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Published Version:
Empathy as a predictor of peripersonal space: Evidence from the crossmodal congruency task / Elena Gherri, Marios Theocharopoulos, Niall Browne, Nazire Duran & Elizabeth J. Austin. - In: CONSCIOUSNESS AND COGNITION. - ISSN 1053-8100. - ELETTRONICO. - 98:(2022), pp. 103267.1-103267.11. [10.1016/j.concog.2021.103267]

Availability:
This version is available at: https://hdl.handle.net/11585/845316 since: 2022-02-22

Published:
DOI: http://doi.org/10.1016/j.concog.2021.103267

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Consciousness and Cognition, Volume 98, 2022, 103267

The final published version is available online at:

https://doi.org/10.1016/j.concog.2021.103267.

Empathy as a Predictor of Peripersonal Space: Evidence from the Crossmodal Congruency Task

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Abstract

To investigate whether individual differences in Empathy predict the characteristics of Peripersonal Space (PPS) representations, we asked participants to complete the IRI questionnaire and a visuo-tactile crossmodal congruency task (CCT) as an index of PPS. In the CCT, they responded to the elevation of a tactile target while ignoring a visual distractor presented at the same (i.e. congruent) or different (i.e. incongruent) elevation. The target-distractor distance was also manipulated in depth, with visual distractors randomly presented at near, middle or far locations (0 cm, 25 cm or 50 cm). The near and middle crossmodal congruency effects (CCE) were inversely related to participants' scores on the Empathic Concern sub-scale (EC). Furthermore, the slope of participants' CCE across locations was related to EC scores, with flatter slopes for higher EC individuals. Thus, higher EC individuals showed reduced visuo-tactile integration responses within PPS and a reduced differentiation between PPS and extra-personal space (EPS).

Keywords

Peripersonal space, Empathic concern, Crossmodal congruency task, Visuo-tactile integration

1. Introduction

The brain constructs multiple representations of space within which everyday interactions with the external environment occur. Converging neurophysiological and neuroimaging evidence have shown that distinct fronto-parietal circuits are responsible for encoding different sectors of space delimited by their relative proximities to the body (e.g., Graziano & Cooke, 2006; Serino, 2019).

The space immediately surrounding the body (peripersonal space, PPS) plays a crucial role in the execution of actions towards reachable objects (Rizzolatti, Fadiga, Fogassi & Gallese, 1997) and also when it is necessary to react to potential threats approaching the body (Graziano & Cooke, 2006; Cléry et al., 2015). Specific populations of visuo-tactile neurons identified in monkeys' brain are thought to contribute directly to the coding of this multisensory action space (PPS) because they respond selectively to tactile stimuli delivered directly to the body and to visual stimuli presented within reach (within PPS), but not to visual stimuli presented beyond the animal's reach (in extrapersonal space, EPS) (e.g. Graziano & Cooke 2006; Rizzolatti et al., 1981). Distance-dependent modulations of the multisensory integration processes measured within and beyond PPS have also been documented in human behavioural studies (for example, see Macaluso & Maravita, 2010; Maravita et al., 2003, for reviews). One task commonly used to investigate the spatial properties of multisensory PPS is the visuo-tactile cross-modal congruency task (CCT) (e.g. Holmes, 2012; Pavani et al., 2000; Spence et al., 2004) in which participants were asked to respond to the elevation of a vibrotactile target delivered to the index or thumb of either hand, while ignoring a simultaneous visual distractor. Responses were slower and less accurate when the visual distractor and tactile target were presented at incongruent compared to congruent elevations. Importantly, the crossmodal congruency effect (CCE) computed as the reaction time difference between incongruent and congruent trials decreased as the distance between the target and distractor increased (e.g. Holmes, 2012; strong CCE at near locations, weak CCE at middle locations -28 cm from the hand - and no CCE at far locations - 56 cm;), providing behavioural evidence for differences in visuo-tactile integration within and beyond PPS[1].

One fascinating aspect of PPS representations is that they are highly flexible and change in response to specific experiences or contexts (cf. di Pellegrino & Làdavas, 2015). For example, after the use of a long tool that allows one to reach objects located in extra personal space, the spatial representation of PPS is extended or remapped as suggested by increased multisensory interactions in far space (e.g. Berti & Frassinetti, 2000; Forsberg et al., 2019; Serino et al., 2007).

Recent evidence has suggested that PPS is not only crucial for motor responses to objects located within reach but might also mediate possible interactions with other individuals (e.g. Heed et al., 2010; Teneggi et al., 2013; for a review see Coello & Cartaud, 2021). When participants perform the classic CCT with a confederate sitting within their PPS, a reduction of the CCE is observed. Such reduction is not present when the confederate sits beyond the participant's PPS, or when she/he is not actively engaged with the participants' task (Heed et al., 2010). This demonstrates that social context modulates the representation of PPS, providing direct evidence for socially induced PPS plasticity (see also Coello et al., 2018). The hypothesis that other individuals' presence and actions modulate PPS representations is further supported by a study demonstrating that a cooperative social interaction between the participant and a confederate can extend the participant's PPS to encompass the cooperative partner (Teneggi et al., 2013). When the social context between a participant and a

[1] It is worth noting that analogous PPS properties in humans have been reported more recently when the features of PPS were assessed through an audio-tactile interaction task (e.g. Canzoneri, Magosso & Serino, 2012; Serino et al., 2015).

confederate was modulated by means of shared sensory experiences rather than cooperative interactions, researchers observed an increase in multisensory integration in the space close to the confederate's body, suggesting that the space around the confederate was remapped into the participant's PPS representation (Maister et al., 2015).

Given this link between PPS plasticity and social context, it is relevant to understand whether the characteristics of PPS are systematically affected by differences in personality. Many different personality traits might in principle contribute to individual differences of PPS representations such as, for example, anxiety (Sambo & Iannetti, 2013) and schizotypy (Di Cosmo et al., 2018). Empathy, the ability to understand and share others' emotions, mental states and beliefs, is known to play a role in a number of different processes that are necessary for social interactions (Bernhardt & Singer, 2012; Singer & Klimecki, 2014) and so represents a candidate trait for examining the associations of personality with PPS representations.

Initial evidence indicates the presence of a positive relationship between empathy and cooperation in cooperative interaction scenarios, showing that the higher the empathy of an individual, the more the participant will share their peripersonal space during a cooperative scenario to help each other, by incorporating others into their PPS, (Boukricha et al., 2011). Thus, individuals with higher and lower empathic abilities might not only behave differently during social interactions with other individuals, but also represent the space in which these social interactions occur differently. Furthermore, pain empathy responses induced by pictures of others' body parts in painful situations were exclusively elicited when the pictures were presented within PPS, but not in extrapersonal space (Mahayana et al., 2014). Taken together these studies suggest a link between Empathy and spatial PPS representation. However, no study to date has directly assessed whether there is a relationship between empathy and the multisensory representation of PPS.

