Positive self-perception and corticospinal excitability: Recalling positive behavior expands peripersonal space boundaries


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ABSTRACT

Converging evidence suggests that peripersonal space has dynamic properties, that can be influenced by motor and cognitive factors. Here, we investigated whether changes in self-perception may impact upon peripersonal representation. Specifically, employing non-invasive brain stimulation, we tested whether corticospinal excitability elicited by objects placed in the vertical peripersonal vs extrapersonal space can be influenced by changes in self-perception after recalling a personal experience inducing the feeling of high power (vs. positivity vs. low power).

In a preliminary study (Study 1, N = 39) participants were presented with an object, whose position was manipulated in the horizontal vs vertical space. We assessed corticospinal excitability by measuring Motor Evoked Potentials (MEPs) using Transcranial Magnetic Stimulation with Electromyography co-registration (TMS-EMG). In the horizontal condition, we replicated the well-known motor facilitation induced by objects falling in the peri vs extrapersonal space, while in the vertical dimension MEPs were higher in the extrapersonal space.

In the main experiment (Study 2), participants (N = 55) were randomly assigned to feel high power, low power, or a general positive emotion and were asked to observe the same object positioned either in the peripersonal or in the extrapersonal vertical space. Results showed that in the low power condition MEPs were higher in the extrapersonal vs peripersonal, as in Study 1, while in high power and positive conditions MEPs were not influenced by distance.

Taken together, our findings suggest a dissociable pattern of motor facilitation underlying vertical vs horizontal space perception and, crucially, that changes in self-perception can influence such a representation.

1. Introduction

Peripersonal space has been defined as the space immediately surrounding individual’s body, within which it is possible to reach and manipulate objects. It can be conceived as a multisensory-motor interface between body and environment, where visual and/or auditory information about external stimuli are integrated with tactile, proprioceptive and kinesthetic information about body parts (Di Pellegrino and Ladas, 2015; Rizzolatti et al., 1981, 1997; see Serino, 2019 for a recent review). Outside the peripersonal stands the extrapersonal space, where objects are unreachable unless moving towards them (Rizzolatti et al., 1983; Coello et al., 2008). Neuropsychological evidence on neglect syndrome patients (e.g. Kimura et al., 2018; see Ladas, 2002 for a review), neuroimaging (Weiss et al., 2000), neurostimulation (Bjoertomt et al., 2002; Lane et al., 2013) and electrophysiological (Valdés-Conroy et al., 2014; Noel et al., 2019) data converge in suggesting that objects falling in the peri vs extrapersonal space are differently represented in the brain. For instance, neuroimaging studies highlighted that performing tasks in the near space involved the dorsal visual system, while the ventral system is involved when tasks are completed in the far space (Weiss et al., 2000, 2003).

Considering peri- and extrapersonal space as two static and well-
and behavioural paradigms (Tucker and Ellis, 2001, 2004). Crucially, this effect can be detected by assessing corticospinal excitability combining Transcranial Magnetic Stimulation (TMS) and electromyography recording (EMG), typically applying TMS over the left motor cortex and recording the motor evoked potentials (MEPs) from hand muscles involved in the grasping movements, usually the first dorsal interosseous (FDI). Corticospinal excitability, as measured by MEPs, is modulated by the presentation of every day’s life objects (Franca et al., 2012), by the possibility to grasp them with a specific movement (Buccino et al., 2009; Makris et al., 2013) and, crucially for the purposes of our study, by their distance from the observer in terms of peripersonal versus extrapersonal space. Cardellicchio et al. (2011), for instance, manipulated the presentation of a graspable (mug) vs a non-graspable (cube) object in peripersonal (30 cm) and extrapersonal (150 cm) space in a virtual 3D experiment. MEPs were higher when the graspable object was placed in participants’ peripersonal space, compared to the observation of either non-graspable object or of graspable object in the extrapersonal space.

The aforementioned works, however, only focused on the horizontal dimension, leaving unexplored whether the corticospinal excitability can be affected in the same way for objects presented at different distance along the vertical dimension. Moreover, they specifically tested distances that clearly belonged to the reachable vs non-reachable space (30 cm vs 150 cm from participants). Building on the evidence described so far, the present research sought to extend and combine different lines of research, exploring the relationship between power, positive feeling and space representation. In particular, we sought to achieve three main aims by means of two studies. A preliminary study (Study 1) aimed to explore the corticospinal excitability modulation (measured via MEPs amplitude) induced by the presentation of objects in the peri-vs extrapersonal space along both the vertical and the horizontal axis. We expected to replicate previous findings along the horizontal plane and to obtain a baseline of corticospinal excitability modulations along the unexplored vertical dimension. As far as we know, this is the first study exploring this type of modulation on the vertical axis. Moreover, in contrast with previous research (e.g. Cardellicchio et al., 2011) which used object positions clearly belonging to close vs far space, we opted for positioning the object in a twilight zone, namely near the boundaries between peri- and extra personal space. In a second main study (Study 2) we explore whether manipulating power experience would affect the surrounding space representation. Here, participants were randomly assigned to three conditions in which they were asked to recall a specific event of their life in which they experienced either high power, low power, or a general positive feeling. Immediately after the recalling, MEPs were recorded using the same experimental paradigm of the preliminary study. We hypothesized that in the high-power condition, due to the modulation of self-perception in terms of height, peripersonal boundaries would expand, such to encode objects presented in the “closer” extrapersonal space as being inside the peripersonal space. Furthermore, we included a control condition designed to induce positive feelings in participants, thus disentangling the effect of power from a more general effect of positive mood.

