Available online at www.sciencedirect.com
ScienceDirect

Cognition 104 (2007) 73–88

COGNITION

www.elsevier.com/locate/COGNIT

Self-attributed body-shadows modulate tactile attention ☆

Francesco Pavani [a,b,*], Giovanni Galfano [c]

[a] *Department of Cognitive Science and Education, University of Trento, via Matteo del Ben 5/b, 38068 Rovereto, Italy*
[b] *Center for Brain/Mind Sciences, University of Trento, Corso Bettini 31, 38068 Rovereto, Italy*
[c] *Department of Developmental Psychology, University of Padua, via Venezia 8, 35131, Padua, Italy*

Received 16 January 2006; revised 11 May 2006; accepted 20 May 2006

Abstract

Our body-shadows are special stimuli in the visual world. They often have anatomical resemblance with our own body-parts and move as our body moves, with spatio-temporal correlation. Here, we show that self-attributed body-shadows cue attention to the body-part they refer to, rather than the location they occupy. Using speeded spatial discrimination for tactile or visual targets at the hands, or for visual targets delivered near the hand-shadows, we demonstrate that mere viewing of task-irrelevant shadows can selectively facilitate tactile discrimination at the body-part casting the shadow (Experiment 1). In addition, such facilitation only develops through time for cast-shadows that have no resemblance with the body-part, but move in spatio-temporal correlation with it (Experiment 2). Conversely, facilitation fades away rapidly for shadow-like images that resemble the stimulated body-part, but are in fact static pictures (Experiment 3). Thus, recognising oneself as the owner of a shadow affects distribution of tactile attention.

Keywords: Body-schema; Body-image; Shadow; Spatial attention; Multisensory; Touch

---

☆ This manuscript was accepted under the editorship of Jacques Mehler.
[*] Corresponding author.
E-mail address: francesco.pavani@unitn.it (F. Pavani).

0010-0277/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.cognition.2006.05.007

1. Introduction

In daily life, shadows are a constant feature of our visual world. Shadows on the surface of objects modify their appearance and provide critical information about their shape, while projected or cast shadows give important cues as to the relative location of objects in the scene (for review see Mamassian, Knill, & Kersten, 1998). Recent years have witnessed a renewed interest for the influence of cast shadows in visual perception, with research showing that cast shadows can change the perceived layout of scenes (Allen, 1999) as well as the perceived trajectory of moving objects (Kersten, Knill, Mamassian, & Bulthoff, 1996; Kersten, Mamassian, & Knill, 1997), their shape identification (e.g., Castiello, 2001) and the trajectory of grasping movements executed towards them (Bonfiglioli, Pavani, & Castiello, 2004).

Our own body also casts shadows in the environment. However, a number of distinct features make our own body-shadows a unique visual stimulus, that should be considered in its own right. Body-shadows not only refer to a location in space different from the one they physically occupy (a feature shared with all cast shadows), they are also visual stimuli in the world that refer to a location (a part of our own body) for which we have interoceptive experience. In addition, body-shadows often have anatomical resemblance with parts of our own body and move as our own body moves, with spatio-temporal correlation. In this respect, body-shadows are visual stimuli that could play a critical role in the consolidation of our perceived image of body shape and extension (the so called body image), in the definition of the internal representation of our own body boundaries and kinematics (the body schema), and more generally in the crucial task of self-recognition.

Pavani and Castiello (2004) were the first to address the special role of body-shadows in relation with the body schema, using a visuo-tactile interference task (e.g., Pavani, Spence, & Driver, 2000; Spence, Pavani, Maravita, & Holmes, 2004). With such a paradigm, robust evidence has been reported that a task-irrelevant visual stimulus presented near a tactually stimulated hand significantly hampers tactile localization performance when it is spatially incongruent with the tactile target location. In the study by Pavani and Castiello (2004), distracting visual stimuli were always presented 30 cm away from the hands but in the vicinity of the shadow cast by one of the two hands, while tactile targets were delivered either to the hand casting the shadow or to the other hand. Participants were instructed to localise tactile stimuli at the hands, and ignore all visual events (i.e., visual distractors and cast shadows). Despite visual distractors being equidistant to either hand, the results showed systematically larger visuo-tactile interference when tactile targets were delivered to the hand casting the shadow compared to when they were presented at the other hand. Such modulation of visuo-tactile interference did not emerge when participants wore polygonal shaped gloves that cast an un-natural hand-shadow, or when participants viewed the static outline of either the stimulated or unstimulated hand in front of them. Pavani and Castiello (2004) argued that natural shadows may favour the binding between personal and extra-personal space, and possibly modify the perceived image of the body shape and extension.

The existence of such links between body parts and their corresponding cast shadows suggests that body-shadows may also act as a powerful visual cue for orienting attention towards the body. Galfano and Pavani (2005) provided initial evidence in support of this hypothesis, using a modified version of the classic exogenous cueing paradigm (e.g., Posner & Cohen, 1984; see Spence & McGlone, 2001, for an example in the tactile modality; see Kennett, Spence, & Driver, 2002, for a visuo-tactile example). Participants were instructed to perform a speeded spatial discrimination task for tactile stimuli delivered to one of the two hands, while seeing the shadow of the right or left hand cast unpredictably in front of them, to the right or left of visual fixation respectively. Despite shadows being totally task irrelevant, and were presented long before (1750 ms) the tactile targets, results showed faster and more accurate tactile discrimination at the hand casting the shadow than at the other hand. In other words, even without any lateralised exogenous stimulus cueing target side *shortly* before target onset, nor any *strategic reason* to orient attentional resources towards the hand casting the shadow, cast shadows biased orienting of attention. In addition, similar to Pavani and Castiello (2004), such orienting of attention was less reliable when the hand-shadow was replaced by the cast shadow of an object with polygonal shape.