In the present study we investigated this relationship by measuring participants' empathy levels measured through the Interpersonal Reactivity Index (IRI), a 28-item empathy scale (Davis, 1980), and the spatial properties of their multisensory PPS representations measured by a modified version of the classic visuo-tactile CCT (e.g. Holmes, 2012; Pavani, Spence & Driver, 2000; Spence et al., 2004). In the CCT, participants were instructed to respond to one tactile target presented to a top or bottom location on one hand while a task-irrelevant visual distractor was presented at a congruent or incongruent elevation at one of three different distances from the tactile target (i.e. next to the hand in near space, 25cm from the hand in middle space, 50cm from the hand in far space, see Figure 1). Results obtained in this CCT were used to compute the crossmodal congruency effect (CCE), a cognitive measure of PPS indicating the strength of visuo-tactile multisensory integration. Individual CCEs were calculated for each participant as the RT difference between congruent and incongruent trials, separately for the three different visuo-tactile distances (near, middle and far locations). We tested the unique relationships between the participants' CCEs and their scores on the IRI empathy scale (Davis, 1980), while controlling for the effects of Age and Sex.

2.1. Method

2.1.1 Participants

Power Analysis. Three different data analyses are reported in this manuscript. The first analysis was necessary to determine the reliability of our PPS measure. Studies using the classic CCT have already shown a decreasing pattern of CCEs as the distance between the tactile target and the visual distractor increases (e.g. Holmes et al., 2007; Holmes, 2012). Thus, we first run a repeated measure ANOVA across all participants to determine whether the results of our CCT replicated the pattern of results already reported in the PPS literature (e.g. Holmes, Calvert & Spence, 2007;

Holmes, 2012). Because results of our CCT task replicated previous ones, we deemed the task appropriate to measure PPS and proceeded to use individual CCEs in the second and main analysis. It is worth noting that Holmes (2012) reported that the spatial modulation of the CCE is characterized by a large effect size (d = 0.82). Accordingly, less than 20 participants were sufficient to replicate the existing literature.

Crucially, however, our sample size was chosen according to power considerations relative to the second data analysis reported in this manuscript in which we tested the relationship between the empathy scores and the individual CCEs, obtained from the CCT data, through a correlational and path analysis. This was the main analysis of interest aimed at addressing the research question investigated in the present study. Although no study to date has directly assessed the relationship between multisensory PPS and empathy, previous meta-analytic studies in the field of individual differences have suggested that the associations of personality with criterion variables seldom exceed the .3 effect size (e.g. Gignac & Szodorai, 2016; Mischel, 1968; Schäfer & Schwartz, 2019). In order to achieve a power of .8 with an effect size of .3, the sample has to include at least 82 participants. We increased the estimated sample size to 100 participants, given the uncertainties about the effect size of the correlation of interest.

The final data analysis reported in the manuscript is an exploratory analysis suggested by one reviewer which allowed us to combine the information relative to the PPS measured at three different locations into one single index. For this reason, this analysis did not inform our sample size selection when we collected the data.

Participants. One hundred and ten participants, from the University of Edinburgh, took part in the study. They were asked to complete both the CCT and the IRI empathy questionnaires. Due to missing data in their IRI questionnaire, ten participants were excluded from further analysis, thus one hundred participants remained in the sample (68 females, aged M = 23.8, SD =3.76, and 32 males, aged M = 25.31, SD = 5.17). Participants gave informed consent and received a small monetary compensation (£10) for their participation. The experimental protocol was approved by the Psychology Research Ethics Committee of the University of Edinburgh.

2.1.2. Measures

Crossmodal Congruency Task.

Participants completed the CCT before they filled the IRI questionnaire. During the CCT, they sat at a table in a dimly illuminated room with head movements restricted thanks to the use of an adjustable chinrest. A white pin (2 mm diameter) was used as a fixation point and glued to a black cardboard panel (70 x 90 cm) which covered the entire table, approximately. Three identical black foam cube blocks (measuring 70 x 35 x 35 mm) were placed on the black cardboard panel on the table: the first was held by the participant (near position), the second was positioned at a distance of 25 cm (middle location) and the third was 50cm (far location) measured from the hand holding the near cube (see Figure 1). That is, the distance of the visual distractor from the hand was manipulated in depth. On different blocks of trials, the tactile targets were delivered either to the participants' left or right hand. Participants were instructed to hold the near foam cube block with the thumb and the index finger of the hand receiving the tactile stimulation (their arm was slightly bent and their elbow rested on the table during the task), and to rest the arm of the other non-stimulated hand on the ipsilateral leg under the table. The white fixation point was centrally aligned with the participants' body midline and positioned at the same distance from the hand as the middle cube 25 cm (see Figure 1). The three cubes were positioned 20 cm to the right (for the right-hand blocks) or 20 cm to the left (for the left-hand blocks) of the central fixation point.

The tactile target was presented through two electromagnetic tappers (diameter = 9 mm) Miniature Solenoid Tappers MST3 and Miniature Solenoid Tapper Controller MSTC3-4® hardware.

The tappers were attached to the side of the top phalanx of the index and thumb and delivered suprathreshold 12Ω electromagnetic vibrations when activated, delivering a distinctly noticeable vibrotactile sensation. The irrelevant visual distractors were presented through LED lights (diameter = 5 mm) and delivered through Heijo Basic Visual Controller291VISB® Hardware. Two green LEDs were fitted on the top and bottom side of each foam cube. After participants sat at the table and placed their left or right forearm on it, they were asked to hold the nearest foam block with the thumb and index fingers (placed on the bottom and top side of the cuboid), making sure that each of the two vibrotactile stimulators was vertically aligned with the LED lights on the first foam block.

In accordance with other studies using a similar task, (e.g. Spence et al., 2004), two foot switches connected to a Serial Response Box 200A® were used to collect responses. One switch was positioned under the toes of one foot while the other switch was positioned under the heel of the opposite foot and were used to indicate the top (index finger) and bottom (thumb) target elevation respectively.

White noise created with Audacity 2.0.3® software and was delivered via loudspeakers throughout each experimental block, to mask any sound made by the operation of the vibrators or the foot pedals. The timing of the stimuli and responses was controlled and recorded by a computer, using a custom programme created with the E-Prime 2.0® software. Responses were collected via Serial Response Box 200A® hardware.

