the bricks, encouraged him, provided occasional helpful suggestions, and assumed a smiling face expression

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

6
7 Finally, a functional link was provided between IP space plasticity and the severity of social deficit
8 in everyday life in ASD children (Candini et al., 2017). To measure the children's social impairment
9 severity in everyday activities, it has been adopted the Wing Subgroups Questionnaire (Castelloe et
10 al., 1993). Specifically, the rating on one item ("*When the child is with unfamiliar adults or children,*
11 *he readily approaches others to interact. His manner of interacting is generally appropriate, not*
12 *awkward or unusual*") was extract and considered as indicator of appropriate IP space regulation.
13 Based on the frequency of inappropriate social responses on this item, we found that the greater was
14 the social impairment severity in social daily interactions, the higher was the impairment observed in
15 interpersonal space plasticity.

16

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

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

25 Recently, to directly compare the functional proprieties of the IP and PP spaces, some studies (Iachini
26 et al., 2014; 2015; Patanè et al., 2016; 2017 Ruggiero et al., 2016) adopted the *Reaching-distance*

1 *task*, as a proxy to estimate the PP space extent, and the *Comfort-distance task*, that is a modified
2 version of the stop-distance paradigm, to measure IP space. In the *Reaching-distance task*,
3 participants have to stop when they think they can reach the other person by extending their limb. In
4 the *Comfort-distance task*, participants have to stop at the point where they still feel comfortable with
5 other's proximity (Candini et al., 2017; 2019; Pellencin et al., 2018).

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

13 In literature, the most prominent modulations of peripersonal space has been described as mainly
14 driven by action-related factors. However, there is also evidence demonstrating that peripersonal
15 space extent is influenced by high-order social factors. In this respect, Teneggi and colleagues (2013)
16 provided the first description that the nature of the interaction with another person affects the PP
17 space dimension. The authors measured the participants' PP space boundary adopting an audio-tactile
18 paradigm, both before and after a fair or unfair social interaction. They found that PP space boundary
19 changed according to the relationship with the other person: an extension of the participants' PP space
20 towards the body of the fair (but not of the unfair) other was found. Furthermore, to explore the
21 existence of possible common mechanisms between peripersonal and interpersonal space, Ruggiero
22 and colleagues (2016) investigated whether these spaces are similarly sensitive to the emotional
23 valence of facial expression in a virtual reality environment. In this study, participants performed the
24 reaching- and the comfort-distance tasks while being approached or walking toward a virtual
25 confederate who exhibited happy, angry or neutral facial expressions. An enlargement of peripersonal
26 space when participants were approached by an angry confederate was found. In the same vein,

1 Iachini and colleagues (2015) examined whether a moral or immoral confederate can influence the
2 reaching- and comfort-distance preferred by participants. They observed that preferred distance
3 chosen by participants actually expanded (shortened) with a confederate described as an immoral
4 (moral) person. The same pattern of results was reported in both spaces, although it was particularly
5 strong in the interpersonal space. In sum, this evidence converged to the idea that the plasticity of the
6 space around the body (both the space in which we interact with other as well as the space for act
7 with objects) allows individuals to dynamically and flexibly react to potentially relevant stimuli,
8 placed close the participant's body.