This initial observation by Galfano and Pavani (2005) raised at least two major issues. First, do body-shadows cue attention to the entire portion of visual space they occupy or instead operate more selectively, directing attention just to the hand casting the shadow? In other words, it would be critical to establish whether body-shadows cue the location they physically occupy as well as the location they refer to, or instead act selectively as a cue for the body-parts casting the shadow. Second, to what extent self-recognition through body-shadows plays a role in the observed attentional orienting phenomenon? In this respect, it would be important to manipulate information that may normally contribute to self-recognition through body-shadows, such as visual cues of similarity that concur to the sense of ownership, and spatio-temporal cues that concur to the sense of authorship (see Jeannerod, 2003).

The series of experiments presented here was designed to address these unresolved issues. To examine the first issue (i.e., whether shadows cue the location they occupy in addition to the location they refer to), we modified the original paradigm of Galfano and Pavani (2005) to include, in addition to tactile targets at the hands, visual targets delivered in the vicinity of the hand-shadows (but far from the hands), and visual targets delivered near the hands (but far from the hand-shadows). If body-shadows cue the location they physically occupy as well as the location they refer to, better performance in the discrimination task should emerge regardless of target location and modality. By contrast, if body-shadows act specifically as a cue for the body part casting the shadow, discrimination performance should improve only for targets at the hands.

To address the second issue (i.e., the role of self-recognition through body-shadows), we devised three separate experimental conditions. In Experiment 1 (real shadows with natural shape), participants viewed the real, un-modified shadows of their hands cast on the table surface in front of them. In Experiment 2 (real shadows with unnatural shape), participants wore polygonally shaped gloves on the hands that resulted in cast shadows that were spatio-temporally correlated with all hand movements the participant made, but had no resemblance with the natural shape of a hand. In Experiment 3 (fake-shadows with natural shape), participants viewed shadow-like images, that resembled in shape and colour the natural shadows cast by their hands, but were in fact static photographs projected from above the table surface. Thus, while in Experiment 1 we favoured self-recognition both through visual similarity and through spatio-temporal correlation between the hands and their shadows, in Experiments 2 and 3 we manipulated these two aspects independently.

2. General methods

2.1. Participants

Forty-two undergraduates students at the University of Trento participated in the study (Experiment 1: 6 males and 8 females; mean age 22 years, SD 3; all right-handed by self-report; Experiment 2: 10 males and 4 females; mean age 25 years, SD 2; two left-handed by self-report; Experiment 3: 7 males and 7 females; mean age 21 years, SD 1). All were unaware of the purpose of the experiment, gave their informed consent and had normal or corrected-to-normal vision. The study was conducted in accordance with the guidelines of the Declaration of Helsinki and after approval by the Ethical Committee at the Department of Cognitive Sciences and Education of the University of Trento.

2.2. Apparatus and stimuli

All experiments were conducted in a darkened room. Participants sat in front of a table with their chin on a chinrest. Their forearms laid on two slanted supports made of polystyrene and cardboard (33.5 cm in width, 14.5 cm in length, and 15.5 cm in height) attached to the tabletop and separated by 40 cm. It is important to note that forearms rested on these supports only up to the wrist, leaving the hands unsupported. This served two aims: first, a full shadow of the hand could be projected on the table surface in Experiments 1 and 2; second, it resulted in constant small adjustments of hand posture in all experiments, to keep the requested hand position throughout each block of trials (see Section 2.3). These repeated posture adjustments, mainly involving wrist movements, were critical to evoke a sense of agency in Experiments 1 and 2, and disrupt it in Experiment 3.

A green light emitting diode (LED) attached to the table-top at 26 cm from the chinrest and along the participants' mid-sagittal plane served as the visual fixation point. Four red LEDs were also attached to the table-top, at the vertex of an imaginary square with sides of 14 cm, centred on visual fixation (see Fig. 1). These red LEDs served as visual targets near the shadows (either real or fake), and were switched on separately for 50 ms when needed. All LEDs on table-top were covered by a large (92 cm in length, 65 cm in width) sheet of white paper, and became visible only when lit.