Vibro-tactile stimuli (250 ms overall stimulus duration) consisted of three simultaneous pulses (each 50 ms long) of one tapper and one LED light, separated by two (50 ms long) gaps during which all devices were switched off, as shown in Figure 1, bottom panel (similarly to Pavani et al., 2000; Spence et al., 2004). Each trial started with the presentation of the visuo-tactile stimuli and was followed by a 2000 ms interval used to collect responses.

Participants completed eight blocks of 72 trials, four consecutive blocks for each tactually stimulated hand. Within each block, congruent and incongruent target-distractor trials were equiprobable (36 trials each) and visual distractors were equally likely to be presented at near, middle or far distances (12 trials for each distractor distance on congruent and incongruent trials). Trials were randomly selected without replacement.

Half of the participants started the task with the left hand, while the other half with the right hand. The position of the foot switches (left heel, right toes and vice-versa) was counterbalanced across participants. The purpose of testing both participants' left and right hand was twofold. First, this allowed us to include in our sample all participants regardless of handedness (both dominant and non-dominant hands were tested). Second, because the position of the foot switches was counterbalanced across participants, testing both hands allowed us to fully eliminate horizontal spatial compatibility effects arising from stimulated hand- responding foot correspondence.

Participants were instructed to keep their gaze on the central fixation point throughout the task while holding the near foam cube with the stimulated hand. They had to respond as quickly and as accurately as possible to the elevation of the tactile target, while ignoring the visual distractor. Researchers monitored participants' gaze direction and posture during each experimental block through an infra-red camera. Whenever necessary, the researcher reminded participants to comply with instructions (e.g. keeping their eyes on the fixation point, etc.) at the end of the block.

I

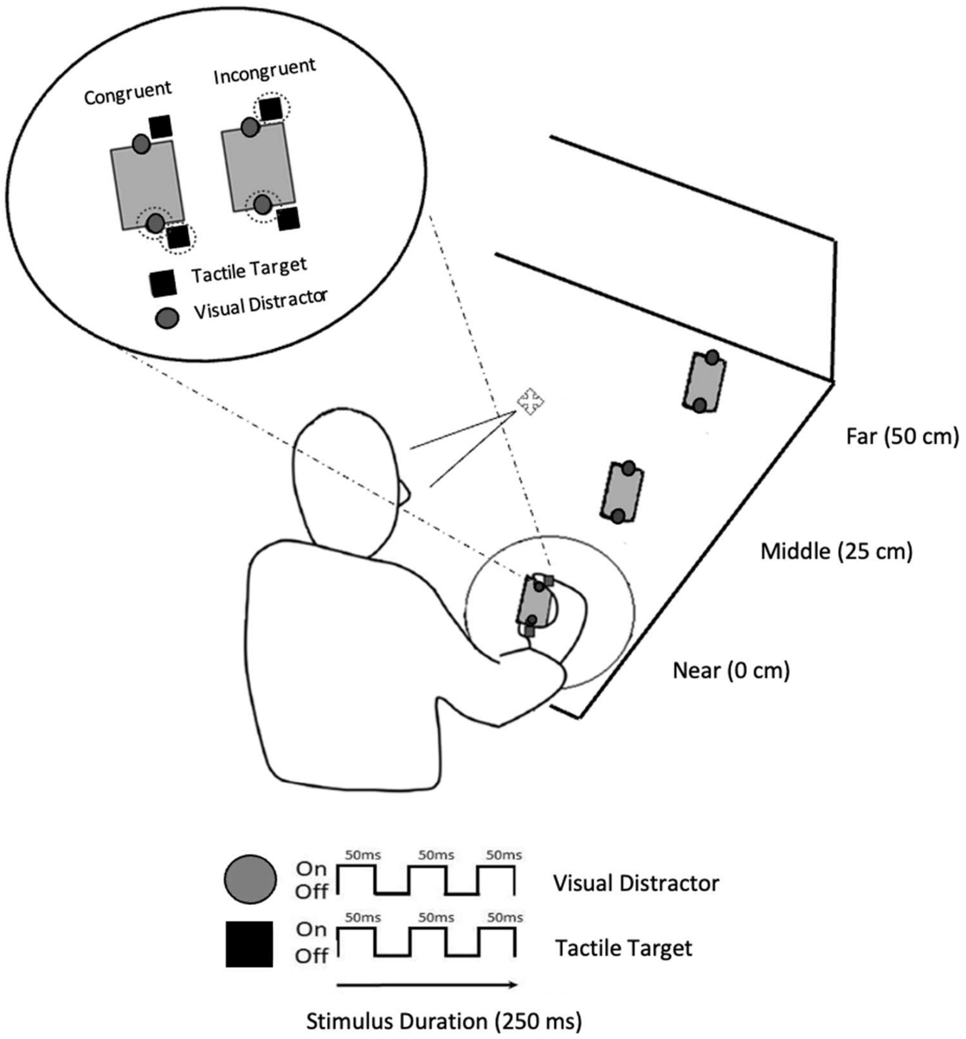


Figure 1. Schematic representation of the experimental set-up for the Cross-modal Congruency Task. The tactile targets were delivered to the index (top target) and thumb (bottom target) of the participants' hand holding the NEAR foam cube (0 cm distant from the hand). The MIDDLE cube was 25 cm while the FAR cube was 50 cm from the hand. One top and one bottom visual distractor were embedded in each foam cube. Participants responded to the elevation of the tactile target (top vs. bottom), while ignoring the simultaneous visual distractor which was presented at a congruent or incongruent elevation (top vs. bottom) and at one of three possible distances from the hand (near, middle and far). The top inset shows congruent and incongruent visuo-tactile trials, while the bottom inset depicts a schematic representation of stimulus duration with the relative timing of the tactile target and the visual distractor.

Empathy. Empathy was assessed using the Interpersonal Reactivity Index (IRI) , a 28-item instrument (Davis, 1980). The items were answered on a 5-point scale (A = *does not describe me* *well*; E = *describes me very well*). This measure has shown good reliability and construct validity (De Corte et al., 2007). The measure has four sub-scales, each consisting of seven items. The scales are: personal distress (PD) (e.g. “Being in a tense emotional situation scares me”); empathic concern (EC) (e.g. “I often have tender, concerned feelings for people less fortunate than me”); perspective taking (PT) (e.g. “I try to look at everybody's side of a disagreement before I make a decision”); and fantasy (FS) (e.g. “After seeing a play or movie, I have felt as though I were one of the characters.”) (Davis, 1980).

