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RESEARCH ARTICLE

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Long-lasting capture of tactile attention by body shadows

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Abstract Four experiments addressed the role of cast shadows of the body in orienting tactile spatial attention to the body itself. We used a modified spatial-cueing paradigm to examine whether viewing of the cast shadow of a hand can elicit spatial shifts of tactile attention to that very same hand. Participants performed a speeded tactile-discrimination task (thumb versus index finger, regardless of touched hand), while viewing the shadow of either the touched or untouched hand cast in front of them by a lateral light-source. The hand casting the shadow changed either between blocks (expt 1) or unpredictably within each block (expts 2–4). In experiments 1 and 2 tactile targets were preceded by central non-informative visual cues delivered near the shadow of the index finger and thumb. Despite the fact that cast shadows were always task-irrelevant and non-predictive of which hand was stimulated, tactile discrimination was consistently faster at the hand casting the shadow than at the other hand. This effect was not modulated by the duration of cue-target asynchrony, nor did it depend on whether the visual cue was present or not (expt 3). In addition, it was still reliable when vision of the hands was precluded, whereas it became inconsistent when the cast shadow of the hand was replaced by the cast shadow of an object (expt 4). Our results suggest that body shadows can induce a long-lasting capture of tactile attention for stimuli at the body itself.

Keywords Body shadows · Tactile attention · Biological cues

Introduction

Despite having been almost neglected by the scientific community for many years (but see Yonas et al. 1978), cast shadows seem to play a significant role in our interaction with the environment (see Mamassian et al. 1998, for review). For instance, cast shadows of objects convey information that can sometimes influence object recognition (e.g. Castiello 2001) and programming movement kinematics underlying object-oriented actions (Bonfiglioli et al. 2004). In addition, cast shadows seem crucial cues for disambiguating the spatial arrangement of objects with reference to the background, and the relationships among different foreground objects (Kersten et al. 1996, 1997).

Recently, Pavani and Castiello (2004) have shown that body shadows may represent a special class of cast shadows, in that they seem to be able to strongly affect perception of spatial relationships between our own body and the stimuli around us, bridging the gap between personal and extrapersonal space. The experiments reported by Pavani and Castiello were based on a visuo-tactile interference paradigm. 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 (e.g. Pavani et al. 2000). Remarkably, visuo-tactile interference is still present when visual distractors are presented to fake hands aligned with the real (unseen) hands (Pavani et al. 2000), and is modulated by active tool-use (Maravita et al. 2002; Holmes et al. 2004), probably as a consequence of the functional plasticity characterizing our "body schema" (Farnè and Ladavas 2000; Maravita et al. 2001; also see Kennett et al. 2001). Pavani and Castiello (2004)

Preliminary results of this study were reported at the Fifth Annual Meeting of the International Multisensory Research Forum (Sitges, Spain), June 2004.

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performed a series of experiments with irrelevant visual stimuli appearing far and equidistant from both hands but in close proximity to the shadow cast by one of the two hands, and showed that visuo-tactile interference was considerably magnified when tactile targets were delivered to the hand casting the shadow compared to when they were presented at the other hand. A control experiment in which participants wore a shaped glove projecting a polygonal shadow near the visual distractors showed that, with such an unnatural shadow, visuo-tactile interference was nearly the same for the hand projecting the polygonal shadow and the hand not casting a shadow. The same pattern of results was obtained in another control experiment in which a line drawing of a hand, instead of the cast shadow, linked one hand with visual distractors. It was concluded that the magnification of visuo-tactile interference observed selectively with cast shadows of the hands was due to personal–extrapersonal binding, and that this effect was specifically mediated by real body-shadows, because merely seeing any shadow extending from the body was not sufficient to modulate visuo-tactile interference.

One further question concerning shadows cast by body parts is whether these may affect the distribution of spatial attention, and particularly attention towards body parts. This phenomenon may arise in at least two ways. First, extrapersonal stimuli distant from the body but in close proximity with the body-shadow may act as exogenous cues for that body-part. This possibility could be expected based on the results of Pavani and Castiello (2004) described above. Second, mere viewing of the body-shadow could by itself orient attention towards the body-part casting it. This hypothesis assumes that body-shadows may act as a biological cue for attention (similar to gaze direction and head orientation; e.g. Langton 2000; Hietanen 2002). This question was explored in four experiments.