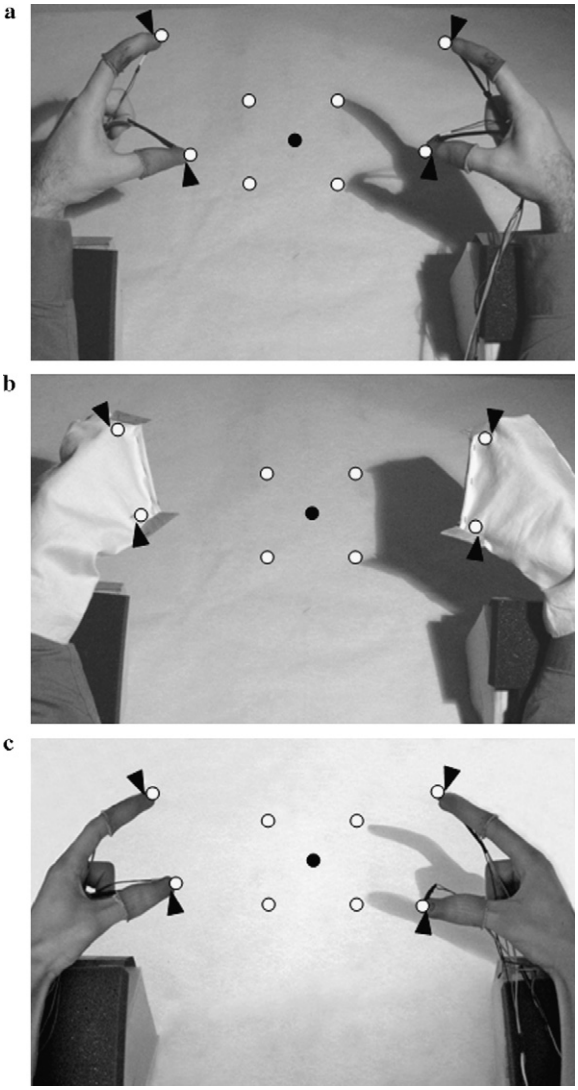

Fig. 1. Schematic view of the experimental set-up, as seen from the participant's perspective in (a) Experiment 1 (real shadow), (b) Experiment 2 (real shadow with un-natural shape), (c) Experiment 3 (fake-shadow with natural shape). White circles indicate all possible positions of visual targets; black triangles all possible positions of tactile targets; black circle indicates fixation.

Participants wore a fitting cotton-silicon sheath on thumb and index finger of each hand. A miniature tapper (MST2, 7.5 × 12 mm, www.byed.co.uk/sol) was placed inside each sheath, in contact with each finger-tip, whereas a red LED was placed outside each sheath, oriented towards the participant. Single 50 ms pulses delivered separately at the four finger-tips served as tactile targets, whereas single 50 ms flashes delivered separately at the four LEDs served as visual targets near the hand. Connecting wires for tappers and LEDs poked through the closed end of the sheath, and were fixed at the wrist with rubber-bands.

In Experiment 1, two desk lamps with three-joint arms were placed on either side of the table, in front of participants. Each lamp mounted a 100 W fluorescent light-bulb, which was suspended at 80 cm from the table top and 58 cm to the left and right with respect to the participants' mid-sagittal plane. These served as light-sources for casting the real shadows of participants' hands on the table surface (Fig. 1a).

In Experiment 2, illumination conditions were identical to Experiment 1, but participants wore flexible shaped-gloves made of cotton-fabric and cardboard on both hands, throughout the experiment. Two cardboard triangles were stapled on each glove and participants were asked to place their index finger and thumb in contact with these cardboard structures. When thumb and index fingers were opened wide apart inside the flexible gloves and were in contact with the cardboard triangles, a stable polygonal shadow was projected on the table surface (Fig. 1b). Note that the cardboard triangles also served two additional purposes: first, they ensured that participants maintained inside the gloves a separation between index finger and thumb comparable to that adopted in Experiment 1, even in the absence of visual information as to finger posture. Second, the clearly identifiable shape of the triangles on the cast shadow allowed participants to align each glove's shadow with the LEDs on the table surface, in a similar fashion to Experiment 1. LEDs at the hands were arranged to poke through holes in each glove.

In Experiment 3, desk lamps were removed as no real shadow was cast in front of participants. Instead fake hand-shadow images were projected on the table surface using an LCD projector (PLUS Data Projector, V-807), suspended at 120 cm above the table with a tripod. Participants were presented with photographs of either a left or a right hand-shadow, carefully edited and placed on the table-top to mimic as much as possible the natural body-shadow that was projected on the table surface during Experiment 1 (Fig. 1c). Thus, just as for real cast-shadows, images were always projected on the ipsilateral visual hemifield as the hand they referred to (i.e., the photograph of the left hand-shadow appeared in left hemispace with respect to fixation, while the photograph of the right hand-shadow appeared in right hemispace), and stretched from the hands towards the LEDs on the table surface.

Tactile stimulators, LEDs, lamps, the LCD projector and two foot-pedals for response collection were interfaced with an IBM compatible Pentium II Computer, equipped with an IO digital acquisition card (DAQ-DIO-24, National Instruments). Custom software written using Cogent libraries (http://www.vislab.ucl.ac.uk/Cogent/) was used for controlling the timing of events and recording both reaction times (RTs) and accuracy.

2.3. Procedure

Before the experiment started, all participants performed two miniblocks composed of four trials each, in which only tactile targets were presented. In case participants reported feeling large subjective differences in the intensity of the four tactile stimulations, the sheaths were removed, adjusted, and positioned again on the four fingers, and the miniblocks were repeated. Participants then performed one practice block of sixteen trials before proceeding into the experimental blocks.

In Experiments 1 and 2, at the beginning of each practice and experimental block, shadows of both hands were cast on the table surface and all LEDs on table top were illuminated. Participants were then instructed to adopt a posture such that the cast shadow of their index fingers could overlap spatially with the red LED at the furthest vertexes of the imaginary square centred on visual fixation, and the cast shadow of their thumbs could overlap with the red LED at the vertexes nearest to them (see Fig. 1a and b). When keeping such a position, visual targets at the furthest vertexes of the imaginary square and visual targets at the index finger of each hand appeared above visual fixation, as seen from the participants' view point. By contrast, visual targets at the vertexes nearest participants and visual targets at the thumb of each hand appeared below visual fixation. Subsequently, only one of the two lamps was turned on during each trial.

In Experiment 3, at the beginning of each practice and experimental block, photographs of both hand-shadows were shown simultaneously and all LEDs on table top were illuminated. Participants were then instructed to adopt with their own hands a posture that could have resulted in a shadow like the one they were presented with. This instruction was usually enough for participants to adopt a posture comparable with that used in Experiment 1; however, when needed, the experimenter inside the room helped participants to mimic the desired hand-posture. Subsequently, only one of the two hand-shadow photographs was presented during each trial.