2.1.3. Data analysis

2.1.3.1. Crossmodal Congruency Task.

Correct responses measured in the CCT were used to calculate mean response times for each participant separately for the different types of trials (congruent vs incongruent, i.e. the vertical position of the visual distractor relative to the elevation of the vibrotactile target) and distractor distances (near, middle, far). These means were submitted to a 2 X 3 repeated measures ANOVA with *congruency* (Congruent vs. Incongruent visuo-tactile trial) and *distance* of the visual distractor from the hand (near vs. middle vs. far) as within-subject factors.

We were specifically interested in the spatial modulation of the CCE measured at near, middle and far distractor distances (as reflected by the interaction between congruence and distance) to assess whether the interference of distractors decreased as a function of the distance in depth between tactile targets and visual distractors, as expected based on existing literature (e.g. Holmes, 2012). Once we established that our task produced results analogous to those observed in previous studies, we proceeded to calculate individual CCE measures in order to extract the PPS indexes needed for the correlational and path analysis (see 2.1.3.2).

CCE index. Next, the CCE index calculated as the differences between the mean RTs on incongruent and congruent visuo-tactile trials was computed for each participant and for each distractor distance (i.e., CCE- near, middle, and far). These individual CCEs were used as indexes of multisensory PPS representations and entered in the correlational and path analysis with individual empathy scores described below (see 2.1.3.2).

2.1.3.2. Correlational and path analysis between individual empathy scores and CCE.

The main analysis of interest was a correlational and path analysis performed to examine the association between the measures of Empathy (as indexed by IRI scores) and PPS (as reflected by the individual CCEs measured for each distractor distance).

2.1.3.3. Correlational analysis between individual EC scores and the estimated slopes of the regression line calculated across the CCEs distractor distances.

Finally, as suggested by one reviewer, an additional correlation was carried out between individuals' EC scores and the estimated slopes of the regression line calculated across the CCEs observed at Near, Middle and Far distractor locations, separately for each participant. As shown by the CCT analysis run across all participants, the size of the CCE decreases as a function of distractor distance. The strength of this reduction at the level of single participants can be summarized by the individual slopes. Thus, the aim of this exploratory analysis was to use one single PPS index (the CCE slopes) able to combine the information about the spatial modulation of CCE observed at individual level across locations and to offer some indications about the segregation between PPS and extra-personal space, EPS. Steeper decreasing slopes, characterized by larger negative values, indicate a stronger differentiation between PPS and EPS (steeper decrease of CCE across locations), whereas flatter slopes, characterised by smaller negative values, indicate a reduced segregation between PPS and EPS (reduced differentiation between PPS and EPS).

2.2. Results

First, we conducted a preliminary analysis to check for missing and invalid data in the empathy questionnaire. As described in the Participants section, ten participants were excluded from the original sample due to missing data in their empathy questionnaires.

Table 1 shows means, standard deviations, and intercorrelations for the main variables of interest. The final data (N=100) were checked for outliers across the measures of Empathy (Empathic Concern, Perspective Taking, Fantasy & Personal Distress) and CCE (Near, Middle & Far). No extreme outliers, defined as observations that fall below or above 3 x IQR of data dispersion, were detected in the data.

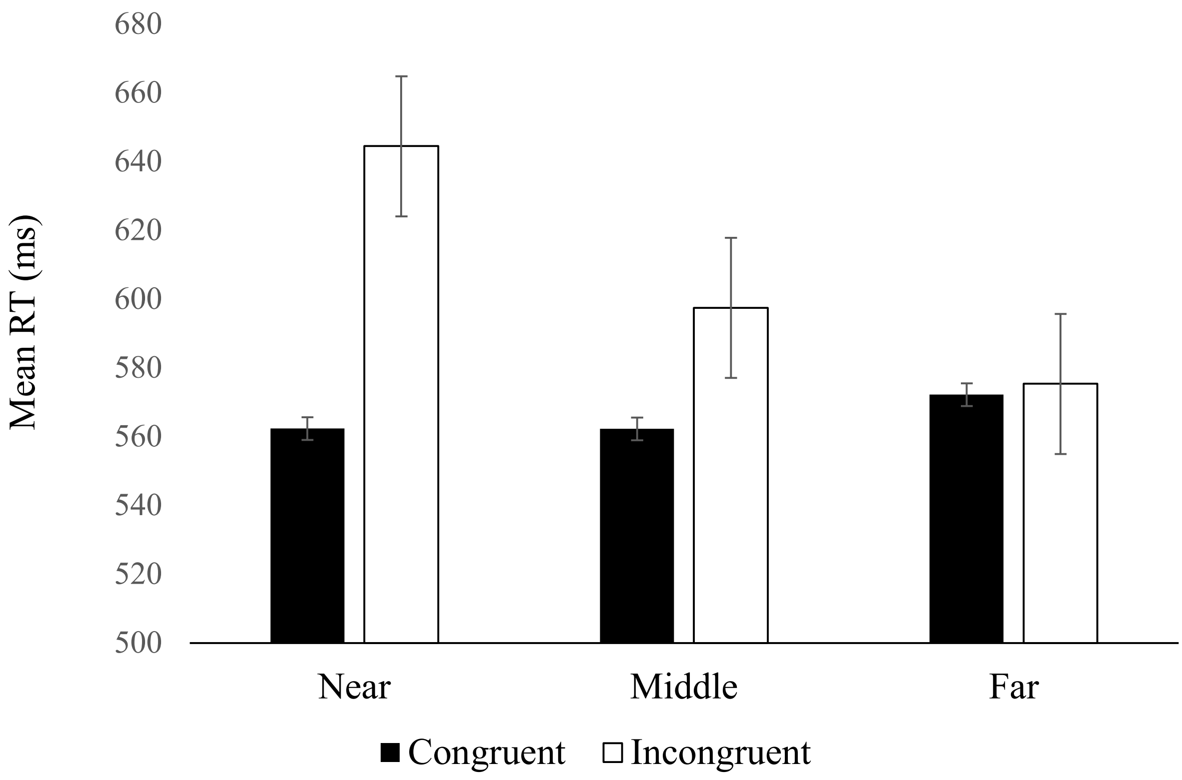
2.2.1. CCT analysis

In the CCT, trials with incorrect responses (error rates = 8.5%) and RTs slower than 1500ms or faster than 200ms (1.9% - regardless of accuracy level) were removed from the RT analysis across all participants (see Spence et al., 2004).

Results of the repeated measures analysis of variance (ANOVA) carried out on correct RTs (congruency and distractor distance as within-subjects factors) revealed statistically significant main effects of congruency, $F(1, 99) = 171.12$, $p < .001$, $\eta^2p = .63$, and distractor distance, $F(1.40, 139.03)$

= 85.25, $p < .001$, $\eta^2p = .46$, in addition to the congruency X distractor distance interaction, $F(1.53, 151.47) = 91.02$, $p < .001$, $\eta^2p = .479$.

