

Reflexive social attention is mapped according to effector-specific reference systems

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Abstract Studies exploring reflexive joint attention report that attention is more powerfully captured by interfering social signals (such as others' gaze or hand orientation) than by non-biological directional cues (such as an arrow). However, what remains unknown is whether these effects are mapped in purely spatial or in body-part specific reference frames. Changes of a central, black fixation point into blue or orange were the imperative instruction signal for the experimental subjects to make a leftward or a rightward movement (saccades in Study 1 and hand pointing in Study 2) while ignoring distracting stimuli (leftward or rightward oriented gaze, hand pointing or arrow). Gaze and pointing hand distracters that were directionally incongruent with the instruction cue impaired the goal-driven saccadic and pointing performance, respectively. This pattern of results indicates that reflexive social attention is mapped not only in spatial but also in body-part specific reference frames.

Keywords Saccadic eye movements · Hand pointing · Social attention · Social cognition · Gaze

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Introduction

Explicit or implicit allocation of attention allows us to orient to the information we consider interesting or salient (James 1890; Posner 1980). Shifts of attention may be triggered by the onset of an uninformative but salient peripheral event (exogenous orienting) or by the presentation of a centrally presented informative symbolic cue such as an arrow pointing towards a specific location of the world (endogenous orienting) (Posner 1980; Corbetta and Shulman 2002; Logan 2005; Gibson and Kingstone 2006).

Attentional shifts may be differentially elicited by non-biological (e.g., a flash of light or a sudden noise) or by social signals (e.g., the gaze of another individual) (Frischen et al. 2007). Orienting to where other people are looking or pointing is a fundamental ability that can allow important socio-cognitive operations such as person judgments (Mason et al. 2004, 2005; Bayliss and Tipper 2006) and, by revealing where other individuals are attending, can indicate potential sources of interest or danger and activate basic motivational–emotional responses and brain systems (Hietanen et al. 2008). Moreover, gaze may help to predict others' behavioral intentions, desires and preferences (Calder et al. 2002; Tomasello et al. 2005; Macrae et al. 2002). Studies in human (Driver et al. 1999; Quadflieg et al. 2004) and non-human primates (Deaner and Platt 2003) demonstrate that seeing images of other individuals with averted gaze may reflexively orient the onlookers' attention to the same direction, either covertly or overtly. Studies suggest that gaze direction coding is processed independently from stimulus spatial coding (Zorzi et al. 2003; Ansorge 2003; Bonato et al. 2008a), supporting the hypothesis that gaze direction relies upon specialized brain mechanisms (Nummenmaa and Calder 2009). Whether the strength of the attentional shifts elicited by eye cues is higher than the

shifts elicited by non-biological cues has been heatedly debated (Friesen and Kingstone 1998; Friesen et al. 2004, 2005; Hietanen 1999; Jonides 1981; Tipples 2002; Eimer 1997; Ristic et al. 2002, 2007; Bonato et al. 2008b; Stevens et al. 2008). However, there is ample consensus that eye gaze is a very powerful cue in modulating social interactions in human and animals alike (Butterworth and Jarret 1991; Emery 2000). Indeed, the eyes play a fundamental role in joint social attention and in developing mindreading abilities (Baron-Cohen 1995). By using a joint attention paradigm similar to the one used in the present study, we demonstrated that healthy subjects tend to imitate the oculomotor behavior of other individuals reflexively (Ricciardelli et al. 2002). Moreover, we found that the distracting effect of others' gaze directed leftward or rightward is significantly higher than the distracting effect of leftward or rightward pointing arrows (Ricciardelli et al. 2002). This interference effect was abolished when using stimuli with reverted gaze polarity that impairs perception of gaze direction (Ricciardelli et al. 2009). It is worth noting that the interferential effect was maximal when the distracter preceded the instruction signal. Therefore, studies that fail to find the effect for simultaneous presentation of distracter and instruction signal (Kuhn and Benson 2007; Tipples 2008) cannot be interpreted as proof that reflexive attention is comparably triggered by gaze and non-biological signals.