1.1. Study 1

1.1.1. Participants

We recruited 39 healthy students (13 male, $M_{age}=22.6$, $SD=\pm 1.6$). Participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971, mean laterality coefficient 0.81, $SD=\pm 0.14$). Participants completed the Adult Safety Screening Questionnaire (Keel et al., 2001) and gave informed written consent before starting the experiment. Participants with any contraindications such as brain injury or surgery, heart attack or stroke and use of medications known to alter cortical excitability (e.g., anti-depressant medication) were excluded (Rossi et al., 2009). The study took place in the TMS laboratory of the University of Milano-Bicocca and was carried out in accordance with the ethical standards of the revised Helsinki Declaration and approved by the local Ethics Committee.
1.1.2. Method

Peri- and extrapersonal space manipulation

Participants were randomly assigned to the vertical (N = 19, male = 7) or the horizontal (N = 20, male = 5) condition. Space was manipulated by changing the position of a real pencil sharpener in the vertical (i.e. along the longitudinal axis) and horizontal (i.e., along the anteroposterior axis) plane. The pencil sharpener was chosen because it is a graspable and familiar tool (Franca et al., 2012).

For the space manipulation along the vertical axis, the pencil sharpener was hung over participants’ head from a hook on the ceiling using a transparent nylon wire. At the other end, the wire was tied to nails distributed on the wall at 5 cm distance from each other. Nails were hidden from participants’ view.

Before starting the experimental session, participants sat on a height-adjustable chair and a midline height of the pencil sharpener was established for each subject. The pencil sharpener was fixed at the nail in the mid position in the wall and the chair’s height was adjusted for each participant such to be the maximal distance at which they could grasp the pencil sharpener holding the shoulder leaning against the back of the chair and stretching their right arm above their head. In this way a midline height was individually established, which delimited the area of reachable objects. It is worth noticing that this was the only height of the pencil sharpener that the participants experimented as graspable.

By moving the wire to the upper or lower nails in the wall, the pencil sharpener could be allocated in peripersonal vs extrapersonal space. In particular, in addition to the midline distance, the object could be positioned closer to the participant, thus falling within the peripersonal space, by moving the wire to nails at 5 and 10 cm below the mid nail; the extrapersonal space instead was tapped by moving the wire 5 and 10 cm over the mid position, thus allocating the object farer from the participant, over the reachable area. For the horizontal condition, instead, the pencil sharpener was hung in front of the participants’ trunk midline by means of a runner positioned on the ceiling, hung to a transparent nylon wire, as for the previous condition. Even in this case, before the beginning of the experiment a midline position was established by moving the pencil sharpener along the runner up to the maximal distance at which they could grasp it holding the shoulder leaning against the back of the chair and extending their arm in front of them. The height of the chair was adjusted so that the extended arm was aligned to the pencil sharpener. Peri- and extrapersonal space were manipulated by moving the wire along the runner, following the same reasoning as for the vertical space: indeed, for the peripersonal condition, the wire could be fixed either at the baseline condition, 5 or 10 cm nearer to participants; for the extrapersonal condition, it could be moved either 5 or 10 cm further from the baseline (see Fig. 2).

During the intersession intervals participant’s eyes were briefly covered so that the experimenter could change the position of the pencil sharpener.

TMS-EMG recordings

TMS was applied with an Eximia TMS stimulator (Nexstim™, Helsinki, Finland) using a focal bi-pulse figure-of-eight 70-mm coil. The coil was positioned tangentially to the scalp with the handle pointing backward and at a 45° angle from the mid-sagittal axis of the subject’s head. This placement induces an electric current flow in the brain in a posterior–anterior direction, perpendicular to the central sulcus, which has been shown to be optimal for trans-synaptic activation of the cortico-

Fig. 1. The figure represents a graphical representation of TMS-EMG recording procedure. Panel A represents coil position over the hotspot (left M1), which was monitored thanks to the continuous updating of a visual feedback (Panel B). The neuronavigation system allows preventing any change in the stimulation site due to small movements of experimenter or participants. Panel C shows an example of the average MEP for object presented in the vertical peripersonal space (Study 1) and the peak-to-peak amplitude measured, which constituted our dependent variable.
spinal pathways (Brasil-Neto et al., 1992; Mills et al., 1992). The coil was moved over the left primary motor area (M1) to identify the TMS hotspot, defined as the point where stimulation evoked the largest MEP from the contralateral first dorsal interosseus (FDI) muscle.