Experiment 1

We started by asking whether a visual stimulus distant from the body but near the cast body-shadow can act as an exogenous cue and attract attention to the body part itself. To this purpose, we exploited a modified version of the classic exogenous spatial cueing paradigm (for the visual modality see, e.g. Cheal and Lyon 1991; for the tactile modality, see Spence and McGlone 2001; for visuo-tactile designs, see Spence et al. 1998), in which a peripheral stimulus captures attention towards a subsequent target. Critically, however, in our study we used a visual cue that was always central, but that appeared adjacent to the lateralized shadow of a hand. If such a stimulus can capture attention towards the hand casting the shadow, we expected the condition where the target was presented to the hand casting the shadow (i.e. valid trials) to produce response time (RT) advantages and fewer errors compared to the condition where the target was delivered to the other hand (i.e. invalid trials).

We also manipulated the stimulus onset asynchrony (SOA) between the central visual cue and target onset, creating a short (50 ms) and a long (750 ms) SOA. Following the studies conducted in exogenous visual (e.g. Cheal and Lyon 1991) and tactile orienting (Spence and McGlone 2001), we expected participants to perform significantly better in valid (i.e. tactile target on shadow-hand) than in invalid trials (i.e. tactile target on non-shadow hand) particularly or exclusively for the short SOA. As for the long SOA, we expected any exogenous effect to either vanish or reverse, possibly as a consequence of inhibition of return (IOR, Posner and Cohen 1984), which can also be elicited when the cue modality is different from the target modality (Spence et al. 2000).

Crucially, participants were explicitly informed that shadows were not predictive of the hand receiving an upcoming tactile target, and thus participants had no motivation for strategically attending to the hand casting the shadow. Under these conditions, the occurrence of top-down influences was reasonably kept to a minimum, as the shadow provided no useful information for performing the task (e.g. Yantis 1993; Turatto et al. 2002, 2004). The hand casting the shadow was varied in different blocks of trials.

Materials and methods

Participants

Sixteen undergraduates (15 females; two participants left-handed by self-report; mean age 22.6 years) participated in the study, 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. All were unaware of the purpose of the experiment, gave their informed consent and had normal or corrected-to-normal vision.

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 table top and separated by about 50 cm. A green light emitting diode (LED; CIE coordinates, $x = 0.424$, $y = 0.572$, 231 cd/m^2) attached to the table top at 38.5 cm from the chinrest and along the participants' mid-sagittal plane served as the visual fixation point. Two red LEDs (CIE coordinates, $x = 0.673$, $y = 0.324$, 143 cd/m^2) were also placed along the participants' mid-sagittal plane on the table top; they flanked the fixation point vertically (7 cm on either side) and served as visual cues. All LEDs were covered by a large (92 cm in length, 65 cm in width) sheet of white paper, and became visible only when lit. 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 lightbulb, which was suspended at 64.5 cm from the table top and 60 cm to the left and right with respect to the participants' mid-sagittal plane. Only one of the two lightbulbs was switched on throughout a block of trials.

Participants maintained their hands in a position such that the cast shadow of their hands was projected on the table surface by the lateral light sources. Specifically, they were instructed to hold a position allowing the cast shadow of their index fingers to overlap spatially with the furthest red LED, and the cast shadow of their thumbs to overlap with the red LED nearest to them (see Fig. 1a). When keeping such a position, the hands were equidistant from the location of the two red LEDs, and the central fixation LED was approximately at the midpoint of the cast shadows of the thumb and index fingers.

Participants wore a fitting cotton-silicon sheath on thumb and index finger of each hand. A miniature tapper (MST2, 7.5 × 12 mm, http://www.byed.co.uk/sol) was placed inside each sheath, in contact with each finger-tip. Connecting wires poked through the closed end of the sheath and were fixed at the wrist with rubber-bands. Tactile targets consisted of a single 50 ms pulse of one of the four stimulators. Tactile targets were delivered with equal probability to either hand.

Throughout each block of trials, participants depressed two foot-pedals located respectively under the toe and heel of their right foot. They were instructed to raise their toe in response to targets at the index fingers, and their heel in response to targets at the thumbs. Participants were instructed to react as fast and as accurately as possible.

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

Procedure

Before the experiment started, participants performed two miniblocks composed of four trials each, in which only tactile targets were presented. If 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 16 practice trials. Before each practice and experimental block, both lamps were turned on, so that participants could see the cast shadows of both hands and move them until they reached the position illustrated in Fig. 1a. Subsequently, only one of the two lamps was turned on throughout each block. Both practice and experimental trials started with the onset of the green fixation LED. This remained visible throughout the trial, and participants were instructed to fixate it. After 1000 ms elapsed, both flanking red LEDs were turned on for 50 ms (central visual cue). After an interstimulus interval (ISI) of either 0 or 700 ms (resulting in either 50 or 750 ms SOAs), the tactile target was presented at one of the four possible digits, with the same probability. Feedback was provided only for errors (wrong foot-pedal releases) and consisted of two brief flashes of the fixation LED. The intertrial interval was