Body parts other than the eyes may play a specific role in triggering reflexive attention. Already 12-month-old infants use declarative pointing to share attention and emotions with others (Liszkowski et al. 2004). Moreover, seeing a hand pointing in a given direction triggers attentional shifts in the same direction even if the stimulus is irrelevant or detrimental to the task performance (Langton and Bruce 2000). This result may indicate that biological stimuli, possibly because of their social relevance, have an inherently higher power in catching attention than non-biological stimuli. Studies demonstrate that observing hand actions triggers the simulation of the very same actions (Fadiga et al. 1995) and facilitates congruent manual responses (Craighero et al. 2002). Presently unknown is whether reflexive spatial attention is non-specifically triggered by the social relevance of biological stimuli or whether it is specifically mapped according to body-centered reference frames. To investigate this issue, we performed two different studies, which compared the effect of distracting, directional biological stimuli with high social valence (gaze and pointing hand) and of non-biological, non-social stimuli (arrows) on goal-driven saccades or hand-pointing movements. A non-specific spatial interference of social stimuli would produce higher interference of gaze and pointing hands than of arrows regardless of the body part performing the action. By contrast, finding a relation between the type of distracting stimulus and the type of response would sug-

gest that additional reference frames are called into play in the task. The results show that distracting gaze stimuli interfere specifically with saccadic performance and distracting hand stimuli with pointing performance. Thus, reflexive attention driven by social stimuli may be automatically mapped according to body-part specific frames of reference.

Study 1

Method

Participants

Eighteen subjects (mean age 23.9, range 19–29, SD 3.7, 10 women), all right-handed according to a standard handedness inventory (Briggs and Nebes 1975) and recruited from a university opportunity sample, were requested to perform an eye movement task. None of the subjects had any previous experience with saccadic tasks. All subjects had a normal or corrected to normal vision and were naïve to the purposes of the study. They provided their written informed consent to participate in the study. Procedures were approved by the local ethics committee.

Apparatus

The study was performed in a quiet room with medium illumination (about 64 cd/m²). Subjects sat on a comfortable chair in front of an LCD monitor, positioned at about 50 cm from their eyes. Eye position and eye movements were measured monocularly in real-time by means of an infrared video-based system (ASL 504 Remote Tracker, Applied Science Laboratories, USA). Gaze position was determined by analyzing video field collected at 60 Hz with an accuracy of 0.5°, using the combined Purkinje-Pupil reflection as tracking method, and measured with a spatial resolution of about 0.25° visual angle. Only the horizontal eye position is considered in this report. Calibration and drift correction of the position signal were repeated every 24 trials. Slight head movements were compensated by the system. Data were analyzed using a specific self-developed software. The experiment was created and run with E-Prime software (version 1.1, Psychology Software Tools, Inc., Pittsburgh, PA) on an IBM compatible computer.

Stimuli and procedure

Each trial started with the appearance of a black central fixation mark (0.21° × 0.21° in size) presented on a light gray (about 47 cd/m²) background, and of two black squares (0.43° × 0.43°) presented at 10.2° of eccentricity in

the left and the right visual field. After 1,500 ms, the color of the central mark changed to either blue or orange. This was the instruction signal for making a fast and accurate saccade toward the left (change into blue) or the right (change into orange) target square. The colored cue remained visible until the end of the trial. A distracter was presented behind the central fixation mark, at different time intervals from the onset of the instruction cue (stimulus onset asynchronies, SOAs: -75 , 0 , 150 ms, in which the distracter preceded, was simultaneous, or followed the instruction cue). Three types of distracting stimuli were used namely a distracting gaze looking left or right, a hand pointing left or right and an arrow indicating the left or the right side. The distracting stimuli consisted of a gray-scale digital photograph or a digital drawing ($6.38^\circ \times 6.76^\circ$). To enhance their saliency, the stimuli were animated by two frames presented in rapid sequence. The first frame (lasting 500 ms) was replaced by a second frame lasting 600 ms. The first frame depicted a straight gaze, an upward pointing fist or a T-like shape. The second frame depicted a gaze, an extended finger or an arrow, which could be oriented leftward or rightward (see Fig. 1a, b and c, respectively).