Practice and experimental trials always started with participants depressing two foot-pedals located respectively under the toe and heel of their right foot. When this instruction was accomplished, the shadow of one of the two hands was presented on table surface through illumination of one of the two lamps (Experiments 1 and 2), or the static image of one of the two hand-shadow photographs appeared (Experiment 3). After 1000 ms visual fixation was turned-on, and after additional 1750 ms either a tactile target, a visual stimulus near the hand or a visual stimulus near the shadow was presented. Participants were instructed to raise their toe in response to visual targets above fixation or tactile targets at the index fingers, and their heel in response to visual targets below fixation or tactile targets at the thumbs (note that tactile targets at the index fingers appeared above fixation as seen from the participants' viewpoint, whereas tactile target at the thumbs appeared below fixation). Participants were instructed to react as fast and accurately as possible. Feedback was provided only for errors (wrong foot-pedal releases or no response within 1500 ms) and consisted of two brief flashes of the fixation LED. The intertrial interval was 1000 ms. Participants were invited to take short breaks between blocks.

All participants were explicitly informed at the beginning of the experiment that shadows or shadow-like images were not informative with regard to either target modality or target location, and were instructed to ignore them as much as possible. In addition, they were strongly encouraged to maintain the posture acquired at the beginning of each block throughout the series of trials, and to keep their eyes at fixation. The experimenter remained in the room where the experiment took place in order to ensure that participants accorded with these instructions.

2.4. Design

In each experiment, participants were tested in a 3 × 2 factorial design. The first factor was Stimulus Type (tactile, visual near hand, visual near shadow). The second factor was Validity of cueing (valid vs. invalid). We adopt the latter terminology because our paradigm can be seen as a modified version of the classic exogenous cueing paradigm. Visual or tactile target at the hand casting the shadow, as well as visual targets on table-top near the cast shadow constituted 'valid' trials; whereas visual or tactile target at the hand not casting the shadow, as well as visual targets at the table top but contralateral to the cast shadow constituted 'invalid' trials. The total number of trials was 384, divided into 4 experimental blocks of 96 trials each. In each block, there were 32 trials (16 valid and 16 invalid trials) for each stimulus type, equiprobable at the possible target locations. Shadow side, target location and target modality were totally unpredictable in each trial.

For all experiments, trials were arranged within each block in pseudo-random order, with 4 complete replications of all experimental conditions every 24 trials. This allowed for later analysis of 4 discrete but, statistically comparable, epochs within each experimental block to examine whether any cueing effect elicited by body-shadows changed across time. A first indication that changes across time may indeed occur emerged from post-hoc analysis in the study by Galfano and Pavani (2005, footnote 1).

3. Results

Preliminary examination of the data sets revealed no serious violations of the assumptions for the parametric tests used in the statistical analyses. In all the analyses reported below, when appropriate, the α level was adjusted for the number of comparisons according to the False Discovery Rate (Benjamini & Hochberg, 1995). In all experiments, RTs for correct responses above or below 2.5 standard deviations from the mean were trimmed. This resulted in the removal of 1%, 4% and 1% of data in Experiments 1, 2 and 3, respectively. For each experiment, filtered RT data and percentage of errors were separately entered into a two-way repeated measures ANOVA with Stimulus Type (visual near hand, visual near shadow and tactile) and Validity of cueing (valid vs. invalid) as factors. Mean RTs and percent errors for each experiment are reported in Table 1 as a function of Stimulus Type and Validity of Cueing. For completeness Table 1 also report Inverse Efficiency (IE) scores, i.e., a standard way to combine RT and accuracy scores to characterize performance using a single score. Following indications put forward by previous studies, we calculated IE as the mean RT divided by the proportion of correct trials (e.g., Spence, Kettenmann, Kobal, & McGlone, 2001; Townsend & Ashby, 1983).

3.1. Experiment 1: Real hand-shadows with natural shape

The ANOVA on RTs revealed no main effect of Validity of cueing ($F < 1$), but a significant main effect of Stimulus Type, $F(2,26) = 14.0$, $p < 0.0001$. This was caused by longer RTs for visual stimuli near the hands ($M = 573$ ms, SE = 18) than visual

Table 1
Mean reaction times (in ms), percentage errors and inverse efficiency scores for valid and invalid trials as a function of stimulus type in the three experiments

	Tactile targets		Visual targets near hands		Visual targets near shadows	
	Valid	Invalid	Valid	Invalid	Valid	Invalid
Experiment 1 (real shadows)						
RT (SE)	515 (13)	531 (14)	579 (22)	567 (15)	535 (12)	535 (13)
% Errors (SE)	1.1 (0.4)	2.0 (0.4)	3.2 (0.8)	2.0 (0.8)	1.1 (0.4)	1.1 (0.3)
Inverse efficiency scores (SE)	521 (13)	542 (15)	598 (23)	580 (18)	541 (11)	542 (14)
Experiment 2 (real shadows with un-natural shape)						
RT (SE)	576 (23)	570 (23)	668 (36)	679 (35)	580 (21)	571 (19)
% Errors (SE)	1.9 (0.6)	2.1 (0.7)	2.0 (0.6)	1.9 (0.5)	2.1 (0.8)	0.8 (0.3)
Inverse efficiency scores (SE)	587 (23)	582 (24)	684 (40)	694 (37)	594 (23)	576 (20)
Experiment 3 (fake shadows, with natural shape)						
RT (SE)	537 (21)	538 (20)	565 (21)	569 (22)	559 (18)	560 (19)
% Errors (SE)	1.1 (0.4)	1.4 (0.5)	1.1 (0.3)	1.1 (0.3)	1.7 (0.5)	1.4 (0.3)
Inverse efficiency scores (SE)	542 (20)	545 (19)	571 (22)	575 (22)	569 (18)	567 (19)

