Action-specific remapping of peripersonal space

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A R T I C L E  I N F O

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Peripersonal space processing in monkeys’ brain relies on visuo-tactile neurons activated by objects near, not touching, the animal’s skin. Multisensory interplay in peripersonal space is now well documented also in humans, in brain damaged patients presenting cross-modal extinction as well as in healthy subjects and typically takes the form of stronger visuo-tactile interactions in peripersonal than far space. We recently showed in healthy humans the existence of a functional link between voluntary object-oriented actions (Grasping) and the multisensory coding of the space around us (as indexed by visual–tactile interaction). Here, we investigated whether performing different actions towards the same object implies differential modulations of peripersonal space. Healthy subjects were asked to either grasp or point towards a target object. In addition, they discriminated whether tactile stimuli were delivered on their right index finger (up), or thumb (down), while ignoring visual distractors. Visuo-tactile interaction was probed in baseline Static conditions (before the movement) and in dynamic conditions (action onset and execution). Results showed that, compared to the Static baseline both actions similarly strengthened visuo-tactile interaction at the action onset, when Grasping and Pointing were kinematically indistinguishable. Crucially, Grasping induced further enhancement than Pointing in the execution phase, i.e., when the two actions kinematically diverged. These findings reveal that performing actions induce a continuous remapping of the multisensory peripersonal space as a function of on-line sensory–motor requirements, thus supporting the hypothesis of a role for peripersonal space in the motor control of voluntary actions.

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1. Introduction

The representation of the space near the body, termed ‘peripersonal’ space (Rizzolatti, Fadiga, Fogassi, & Gallese, 1997; Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981), relies on multisensory processing both in human and non-human primates. In monkeys, bimodal neurons have been described in inferior parietal areas (Hyvärinen & Poranen, 1974) and premotor cortex (Duhamel, Colby, & Goldberg, 1998; Fogassi et al., 1996; Graziano & Cooke, 2006; Graziano & Gross, 1995). These neurons have the characteristics to be activated by visual as well as somatosensory stimulations with a higher activity for closer than farther visual stimuli. The activity of these cell assemblies across parieto-frontal and subcortical structures codes for tactile events on a body-part (e.g., the hand) and visual events near that body-part, thus giving rise to body-centred representations of peripersonal space (Gentilucci, Scandolara, Pigarev, & Rizzolatti, 1983; Rizzolatti et al., 1981, 1997; see for review Rizzolatti, Fogassi, & Gallese, 2002). In humans, a functionally homologous coding of peripersonal space is largely supported by behavioural studies, showing stronger visual–tactile interaction in near than far space in brain-damaged (Brozzoli, Demattè, Pavani, Frassinetti, & Farnè, 2006; di Pellegrino, L dáv as, & Farnè, 1997; Farnè, Demattè & L dá v as, 2005; Farnè, Pavani, Meneghello, & L dá v as, 2000; L dá v as & Farnè, 2004) and healthy individuals (Bremmer, Schlack, Duhamel, Graf, & Fink, 2001; Pavani & Castiello, 2004; Spence, Pavani, & Driver, 2004; Spence, Pavani, Maravita, & Holmes, 2004). The investigation in neurological patients, for example, revealed that visual events occurring in the immediate proximity to the body induce more severe visual–tactile extinction than farther events (Brozzoli et al., 2006; Farnè et al., 2000). Similarly, in healthy individuals, visual–tactile interaction has been shown to be stronger when visual information is presented close to the body than far from it (Spence, Pavani, & Driver, 2004; Spence, Pavani, Maravita, et al., 2004). In addition to behavioural evidence, recent functional neuroimaging and electrophysiological studies support the existence of similar multisensory integrative structures in the human brain (Bremmer, Schlack, Duhamel, et al., 2001;
Despite the large body of knowledge accumulated across species on the multisensory properties of peripersonal space, little is known about its function as this issue has been assessed in humans only recently (Brozzoli, Pavan, Urquizar, Cardinali, & Farnè, 2009; Cardinali, Brozzoli, & Farnè, 2009). Two not mutually exclusive hypotheses have been proposed on the basis of the neurophysiological findings in the monkey. By acting as an anticipatory sensorimotor interface, peripersonal space may serve early detection of potential threats approaching the body to drive involuntary defensive movements (Graziano & Cooke, 2006). The most direct evidence in favour of this hypothesis is the result of cortical stimulation studies. When multisensory areas where visuo-tactile neurons have been found (Graziano & Cooke, 2006) are electrically stimulated, a pattern of movements is elicited that is compatible with defensive arm movements and withdrawing of the arm or the head. Analogously, in humans, corticospinal excitability during motor preparation has been shown to be modulated by visually approaching objects in a hand-centred fashion (Makin et al., 2009).