The significant interaction of interest, congruency x distractor distance (see Figure 2), confirmed that the congruence effect was modulated by the distance between the tactile target and the visual distractor. Although it is possible to explore this 2 x 3 interaction in different ways, in the present study we used the CCE as an index of PPS (e.g. Brozzoli et al., 2009; 2010). Hence, we were specifically interested in determining 1) the presence of reliable CCEs (comparing congruent and incongruent RTs) at each location and 2) whether the CCE becomes progressively smaller with increasing target-distractor distance (testing whether there is a significant difference between the CCEs measured at the different distractor locations). First, we assessed the presence of significant CCEs at each distractor location, using planned comparisons which contrasted the mean RTs for congruent and incongruent trials observed at near, middle and far distances. A reliable CCE was observed at Near $t(99) = -12.01$, $p < .001$, (Congruent $M = 562.4$ ms, Incongruent $M = 644.5$ ms; CCE Near = 82.1 ms) and Middle distractor locations, $t(99) = -10.35$, $p < .001$ (Congruent $M = 562.3$ ms, Incongruent $M = 597.5$ ms; CCE Middle. = 35.2 ms) but not at Far locations $t(99) = -1.44$, $p = .153$ (Congruent $M = 572.2$ ms, Incongruent $M = 575.4$ ms; CCE Far = 3 ms). The CCEs at Near and Middle distractor locations remained significant when *p values* were adjusted for multiple comparisons using the Bonferroni Method, $p < .017$). Next, we tested whether the size in ms of the CCE differed significantly across distractor locations. To this aim, the differences between RTs on congruent and incongruent trials (the CCEs) were calculated separately for the three distances. Three contrasts (adjusted for multiple comparisons using the Bonferroni Method, $p < .017$) were carried out revealing that the size of the CCE differed across all distractor locations: near vs. middle CCE ($t(99)= 7.09$, $p < .001$), middle vs. far CCE ($t (99) = -8.12$, $p < .001$) and near vs. far CCE ($t(99) = -11.78$, $p < .001$), see Table 1 for these CCE values. In line with existing evidence (e.g. Holmes, 2012), these findings indicate that the interference induced by the visual distractor was maximal at near locations and decreased as the target-distractor distance increased[2]. Furthermore, the fact that reliable CCEs were present at near and middle locations but not at far locations, confirms that both near and middle distractors were located within PPS while the boundary between PPS and EPS was located between the middle and the far distractor locations.



2 The raw magnitude of the CCE has been interpreted as an index of multisensory representation of space near the hand in several studies despite the fact that visual stimuli presented at different distances in depth are characterized by different visual angles (e.g. Brozzoli et al., 2009; 2010; Maravita et al., 2002). As such this factor may have contributed at least in part to the differences between CCEs across distances. Nevertheless, the aim of this study was to investigate individual differences in PPS and we used the CCE as an objective way to assess these. Because all participants performed the same task, distance-related possible confounds should have affect all participants in a similar manner. Hence, differences across participants should be driven by other cognitive or personality factors.

Figure 2. The congruency x distractor distance significant interaction emerged in the RT analysis of variance. Error bars represent the standard error of the means.

2.2.2. Correlational and path analysis of empathy scores and CCEs

All 7-item scales of the IRI showed sufficient internal consistencies: empathic concern (Cronbach's α = .77), Fantasy Scale (Cronbach's α = .80), perspective taking (Cronbach's α = .76) and personal distress (Cronbach's α = .78).

The overall pattern of correlations is shown in Table 1 which examines the relationship between personality traits and CCE scores across the three distance conditions.

			Correlations						
Variables	M	SD	**EC**	**PT**	**FS**	**PD**	**CCE Near**	**CCE Middle**	**CCE Far**
EC	19.90	4.37	-						
PT	18.66	4.36	**.27**	-					
FS	18.35	5.22	**.36**	-.07	-				
PD	11.88	5.15	-.07	.03	.09	-			
CCE Near	82.07	68.30	**-.25**	.01	-.18	-.05	-		
CCE Middle	35.17	33.95	**-.28**	-.17	-.12	.01	**.31**	-	
CCE Far	3.18	21.71	-.13	-.16	.14	.10	.22	.05	-

Table 1. Associations between the CCEs measured in milliseconds at Near, Middle and Far distractor locations and scores on the IRI empathy sub-scales Empathic Concern (EC), Perspective Taking (PT), Fantasy

Scale (FS) and Personal Distress (PD). Significant effects are shown in bold. All *p* values are adjusted for false-discovery rate (Benjamini & Hochberg, 1995).

Bivariate Pearson correlations analysis and 95% bootstrapped (bias corrected, accelerated) confidence intervals (10000 iterations) suggested that there was a significant negative relationship between CCE Near – Empathic Concern (r = -.25, p = .050, 95% CI [-.417, -.083], as well as CCE Middle – Empathic Concern (r = -.28, p = .036), 95% CI [-.466, -.094], see Figures 3 and 4.

Moreover, a significant correlation (r = .31, p =.016), 95% CI [.105, .523], was found between CCE Near and CCE Middle. We could assume a unitary visuotactile multisensory integration mechanism between the two, to differing strength degrees, employed by participants in both Near and Middle conditions.