Standard errors are indicated in parenthesis.

stimuli near the shadow ($M = 535$ ms, SE = 12; $t(13) = 4.13$, $p < 0.001$) or tactile stimuli ($M = 523$ ms, SE = 14; $t(13) = 4.33$, $p < 0.001$). Such difference likely reflects the larger eccentricity of visual targets near the hands as compared to visual targets near the shadow, which was the direct consequence of the hand posture we imposed on participants to obtain the desired geometry of light sources and cast-shadows locations (see Fig. 1a). More important for the purpose of the study, the analysis also revealed a significant Validity of cueing × Stimulus Type interaction, $F(2,26) = 3.4$, $p < 0.05$. Discrimination RTs were significantly faster in valid (M = 515 ms, SE = 13) than invalid trials ($M = 531$ ms, SE = 14; $t(13) = 3.07$, $p < 0.01$), selectively for tactile targets. Instead, no difference between valid and invalid conditions emerged for visual targets near the shadows ($t(13) = 0.1$, n.s., see Table 1) or for visual target near the hands ($t(13) = 1.14$, n.s., see Table 1).

A similar analysis on percentage of errors (overall errors 1.8%) only revealed a significant main effect of Stimulus Type, $F(2,26) = 4.94$, $p < 0.02$. This was caused by more errors for visual targets near the hands ($M = 2.6\%$, SE = 0.6) than visual targets near the shadow ($M = 1.1\%$, SE = 0.2, $t(13) = 2.66$, $p < 0.02$), presumably reflecting again the larger visual eccentricity of visual targets near the hands. Percentage errors for tactile targets ($M = 1.6\%$, SE = 0.4) did not differ statistically from percentage errors in either of the visual conditions.

3.2. Experiment 2: Real hand-shadow with unnatural shape

Unlike Experiment 1, the ANOVA on RTs revealed no significant main effect of Validity of cueing, $F(1,13) = 0.1$, or interaction between Validity of cueing and Stimulus Type, $F(2,26) = 1.9$. Instead, a significant main effect of Stimulus Type emerged again, $F(2,26) = 17.6$, $p < 0.0001$, caused by longer RTs for visual stimuli near the hands ($M = 674$ ms, SE = 35) than visual stimuli near the shadows ($M = 576$ ms, SE = 20; $t(13) = 4.22$, $p < 0.001$) or tactile stimuli ($M = 572$ ms, SE = 23; $t(13) = 4.44$, $p < 0.001$). A similar ANOVA on percentage of errors revealed no significant sources of variance (all Fs < 2.2; overall errors 1.8%).

3.3. Experiment 3: Fake hand-shadows with natural shape

As for Experiment 2, the ANOVA on RTs revealed no significant main effect of Validity of cueing nor a significant Validity of cueing × Stimulus Type interaction (both Fs < 1). A significant main effect of Stimulus Type emerged, $F(2,26) = 6.8$, $p < 0.004$, caused by longer RTs for visual stimuli near the hands ($M = 567$ ms, SE = 22) and visual stimuli near the static shadow-like images ($M = 560$ ms, SE = 18) than for tactile stimuli ($M = 538$ ms, SE = 21; $t(13) = 3.25$, $p < 0.006$ and $t(13) = 2.42$, $p < 0.03$, respectively). A similar ANOVA on percentage of errors revealed no significant sources of variance (all Fs < 1).

In sum, a significant effect of Validity of cueing emerged only for Experiment 1, selectively for tactile targets, whereas Validity of cueing did not affect overall performance in Experiments 2 and 3 for neither tactile of visual targets. This pattern was confirmed statistically by means of a mixed ANOVA with Stimulus Type and Validity of cueing as within-participants factors, and Experiment as between-participants factor. As expected, this ANOVA revealed a significant three-way interaction, $F(4,78) = 3.11$, $p < 0.02$.

3.4. Changes in validity of cueing effects across time

Having established that overall validity of cueing effect for touch emerged only when real hand-shadows were used, we turned to address whether such effect might have changed as a function of time during the experimental blocks. This question is particularly relevant for Experiments 2 and 3, in which resemblance and spatio-temporal correlation between the shadow stimulus and the hand were dissociated. In particular, since small but repeated posture adjustments of the hands did indeed occur during the experiments (as a result of the hands being supported only up until the wrist), self-attribution of the hand-shadows with un-natural shape used in Experiment 2 could have developed through time, by a sense of agency. Conversely, self-attribution for the fake hand-shadow with natural shape used in Experiment 3, could have faded through time, given the probable absence of any sense of agency for the static image.

To address these possibilities we re-examined our data for Experiments 1–3 to compare validity of cueing effects for tactile stimuli at four different epochs during the blocks. To this aim, for each experiment, we pooled together data from the first 24 trials of each block (trials 1–24), and repeated the same procedure with data from the second (trials 25–48), third (trials 49–72) and fourth (trials 73–96) set of 24 trials. For each of these new dataset, we next computed Inverse Efficiency scores as a measure of performance in valid and invalid trials. Finally, we subtracted IE scores in invalid and valid trials to obtain measures of validity of cueing at each epoch (see Fig. 2).