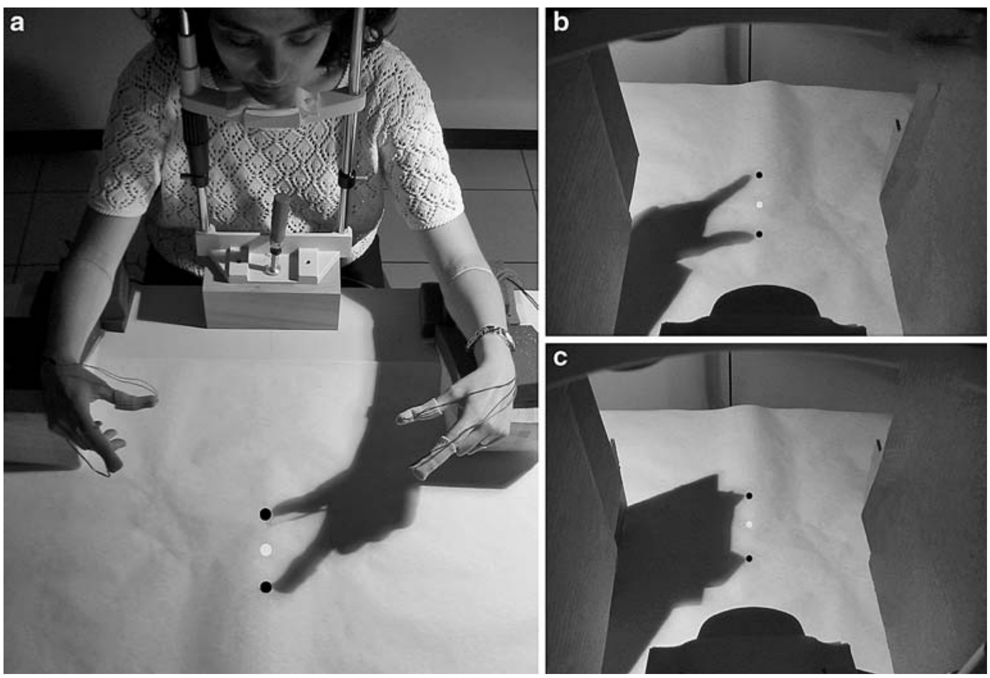

Fig. 1 Photograph of the experimental set up in experiments 1–3 (**a**). Participant's view of the set-up in experiment 4 during the body-shadow condition (**b**) and the object-shadow condition (**c**). The *white circle* indicates the position of fixation LED; *black circles* indicate the position of visual cues LEDs (see text for details)

Table 1 Mean reaction times (ms), percentage errors, and actual validity effect (with standard errors in brackets) for valid and invalid trials as a function of SOA (expts 1 and 2), cue presence (expt 3), and shadow type (expt 4)

	Experiment 1		Experiment 2		Experiment 3		Experiment 4	
	SOA		SOA		Cue presence		Shadow-type	
	50	750	50	750	Present	Absent	Body	Object
Valid								
RT (SE)	519 (27)	492 (27)	530 (15)	498 (20)	476 (19)	483 (21)	490 (18)	490 (15)
% Errors (SE)	2.3 (0.5)	2.6 (0.6)	2.4 (0.6)	1.9 (0.6)	1.5 (0.7)	1.4 (0.4)	1.9 (0.3)	1.2 (0.3)
Invalid								
RT (SE)	528 (28)	508 (26)	534 (17)	513 (17)	486 (21)	503 (20)	504 (20)	484 (15)
% Errors (SE)	1.9 (0.4)	2.7 (0.6)	2.5 (0.4)	2.3 (0.7)	2.2 (0.9)	1.4 (0.4)	2.3 (0.5)	2.8 (0.7)
Validity effect								
RT (SE)	8 (5)	16 (7)	3 (5)	13 (7)	9 (5)	20 (6)	14 (6)	−6 (5)
% Errors (SE)	−0.4 (0.6)	1.0 (0.6)	0.1 (0.5)	0.4 (0.6)	0.7 (0.7)	0.0 (0.6)	0.4 (0.6)	1.6 (0.6)

1000 ms. Participants were allowed to take short breaks between blocks.

Each participant was explicitly informed that the shadow was not predictive with regard to the hand receiving the upcoming target, and were instructed to ignore the shadows as much as possible. Before the experimental session begun, they were strongly encouraged to hold their hands still throughout each block 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 the instructions.