TMS intensity was adjusted to establish the individual motor threshold that is the lowest intensity of the stimulator output that evoked MEPs with an amplitude of at least 50 μV in the contralateral FDI muscle with a 50% probability when the subject kept the muscle relaxed (Rossini et al., 1994). Then the intensity was increased to evoke MEPs of approximately 1 mV amplitude in the relaxed right FDI (Koch et al., 2009).

MEPs were recorded from the FDI muscle of the right hand using 9-mm diameter Ag–AgCl surface cup electrodes. The active electrode was placed over the FDI muscle and the reference electrode over the metacarpo-phalangeal joint of the index finger. Responses were amplified and recorded using eXimia EMG (Nexstim™, Helsinki, Finland) amplifier, filtered with a band pass of 10–500 Hz and digitized at a sampling rate of 3 kHz.

An NBS Nextim neuronavigation system was used during the experiment, to monitor coil-positioning over the hotspot and prevent any change in the stimulation site due to small movements of the participant’s head during data collection (Sartori et al., 2013). See Fig. 1 for a graphical representation.

Experimental procedure

After setting the midline position of the pencil sharpener, the electrodes were placed on the subject’s right hand and the TMS hotspot and motor threshold were assessed. The experiment was composed of 5 blocks, each made of 40 trials. In each block the pencil sharpener had a fixed distance from participants, (extrapersonal: midline, −5, −10; extrapersonal: +5, +10). The order of the blocks was counterbalanced across subjects (see Fig. 2 for the experimental setting in the vertical plane).

Within each block, during each trial participants heard one out of ten randomized Italian acoustic word: five representing action verbs (i.e., rotate, use, draw, take, touch) and five representing perceptual adjectives (i.e., blue, red, green, cold, hot). Auditory stimuli were given through two speakers, which were in front of participants, at about 100 cm. We asked the subjects to watch the pencil sharpener and imagine the word heard related to it; for instance, if they heard the word “take” they had to imagine grasping the object, if they heard the word “red” they had to imagine a red pencil sharpener. It is important to highlight that the rationale for using acoustic stimuli was to direct participants’ attention toward the pencil sharpener in concomitance with the TMS pulse and MEP recording. Indeed, differently from previous studies (Franca et al., 2012; Cardellicchio et al., 2011), in our paradigm the object was always visible to participants, with the potential risk that participants did not pay attention to it. Therefore, given the issue that we did not have an exact time of appearance of the visual stimulus, TMS pulses were randomly delivered between 150 and 300 ms after the end of the acoustic stimuli and MEPs were recorded. TMS timing was based on previous studies testing affordance effects with object presentation and showing effective corticospinal excitability modulation within this time interval (Buccino et al., 2009; Coello et al., 2008; Franca et al., 2012; Makris et al., 2011). The auditory stimuli and the TMS stimulation were controlled by E-Prime Software 2.0.

1.1.3. Results

Trials with EMG activity greater than 100 μV in the 100 ms before TMS were excluded from the analysis to avoid MEP measurements contamination by background activity, as well as MEPs smaller than 100 μV or with a latency inferior to 5 ms. For each session the peak-to-peak amplitude of the MEPs was measured off-line and outlier trials (±2 SD from the subject’s mean value) were identified and removed from subsequent analysis. After this procedure the 5.4% of MEPs was discharged (see the Supplementary materials to see the average MEPs amplitude for the five separated distances). The remaining MEPs were then normalized using natural logarithm. On this final dataset, we run a 2 (Distance: peripersonal vs extrapersonal) x 2 (Axis: horizontal vs vertical) x 2 (Word: motor vs perceptual) linear mixed model with subject intercept as random factor on MEP amplitude. Statistical analyses were performed by using SPSS 24 and post-hoc interactions were tested with Bonferroni correction. To provide a better description of our findings we added the confidence intervals (CI) for the mean difference and the classical Cohen’s d to estimate effect size of significant main

The analysis did not yield significant main effects of either Axis, $F(1, 37) = 0.31, p = .58$, Distance, $F(1, 6623) = 0.21, p = .64$ and Word, $F(1, 6623) = 0.16, p = .68$.

Crucially, the interaction between Distance and Axis was significant, $F(3, 6623) = 11.4, p = .001$: post-hoc analysis highlighted that for vertical distance manipulation MEPs were higher for the extrapersonal as compared to the peripersonal space ($p = .043, d = 0.073; CI: 0.024; 0.128$), whereas for the horizontal manipulation MEPs were higher for the peripersonal vs the extrapersonal space ($p = .006, d = 0.095; CI: 0.122; -0.017$ see Fig. 3).