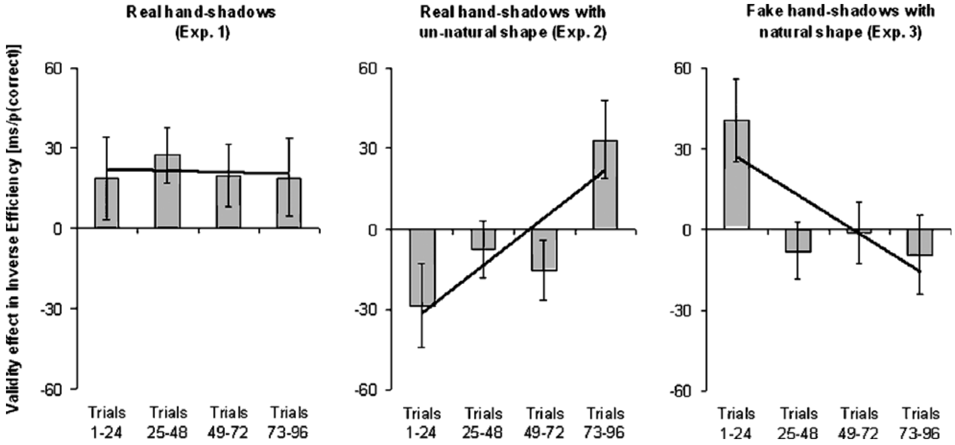

Fig. 2. Validity of cueing effect measured in inverse efficiency (IE) in the three Experiments, as a function of Epoch (see text). Positive values indicate better performance in valid than invalid trials, suggesting attentional orienting effects. Best linear fit for each of the data set are also shown.

Validity of cueing effects calculated with this procedure were entered in a mixed ANOVA with Epoch as within-participant factor, and Experiment as between-participant factor. This ANOVA revealed a significant main effect of Experiment, $F(2,39) = 5.07$, $p < 0.01$, and more importantly a significant interaction between Experiment and Epoch, $F(2,39) = 4.66$, $p < 0.02$. As it can be clearly seen in Fig. 2, validity of cueing effect for tactile stimuli changed as a function of Epoch, in opposite directions in Experiments 2 and 3. Specifically, validity of cueing effect increased significantly in Experiment 2 from the first (mean = −29, SE = 16) to the last epoch (mean = 33, SE = 19; $t(13) = 2.19$, $p < 0.05$). By contrast, validity of cueing effect decreased significantly in Experiment 3 from the first (mean = 41, SE = 17) to the last epoch (mean = −9, SE = 9; $t(13) = 2.25$, $p < 0.04$). No modulation of validity of cueing effects for tactile stimuli emerged in Experiment 1 from the first (mean = 19, SE = 14) to the last epoch (mean = 19, SE = 13; $t(13) = 0.02$, n.s.).

For completeness, we computed validity of cueing effects in IE scores also for visual targets near the shadows and visual targets near the hands. However, in both cases, ANOVAs similar to the one used for tactile targets revealed no significant main effect or interaction (all Fs $\leqslant 2$).

4. General discussion

The results of the present study show that body-shadows attract attention to the body location they refer to, rather than the portion of visual space they occupy. In addition, this attentional benefit for the body part casting the shadow was selective for tactile stimuli, as no validity of cueing effects were observed for visual targets presented near the hands. Finally, our findings clearly show that information that contribute to recognising oneself as the owner of the body-shadow, namely visual similarity and spatio-temporal correlation between the shadow and the body, determine whether body-shadows will direct attention to the body part or not. We will first discuss the implications of selective attentional orienting for touch at the body and then examine the relations between self-attribution and orienting of tactile attention.

The finding that a hand-shadow influenced discrimination performance only for tactile targets delivered at the hand casting the shadow makes it clear that hand-shadows did not merely attract attention to the entire visual hemispace they occupied. This possibility remained open in our previous study (Galfano & Pavani, 2005), in which only tactile targets were presented, but it is discarded by the present results. Our new findings expand the notion of body-shadows as cues for attention by showing that they operate in a highly selective manner, even in the absence of any strategic reason to orient attention endogenously (i.e., when they are task-irrelevant). In this respect our results also discard a potential alternative interpretation that the observed cueing effect may be the consequence of unbalanced distribution of light in our naturalistic experimental setup. Indeed, in the study by Galfano and Pavani (2005), as well as here, the hand casting the shadow was always on the side of space illuminated more strongly (i.e., the same side of space as the lit desk lamp). Clearly, however, a cueing effect determined generically by the uneven distribution of light in the environment should have cued all target stimuli. Instead, our findings showed that body-shadows favoured selectively the corresponding body part (rather than the shadow itself or the entire visual hemispace), and oriented attentional resources specifically for touch.

Such selective attentional benefit for touch raises the interesting possibility that body-space can be cued independently from peri-personal space under some circumstances. The notion of peri-personal space stemmed originally from the neurophysiological evidence of bimodal visuo-tactile neurons in animals responding both to tactile stimuli at the body and to visual stimuli in close proximity with the same body part (Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981; see Graziano & Gross, 1995 for a review). This concept has now been extended to humans (di Pellegrino, Ladavas, & Farnè, 1997; for reviews see Ladavas & Farnè, 2004; and Holmes & Spence, 2004) and evidence has been provided that directing attention to a body location for touch, either through exogenous tactile cues (Kennett et al., 2002) or via explicit instructions to attend for touch (Spence, Pavani, & Driver, 2000), produces attentional benefits for visual targets near that body part. Our finding that hand-shadows cue tactile but not visual attention to the hands may thus reveal that, under particular circumstances, attention can favour a purely somatosensory representation of the body, instead of a multisensory representation that includes peri-personal space.