The same anticipatory feature, however, may have also evolved to serve voluntary object-oriented actions (Gallelli, Kutz, Camperini, Breveglieri, & Fattori, 2003; Gardner, Babu, Reitzen, Ghosh, & Brown, 2007; Rizzolatti et al., 1981, 1997). In support to this view are the results of single units recording studies showing the motor properties of both parietal (Gardner et al., 2007; Hyvärinen & Poranen, 1974; Leinonen, 1980; Mout cascade, Lynch, Georgopoulos, Sakata, & Acuna, 1975) and periarcuate (Gentilucci et al., 1983; Rizzolatti & Gentilucci, 1988; Rizzolatti et al., 1981, 1987) visuo-tactile neurons. In particular, the visual sensory activation of bimodal neurons seems to be enhanced whenever a reaching movement is performed towards an object (Godschalk, Lemon, Kuyperes, & van der Steen, 1985). Such a parieto–frontal network would thus compute the sensory–motor transformations that allow a body-centred coding of space. This, in turn, could be useful for the execution of voluntary actions toward objects (e.g., Fogassi et al., 1992). Recently, we provided evidence in humans of an involvement of the peripersonal space representation in the execution of a Grasping (Brozzoli et al., 2009). When compared to a Static (no action) condition, the initiation of a Grasping movement increased the interaction between visual inputs originating from the to-be-grasped object and tactile inputs delivered to the Grasping hand. This action-dependent multisensory remapping was further enhanced during movement execution when the hand was brought towards the object, but still well before any hand-object contact. Notably, when the stimulated right hand remained still while the left (unstimulated) hand performed the same action these modulations of the multisensory interactions no longer emerged, suggesting that the observed effect was strictly hand-centred. These hand-centred effects of action on multisensory perception support the role of peripersonal space in voluntary object-oriented actions in humans.

In the present study, we took a step forward in the understanding of the functional link between peripersonal space coding and voluntary control of action by testing whether different object-oriented actions would induce different on-line modulations of multisensory coding of peripersonal space. We hypothesized that, if peripersonal space serves the control of voluntary object-oriented actions, action-dependent multisensory remapping should be more important whenever the action to be performed requires relatively more complex sensory–motor transformations. Two hand actions that differ clearly in this respect are reach–to-point and reach–to-grasp. When Pointing the hand (closed in a fist configuration) towards an object without touching it, the brain needs to take into account only object’s spatial position relative to the acting body-part (a so-called extrinsic object property; Jeannerod, 1986, 1988). In contrast, when Grasping the same object with the hand, the brain needs to take into account the spatial position of the target object with respect to the Grasping hand (extrinsic object properties), as well as the shape, size of the target object (intrinsic object properties; Jeannerod, 1986, 1988). In addition, because Grasping requires hand-object contact by definition, the intrinsic object properties determine the available landing surface for the fingers and the appropriate wrist orientation for achieving an optimal functional grip on the object. The pre-shaping of the hand (grip component) is smoothly implemented in the reaching phase (transport component), while the hand approaches the object (see Castiello, 2005, for a review). Therefore, while both Pointing and Grasping are composed by a reaching phase during which the hand is brought in the object’s vicinity, the two actions are substantially different in the final part of the movement, with additional sensorimotor transformations implemented selectively for Grasping movements. To test our prediction that action-dependent multisensory remapping is modulated as a function of the sensorimotor transformations complexity, we contrasted the visual–tactile effects produced by performing a relatively simple action (Pointing) with those produced by performing a more complex action (Grasping). In the former condition, participants were asked to reach a target object with their right hand without touching it, keeping a fist hand-configuration (with a closed index–thumb pinch–grip) along the entire movement. In the latter condition, participants reached and grasped the object using a precision grip with the same right hand. Kinematic recording was used to compare the reaching phase of both actions. Visual–tactile interaction was measured on-line in both conditions, by asking participants to discriminate the elevation of tactile stimuli delivered on either the index finger (up) or thumb (down) of the acting hand while ignoring visual distractors embedded into the target object.