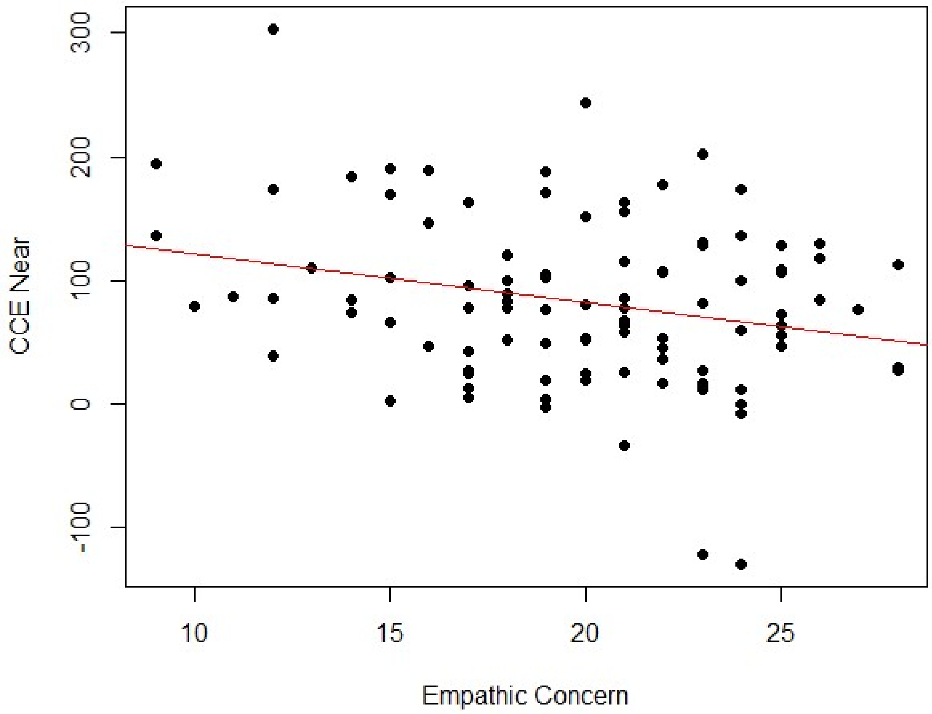


Figure 3. Inverse relationship between the CCE (ms) observed at NEAR distractor locations and participants' EC scores.

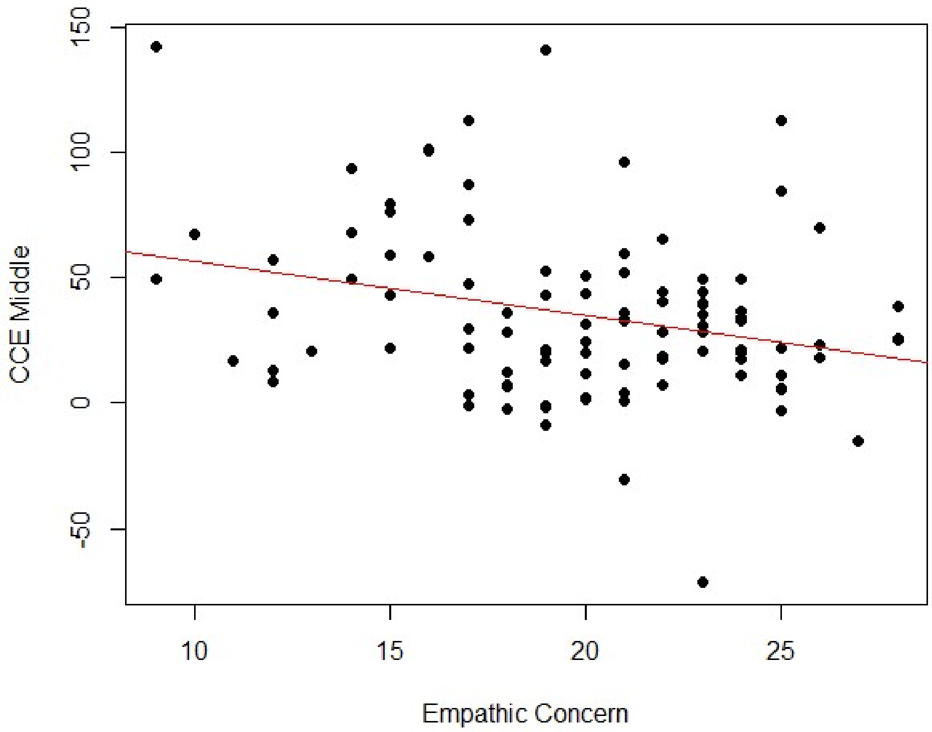


Figure 4. Inverse relationship between the CCE (ms) observed at MIDDLE distractor locations and participants' EC scores.

The path analysis models were built using lavaan 0.6-4 for Windows. Multiple fit indices were used, namely, the χ^2 test, the comparative fit index (CFI), the root-mean square error of approximation (RMSEA), and the expected cross-validation-index (ECVI).

Two models were tested: Model 1, the full model, specified that EC, FS, PT and PD predict CCE in the Near, Middle and Far Condition, while controlling for the effects of Age and Sex. All variables were entered into the model simultaneously. This model did not fit the data sufficiently (RMSEA = .13, χ^2 = 2.74 (*df* = 1, *p* =.097), CFI = .96, ECVI = .90).

Model 2: Modification indices and parameter change were considered to evaluate whether paths should be deleted or added to the model. Only paths that made substantial sense in predicting outcomes were added to the model, with fit statistics investigated after each addition or deletion. By comparison to Model 1, Model 2 fit the data well (RMSEA = 0, χ^2 = 3.49 (*df* = 5, *p* =.624), CFI = 1, ECVI=.23; see Figure 5). We observed a significant inverse relationships as indicated also by the 95% bootstrapped confidence intervals (10000 iterations) between Empathic Concern and CCE for the Near (β = -.25, p = .009, 95% CI[-7.006, -.979]) and Middle distances (β = -.28, p = .004, 95% CI [-3.78, -.612]).