Design

Participants were tested in a 2×2 factorial design. The first factor was SOA between the onset of the visual cues and the onset of tactile targets (50 versus 750 ms). The second factor was Validity (valid versus invalid). Note that validity here only refers to the congruency between which hand cast the shadow and which hand received the tactile target (i.e. a tactile target delivered at the hand casting the shadow constituted a "valid" trial, whereas a tactile target delivered at the no-shadow hand constituted an "invalid" trial).

The total number of trials was 256, divided into four experimental blocks of 64 trials each. In each block, there were 32 trials (16 valid and 16 invalid trials) for each of the two SOAs. Two blocks were performed with only the left lamp turned on (i.e. participants could see only the cast shadow of their left hand), and two blocks with only the right lamp turned on (i.e. participants could see only the cast shadow of their right hand). The order of blocks was counterbalanced across participants.

Results

RT analysis

In this and in the following experiments, before the analysis was carried out, RTs for correct responses lower than 150 ms and higher than 1,000 ms were trimmed. This resulted in the removal of 0.9% of the data in the present experiment. RT data were entered into a two-way repeated measures ANOVA with SOA and Validity as factors. Participants responded faster at the long SOA (mean = 500 ms, SE = 26) than at the short SOA (mean = 524 ms, *SE* = 27), which resulted in a significant main effect of SOA [$F(1,15) = 20.812$, MSe = 438, $P < .0001$], possibly reflecting the well known temporal warning effect (e.g. Sanders 1975). More interestingly, the main effect of Validity was also significant [$F(1,15) = 8.248$, MSe = 276, $P = 0.01$], revealing that participants responded faster when tactile targets appeared at the hand casting the shadow (mean = 506 ms, SE = 27), than when they appeared at the no-shadow hand (mean = 518 ms, SE = 27). This pattern did not vary as a function of SOA, as the two-way interaction was not significant ($F < 1$; see Table 1 and Fig. 2)

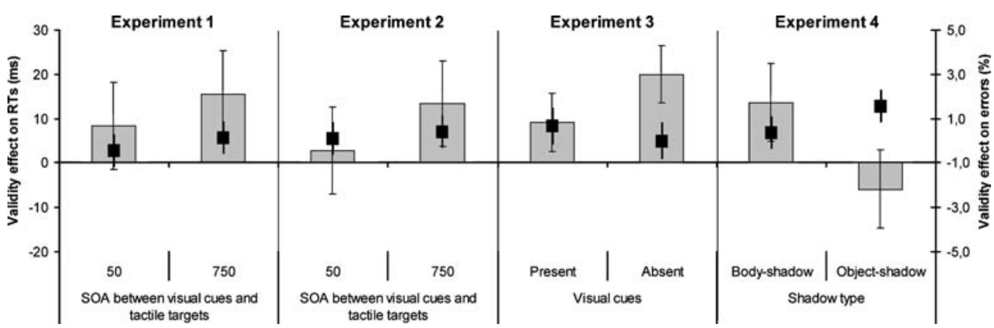

Fig. 2 Plots of validity effect for RTs (*bars*) and errors (*squares*) in experiments 1–4. *Error bars* indicate 95% confidence interval for paired contrast within each experiment

Error analysis

Overall percentage of errors was lower than 2.5%. An ANOVA with the same factors as in the RT analysis revealed no statistical differences in error distribution across conditions (all $F < 2$).

Discussion

The RT pattern obtained in the present experiment suggests an influence of body-shadows on tactile attentional orienting. It is important to note that the 12-ms advantage for tactile targets at the hand casting the shadow was observed despite the fact that tactile targets were equiprobable on either hand, thus giving no strategic reason to orient attention towards one hand or the other. Moreover, participants were fully aware that the shadows were spatially non-predictive, and they were encouraged to disregard the shadows as much as possible.

The results of experiment 1 also revealed the absence of any modulation of the effect of alidity by SOA, with the advantage for tactile targets at the hand casting the shadow being reliable at the short as well as the long SOA. This aspect of the data does not seem consistent with the presence of exogenous attentional control, at least if one refers to the literature concerning unimodal visuospatial orienting (see Klein 2000). According to this evidence, exogenous allocation of attention results in a biphasic pattern, with valid trials showing a short-lasting advantage in performance over invalid trials, decaying, and then reversing as SOA increases because of IOR taking place. In the present experiment, the presence of a biphasic pattern should have resulted in a significant interaction, which was not the case.

One possibility is that a biphasic pattern could have emerged using a higher SOA value. In the context of exogenous crossmodal orienting mixed results have been obtained concerning the onset of IOR. For instance, Tassinari and Campara (1996) found it as early as 200 ms after cue onset, while Spence et al. (2000) found IOR in the time interval 950–1,250 ms, albeit with a substantially different paradigm. However, note that in unimodal visual studies (e.g. Lupiàñez et al. 1997) a 700 ms SOA was long enough to observe significant IOR effects when a cue-target paradigm combined with a discrimination task was adopted (as in the present study).