2. Materials and methods
2.1. Participants
Sixteen neurologically healthy participants (8 male, mean age 25 year old, ±4) took part in the experiment. Participants had normal or corrected-to-normal visual acuity and reported normal tactile sensitivity. All participants gave their verbal informed consent to take part in this study, which was approved by the local INSERM U864 ethics board.

2.2. Apparatus
The target object was a wooden cylinder (7 cm height, 1.7 cm diameter) located at a distance of 47 cm from the starting position of the participant’s hands, at eye-level (Fig. 1a). Two red LEDs were used to present visual distractor stimuli. These were embedded into the cylinder, each at 1 cm from the cylinder’s extremities. Visual distractors consisted of a single flash (200 ms) from either the top or bottom LED embedded into the cylinder, delivered concurrently with the electro-cutaneous stimulation (see below). A dot (1 cm diameter) was marked in the center of the cylinder (between the two LEDs) to serve as visual fixation (Fig. 1a, upper circle). To ensure that subjects planned a new action on each trial, the cylinder was unpredictably rotated manually from behind the wooden panel into one of four different orientations: 18° or 36° from the vertical position, in clockwise or anti-clockwise directions, around the virtual axis perpendicular to the longitudinal axis of the cylinder and passing through the fixation point. Disposable neurology electrodes (700 15-K, Neuroline, Ambu) were used to present supra-threshold electro-cutaneous stimuli. Tactile target stimulation consisted of squared-wave single pulse (100 μs, 400 V) delivered through constant-current electrical stimulators (DST2 Digitimer Ltd., UK) either on the index finger (upper stimulation) or on the thumb (lower stimulation) surface of the right hand (Fig. 1a, lower circle). With respect to the classical studies adopting the cross-modal congruency task, here electrodes were fixated on the acting hand and stayed attached to it during the duration of the action movement. Electro-cutaneous target intensities were set individually for each subject and stimulated location, so that participants could detect 100% of the stimuli in a serie of ten trials for index finger and thumb [thumb mean current (s.e.m.) = 11.0 mA (0.6); index finger mean current 11.0 mA (0.5)]. Participants were instructed to respond to the tactile target as fast as possible by releasing one of two foot-pedals (Herga Electric Ltd., England). The real-time spatial position of the participant’s Grasping hand was recorded by means of an Optotrak 3020 sys-
Participants performed two concurrent tasks during each trial: the perceptual task (speeded tactile discrimination) and the motor task. Across blocks, the motor task consisted in Grasping the cylinder along its longitudinal axis with the index and thumb (precision grip, Fig. 1b, upper circle) or Pointing the closed hand towards the object (i.e., up or down) (Fig. 1b, lower circle). In this latter condition, participants were instructed to stop the movement in close vicinity of the object but avoid contact with it. Each trial started with an auditory warning signal. After a variable delay (1500–2200 ms) a second auditory signal constituted the GO for the motor task. The motor task was performed using the stimulated right hand in both the Pointing and Grasping blocks. Regardless of which action had to be performed, visuo-tactile stimulation was unpredictably delivered between trials: (1) before movement start (Static condition) or (2) at the beginning of the movement (action Start condition) or (3) during the execution of the movement (action Execution condition). At the beginning of each trial the tip of the thumb and the index finger of each hand were kept in a closed pinch-grip posture on the start-switches. Start-switch release was used to trigger the visuo-tactile stimulation in the Start (0 ms) and Execution condition (with a 200 ms delay). Each trial was started manually by the experimenter concealed behind the apparatus, after the dowel had been rotated into one of the four possible orientations.

3. Results

3.1. Multisensory remapping of space

In a first ANOVA analysis, we contrasted all four factors: Action (Grasping vs. Pointing), Phase (Static vs. Start vs. Execution), Object Orientation (Anti-Clockwise vs. Clockwise) and Stimulation (Congruent vs. Incongruent). Briefly, we found a highly significant main effect of Stimulation \( F(1,15) = 15.57, p < .001 \), confirming the presence of the typical cross-modal congruency effect (CCE, see Brozzoli et al., 2009; Spence, Pavan & Driver, 2004; Spence, Pavani, Maravita, et al., 2004): participants proved faster in responding to congruent (420 ms) than incongruent (469 ms) trials, with a similar pattern of results also for the accuracy score [95% for congruent vs. 85% for incongruent trials, \( F(1,15) = 17.61, p < .001 \)]. Hereafter, the dependent variable will thus be the CCE, calculated as the performance difference between incongruent and congruent trials, in that it quantifies the strength of the interaction between visual and tactile inputs. Unless otherwise specified, CCE will refer to the performance difference in terms of response times, which typically proved more sensitive in this type of experimental paradigms. However, we also examined the accuracy CCE (i.e., accuracy difference between congruent and incongruent trials) to exclude any speed-accuracy trade-offs. As a consequence, the following analyses only included Action (Grasping vs. Pointing), Phase (Static vs. Start vs. Execution) and Object Orientation (Anti-Clockwise vs. Clockwise) as variables.