Interestingly, the analysis also showed a significant interaction effect between Axis and Word, $F(1, 6623) = 4.2, p = .040$: post-hoc analysis showed that in the vertical plane no differences were traceable between motor and perceptual words ($p = .251, CI: -0.015; 0.053$), whereas for the horizontal axis a trend toward significance was found, with higher MEPs for motor words as compared to perceptual ones ($p = .078, d = 0.061; CI: 0.004; 0.090$ see Fig. 4).

To conclude, the interaction between Distance and Word, $F(4, 6632) = 0.32, p = .57$, and the three-way interaction among Distance, Axis and Word were not significant, $F(4, 6623) = 0.18, p = .67$.

1.1.4. Study 1: discussion

In this study we measured MEPs amplitude during the observation of a graspable object presented in the peri-vs extrapersonal space, along the vertical and horizontal dimension. Previous studies suggested that the presentation of objects located in reachable positions induces higher MEPs as compared to no-object conditions (Franca et al., 2012) and to object presented in a no-reachable space (Cardellinocio et al., 2011). In Cardellinocio et al., for example, MEPs were higher for virtual objects presented in front of participants at 30 (reachable space) vs 150 cm (non-reachable space). In the current study, we tested whether corticospinal excitability was sensitive to a narrower distance manipulation, thus building a baseline condition for our main experiment.

Results showed an opposite pattern of corticospinal modulations induced by the object position in the peri-vs extrapersonal space in the horizontal and vertical plane. In the horizontal plane object positions in the peripersonal space elicited higher MEPs than in the extrapersonal space. Such finding is in line with the concept of affordances as argued by Gibson and investigated by previous studies showing corticospinal facilitation induced by the sight of a graspable object falling in individual’s peripersonal space (Cardellinocio et al., 2011; Franca et al., 2012).

Conversely, in the vertical plane MEPs were significantly lower when the pencil sharpener was positioned in the peripersonal in comparison to the extrapersonal one, thus suggesting a different modulation of object positioning along the two axes.

Despite being unexpected, we found the dissociation between vertical and horizontal dimension quite interesting and based on the available literature we tried to explain our findings.

In line with previous studies, it seems possible that MEPs amplitude decreases in peripersonal vertical space because of a freezing-like effect. Peripersonal space has indeed an evolutionary value: as first suggested by Hediger (1955), animals have a special area around the body called “flight zone”. This region of space corresponds to a margin of safety around animal’s body (e.g. Dosey and Meisels, 1969) and when threatening objects are in this space animals escape. In line with this claim, prior research showed an inhibitory modulation of corticospinal excitability occurring in different conditions, such as the presentation of salient cues (Tambrun et al., 2001; Farina et al., 2001; Urban et al., 2004), loud acoustic stimuli (Furubayashi et al., 2000), unexpected visual flashes (Cantello et al., 2000), images depicting pain in others (Avenanti et al., 2009; Fectue et al., 2008; Minic-Paluello et al., 2006), visual approaching stimuli (Makin et al., 2009) and auditory signals presented near or far from the hand (Avenanti et al., 2012; Serino et al., 2009). In our study the pencil sharpener was static but hung over participants’ head; hence it is possible that, specifically for the vertical dimension, they could have perceived it as instable as it could at every moment fall on them. Such interpretation is in line with previous studies based on hand-eye blink reflex paradigm (Bufacchi et al., 2015; Bufacchi and Iannetti, 2016), skin conductance modulation induced by approaching stimuli in the vertical vs horizontal dimension (Rossetti et al., 2015) and visual perception studies suggesting vertical asymmetries (Rezaul Karim and Kojima, 2010). In a similar vein, a recent line of research (see Pfeiffer et al., 2018) suggested the vestibular system to play a crucial role in updating peripersonal space boundaries to track object’s position and spatial self-representation. Given the central role played by the vestibular system in perceiving gravity (see for a review Zago and Lacquinti, 2005), it is possible that the vestibular system plays a crucial role in detecting object’s position along the vertical dimension.

In line with our idea of gravity being involved in MEPs modulation, the dissociation between horizontal and vertical space perception might be due to two different underlying processes. Indeed, MEPs increase in the vertical dimension may be the consequence of a motor preparation to react and avoid stimuli that can potentially fall and hit participants, thus reflecting a defensive motor preparation. This result is in line with our previous study (Pisoni et al., 2014), in which the increase of corticospinal excitability was linked to a potential action to respond to a potential harmful partner. At the opposite, the increase in MEPs found for objects presentation in the peripersonal space along the horizontal dimension might reflect an automatic motor preparation for appetitive action to reach and grasp stimuli. This interpretation is in line with the evidence that in our data action verbs (as compared to perceptual stimuli) increased MEPs amplitude in the horizontal but not vertical dimension, highlighting that the suggested action might impact corticospinal excitability only in the case participants wanted to interact with the object and not only defend themselves from it (for a more detailed discussion on this point see the general discussion).