The second main finding of the present study is the relation between self-attribution of body-shadows and tactile attention. Our results show that immediate and persistent orientation of tactile attention by body-shadows occurs only when both visual similarity and spatio-temporal correlation between the shadow and the hand are present. Instead, when the shadow does not resemble the body part, and self-attribution can only occur through a sense of agency, orienting of tactile attention only seems to develop with time (see Maravita, Spence, Kennett, & Driver, 2002 for a related evidence with tool-use). Conversely, when the shadow is static but resembles the body part, self-recognition and orienting of tactile attention appears to be initially mediated by a sense of ownership which, however, rapidly fades away in the absence of movement correlation between the body and the shadow.

While orientation and spatio-temporal contingency between the body and its images in the visual world (i.e., video reproduction, rubber-arms, mirror-reflections or shadows, as here) are known to affect self-attribution (Botvinick & Cohen, 1998; Pavani et al., 2000), the role of visual similarity between the body and its images in the external world has been debated (see Armel & Ramachandran, 2003). Our findings show that dissimilarity prevents immediate self-attribution, at least when body-shadows are involved (see Tsakiris & Haggard, 2005 for related evidence comparing rubber-hands vs. other three-dimensional objects). Conversely, similarity initially favours self-attribution even for static images, presumably because self-attribution appears to be the default attribution until no further cues for self-recognition are available (van den Bos & Jeannerod, 2002). Our results also show that, in agreement with the literature (Daprati et al., 1997; van den Bos & Jeannerod, 2002), the most critical factor mediating self-attribution is the correlation of movements between the body and its images in the world, that concurs to a sense of agency and mediates self-attribution especially when movements are actively generated (Tsakiris, Haggard, Franck, Mainy, & Sirigu, 2005)[1].

To our knowledge, the results of the present study provide the first evidence that modulation of tactile performance through vision of body parts (here occurring through body-shadows) may critically depend on self-attribution of the visible image of the body. A number of studies has now shown that viewing the body can directly influence tactile perception (e.g., Kennett, Taylor-Clarke, & Haggard, 2001; Ro, Wallace, Hagedorn, Farnè, & Pienkos, 2004; Taylor-Clarke, Kennett, & Haggard, 2004; Tipper et al., 1998, 2001). In all these studies, the body part was either viewed directly (Kennett et al., 2001), through real-time video monitoring (Tipper et al., 1998) or through mirror reflections (Ro et al., 2004), thus preserving intact sense of agency for the body part which showed an improvement in the tactile tasks. Notably, any tactile benefit disappeared when viewing of the body was replaced by viewing of *static* objects. Our novel observation that the beneficial effect for touch is closely linked with self-attribution raises the interesting prediction that the well-described phenomenon of visual enhancement of tactile perception can also be critically modulated by

---

[1] It should be noted that unlike Experiments 1 and 2, in which shadows were always cast by the participants' real hands, in Experiment 3 participants were fully aware that the shadow was not cast by their own body. Thus, it could be argued that the absence of validity of cueing in Experiment 3 reflects conscious disownership of shadows rather than the absence of spatio-temporal correlation between the shadows and the body. If this is the case, validity of cueing effects should emerge if the projected *static* hand-shadow belongs to the participant (e.g., it is a previously photographed image of the participant's hand-shadow) and the participant is made aware of this aspect of shadow ownership. We thank an anonymous reviewer for suggesting this alternative account.

self-attribution. In other words, no tactile enhancement should emerge when participants view a body part that they do not attribute to themselves (see Whiteley, Kennett, Taylor-Clarke, & Haggard, 2004, p. 312, for a similar point on visual discrimination at body locations).

A final aspect of our findings that deserves discussion is the fact that hand-shadows acted as cue for directing tactile attention, despite being task-irrelevant (they were spatially uninformative as to target location), and occurring more than 2 s before target onset. This result is in agreement with our previous report (Galfano & Pavani, 2005), and raises the possibility that attentional orienting mediated by body-shadows is neither exogenous nor endogenous, at least in the sense that it does not fully conform to either forms of attentional control, as traditionally investigated in laboratory set-ups. Another type of cue that also does not conform to typical rules of exogenous or endogenous attentional control is gaze (e.g., Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003). Similar to body-shadows, spatially non-predictive gaze cues elicit a long-lasting capture of attention to the location suggested by gaze direction (e.g., Friesen & Kingstone, 1998). Body-shadows, just like gaze, are likely to possess a high biological relevance for our attentional orienting. They have presumably accompanied humans throughout evolution providing important cues for self-recognition, as well as recognition of bodies of other approaching living creatures. Exploring the similarities between these two types of ecological cues, for instance by comparing the time-course of attentional orienting for gaze and body-shadows, could thus be critical to delineate the exact nature of the new attentional orienting phenomenon we have reported.

Acknowledgements

A preliminary version of this work was presented at the 6th Annual Meeting of the International Multisensory Research Forum (June 5–8 2005, Rovereto, Italy). We are grateful to Jacopo Giovanni Romani and Gianluca Godino for help in data collection, to Maurizio Dal Bosco for help with the figures, and to Massimiliano Pastore for helpful suggestions concerning data analysis.

References

Allen, B. P. (1999). Shadows as sources of cues for distance of shadow-casting objects. *Perceptual and Motor Skills, 89*, 571–584.

Armel, K. C., & Ramachandran, V. S. (2003). Projecting sensations to external objects: evidence from skin conductance response. *Proceedings of the Royal Society, B, Biological Sciences, 270*, 1499–1506.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistic Society, B, 57*, 289–300.

Bonfiglioli, C., Pavani, F., & Castiello, U. (2004). Differential effects of cast shadows on perception and action. *Perception, 33*, 1291–1304.

Botvinick, M., & Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature, 391*, 756.