A significant main effect of Phase \( F(2,30) = 16.18, p < .0001 \) showed the dependence of CCE on the phase of the action in which subjects received the visuo-tactile stimulation. As Fig. 2 (upper panel) shows, an increase of the CCE was observed as soon as the stimulated hand started the action: the CCE was stronger when visuo-tactile stimuli were delivered at action Start (55 ms) than in the Static condition (26 ms; \( p < .001 \), Newman–Keuls post hoc test). The increase of CCE was also observed during the execution phase of the action (66 ms; \( p < .01 \) with respect to the Static condition). The same effect was present in the accuracy CCE \( F(2,30) = 4.43, p < .05 \); 6% for the Static condition, 7% for the Start (\( p = .05 \) with respect to Static) and 9% for the Execution (\( p < .05 \) with respect to Static). Critically, the effect of the Phase was differently modulated as a function of the action that participants were performing, as witnessed by the significant Phase \( \times \) Action interaction \( F(2,30) = 6.19, p < .01 \) in the CCE (Fig. 2, upper panel). In the Grasping condition, the CCE increased significantly in the Start (55 ms) with respect to the Static condition (22 ms, \( p < .001 \)); and increased even further in the execution phase (79 ms, \( p < .001 \) with respect to Static and \( p < .01 \) with respect to Start condition). In the Pointing condition, the CCE was similarly increased in the Start (56 ms) with respect to the Static condition (29 ms, \( p < .01 \)), but no further increase was observed during the execution phase (53 ms, \( p < .01 \) only with respect to Static condition, see Fig. 2, upper panel). Finally, a direct comparison between the two types of action showed a signifi-
Fig. 2. Action-specific remapping of visuo-tactile interaction. (Upper panel) Means and standard errors are shown for the amplitude of the CCE as function of action phase. (Lower panel) Means and standard errors of the parameters of the reaching component for both actions: peaks of Acceleration (left part), Velocity (central part) and Deceleration (right part).

As expected, the two actions differed in the ending part of the reaching phase. As shown in Fig. 2 (lower panel), the deceleration peak was influenced by the kind of action as a main effect $[F(1,15) = 14.72, p < .01]$: when participants pointed to the object, their deceleration was more important (9668 mm/s²) than when...
they had to grasp it (8104 mm/s²). No modulation was observed for the Velocity and Acceleration Peaks of both Grasping and Pointing movements. The latencies of these kinematic peaks were only partially modulated by the different kinds of actions to be performed. Indeed, the kind of action impacted only on the Latency of Deceleration Peak, which occurred later in case of Pointing (434 ms) than in case of Grasping (424 ms) in all experimental conditions (p < .05 in all comparisons) with only two exceptions, where the same non-significant trend was present (movements towards anti-clockwise tilted object in the Start condition and movements toward clockwise tilted object in the Execution condition).

3.3. Influence of the perceptual task on kinematics

Movement kinematics was partially affected by the different temporal coupling between the motor task and visuo-tactile stimulation. The incongruent trials presented delayed latencies of Acceleration, Velocity and Deceleration Peaks when stimulation occurred in Static (145, 310 and 434 ms, respectively, for the three parameters) rather than Start (136, 305 and 423 ms, p < .05) or Execution (136, 304 and 428 ms, p < .05) conditions. This is witnessed by the significant Phase X Stimulation interactions for Acceleration [F(2,30) = 4.04, p < .05], Velocity [F(2,30) = 7.00, p < .01] and Deceleration [F(2,30) = 7.14, p < .01]. These modulations were present regardless of which action was performed, Grasping or Pointing. Among the peaks, only the Acceleration Peak showed to be marginally modulated by the stimulation [Phase X Stimulation interaction, F(2,30) = 4.45, p < .05]: in case of congruent trials, Acceleration Peak resulted more important when stimulation occurred before (Static condition, 9411 mm/s²) than on (Start condition, 9059 mm/s², p < .05) or after (Execution condition, 9101 mm/s², p < .05) the movement onset. Again, this effect was present both in case of Grasping and Pointing movements. No modulation was present for Velocity and Deceleration Peak as a function of the Stimulation. Finally, neither movement time nor motor reaction times resulted affected by the perceptual task (Table 1).