A second possible explanation brings into play the concept of motor planning and of the required effort necessary to perform an action. Specifically, TMS studies measuring corticospinal excitability during imagined actions showed an increase in MEP amplitude for effortful movements (e.g., Helm et al., 2015). However, this interpretation would only explain results related to the vertical axis, along which MEPs were higher for extra-as compared to peripersonal positions, but not MEPs pattern along the horizontal dimension, in which MEPs increased when the pencil sharpener fell in the peripersonal space.

In conclusion, our findings in Study 1 did not have an unequivocal explanation and further ad hoc experiments are needed to explore the mechanism underlying the different corticospinal modulation induced by object presentation in the vertical plane. However, for our purpose of exploring power modulation on peripersonal space representation, they provided a baseline measure for the main study (Study 2).

1.2. Study 2

1.2.1. Participants

55 healthy volunteers (18 male, $M_{age} = 23.1, SD = 2.5$) participated in the study. All participants were right-handed with a mean laterality coefficient of 0.81 ($SD = 0.16$) on the Edinburgh Handedness Inventory (Oldfield, 1971). Each participant completed an Adult Safety Screening Questionnaire (Keel et al., 2001) and gave informed written consent prior to study procedures. We excluded participants with any contra-indication for TMS (Rossi et al., 2009). The study took place in the TMS laboratory of the University of Milano-Bicocca and it was carried out in accordance with the ethical standards of the revised Helsinki Declaration and approved by the local Ethics Committee.

1.2.2. Method

Power manipulation
Participants were randomly assigned to one out of three conditions: high-power (N = 20; male = 7), low-power (N = 17; male = 3) and positive condition (N = 18; male = 8). We manipulated power by asking participants to recall an episode in their lives in which they felt a specific emotional state (for a similar procedure, Galinsky et al., 2003; see also Lammers et al., 2017).

In particular, participants assigned to the high-power condition received the following instruction: “Please recall an episode of your life in which you felt powerful. Specifically, we ask you to think of an occasion in which you felt competent, to be able to influence others or events, or an episode in which you excelled or had taken a position of high status. Please describe the situation, the dynamic, as well as the emotions and the feelings you experienced on that occasion”.

Participants assigned to the low-power condition received the following instruction:

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\(^{1}\) Each group included 20 participants, but in the positive and low-power conditions respectively 2 and 3 participants reported a story which was not coherent with the assigned condition, therefore they were excluded from electrophysiological analysis.
“Please recall an episode of your life in which you felt powerless. Specifically, we ask you to think to an occasion in which you felt incompetent, to be influenced by others or events, or an episode in which you felt weak and had taken a position of submission. Please describe the situation, the dynamic, as well as the emotions and feelings you experienced on that occasion”.

Then, participants assigned to the positive condition were asked to recall a positive episode occurred in their life:

“Please recall an episode of your life in which you felt relaxed. Specifically, we ask you to think to an occasion in which you felt happiness, serenity, or an episode in which you felt at ease and peaceful. Please describe the situation, the dynamic, as well as the emotions and feelings you experienced on that occasion”.

Experimental procedure

We followed the same TMS-EMG recording procedures used in the preliminary study (Study 1). After individually setting the midline height of the pencil sharpener and the stimulation intensity, participants were asked to recall and tell the event corresponding to the condition they were randomly assigned to.

Even in this case the experiment was composed of 5 sessions, made of 40 trials and corresponding to the five different positions of the pencil sharpener, but exclusively on the vertical plane.

We then followed the same procedure than Study 1.

During the intersessions interval participants’ eyes were briefly covered so that the experimenter could change the position of the pencil sharpener and they were asked to recall for a minute the episode they reported at the beginning of the experiment.

To check the efficiency of our manipulation at the end of the experiment participants were asked to indicate the extent to which they feel power on three items (i.e., “I feel ... influential”, “powerful”, “important”, α = 0.94). Participants provided their answers on 7-point Likert scale ranging from 1 (not at all) to 7 (extremely).

1.2.3. Results

Power manipulation check

The items included in the manipulation check were averaged to form a power index. Then, a one-way analysis of variance (ANOVA) was carried out on the power index using Condition (high power, low power and positive) as between subject factor. Results showed a main effect of condition, F(2, 54) = 12.9, p < .001, ηp² = .332; post-hoc analysis with Bonferroni correction showed that participants in the high power condition (M = 4.46, SD = 0.79) reported significantly higher power feelings compared to positive (M = 3.51, SD = 1.54; p = .043) and low power conditions (M = 2.51, SD = 1.05; p < .001); positive condition experienced higher power feelings compared to low power one (p = .044).

In sum, our manipulation was successful. Indeed, in the high power condition, participants felt more powerful than in the low power and positive condition. In a similar vein, participants assigned to the low power condition, felt less powerful than in the other two conditions.