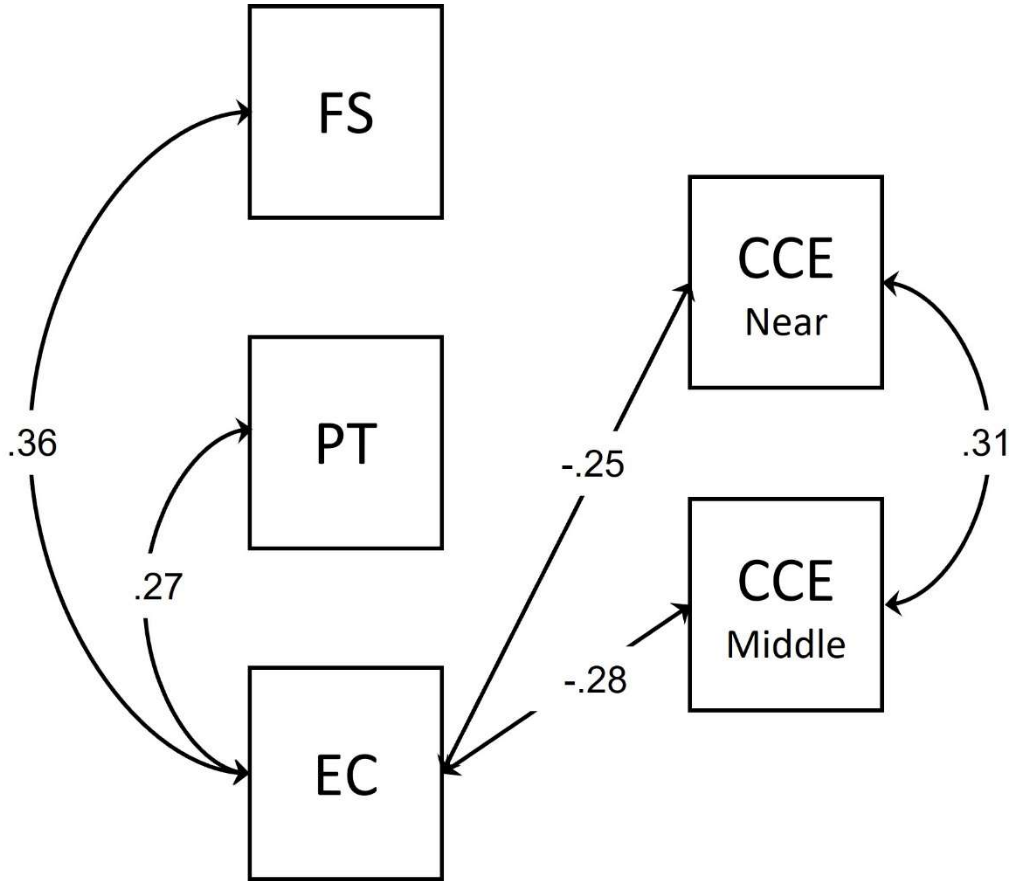


Figure. 5. Path Analysis. EC= Empathic Concern, PT=Perspective Taking, FS=Fantasy Scale, CCE Near, CCE Middle

2.2.3. Correlational analysis of EC scores and CCE slopes

To further characterise the spatial properties of participants representations of the space surrounding their bodies we estimated participants' slopes of the regression lines between the CCEs measured at near, middle and far locations. This individual measure, considered as an index of the segregation between peri-personal and extra-personal space (steeper slopes reflected an increased differentiation between the coding of visuo-tactile stimuli presented at the different distances from the body) was correlated with participants EC scores. Bivariate Pearson correlations analysis and 95% bootstrapped (bias corrected, accelerated) confidence intervals (10000 iterations) revealed the presence of a significant positive relationship between participants' slopes and their Empathic Concern scores, r = .21,p= .032, 95% CI [.028, .396] (see Figure 6).

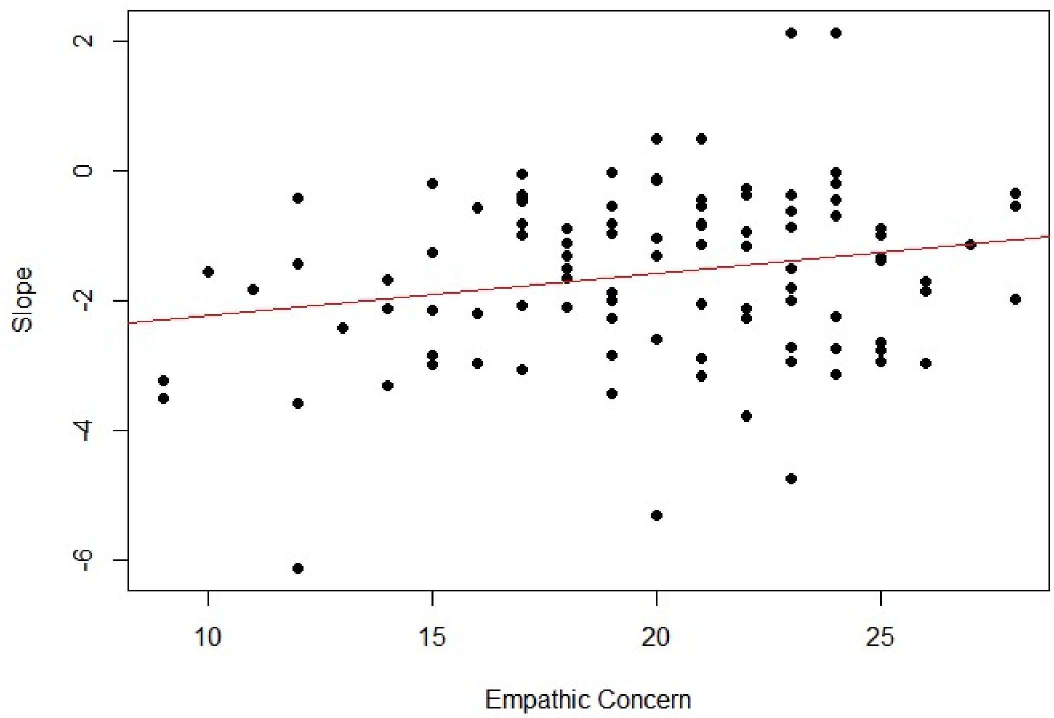


Figure 6. Direct relationship between the slope of the regression line inserted between CCE (ms) observed at NEAR, MIDDLE and FAR distractor locations and participants' EC scores.

3. Discussion

The present study examined whether the properties of individual participants' PPS as indexed by the crossmodal congruency effect[i] (CCE, e.g., Pavani et al., 2000) are related to their empathy levels as measured by the IRI questionnaire (Davis, 1980). Results revealed the presence of an inverse relationship between the strength of the CCE observed at near and middle distances and empathic concern (EC), with reduced visuo-tactile interactions for individuals with higher EC (see Figures 3-4). Furthermore, participants with higher EC scores also showed smaller differences between the CCEs measured at near, middle and far locations, as indicated by the association between the estimated (negative) slopes of the CCEs calculated across the three distances and the EC scores, with flatter negative slopes (closer to zero) in higher EC individuals (see Figure 6). Thus, not only individuals with higher EC scores appear to have a 'weaker' representation of PPS (irrelevant stimuli presented within PPS, at near and middle locations, elicit a weaker interference response) as compared to lower EC individuals, they also show less differentiation between the representation of the space immediately surrounding the body (PPS) and the space beyond reach (extra-personal space, EPS).

The multisensory representation of the space near the body where body-object interactions occur is characterized by plastic properties, with PPS boundaries shaped by the intention to execute a goal-directed movement (e.g. Brozzoli et al., 2009; 2010; Canzoneri et al., 2012; Noel et al., 2014) and by temporary or permanent changes to the body that restrict or increase the range of possible movements (e.g. Canzoneri et al., 2013; Holmes, 2012; Maravita et al., 2001; Serino et al., 2007).