Another possible account for the absence of a biphasic pattern may reflect a specific manipulation of experiment 1, namely the presence of a peripheral stimulus (the shadow) whose side was fixed throughout each block of trials. This could have induced participants voluntarily to attend to the shadow side or the hand casting the shadow, although the shadow was spatially non-predictive. Had participants adopted such a voluntary strategy, then it would be no surprise to find faster responses to valid than invalid trials even at a long SOA. We tested this possibility in experiment 2.

Experiment 2

If blocking the hand casting the shadow in experiment 1 generated an implicit strategy leading to constant orienting of attention to the hand casting the shadow, then we expected the validity effect to change as a function of SOA in this second experiment, because the hand casting the shadow varied unpredictably within each block of trials, and participants were again strongly encouraged to disregard the shadow.

Materials and methods

Participants

Twelve undergraduates (nine females; three participants left-handed by self-report; mean age 27.7 years.) participated in the study. All had normal or corrected-to-normal vision. None of them had taken part in experiment 1.

Apparatus and stimuli

These were the same as in experiment 1.

Design and procedure

The experiment proceeded as in experiment 1, except that participants did not know in advance which hand cast the shadow, as this varied unpredictably from trial to trial, with the constraint that the hand casting the shadow could not be the same for more than three consecutive trials. Note that unlike experiment 1, the shortest time intervals between shadow onset and target onset were either 1050 or 1750 ms, depending on the SOA condition.

Results

RT analysis

Application of the outlier-latency criterion resulted in the trimming of 0.1% of the data. A two-way repeated measures ANOVA with SOA and Validity as factors was conducted on RT data for correct responses. The main effect of SOA was significant [$F(1,11) = 13.621$, $MSe = 609$, $P < 0.005$], as participants responded faster at the long SOA (mean = 505 ms, SE = 19) than at the short SOA (mean = 532 ms, SE = 16). The main effect of Validity was also significant [$F(1,11) = 5.047$, $MSe = 157$, $P < 0.05$], indicating that participants responded overall faster in valid (mean = 514 ms, SE = 17) than in invalid trials (mean = 524 ms, SE = 17). However, the Validity×SOA interaction was not significant ($F < 2$; see Table 1 and Fig. 2).

Error analysis

Overall error rate was $<2.5\%$. An ANOVA with the same factors as in the RT analysis did not reveal any statistical differences in error distribution across conditions (all $F<1$).

Discussion

The results closely paralleled those of the previous experiment, showing that participants consistently oriented their tactile attention to the hand casting the shadow. This effect persisted also when the SOA between the central visual cue onset and target onset was long, consistently with experiment 1. In order to gather stronger evidence supporting this conclusion, we performed an additional ANOVA on RTs for correct responses with the additional between-participants factor of Experiment. Both the Validity×SOA interaction and the second order Experiment×Validity×SOA interaction were not significant (all $F<2$), thus suggesting that blocking the hand casting the shadow was not responsible for the persistence of the shadow-driven validity effect at the long SOA. This, in turn, can reasonably rule out that the validity effect in the previous experiment reflected only a strategic orienting of attention, and indicates instead the existence of non-intentional orienting of some sort, because participants were fully aware that the shadows were spatially non-predictive and task-irrelevant.

This leaves us with the possibility that the shadow itself acted as a non-intentional cue directly orienting attention to the body part casting it, whereas visual cues acted, if anything,as an additional exogenous cue attracting attention back to external space (specifically, towards fixation). It is indeed interesting to note that the size of validity effect was smaller (both in expts 1 and 2) with shorter than with longer SOA. One may speculate that this difference could be due to the cueing effect of the central LED, which draw attention away from the hand (thus counteracting any attentional orienting caused by the body shadow). The next experiment was designed to clarify this issue and address directly whether the presence of the central visual cue was a necessary condition for observing our shadow-driven modulation of tactile attention.

Experiment 3

The purpose of the present experiment was 2-fold. Firstly, we wanted to test the robustness of the shadow-driven validity effect at the long SOA further. Thus, we focused on the 750 ms SOA only. Secondly, we compared the condition tested in the previous experiments with a condition in which no central visual cue was shown in order to establish whether shadows in our paradigm exerted their effects as an indirect medium to link personal and extrapersonal space (i.e. in the same way as in the visuo-tactile interference paradigm adopted by Pavani and Castiello 2004), or as a direct cue by themselves. To this purpose, we had participants performing two blocks of trials with the same stimuli and procedures as in experiment 2 and two additional blocks where no central visual cues were presented.