Preliminary analyses

We applied the same pre-processing procedure than Experiment 1, in this way the 6.8% of MEPs was discharged. The remaining MEPs were then normalized using natural logarithm.

Mirroring Study 1, the 5 distances were collapsed in peripersonal (peripersonal 1 and 2, midline) vs extrapersonal (extrapersonal 1 and 2) space (see the Supplementary materials for the average MEPs across the five distances).

EMG results

A linear mixed model was run to analyze the effects of the within-participants’ factors Distance (2 levels: peripersonal vs extrapersonal space), Word (2 levels: motor vs. perceptual) and of the between-participants factor Condition (3 levels: high power, low power, positive) on the MEP amplitude response, with subject intercept as random factor and experienced power (as rated by each subject) as covariate.

All statistical analyses were performed by using SPSS 24. We opted for a linear mixed-model analysis to account for random effects elicited by the interdependence of responses (MEPs) that come from the same subject. Since the analysis yielded neither a main effect of Word (p = .625) nor interaction effects of this variable with the other three factors (ps > .167), data were collapsed across this factor.

The analysis did not show a main effect of Condition, F(2, 49) = 1.97, p = .252. Consistent with Experiment 1, the model revealed a significant main effect of Distance, F(1, 9313) = 5.53, p = .019 (CI: 0.008; 0.091) with higher MEPs when the pencil sharpener was in the extrapersonal (M = 6.45, Standard Error (SE) = 0.08) as compared to the peripersonal space (M = 6.4, SE = 0.075).

Interestingly and in line with the hypothesis of a modulation of MEPs by social variables, the analysis carried out a significant interaction effect between Condition and Distance, F(2, 9313) = 3.20, p = .041 (see Fig. 5). As revealed by the post hoc comparisons, in the preliminary first experiment, in the powerless condition MEPs were significantly higher when the object was in the extrapersonal space than in the peripersonal one (p = .001, d = 0.172; CI: 0.059; 0.220). In contrast, in high power condition this difference was not significant and corticospinal excitability was analogous when the graspable object was presented in the peripersonal or in the extrapersonal space (p = .511, CI: 0.016: 0.089). Moreover, and crucially to explore the specificity of the power effect, also in positive condition such a difference disappeared (p = .176, CI: 0.016; 0.089). The direct comparison between the three groups on the peripersonal vs extrapersonal space did not show differences (all ps < .595).

2. General discussion

Peripersonal space is a dynamic space whose boundaries are influenced by endogenous and exogenous factors. In a previous experiment, Pellencin et al. (2018) suggested that the social perception of others influences surrounding space representation. Here, we aimed at extending prior findings by investigating whether changes in self-perception influence peripersonal boundaries. Among social constructs, we decided to manipulate self-perception in terms of experienced power. Our choice was based on previous studies showing a symbolic association between power and verticality (Duguid and Gontcalo, 2012; Schubert, 2005; Yap et al., 2013). The psychological experience of power, for example, has been linked to individuals’ self-perception and to the subjective sense of height: people perceived themselves as taller when they felt more powerful (Duguid and Gontcalo, 2012). Research on this topic, however, typically compared high power vs low power or neutral conditions (e.g. Duguid and Gontcalo, 2012; Hogeveen et al., 2014), thus preventing from disentangling whether the reported effects are specific to power manipulation or may due to a valence effect (i.e., induced positive self-perception). Actually, the experience of power not only induce participants to perceive more control, but also increases positive feelings and optimism about the future, promotes goal pursuit and makes individuals more prone to act (Anderson and Berdahl, 2002; Anderson and Galinsky, 2006; Burgmer and English, 2013; Cuddy et al., 2012; Galinsky et al., 2008; Guinote, 2007). Therefore, differently from previous studies, our research aimed at assessing whether self-perception can affect surrounding space representation and if this effect is specific for power or it is more generally linked to a positive valence experience. To deeper investigate this issue, we implemented an experimental paradigm with three experimental conditions: high power, low power, vs. general positive feeling. Changes in space representation were investigated by employing a neurophysiological implicit measure of this phenomenon, namely MEPs.

We first ran a preliminary experiment in which individual’s reaching distance was used as a rough index to characterize peripersonal space.
As previously reported, this is the first study contrasting power vs. positive valence, thus suggesting the need of a careful interpretation of prior research where the valence (or positive mood) was not considered.

In line with our interpretation, a recent work by D’Angelo et al. (2018), suggested that own sense of agency affected peripersonal space. In their task, the sense of agency was manipulated through a 3D virtual reality paradigm. More specifically, participants could move a 3D virtual hand using a motion controller positioned near the palm of the right hand. In the high agency condition, virtual hand movements were time locked to participants’ own movements, while in the low agency condition virtual hand movements had a 3-s delay as compared to participants’ movement. Authors showed an extension of peripersonal space after high agency compared to low agency training when virtual hand projected in the far space, in line with literature studying space modification due to tool use (e.g., Berti and Frassinetti, 2000).