### Table 1

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4. Discussion

In a recent study we showed that, when performing an action, our brain updates the relationship between distal visual input and tactile information at the acting hand well before the hand contacts with the object (Brozzoli et al., 2009). This perceptual re-weighting occurs already at the very early stages of the action, when the hand has barely moved from its starting position. Furthermore, it is updated continuously as the action unfolds. This finding showed for the first time that the brain can update the interaction between initially separated visual and somatosensory inputs, as a function of the sensori–motor transformations required by the action itself and suggested a functional link between visuo-tactile peripersonal space and voluntary actions.

4.1. Action-specific remapping of peripersonal space

In the present study, we took one step forward and contrasted the effects of two different actions, Grasping and Pointing, on visual–tactile interaction to assess any specificity in the modulation of peripersonal space as a function of the required action. For both actions, the interaction between task-irrelevant visual information on the target object and the tactile information delivered on the acting hand increased already at action start, thus providing further support to our original observation (Brozzoli et al., 2009). However, a different updating of the visuo-tactile interplay took place during the execution phase of the two different actions. While in the Grasping action the magnitude of the CCE was further increased during the execution phase, in the Pointing action the visuo-tactile interaction did not present any further increase during execution with respect to movement onset. In other words, during the actual approaching phase of the movement, Grasping triggered stronger visual–tactile interaction than Pointing.

This finding adds to our previous results by revealing not only that a continuous updating of peripersonal space occurs during action execution, but also that this remapping varies with the characteristics of a given motor act. If (part of) the remap-
ping of peripersonal space is already effective at the onset of the motor program, the perceptual modulation can be either further enhanced in case of relatively complex object-oriented actions like Grasping, or kept unchanged in case of simpler Pointing actions. This on-line, motor-evoked “monitoring” of the action space opens the possibility of very fast modulations of the peripersonal space representation as a function of more ecological needs during actions execution. One could speculate that such rapid on-line updating, for instance, could parallel the fast, on-line motor corrections documented in motor control studies (Desmurget et al., 1999; Farnè et al., 2003; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991; Pisella et al., 2000). Since deficits of the so-called “automatic pilot” (Pisella et al., 2000) have been documented after lesions of the posterior parietal cortex in humans, as well as in healthy subjects after parietal TMS (Desmurget et al., 1999), one could suggest that the mechanism underlying the rapid remapping of peripersonal space could be damaged in these patients, thus depriving them from the “monitoring” of the action space. Ongoing research in our laboratory will help clarifying this hypothesis.

4.2. Peripersonal space remapping is selectively modified by specific kinematic patterns

The second main finding of the present study is that the kinematic results appeared remarkably associated with the perceptual modifications. We directly compared the transport component of the Pointing and Grasping actions. The overall kinematic structure of either Pointing or Grasping was not disrupted by the concurrent perceptual task. Whenever the tactile task affected some movement parameters both types of movement were affected similarly, thus showing that the visuo-tactile task did not differentially affect the kinematic pattern of Pointing and Grasping actions. Crucially, however, the opposite was not true, in that different kinematic patterns between Pointing and Grasping had a clear impact on the visuo-tactile task, which we used as a proxy of peripersonal space remapping. The only substantial difference appeared towards the end of the reaching component of the movement, during the deceleration phase. Namely, when subjects pointed towards the object, they needed to decelerate more than when they grasped it. This difference reflects the need for the subject to stop the movement before the collision with the object, with respect to the Grasping, where deceleration is weaker due to the need of achieving a stable grip when the fingers contact the target. It is to worth noting the parallel between the kinematic evolution of the two actions and the perceptual modulation of the visuo-tactile interaction. When the visuo-tactile interplay was assessed in the phase of the movement that did not present kinematic differences between Pointing and Grasping (i.e., start phase), a similar remapping of peripersonal space was found across the two different actions. By contrast, when the visuo-tactile interaction was assessed in the execution phase, i.e., when Pointing and Grasping differ from a kinematic point of view, the peripersonal space was also differently remapped. This parallel between the perceptual and the motor behaviour strengthens our proposal of a link between multisensory peripersonal space representation and the execution of voluntary actions. Moreover, the kinematic results allow us ruling out the possibility that peripersonal space remapping might be induced by the relative approaching velocity of hand and object. Indeed, the visual receptive fields of monkeys’ bimodal neurons have been shown to present dynamic modifications depending on the velocity of an object approaching the corresponding tactile receptive field on the body (Fogassi et al., 1996). Thus, it would in principle be possible that the different increase of visuo-tactile interaction observed as a function of the required action might reflect differences in hand velocity between types of movement. However, no significant difference was observed between Grasping and Pointing velocities, with instead a tendency for the peak to be higher in the Pointing with respect to the Grasping action. If the perceptual remapping reported here were due to on the object’s approaching velocity, we should expect higher visuo-tactile interactions in case of Pointing rather than in the Grasping. Instead, the opposite was observed, clearly supporting the notion that the remapping of peripersonal space we reported in this study is induced by the execution of a voluntary action towards the object and can be modified on-line as a function of the action requirements.