The direction of the distracter and that indicated by the instruction cue could be congruent (both leftward and rightward) or incongruent (one leftward and the other rightward). Note that subjects were instructed to ignore the distracting stimulus and to focus their attention on the central mark color change. Subjects were tested in three separate blocks, each associated with one type of distracter. In each block, the two instruction cues (leftward or rightward), the two distracters (congruent or incongruent) and the three SOAs (-75 , 0 , 150 ms) were equally probable and were presented in a random sequence. Each of the 12 possible combinations was repeated 12 times, for a total of 144 trials per block. Before beginning each experimental

block, each subject completed eight practice trials which were not included in the analysis. In order to avoid possible subjects anticipating stimuli, a random inter-trial interval ranging from 500 to 3,000 ms was used. The order of the three experimental blocks was counterbalanced across subjects. Eye movements, fixations and pupil diameters were recorded using the ASL Eye Tracker Interface Software (ver.1.55.0.1, Applied Science Laboratories, USA). Data were analyzed off-line using ad hoc developed software. We analyzed subjects' directional accuracy by focusing on the first horizontal saccade that followed the instruction cue and had an amplitude larger than 2° . We computed the percentage of eye movements opposite to the instruction cue (an example is provided in the upper right part of Fig. 2). Saccadic RTs were also collected. Only RTs for correct trials were considered. A trial was rejected from the analysis described below if the latency was either less than 100 ms (anticipations) or greater than 500 ms (delays). The proportion of rejected trials was 2.3% of the total trials.

Results and discussion

Percent of erroneous saccades and saccadic RTs in correct trials (in ms) as a function of distracter type (gaze, hand or arrow), congruency (congruent or incongruent) and SOA (-75 , 0 and 150 ms) is reported in Table 1.

Two separate analyses of variance (ANOVA) were performed one for RTs and one for accuracy (inferred from the percentage of errors), with distracter (gaze, hand and arrow), congruency (congruent or incongruent) and SOA (-75 , 0 and 150 ms) as within-Ss variables. Post hoc multiple comparisons were performed using the Duncan test. For each theoretically relevant comparison, we computed an effect size index that, unlike standard significance tests, is independent from sample size. Effect size was computed in

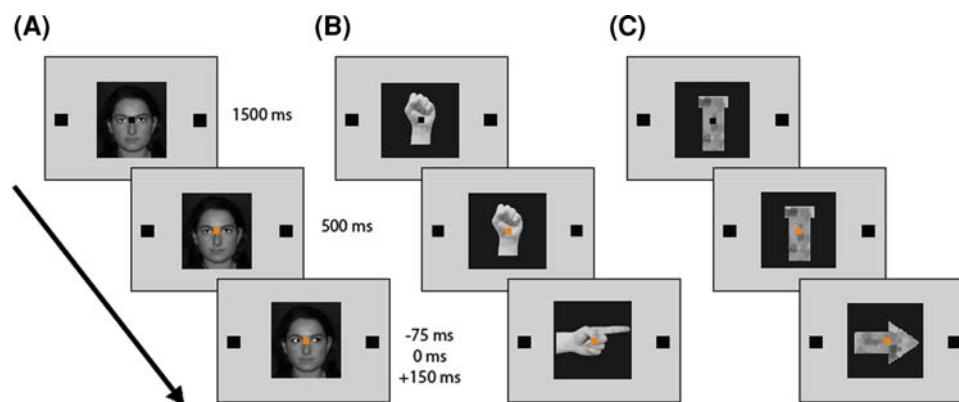


Fig. 1 Schematic representation of a trial event with the three possible distracting stimuli: **a** gaze, **b** pointing hand, **c** arrow (used in both Study 1 and Study 2). Turning the *black fixation point* into *orange* (gray in the print version) is the imperative instruction signal for right-

ward saccades (Study 1) or hand-pointing movements (study 2). Only congruent conditions are represented for the sake of simplicity. -75 , 0 , $+150$ indicates that the distracting animation precedes, is simultaneous or follows the instruction signal