Even if we did not directly test such hypothesis, it seems conceivable to assume that recalling a powerful or a positive experience (as compared to a powerless one) also increases our participants’ sense of agency. In this sense, our study generalized previous effect, showing that it is possible to induce changes in peripersonal space even when contingent visuo-motor feedbacks did not take place.

Our experimental procedure entailed the auditory presentation of motor vs. non-motor words to be associated to the pencil sharpener, in order to bring participants attention to it at the moment of TMS pulse delivery. In Study 1, an interaction between axis and type of word was found, which indicated that when distance was manipulated along the horizontal axis, MEPs were higher for motor vs perceptive words. However, such difference in MEPs disappeared for distance manipulation along the vertical dimension and the same result was replicated in Study 2. It is true that action-verbs as compared to nouns or abstract sentences are typically reported to induce corticospinal modulation. On the other hand, the direction of such modulation is less clear, with some research indicating MEP size decreasing for sentences expressing hand and foot actions compared to abstract sentences (Buccino et al., 2005) and others highlighting higher excitability for motor as compared to non-motor words (Gianelli and Dalla Volta, 2015; Innocenti et al., 2014).

Such heterogeneity in results can be explained by divergence in the TMS timing, namely the temporal interval between the onset of the stimulus and TMS pulse delivering (Papeo et al., 2009). Although the effect of the type of word was not the focus of the present work, we can

(for a discussion on this point see Noel et al., 2019). The findings confirmed the feasibility of inducing changes in corticospinal excitability through the distance manipulation of an object along the vertical space. Specifically, MEPs were higher when the pencil sharpener fell in the extrapersonal as compared to the peripersonal space, with the type of word (motor vs non-motor) not modulating such effect.

Using the same experimental setting of Study 1, in Study 2 we added a manipulation of self-perception: immediately before MEPs recording, individual’s self-perception was manipulated asking participants to recall an episode of their life in which they experienced either high power, low power, or a general positive feeling. The results showed that our self-perception manipulation was effective, with participants feeling more powerful in the high power than in the low power and positive condition. In a similar vein, participants assigned to the low power condition, felt less powerful than in the other two conditions.

In line with our prediction and with literature on embodied cognition, which associates power to verticality, MEPs results revealed that in high power condition the corticospinal excitability was comparable during the presentation of the pencil sharpener in vertical extrapersonal and peripersonal space. By contrast, the low power condition followed the same trend arose in Study 1 along the vertical axis, namely greater excitability when the object was in extra-as compared to peripersonal space. Moreover, in contrast with our hypothesis, results showed that not only in the high power, but also in the positive condition, MEPs did not differ between the peripersonal and extrapersonal space.

These findings are in line with prior work revealing a relation between the vertical dimension and a more general social goodness (e.g., Meier et al., 2004). Following this line, we interpreted these results as indicating that not only power, but other positive experience involving the self are able to induce a change in surrounding space representation that is traceable at the corticospinal level and arises from a remapping of peripersonal boundaries. In other words, in the high power and positive conditions, the pencil sharpener in the extrapersonal space was perceived as being in the peripersonal one due to a remapping of surrounding space representation, suggesting that such effect is induced by the positive valence of the manipulation more than by the power itself. As previously reported, this is the first study contrasting power vs positive valence modulation and our findings point out that the trigger inducing neurophysiological changes is not power per se but the positive valence, thus suggesting the need of a careful interpretation of prior research where the valence (or positive mood) was not considered.

In line with our interpretation, a recent work by D’Angelo et al. (2018), suggested that own sense of agency affected peripersonal space. In their task, the sense of agency was manipulated through a 3D virtual reality paradigm. More specifically, participants could move a 3D virtual hand using a motion controller positioned near the palm of the right hand. In the high agency condition, virtual hand movements were time locked to participants’ own movements, while in the low agency condition virtual hand movements had a 3-s delay as compared to participants’ movement. Authors showed an extension of peripersonal space after high agency compared to low agency training when virtual hand projected in the far space, in line with literature studying space modification due to tool use (e.g., Berti and Frassinetti, 2000).

Even if we did not directly test such hypothesis, it seems conceivable to assume that recalling a powerful or a positive experience (as compared to a powerless one) also increases our participants’ sense of agency. In this sense, our study generalized previous effect, showing that it is possible to induce changes in peripersonal space even when contingent visuo-motor feedbacks did not take place.