This functional role is not (see Brozzoli et al., 2009) in contrast with the view that peripersonal multisensory space serves involuntary defensive re-actions in response to objects approaching the body (Graziano & Cooke, 2006; Graziano & Gross, 1995; Makin et al., 2009). However, here we considerably add to this view by showing that in humans such multisensory–motor interfaces may be functionally involved in voluntary control of actions that bring the body towards objects. In particular, the present findings show a specific sensitivity of the peripersonal space to the kind of sensory–motor transformation that is required to execute an action. This fits well with the functional properties of visuo-tactile neurons documented in parieto-frontal circuits in the monkey, which code for peripersonal space. These neurons present spatially organised visual and tactile receptive fields (Avillac, Denève, Olivier, Pouget, & Duhamel, 2005; Duhamel et al., 1998; Fogassi et al., 1996; Graziano, 1999; Graziano & Gross, 1995; Rizzolatti et al., 1981, 1997) allowing this bimodal circuitry to represent an object in a coordinate system centred on the body and to be continuously updated during bodily movements. Indeed, some bimodal neurons also respond when the arm is voluntarily moved within the reaching space (Fattori, Kutz, Brevgliere, Marzocchi, & Galletti, 2005; Galletti et al., 2003; Gardner et al., 2007; Gentilucci, Fogassi, Luppino, Matelli, & Camarda, 1988; Marzocchi, Brevgliere, Galletti, & Fattori, 2008) and have been previously proposed to code goal-directed actions (Gentilucci et al., 1988; Rizzolatti et al., 1981, 1997). Neurophysiological studies in monkeys have additionally shown activation in the posterior parietal cortex during a Grasping movement, in the early phase of the action, when the hand has not yet reached the object. This activation gradually shifts towards the somatosensory cortex when the hand enters in contact with the object (Gardner et al., 2007). The on-line enlargement of the visual receptive fields of bimodal neurons in response to approaching objects (Graziano & Gross, 1995) or tool-use (Berti & Frassinetti, 2000; Bonifazi, Farnè, Rinaldesi, & Làdavas, 2007; Farnè, Bonifazi & Làdavas, 2005; Farnè, Iriki & Làdavas, 2005; Farnè, Serino & Làdavas, 2005; Holmes & Spence, 2004; Iriki, Tanaka, & Iwamura, 1996; Maravita, Spence, & Driver, 2003) converge in supporting the involvement of the bimodal system in the updating of the peripersonal space representation in dynamic conditions.

In conclusion, this study provides evidence that voluntarily acting on objects triggers specific remapping of multisensory perception as a function of action requirements, as specified possibly by the motor complexity alone, or its coupling with spatial information about the target object. Future studies will ascertain whether such a remapping mainly depends upon intrinsic (vs. extrinsic) properties, or reach-to-grasp (vs. reach only) components of movement. Most important at this stage is the fact that by showing that such a remapping is similar when action starts, but differs according to the differential kinematics of Grasping and Pointing during execution, we additionally demonstrate that action-dependent remapping of space is regulated in real-time and linked to the kinematic characteristics of the action. The multisensory–motor neural machinery acting as an anticipatory interface between the body and nearby events may thus have been selected throughout evolu-
tion to drive voluntary approaching movements via a continuous monitoring of action space.

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