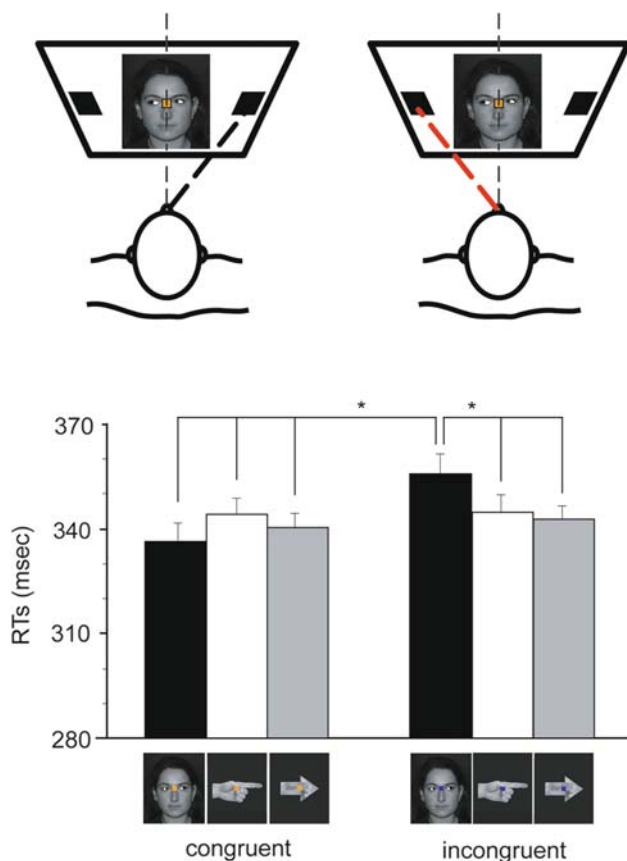


Fig. 2 Upper panel Schematic example of participants' correct or erroneous performance in the saccadic response task. The left part of the panel schematically represents a correct saccadic response (black stippled line), i.e., performed according to the instruction cue (the orange color—gray in the print version)—indicates that rightward movements have to be performed). The right part of the panel shows an incorrect saccadic response (red stippled line, gray in the print version), namely a response in which the detrimental influence of the distracting gaze is clearly visible. Lower panel Mean saccadic reaction time plotted as a function of congruency between instruction cues and direction of the different distracters (Study 1). Vertical bars denote standard error

terms of Cohen's d values where $d = 0.8$ represents/indicates a large, $d = 0.5$ a medium and $d = 0.2$ a small effect size (Cohen 1992).

Accuracy of saccadic responses

The significance of the main effect of Congruency, $F(1,17) = 32.45$, $p = 0.0001$, $d = 1.25$, is accounted for by the higher number of errors when directional information from distracters and instruction cues was incongruent (11.7%) than congruent (8%). The main effect of SOAs was also significant, $F(2,34) = 18.36$, $p = 0.0001$, in that performance at -75 ms (12%) was significantly less accurate than at 0 ms (9%, $p = 0.0001$, $d = 0.97$) and 150 ms (8.5%, $p = 0.0001$, $d = 0.86$). The significance of the interaction Congruency \times SOA, $F(2,34) = 12.36$, $p = 0.0001$, was due to higher percentage of errors in incongruent than congruent conditions at -75 ms (15.6 vs. 8.3%, $p = 0.0000$, $d = 0.81$) and at 0 ms (10.7 vs. 7.3%, $p = 0.0001$, $d = 0.039$) but not at 150 ms (8.2 vs. 8.8%, $p = 0.63$, $d = 0.05$).

This indicates that at the first two SOAs all the distracters induced comparable interference effects. No other main effects or interactions were significant.

Saccadic reaction times

The main effect of Congruency was significant, $F(1,17) = 13.24$, $p = 0.0020$, $d = 0.19$, because RTs were higher for the incongruent than for the congruent condition (347.3 vs. 339 ms). The significance of the main effect of SOA, $F(2,34) = 64.14$, $p = 0.0001$, is explained by the fact that RTs at -75 ms were significantly slower than those at 0 ms (360.4 vs. 324.5 ms, $p = 0.0001$, $d = 1.01$) and at 150 ms (344.5 ms, $p = 0.0001$, $d = 0.43$).

Importantly, the interaction Distracter \times Congruency was significant, $F(2,34) = 8.45$, $p = 0.0042$. In the incongruent condition, the difference between gaze and hand was significant (355.2 vs. 344.5 ms, $p = 0.008$, $d = 0.24$), as was the difference between gaze and arrow (342.3 ms, $p = 0.003$, $d = 0.31$); hand and arrow did not differ from one another ($p = 0.58$). Note also that the incongruent minus congruent difference (I – C) was significantly different for gaze (355.2 vs. 336 ms, $I - C = 19.2$, $p = 0.0000$, $d = 0.43$).