Notably, the system responsible for PPS appears to be involved also in the representation of other people whose PPS is likely to overlap with one's own during social interactions (social PPS; e.g. Bogadova et al., 2021; Brozzoli et al., 2014; Coello & Cartaud, 2021; Di Pellegrino & Ladavas, 2015; Serino, 2019). Social factors such as the presence of other individuals and the type of collaborative interactions occurring with them can modulate the boundaries of PPS representations (e.g. Heed et al., 2010; Hobeika et al., 2019; Teneggi et al., 2013). The neural mechanisms responsible for the representation of an individual's own PPS may be also responsible for the perception of others' PPS (Brozzoli et al., 2013; Ishida et al., 2010). In non-human primates, visuo-tactile parietal neurons with tactile receptive fields (RFs) anchored to a specific body part respond not only to visual stimuli near that body part but also to stimuli close to the corresponding body part of another individual (Ishida et al., 2010). Notably, similar neural mechanisms also seem to exist in humans (e.g., Brozzoli et al., 2013). Behavioural studies have shown that shared sensory experiences between two people such as those elicited by the enfacement illusion can result in a remapping of "other's" PPS onto the participant's own (Maister et al., 2015). Furthermore, responses to tactile stimuli presented to the participant's hand are faster not only when a visual stimulus approaches their hand in near space, but also when it approaches the hand of a different individual, in the participant's far space (Teramoto, 2018). Together, these findings suggest that one's own PPS system is also involved in the mapping of the PPS of others, contributing to the spatial matching between the self and others (see also Mahayana et al., 2014). Results of the present study can be better understood in light of this putative role of PPS in mapping the space around others into one's own PPS representation. Empathy plays a pivotal role in social interactions (Batson & Ahmad, 2009; Bernhardt & Singer, 2012), with higher EC individuals showing increased levels of prosocial and altruistic behaviour (Bekkers, 2005; 2006). The observation that participants characterised by higher EC scores showed weaker PPS representations and a reduced segregation between PPS and EPS may reflect their natural predisposition or ability to interact with others in a more extended space. PPS has been suggested to serve as a buffer in the spatial adjustments required by social interactions (see Coello & Cartaud, 2021, for a review). In this context, while social and public space corresponds to distances that match the EPS (i.e. the space of others), intimate and personal space correspond roughly to PPS (i.e. the space of the self) (Hall, 1966). W*e speculate* that the decreased differentiation between PPS and EPS (i.e. between the space of the self and the space of others) mediates the facilitation in the perception, representation and evaluation of the experiences of others, characteristic of higher EC individuals. Further, we speculate that this spatial feature of PPS may support the subtle calibration between the necessity to get close to another individual during a social interaction without invading their PPS (Coello & Cartaud, 2021). Thus, the specific spatial properties of PPS observed in higher EC individuals may facilitate the representation of and the interaction with other individuals. The speculative nature of these hypotheses stem from the fact that participants in the present study were tested in isolation, that is we measured their multisensory PPS and not their social PPS, which is typically engaged by the representation of other people during social interactions (e.g. Bogadova et al., 2021; Brozzoli et al., 2014; Cartaud et al., 2018; Coello & Cartaud, 2021; Di Pellegrino & Ladavas, 2015; Serino, 2019). Although it has been suggested an overlap between the mechanisms responsible for multisensory PPS and for social PPS, future studies should directly investigate whether the spatial features of multisensory PPS in higher EC individuals can also be observed for social PPS.

Only recently researchers have started to systematically investigate *individual differences* in PPS representations (e.g. Longo & Lourenco, 2007). Increased/extended PPS boundaries around the body of participants are observed in response to threatening or fear-inducing stimuli (e.g. Lourenco et al., 2011; Sambo et al., 2012a; Sambo et al., 2012b; Sambo & Iannetti, 2013). For instance, participants suffering from higher rates of claustrophobic fears show extended representations of near space (Lourenco et al., 2011). Furthermore, PPS boundaries are shaped by anxiety levels, as suggested by the positive correlation between trait anxiety and the extension of peripersonal space (Sambo & Iannetti, 2013; see also Taffou & Viaud-Delmon, 2014, for analogous findings with fear-relevant stimuli). It is relevant to note that these studies assessed the characteristics of the "safety margin" surrounding the body, labelled defensive peripersonal space (DPPS) due to the 'potentially dangerous' nature of the stimuli used. Crucially for the aim of this study, participants' levels of EC were found to modulate this "safety margin" surrounding the body (DPPS) (Fossataro et al., 2016). Individuals with higher levels of EC showed increased defensive responses (as indexed by the enhanced hand-blink reflex, HBR) not only when a potential threat entered their own DPPS but also when they observed it entering somebody else's DPPS (Fossataro et al., 2016). Thus, higher EC individuals were better able to remap their DPPS when interacting with others.

Our results complement and expand these observations by demonstrating that the association between EC and PPS is not only restricted to the processing of potentially harmful stimuli within DPPS (Fossataro et al., 2016), but can also be observed during the processing of visuo-tactile stimuli typically used to measure the encoding of multisensory PPS. Recently, researchers have suggested that the mechanisms responsible for the encoding of potentially harmful stimuli entering one's own DPPS can be dissociated from those subserving the implementation of (inter)actions with objects and other individuals within PPS (de Vigemont & Iannetti, 2015). According to this hypothesis, PPS and DDPS not only serve different functions, but their key features are also shaped by distinct principles (de Vigemont & Iannetti, 2015). In line with this, in the present study individuals with higher EC scores showed a reduced differentiation between the multisensory responses to stimuli within and beyond PPS, possibly reflecting an increased ability to encode the presence of other objects/individuals in a more extended interaction space, while they were characterized by an increased defensive response to threatening stimuli entering DPPS (Fossataro et al., 2016), likely depending on their higher concerns for one's own and others safety. Together these results reveal that EC levels differentially modulate the distinct representations of the space surrounding the body.

It is worth noting that while we observed a significant relationship between PPS and EC, in line with existing evidence on DPPS (Fossataro et al., 2016), no such association was observed between PPS and the other three subscales that characterise IRI (Davis, 1980). Empathy is defined as a multidimensional concept in the IRI. Cognitive empathy is measured by the Perspective Taking and Fantasy subscales, whereas affective empathy is assessed by the Empathic Concern and Personal Distress subscales. However, despite the fact that the IRI is one of the most commonly used tools to measure empathy, its factor structure is not well-defined. Studies using confirmatory factor analysis have produced mixed results both for the four-factor model and for higher-order models with cognitive and affective factors (c.f. Wang et al., 2020). Therefore, it is important that future studies will use different tools with clearly-defined structures (e.g. Reniers et al., 2010) to confirm the link between affective empathy and PPS.

Overall, the current study points towards a key role of empathy, and specifically of EC, in the construction of PPS representations. We observed an inverse relationship between levels of EC and the strength of visuo-tactile integration within PPS together with a reduced segregation between PPS and EPS. These findings may reflect an increased ability of higher EC individuals to encode the presence of others in a more extended interaction space.

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Acknowledgements:

We would like to thank the Editor, one anonymous reviewer and Andrea Serino for their helpful comments and suggestions which helped us to improve substantially the manuscript.