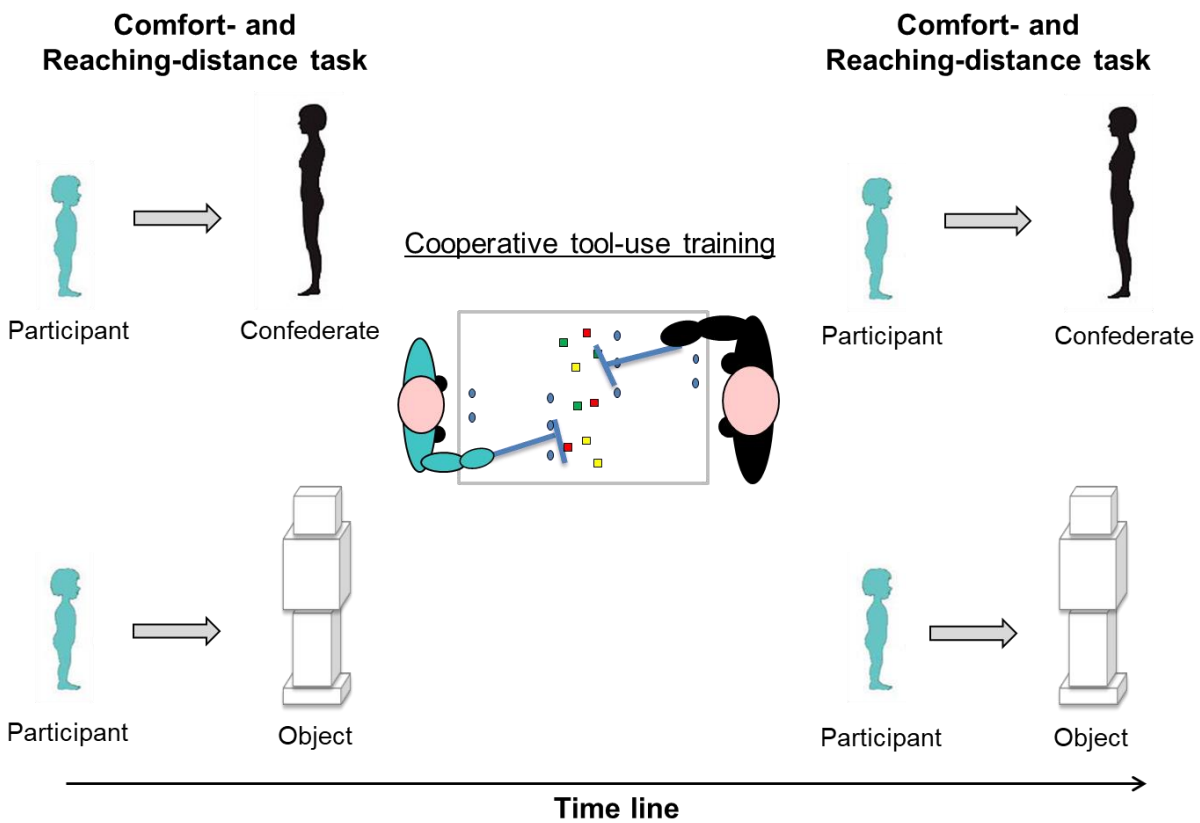
9 It is worth to note that the social modulations of PP space previously described in literature (Iachini
10 et al., 2015; Ruggiero et al., 2016) emerge especially when the participant's response has a protective
11 valence, thus emphasizing the defensive nature of the action space. According to the interpretation
12 proposed by de Vignemont and Iannetti, (2015), and further discussed by Bufacchi and Iannetti
13 (2018), the space close to the body is a dynamic interface to safely interact with the physical and
14 social environment.

15 More recently, several empirical findings have been provided to clarify the functional relationship
16 between action and social space (Cartaud et al., 2018; Iachini et al., 2014; 2015; Patanè et al., 2016;
17 2017; Pellencin et al., 2018). For instance, Patanè and colleagues (2016) directly compared the PP
18 and IP space plasticity measured toward a confederate, by using the reaching- and the comfort-
19 distance, before and after a cooperative tool-use training. In this training, participant and confederate
20 jointly cooperate to reach objects located beyond the arm reaching distance, by using a long tool.
21 Intriguingly, the training evokes opposite effects on PP and IP spaces: the former extends, whereas
22 the latter reduces as compared to before cooperative tool-use training (Patanè et al., 2017). These
23 findings are in accord with the dynamical properties of the space surrounding the body already
24 described (Berti and Frassinetti, 2000; Candini et al., 2017; Gessaroli et al., 2013; Longo and
25 Lourenco, 2006), but also demonstrated that dissociable plastic mechanisms underlying the action

1 and social spaces. Accordingly, PP space is sensitive to tool-use, whereas IP space is sensitive to
2 social cooperation with another person.

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

8



9

10 **Figure 3** Schematic representation of the experimental procedure adopted in Candini et al.'s study
11 (2019). Participants have to stop at the point *where they still feel comfortable with stimuli's proximity*
12 (Comfort-distance Task) and *when they think they can reach the stimuli by extending their limb*
13 (Reaching-distance Task). Both tasks were performed in two experimental conditions: facing either a
14 female unfamiliar adult (confederate) or an inanimate object, before and after a cooperative tool-use