Table 1 Mean (\pm SEM) percentages of erroneous saccades and saccadic RTs (in ms) as a function of distracter, congruency, and SOAs

	-75		0		150	
	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
Experiment 1: saccadic errors						
Gaze	4.05 (1.2)	13.77 (2.1)	5.44 (1.8)	9.38 (1.9)	6.37 (2.2)	7.29 (1.9)
Hand	12.04 (2.2)	15.97 (2.3)	10.19 (2.2)	12.62 (2.1)	9.84 (2.3)	11.34 (2.5)
Arrow	8.91 (1.9)	17.25 (2.2)	6.48 (1.7)	10.07 (1.9)	8.68 (2.4)	7.75 (2.3)
Experiment 1: saccadic RTs						
Gaze	364.68 (6.9)	386.91 (10.7)	307.14 (7.1)	325.7 (8.9)	336.17 (9.2)	352.98 (9.1)
Hand	353.9 (8.9)	355.53 (9.4)	328.31 (7.7)	340.98 (8.6)	348.74 (9.8)	337.23 (8.8)
Arrow	349.92 (5.2)	351.81 (8.7)	318.67 (6.8)	326.68 (5.3)	343.54 (5.2)	348.58 (7)

but not for hand (344.5 vs. 343.6 ms, $I - C = 0.9$, $p = 0.08$, $d = 0.02$) and arrow (342.3 vs. 340.1, $I - C = 2.2$, $p = 0.19$, $d = 0.06$) (see Fig. 2, lower panel).

Moreover, the interaction Distracter \times SOA was significant, $F(4,68) = 8.75$, $p = 0.0001$. Post hoc comparisons revealed the following: at -75 ms saccadic RTs were significantly higher for gaze than hand (375.8 vs. 354.7 ms, $p = 0.0002$, $d = 0.05$) and arrow distracters (350.8 ms, $p = 0.0001$, $d = 0.07$); at 0 ms saccadic RTs were significantly higher for hand (334.6 ms) than gaze (316.4 ms, $p = 0.001$, $d = 0.52$) and arrow distracters (322.6 ms, $p = 0.02$, $d = 0.39$); no differences were observed at 150 ms. No other main effects or interactions were significant.

The directional incongruency between distracters and instruction signal was maximal when the latter preceded the former, as indicated by both accuracy and RT results. This suggests that interfering effects are most likely to occur before the saccadic motor program towards a specific target was completed. Crucially, incongruent gaze induced a significantly slower performance than all the other conditions. This finding may suggest that the model's distracting eyes specifically influence the subjects' saccadic performance and thus hint at a specific input–output mapping process. However, the effect may also be due to the higher social valence of gaze not only with respect to arrows but also to hands.

Study 2

The main finding of Study 1 is that eyes catch our attention more than pointing hands or arrows. This second experiment assessed whether this effect is present also when the experimental task requires a hand movement rather than a saccade.

Method

Participants

Eighteen subjects (mean age 25.5, range 20–32, SD 3.3, 8 women), all right-handed according to a standard handedness inventory (Briggs and Nebes 1975) and recruited from a university opportunity sample, performed a pointing task. Subjects had no previous experience with pointing tasks, a normal or corrected to normal vision and were naïve to the purposes of the study. Ethics procedures were identical to Study 1.

Apparatus, stimuli and procedure

The visual stimuli were almost identical to those of Study 1 (see Fig. 1). A minor difference is that the lateral black

squares were mounted on a transparent Plexiglas board positioned vertically on the desk between the subject and the computer screen. A fundamental difference is that, in Study 2, color changes of the central cue instructed hand-pointing movements towards the left or the right lateral square. An electromagnetic Pohlemus Fastrack (Pohlemus, USA) marker was taped over the nail of the right index finger. Hand trajectories were sampled at 100 Hz. A calibration procedure to set the spatial points of reference was performed at the beginning of each experimental block. A schematic representation of pointing responses is shown in the upper part of Fig. 3. We considered as erroneous, the pointing movements in which the subject, instead than following the instruction cue, moved at least 2 cm in the incorrect direction (i.e., the one indicated by the distracter) before reaching the appropriate target (see Fig. 3, upper right part). Pointing reaction times (latency between the appearance of the colored instruction cue and the beginning of the movement toward the target) were calculated starting from a 1 cm increase on the vertical axis. Trials in which subjects did not start moving 800 ms after the instruction cues (<1%) or touched the wrong target, probably due to attentional loss (<1%), were discarded from the analysis. During the experiment, all participants were instructed to look at the fixation point; eye position was monitored, and fixation was checked continuously by means of a rearview mirror.