Our experimental procedure entailed the auditory presentation of motor vs. non-motor words to be associated to the pencil sharpener, in order to bring participants attention to it at the moment of TMS pulse delivery. In Study 1, an interaction between axis and type of word was found, which indicated that when distance was manipulated along the horizontal axis, MEPs were higher for motor vs perceptive words. However, such difference in MEPs disappeared for distance manipulation along the vertical dimension and the same result was replicated in Study 2. It is true that action-verbs as compared to nouns or abstract sentences are typically reported to induce corticospinal modulation. On the other hand, the direction of such modulation is less clear, with some research indicating MEP size decreasing for sentences expressing hand and foot actions compared to abstract sentences (Buccino et al., 2005) and others highlighting higher excitability for motor as compared to non-motor words (Gianelli and Dalla Volta, 2015; Innocenti et al., 2014).

Such heterogeneity in results can be explained by divergence in the TMS timing, namely the temporal interval between the onset of the stimulus and TMS pulse delivering (Papeo et al., 2009). Although the effect of the type of word was not the focus of the present work, we can
speculate that imagining actions for objects placed along the horizontal plane could be more ecological than on the vertical plane, thus influencing motor preparation for appetitive actions to reach and grasp the pencil sharper.

In conclusion, Study 1 represents the first attempt to investigate corticospinal excitability induced by object distance manipulation along the vertical dimension. To allow a comparison with previous works on affordances in peripersonal and extrapersonal space measured through corticospinal excitability, we implemented a horizontal manipulation of distance. Differently from prior work focusing on the horizontal space, we employed smaller distances between the different object positions (5 cm of inter-position intervals).

Our findings highlighted a dissociation between vertical vs horizontal perception and, in line with previous behavioural and physiological research, suggested a key role played by gravity underlying corticospinal modulation. Indeed, as argued in Study 1 discussion, our findings are compatible with both a freezing-like effect induced by objects which can potentially fall down vs a motor preparation, to defend themselves (vertical space) or to interact with objects (horizontal space). We acknowledge that our results are not conclusive in disentangling which mechanisms underlie our findings and that specific ad hoc further experiments are required to go deeper in this sense. In our lab we are currently working in this direction. However, explaining and fully understanding the mechanism underlying the different modulation induced by the vertical plane in comparison to the horizontal one falls outside the focus of the present study. The aim of study 1, indeed, was only to test the feasibility of modulating MEPs by changing object’s distances on the vertical space, in order to provide an empirical baseline for Study 2.

We employed the same paradigm in Study 2. Specifically, we aim at assessing whether a power experience would modulated peripersonal representation boundaries. In this study the main novel point was the implementation of a low power condition in addition to the power manipulation. Indeed prior work has tended to compare a power manipulation to a low power condition, thus preventing to disentangle whether behavioural effects are due to power per se or to a generally positive valence experience. Following our manipulation, both high power and positive conditions caused a change in peripersonal space representation as compared to the low power condition, which replicated Study 1 results. Based on these findings, future studies could expand this exploratory study applying the power manipulation in a within-subject design, in order to clarify whether the psychological mechanisms underlying the comparable outcome of power and of positive feeling manipulation are the same (association between Self and positive trait) rather than different (i.e., two different metaphors: tall = powerful; up = good). Indeed, as for the horizontal vs vertical manipulation, it is always difficult make comparisons between-subjects for MEPs, given their prominent variability at inter-individual level (Kiers et al., 1993; Magistris et al., 1998; Rosler et al., 2002; Cuypers et al., 2014). To minimize individual differences, however, we ran mixed models analyses which, by means of a by-subject intercept as random factor, was able to account for such variability (Baayen et al., 2008). Moreover, next studies could also extend a similar procedure to the horizontal space, following the idea that power could extend peripersonal space in all directions and not only along the vertical dimension (Fessler et al., 2012).

3. Limits of the present study

Although our work has some strengths, it also has some limitations. A key critical issue is the lack of a clear interpretation of the higher corticospinal excitability induced by the pencil sharpener presentation in the extrapersonal vertical space, which was found both in Study 1 and in the low power condition in Study 2.

Indeed, as argued in Study 1 discussion, we cannot disentangle whether this finding reflects an inhibition of corticospinal excitability for object presented in the peripersonal space vs a motor preparation to defend themselves from objects that being farer from participants can be more dangerous in terms of potentially hurting participants. We acknowledge that our results are not conclusive in revealing the mechanisms underlying our findings and that future work are required to go deeper in this sense. Even if we are unsure about the exact mechanism(s) driving our findings, the current set of studies provide a novel contribution on the interplay between self-perception and space representation.

CRediT authorship contribution statement

A. Vergallito: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. E. Lo Gerfo: Conceptualization, Writing - review & editing. E. Varoli: Conceptualization, Data curation, Writing - review & editing. M. Brambilla: Conceptualization, Writing - review & editing. S. Sacchi: Conceptualization, Writing - review & editing. S. Anzani: Data curation, Writing - review & editing. L.J. Romero Lauro: Conceptualization, Writing - original draft, Writing - review & editing, Supervision.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuropsychologia.2019.107224.

References