Materials and methods

Participants

Twelve undergraduates (six females; two participants left-handed by self-report; mean age 23.7 years) participated in the study. They were unaware of the purpose of the experiment and had not taken part in the previous experiments. All reported normal or corrected-to-normal vision.

Apparatus and stimuli

These were the same as in the previous experiments.

Procedure

This was the same as in experiment 2, except that the presence of the central visual cues was manipulated between blocks. Two blocks of trials were performed with the same procedure as in the previous experiment, but with a fixed 750 ms SOA with tactile targets presented at the earliest 1750 ms after shadow onset, whereas two additional blocks were performed with no visual cues. Participants were informed at the beginning of each block, about the presence or absence of the central visual cues. In the no-cue condition, in order to maintain timing parameters fixed, tactile targets were presented at the earliest 1750 ms after shadow onset.

Design

Participants were tested in a 2×2 factorial design. The first factor was Validity (valid versus invalid). The second factor was Cue presence (present versus absent). The total number of trials was 256, divided into four experimental blocks of 64 trials each. Two blocks were performed with the central visual cues, and two blocks without visual cues. The order of blocks was counterbalanced across participants.

Results

RT analysis

As a consequence of the outlier-latency criterion, 0.4% of the data were trimmed. Mean correct RTs were entered into a two-way repeated measures ANOVA with

Validity and Cue presence as factors. Validity yielded a significant main effect [$F(1,11) = 10.626$, MSe = 240, $P = 0.008$]. Overall, RTs were lower in valid (mean = 479 ms, SE = 18), than in invalid trials (mean = 494 ms, SE = 20). Both the main effect of Cue presence [$F(1,11) = 2.549$, MSe = 697, $P = 0.13$], and the Validity×Cue Presence interaction [$F(1,11) = 3.313$, MSe = 106, $P = 0.09$] fell short of significance. Note, however, that the validity effect was numerically larger in the cue-absent than the cue-present condition (see Table 1 and Fig. 2).

Error analysis

Overall error rate was $< 2\%$. An ANOVA with the same factors as in the RT analysis did not reveal any statistical differences in error distribution across conditions (all $F < 1$).

Discussion

First, the results in the cue-present condition confirm that the advantage for valid over invalid trials observed with a 750 ms SOA in the previous experiments was a robust effect. This, in turn, is evidence that tactile attentional capture by body shadows is a long-lived phenomenon. Second, the significant main effect of Validity regardless of presence or absence of the visual cue suggests that vision of body-shadows may suffice to obtain the attentional orienting effect observed in experiments 1–3. Although the marginally significant two-way interaction does not allow to completely rule out a role of visual cues (and thus a role of body shadows in mediating the binding of personal and extrapersonal space, as we originally hypothesized based on the results of Pavani and Castiello 2004), it should also be noted that the smaller cueing effects in the cue-present condition are again compatible with an account that central visual cues draw attention away from the hands when present.

In our final experiment, we explored the degree of specificity of the shadow-driven attentional capture by including two control conditions. One in which participants saw the cast shadow of an object instead of the cast shadow of a hand. The other in which we examined whether any performance advantage on valid trials might simply have resulted from the fact that the visible hand casting the shadow was illuminated more strongly than the other hand (see Fig. 1a). If this were the case, then shadows would play no causal role, and no validity effect should be expected when vision of the hands is prevented.

Experiment 4

In this experiment, participants could not see their own hands (see Fig. 1b, c). This was made possible by attaching two pieces of cardboard to the chinrest that precluded sight of the periphery of the visual field (thus allowing participants to see only the cast shadows of their hands). Thus, if the validity effect was simply due to viewing one hand that was more strongly illuminated, it should have vanished in the present experiment.

Moreover, two conditions were created in separate blocks of trials. The first one (body-shadow condition) was a close replication of the no-cue condition of experiment 3. The second condition (object-shadow condition) consisted of the placement of two outlined objects out of the participants' sight, simulating the position of the participants' real hands. In the object-shadow condition, participants could not see the cast shadow of their hand, but they saw the cast shadow of the outlined objects instead (see Fig. 1c). If the validity effect was specific to body shadows, the prediction was that it should have disappeared in the object-shadow condition, while remaining reliable in the body-shadow condition. This pattern should have resulted in a significant Validity×Shadow type interaction.

The same SOA as in the previous experiment was used.

Materials and methods

Participants

Sixteen undergraduates (seven females; two participants left-handed by self-report; mean age 24.3 years) participated in the study. All reported normal or corrected-to-normal vision. None of them had taken part in the previous experiments.