Results and discussion

Percent accuracy and mean correct hand-pointing RTs as a function of distracter type (gaze, hand or arrow), congruency (congruent or incongruent) and SOA (-75 , 0 and 150 ms) are reported in Table 2.

Data were submitted to the same type of statistical analysis as in Study 1.

Hand-pointing accuracy

The main effect of Distracter, $F(2,34) = 4.74$, $p = 0.01$, was significant, because error rates were higher for hand (3.8%) and arrow (3.7%) than for gaze (2.7%, $ps = 0.01$, $ds = 0.52$). Errors with hand and arrow distracters were not different ($p = 0.84$). The main effect of Congruency was significant, $F(1,17) = 62.94$, $p = 0.0001$, $d = 1.63$, because of lower accuracy in the incongruent (5% errors) than the congruent condition (1.8% errors). The main effect of the SOA was also significant, $F(2,34) = 23.44$, $p = 0.0000$. This is accounted for by the fact that the percentage of errors at SOA -75 ms condition was significantly higher than at 0 ms (6 vs. 2.3%, $p = 0.0001$, $d = 0.78$) and at 150 ms (2%, $p = 0.0001$, $d = 0.78$). Moreover, the interaction

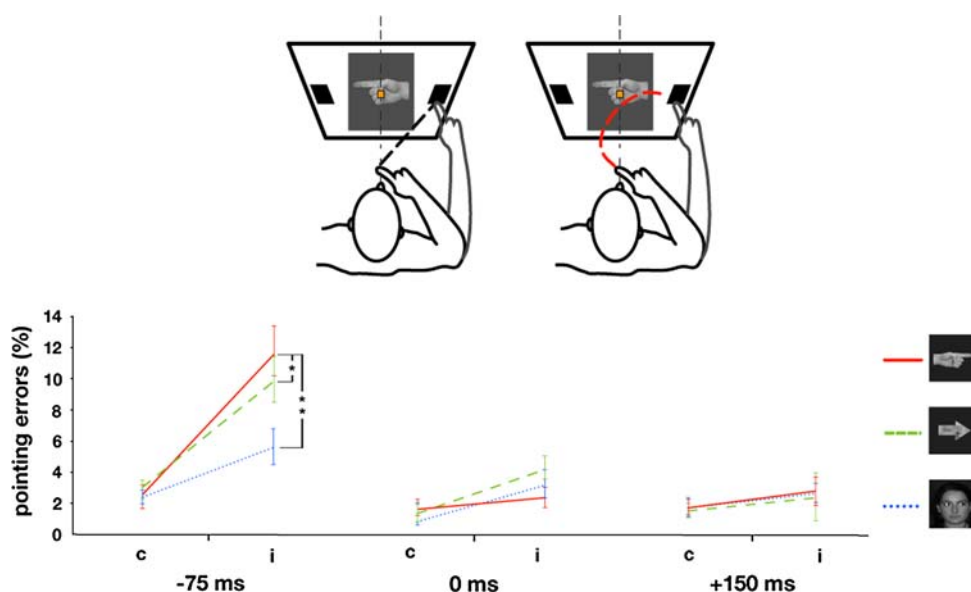


Fig. 3 Upper panel Schematic representation of a correct hand pointing (stippled black line), i.e., a response performed according to the instruction cue (left part); representation of an incorrect hand-pointing movement (stippled red line, gray in the print version), i.e., a response performed under the influence of the distracting stimulus rather than under the influence of the instruction signal (right part). Lower panel

Subjects' hand-pointing accuracy plotted as a function of congruency between instruction cues and direction of the different distracter at the different SOAs (Study 2). Vertical bars denote standard error. Note that distracting eyes, hands and arrows are presented in both studies. C congruent, I incongruent

Table 2 Mean (\pm SEM) percentages of erroneous pointing responses and hand-pointing RTs (in ms) reported as function of the different distracters, congruency and SOAs