1 training session in which the participant (green) and the confederate (black) jointly cooperate to reach
2 colored chips placed in the unreachable space by using a rake.
3
4 Authors found that both TD and ASD children preferred larger Comfort- than Reaching-distance.
5 This result could be easily accounted for by the fact that participants were children facing an
6 unfamiliar adult, a situation in which they may have felt distress (Dean et al., 1976; Severy et al.,
7 1979). Supporting this interpretation, the Comfort-distance was modulated by the type of stimulus
8 approached: greater IP space was found when participants moved toward the person compared to the
9 object. A possible explanation is that the inanimate object was perceived as potentially more safe or
10 predictable compared to an unfamiliar adult, thus allowing children to tolerate a closer distance when
11 facing the object than the person. Indeed, when one's own IP space is invaded by an unfamiliar
12 person, a feeling of anxiety can increase resulting in the need to keep other people farther away (Perry
13 et al., 2013; 2015; Strube and Werner, 1984). By contrast, when participants estimated the Reaching-
14 distance toward the person or the object no differences emerged, thereby suggesting that
15 interpersonal, but not peripersonal, space is modulated by the social valence of stimuli. Moreover, a
16 positive correlation between preferred reaching distance and participants' arm length demonstrates
17 that 8 to 13 years old children considered their arm length to evaluate stimulus reachability. This
18 evidence confirms previous developmental studies which suggests that PP space representation is
19 deeply rooted in the action potentialities of their own body (Caçola and Gabbard, 2012; Rochat, 1995)
20 (for similar results in adult population, see Witt et al., 2005; Witt and Proffitt, 2008).

21 Nevertheless, a critical difference between TD and ASD children emerged when the plastic properties
22 of PP and IP space are considered. Indeed, in TD children, following the cooperative tool use training,
23 PP space extended, both toward the confederate and the object, whereas IP space reduced toward the
24 confederate, but not the object, as compared to before the training. Conversely, in ASD group, both
25 PP and IP spaces extended, regardless of whether they approached the object or confederate. When
26 the effects of cooperative tool-use training were compared in TD and ASD children, similar results

1 emerged in the Reaching- but not in the Comfort-distance task: peripersonal space extended in both
2 groups, whereas interpersonal space reduced in TD but not in ASD children. Thus, in ASD population
3 the tool use is effective in shaping the PP space, whereas the social interaction, during which the tool
4 is used with the confederate, does not contract IP space.

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

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

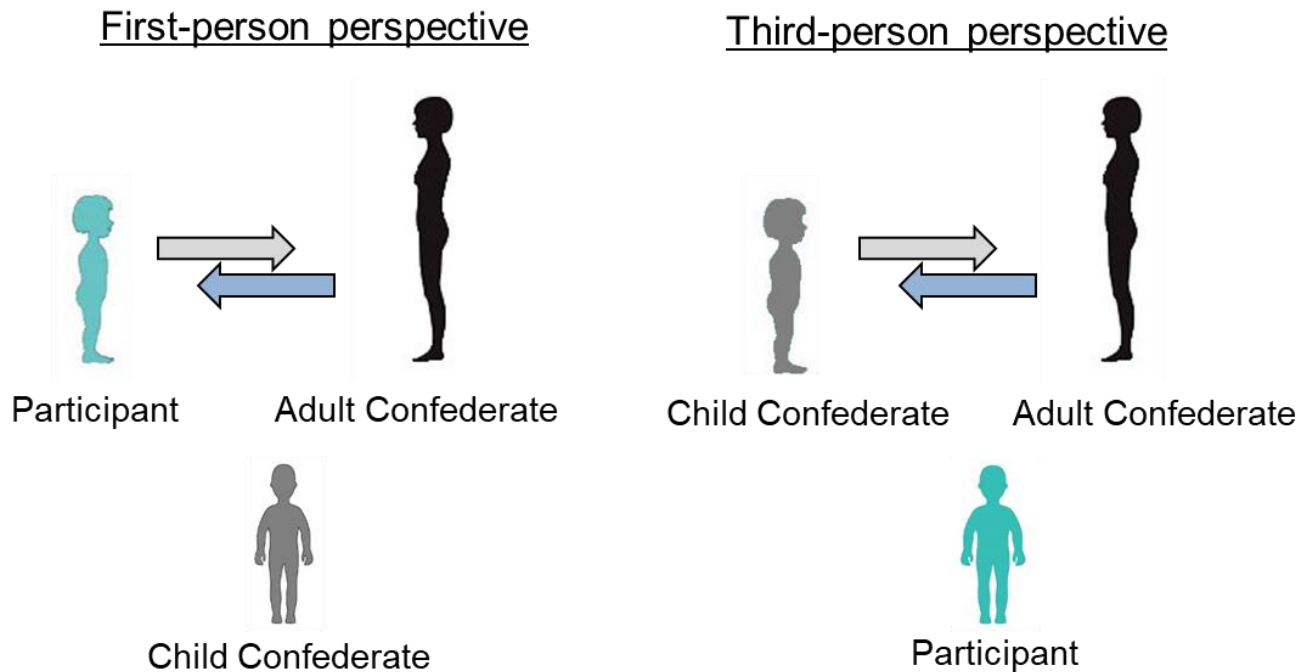
1 More recently, Mul and colleagues' study adopted an audiotactile reaction time task to assess the
2 multisensory component of peripersonal space in ASD adults. They found that multisensory
3 integration of auditory and tactile stimuli in ASD individuals occurs later as compared to controls.
4 A possible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

8 **5. An impairment in estimating others' interpersonal space preference**

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

1 first- and in third-person perspective. Taken together, these results suggest that the ability to
2 dynamically adapt and regulate interpersonal space between themselves and others is not sufficient
3 to appropriately estimate interpersonal space between others.