Castiello, U. (2001). Implicit processing of shadows. *Vision Research, 41*, 2305–2309.

Daprati, E., Franck, N., Georgieff, N., Proust, J., Pacherie, E., Dalery, J., & Jeannerod, M. (1997). Looking for the agent: an investigation into consciousness of action and self-consciousness in schizophrenic patients. *Cognition, 65*, 71–86.

di Pellegrino, G., Ladavas, E., & Farnè, A. (1997). Seeing where your hands are. *Nature, 338*, 730.

Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive cue gaze. *Psychonomic Bulletin & Review, 5*, 490–495.

Galfano, G., & Pavani, F. (2005). Long-lasting capture of tactile attention by body shadows. *Experimental Brain Research, 166*, 518–527.

Graziano, M. S. A., & Gross, C. G. (1995). The representation of extrapersonal space: a possible role for bimodal, visual-tactile neurons. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 1021–1034). Cambridge, MA: MIT Press.

Holmes, N. P., & Spence, C. (2004). The body schema and multisensory representation(s) of peripersonal space. *Cognitive Processing, 5*, 94–105.

Jeannerod, M. (2003). The mechanism of self-recognition in humans. *Behavioural Brain Research, 142*, 1–15.

Kennett, S., Taylor-Clarke, M., & Haggard, P. (2001). Noninformative vision improves the spatial resolution of touch in humans. *Current Biology, 11*, 1188–1191.

Kennett, S., Spence, C., & Driver, J. (2002). Visuo-tactile links in covert exogenous spatial attention remap across changes in unseen hand posture. *Perception and Psychophysics, 64*, 1083–1094.

Kersten, D., Knill, D. C., Mamassian, P., & Bulthoff, I. (1996). Illusory motion from shadows. *Nature, 379*, 31.

Kersten, D., Mamassian, P., & Knill, D. C. (1997). Moving cast shadows induce apparent motion in depth. *Perception, 26*, 171–192.

Kingstone, A., Smilek, D., Ristic, J., Friesen, C. K., & Eastwood, J. D. (2003). Attention, researchers! It is time to take a look at the real world. *Current Directions in Psychological Science, 12*, 176–180.

Ladavas, E., & Farnè, A. (2004). Visuo-tactile representation of near-the-body space. *Journal of Physiology Paris, 98*, 161–170.

Mamassian, P., Knill, D. C., & Kersten, D. (1998). The perception of cast shadows. *Trends in Cognitive Sciences, 2*, 288–295.

Maravita, A., Spence, C., Kennett, S., & Driver, J. (2002). Tool-use changes multimodal spatial interactions between vision and touch in normal humans. *Cognition, 83*, B25–B34.

Pavani, F., & Castiello, U. (2004). Binding personal and extrapersonal space through body shadows. *Nature Neuroscience, 7*, 13–14.

Pavani, F., Spence, C., & Driver, J. (2000). Visual capture of touch: Out-of-the-body experiences with rubber gloves. *Psychological Science, 11*, 353–359.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X* (pp. 531–556). Hillsdale, NJ: Erlbaum.

Rizzolatti, G., Scandolara, C., Matelli, M., & Gentilucci, M. (1981). Afferent properties of periarcuate neurons in macaque monkeys II. Visual responses. *Behavioral Brain Research, 2*, 147–163.

Ro, T., Wallace, R., Hagedorn, J., Farnè, A., & Pienkos, E. (2004). Visual enhancing of tactile perception in the posterior parietal cortex. *Journal of Cognitive Neuroscience, 16*, 24–30.

Spence, C., & McGlone, F. (2001). Reflexive spatial orienting of tactile attention. *Experimental Brain Research, 141*, 324–330.

Spence, C., Pavani, F., & Driver, J. (2000). Crossmodal links between vision and touch in covert endogenous spatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 1298–1319.

Spence, C., Pavani, F., Maravita, A., & Holmes, N. (2004). Multisensory contributions to the 3-D representation of visuotactile peripersonal space in humans: evidence from the crossmodal congruency task. *Journal of Physiology Paris, 98*, 171–189.

Spence, C., Kettenmann, B., Kobal, G., & McGlone, F. P. (2001). Shared attentional resources for processing visual and chemosensory information. *Quarterly Journal of Experimental Psychology, 54A*, 775–783.

Taylor-Clarke, M., Kennett, S., & Haggard, P. (2004). Persistence of visual–tactile enhancement in humans. *Neuroscience Letters, 354*, 22–25.

Tipper, S. P., Lloyd, D., Shorland, B., Dancer, C., Howard, L. A., & McGlone, F. (1998). Vision influences tactile perception without proprioceptive orienting. *NeuroReport, 9*, 1741–1744.

Tipper, S. P., Phillips, N., Dancer, C., Lloyd, D., Howard, L. A., & McGlone, F. (2001). Vision influences tactile perception at body sites that cannot be viewed directly. *Experimental Brain Research, 139*, 160–167.

Townsend, J. T., & Ashby, F. G. (1983). *The stochastical modeling of elementary psychological processes*. Cambridge: Cambridge University Press.

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 80–91.

Tsakiris, M., Haggard, P., Franck, N., Mainy, N., & Sirigu, A. (2005). A specific role for efferent information in self-recognition. *Cognition, 96*, 215–231.

van den Bos, E., & Jeannerod, M. (2002). Sense of body and sense of action both contribute to self-recognition. *Cognition, 85*, 177–187.

Whiteley, L., Kennett, S., Taylor-Clarke, M., & Haggard, P. (2004). Facilitated processing of visual stimuli associated with the body. *Perception, 33*, 307–314.