Apparatus and stimuli

These were the same as the previous experiments. In addition, the chinrest underwent some modifications aimed at preventing participants seeing their own hands. First, one piece of cardboard (23 cm in length, 13 cm wide) was fixed above the chinrest in order to prevent vision of the light sources. Second, two additional pieces of cardboard (40 cm in height, 27 cm wide) were placed at the lateral borders of the chinrest for preventing vision of the hands. The outlined objects for the object-shadow condition were made of cardboards (20 cm in height, 23 cm in width) and were placed parallel to both forearms. When present, the object shadow overlapped and completely masked any shadow cast by the hand (see Fig. 1c).

Procedure

The sequence of events was the same as in the no-cue condition of experiment 3. In the object-shadow condition, participants were required to place their forearms on the supports, and to hold their hands in the same posture as in the body-shadow condition.

Design

Participants were tested in a 2×2 factorial design, with Validity (valid versus invalid) and Shadow type (body shadow versus object shadow) as factors. The total number of trials was 256, divided in four blocks of 64 trials. Two blocks were performed with cast shadow of the hands. The remaining were performed with cast shadow of the objects. Order of blocks was counterbalanced across participants.

Results

RT analysis

Application of the outlier-latency criterion resulted in trimming 0.3% of the data. Mean RTs for correct responses were entered into a two way repeated measures ANOVA with Validity and Shadow type as factors. Neither main effects were significant (all $F < 2$), whereas the Validity×Shadow type interaction was significant [$F(1,15) = 5.584$, MSe = 272, $P = 0.03$]. Planned comparisons (two-tailed paired *t*-tests) revealed that, in the body-shadow condition, participants responded significantly faster on valid trials (mean = 490 ms, SE = 18) than on invalid trials (mean = 504 ms, SE = 20) [$t(15) = 2.29$, $P = 0.04$]. By contrast, in the object-shadow condition, a non-significant [$t(15) = 1.17$, $P = 0.3$] opposite pattern emerged (see Table 1 and Fig. 2).

Error analysis

Overall error rate was 2%. An ANOVA with the same factors as in the RT analysis revealed a trend towards significance for both the main effect of Validity [$F(1,15) = 4.153$, MSe = 3.62, $P = 0.06$], and the Validity×Shadow type interaction, $F(1,15) = 3.584$, MSe = 1.57, $P = 0.08$], whereas the main effect of Shadow type was far from significance ($F < 1$). Inspection of Table 1 suggests that the latter non-significant trend may reflect higher percentage errors in invalid than valid trials for the object-shadow condition.

Discussion

The results of experiment 4 clearly indicate that the validity effect observed for tactile targets presented at the hand casting the shadow cannot result from participants seeing the shadow-casting hand illuminated more strongly than the other hand (given that vision of both hands was occluded throughout). In addition, they indicate that attentional orienting effects may be specific to body-shadows, in that a lateralized cast shadow of an object did not produce a similarly consistent pattern of data.

However, two important issues concerning the object-shadow condition deserve further attention. First, in experiment 4 the object-shadow was stationary throughout each block of trials, unlike the hand-shadow, for which minimal occasional moments could have occurred. This raises the possibility that any difference of validity effect between the two conditions does not reflect the difference in shape between the two shadow conditions, but rather a difference in spatio-temporal correlation between the shadow and the participant's body movement. While this issue of observer's control over the shadow clearly deserves further attention in future research, it should be reminded that in the original work of Pavani and Castiello (2004) the unnatural polygonal-shadow led to different results than the hand-shadow despite the fact that it resulted from a glove wore by participants on the hand (and thus always spatio-temporally correlated with body movements).

The second issue concerning the object-shadow is whether some validity effect may emerge even for a stationary unnatural shape, especially after repeated exposure to the object-shadow in a position which is congruent with the body-posture adopted by the participant (see Fig. 1b, c). In other words, it can be speculated that unnatural shadows aligned with the body may be incorporated into the body-schema when given enough time (e.g. see Maravita et al. 2002 for a similar evidence from tool-use). Although experiment 4 was not designed to address this specific issue, preliminary evidence in support of this account can be obtained by examining modulations of validity effect across time during the object-shadow experimental blocks. [1]

General discussion

On the whole, the present study showed that body shadows can act as a cue for directing tactile attention, despite being task-irrelevant and spatially non-predictive. This effect was reliable in all experiments and suggests that body-shadows could have elicited exogenous orienting of attention. However, this very same effect proved to be surprisingly long-lasting, with faster tactile discrimination responses for valid than invalid trials even when the time interval between shadow onset and target onset was 1700 ms. Thus, the persistence of the