Comfort-distance task



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

10
11 One fascinating point which should be addressed by future studies concerns the relationship between
12 the ability to discriminate between self and other and the ability to regulate the distance between
13 confederate's and participant's body. Since several evidence suggest that integration of body-related
14 multisensory signals within the space around the body participate in the differentiation between self
15 and others, it seems relevant to investigate the link between high-order social cognitive processes and
16 bodily self-representation.

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

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

19

20 **6. Social anxiety and interpersonal space in Autism**

21 The presence of abnormal interpersonal space in ASD children may reflect overarousal and enhanced
22 fear induced by the presence of other individuals intruding their social space. Supporting this
23 hypothesis, Corbett and colleagues (2010) adopted an ecological paradigm designed to emulate a
24 "real life" playground in order to determine whether such environment would be deemed
25 physiologically stressful in a group of children with and without ASD. They found that, during peer-
26 to-peer social interactions, children with autism have significant higher levels of cortisol than typical

1 developmental children. Thus, it is reasonable to hypothesize that ASD children, due to enhanced
2 fear and hyperarousal following other people approaching and the potential violation of interpersonal
3 space, regulate IP space differently, resulting in an inappropriate distance from other individuals.
4 Coherently to this scenario, several studies suggested that a potential candidate to account for high
5 level of anxiety and abnormal fears in ASD children is an excessively functioning amygdala. Indeed,
6 the amygdala it has been proposed as a key structure implicated in the neuropathology of autism
7 (Juranek et al., 2006; Schumann et al., 2004), and its dysfunction could contribute to impaired social
8 interactions and avoidant behaviours in these individuals (Corbett et al., 2006; 2010; Hirstein et al.,
9 2001; Schulkin et al., 2006; Swartz et al., 2011).

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

23 In a recent systematic review, Spain and colleagues (2018) reported that social anxiety commonly co-
24 occurs with autism spectrum disorders and it is associated with poorer social skills, competence and
25 social motivation. Therefore, a possible explanation is that, during social engagement, individuals
26 with high social anxiety levels may feel earlier distress due to poor elaboration of social cues, which

1 would lead them to stand farther away and perpetuate a cycle of less communicative and appropriate
2 social interactions.

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

12

13 **7. Functional anatomy of interpersonal space in Autism**

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

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

23 Moving to neuropsychological studies, atypical approach-avoidance behaviours are reported in
24 patients with lesion of amygdala (Harrison et al., 2015; Kennedy et al., 2009). For instance, Kennedy
25 and colleagues (2009) reported a single case study in which a patient affected by a bilateral amygdala
26 damage showed a significant reduction of IP space, both in first and in third-person perspective,

1 compared to controls. These findings reveal that a bilateral damage to the amygdala results in an
2 abnormally small interpersonal space, thereby suggesting a key role for this subcortical structure in
3 the neural substrate of social space regulation.

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

13 Linking this anatomical evidence to the reduced tolerance of physical closeness with a stranger and
14 the lack of flexibility of interpersonal space emerged in ASD children, it is reasonable to hypothesize
15 that a cortico-subcortical network, involving amygdala and OFC is responsible to mediate the ability
16 to evaluate the relevance of social stimuli in order to choose the appropriate interpersonal distance.
17 This hypothesis is further supported by recent neuroimaging studies indicating that an excessively
18 functioning amygdala may account for the increased anxiety and fear found in population with autism,
19 thereby leading to withdrawal from reciprocal social interaction (Kleinmans et al., 2009; Swartz et al.,
20 2013). Additionally, atypical connectivity between frontal and limbic networks in ASD individuals
21 have also been reported (Cerliani et al., 2015; Glerean et al., 2016; Kleinmans et al., 2016).
22 Collectively, these findings advance our knowledge concerning the neural correlates underlying the
23 space close to the body and provide a starting point for future studies examining the extent to which
24 these representations are flexible both in typical and atypical developmental age.

25

26 **Concluding remarks**

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

7

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9

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