[1] To examine whether validity effect changed across time during the object-shadow experimental blocks, we analysed the first and the second halves of each block separately. For simplicity (and also in consideration of a potential speed-accuracy trade-off in this data set) we calculated a combined measure of RTs and accuracy known as inverse efficiency (IE) as the mean RT divided by the proportion of trials correct (Spence et al. 2001; Townsend and Ashby 1983). Mean IE scores for each participant were submitted to an ANOVA with two within-participants factors: trials (first versus second halves) and Validity (valid versus invalid). This ANOVA revealed a two-way interaction [$F(1,15) = 5.506$, MSe = 896.229, $P = 0.03$], caused by larger (and positive) validity effect for the trials belonging to second (mean = 19, SE = 9) than first halves of the object-shadow blocks (mean = –16, SE = 10). This may constitute preliminary evidence that a validity effect for object-shadow can build up over time.

effect well beyond the standards indicated by unimodal studies using non-predictive peripheral visual stimuli suggests that some sort of endogenous orienting was taking place.

This raises the interesting possibility that attentional orienting due to 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. It is now well known that particular types of cues, such as gaze, do not exhibit all of the features traditionally associated with exogenous or endogenous orienting (e.g. Kingstone et al. 2003). Spatially non-predictive gaze cues elicit a long-lasting capture of attention to the location suggested by gaze direction (e.g. Friesen and Kingstone 1998). Moreover, Friesen and Kingstone (2003) have recently demonstrated that non-predictive abrupt onsets and gaze elicit independent exogenous attentional shifts, with gaze showing a persistent advantage for valid trials at the same SOA in which IOR had appeared for abrupt onsets. We speculate that body shadows, just like gaze, may evoke a form of attentional control different from that generally induced by abrupt onsets. In particular, the long-lived validity effect observed in our experiments may depend on the fact that body shadows possess a high biological relevance. In the present series of experiments, the SOA between shadow and target onset was not varied systematically, however it would be of great interest to manipulate this parameter to examine the time-course of the shadow-driven attentional orienting.

Cast shadows of the body may be involved in the construction of the "body schema", a representation crucial for segregating the self from the environment (Gallagher 2000; Haggard et al. 2003). This argument has recently been proposed by Pavani and Castiello (2004), who observed that body-shadows can be incorporated into the body schema, bridging the gap between personal and extrapersonal space. The persistence of the validity effect regardless of the presence or absence of the central visual cues in experiment 3 does not seem to be fully consistent with this account. In experiment 3, orienting of tactile attention emerged as a consequence of mere vision of the body-shadow rather than as a result of any binding between the central visual cues and the hand casting the shadow. However, at least two aspects could account for this discrepancy. First, in the present experiments we employed a spatial-cueing paradigm, while Pavani and Castiello (2004) adopted a visuo-tactile interference paradigm. Although both paradigms require spatial discrimination of tactile targets, recent evidence suggests that visuo-tactile interference may operate independently from attentional orienting in the tactile modality (see expt 1 in Spence et al. 2004), suggesting that visuo-tactile interference and spatial-cueing paradigms may tap at least partially into different cognitive processes. Second, it is possible that any attentional orienting due to binding of visual cues with the hand casting the shadow could have been masked by the prominent and long-lasting effect produced by vision of the body-shadow.

Whether or not body-shadows exert their effects on attentional orienting following the same mechanisms as those underlying gaze remains an open empirical question. Gaze has been extensively investigated, and some neuroimaging studies have identified in the "fusiform face area" specialized for face processing (e.g. Kanwisher et al. 1997), the possible neural substrate for gaze-driven attentional orienting (George et al. 2001). Interestingly, recent neuroimaging evidence has shown an area of the lateral occipitotemporal cortex ("extrastriate body area", EBA) that responds to images of the human body selectively (Downing et al. 2001) and also seems to be crucially involved in the representation of the observer's body, because its response is strongly modulated by limb movements (Astafiev et al. 2004). To our knowledge, the only study addressing the possible neural correlates of shadow processing has been conducted by Castiello et al. (2003), who have reported a neuropsychological dissociation concerning the ability of neglect patients to implicitly process cast shadows of objects. In particular, neglect patients with lesions involving the right temporal lobe were unable to implicitly process shadows, unlike neglect patients with lesions sparing the temporal lobe. This may suggest that the temporal lobe is necessary for shadow processing. Although our findings suggest that body-shadows and object-shadows do not have the same ability to capture tactile attention, it is possible that both the EBA and other, less specialized, areas of the temporal lobe may play a role in modulating tactile attentional orienting by body-shadows.

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