	-75		0		150	
	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
Experiment 2: erroneous pointing responses						
Gaze	2.43 (0.4)	5.79 (1.1)	0.93 (0.3)	3.24 (0.8)	1.74 (0.5)	2.55 (0.6)
Hand	2.54 (0.6)	12.04 (1.6)	1.74 (0.5)	2.45 (0.6)	1.73 (0.5)	2.66 (0.8)
Arrow	3.01 (0.6)	10.19 (1.5)	1.39 (0.5)	4.28 (0.7)	1.5 (0.4)	2.31 (0.5)
Experiment 2: hand-pointing RTs						
Gaze	446.64 (9.4)	460.65 (8.1)	403.95 (9.2)	411.9 (8.2)	429.39 (11)	430.01 (7.1)
Hand	446.66 (9.7)	461.16 (10.9)	409.55 (9.7)	424.63 (11.4)	425.37 (9)	421.02 (11.4)
Arrow	447.2 (11.5)	462.42 (8.4)	413.92 (9.9)	425.85 (11.1)	429.72 (9.6)	427.45 (10.4)

Congruency \times SOA was significant, $F(2,34) = 24.29$, $p = 0.0000$. A post hoc analysis revealed that the interaction was due to the significant lower accuracy in the incongruent than the congruent condition at -75 ms (9.3 vs. 2.6%, $p = 0.0001$, $d = 0.65$) and at 0 ms (3.3 vs. 1.3%, $p = 0.006$, $d = 0.39$) but not at 150 ms ($p = 0.18$). The significance of the interaction Distracter \times Congruency, $F(2,34) = 4.56$, $p = 0.0175$, is explained as follows: accuracy in the incongruent condition was significantly lower when the distracter was a hand (5.7%) or an arrow (5.5%) with respect to a gaze (3.8%, $p = 0.0001$, $d = 1.08$ and $p = 0.002$, $d = 1.06$, respectively). The interaction Distracter \times SOA was significant, $F(4,68) = 3.46$, $p = 0.0124$, because subjects

tended to be less accurate at -75 ms when the distracter was a hand (7.2%) and an arrow (6.6%) compared to a gaze (4.1%, $p = 0.0000$, $d = 0.56$ and $p = 0.001$, $d = 0.50$, respectively). Crucially, the interaction Distracter \times Congruency \times SOA, $F(4,68) = 6.12$, $p = 0.0002$, was highly significant. Post hoc comparisons revealed the following: accuracy for incongruent condition was significantly lower at -75 ms when the distracter was a hand (12%) or an arrow (10.8%) with respect to gaze (5.7%, $p = 0.000$, $d = 1.02$ and $p = 0.001$, respectively). Importantly, hand condition was significantly different from arrow ($p = 0.03$, $d = 0.30$). No other differences were significant (see Fig. 3, lower panel).

Hand reaction times

The ANOVA revealed a significant main effect for SOA, $F(2,34) = 61.90$, $p = 0.000$, because RTs at -75 ms were significantly different from those at 0 ms (454.12 vs. 414.97 ms, $p = 0.0001$, $d = 0.97$) and at 150 ms (427.14 ms, $p = 0.0001$, $d = 0.65$); moreover, RTs at 0 ms SOA were significantly different from RTs at 150 ms ($p = 0.001$, $d = 0.28$). The main effect of Congruency was significant, $F(1,17) = 11.26$, $p = 0.003$, due to the slower performance in the incongruent than congruent conditions (428 vs. 436.1 ms, $d = 0.25$). The interaction Congruency \times SOA was significant, $F(2,34) = 8.74$, $p = 0.0009$, indicating that RTs were significantly faster when the distracter was congruent than when it was incongruent with the instruction cue at -75 ms (446.83 vs. 461.41 ms, $p = 0.000$, $d = 0.39$) and at 0 ms (409.14 vs. 420.8 ms, $p = 0.000$, $d = 0.27$). This result indicates that, at the first SOAs, all the distracters exerted a comparable interference effect on hand-pointing RTs.

As in Study 1, incongruent conditions were more difficult than congruent ones, particularly when the distracting stimuli preceded the instructions signal. However, unlike Study 1, the hand interfered with the performance more than the eyes. This effect hints at a specific relation between the distracting and the moving body part. It is also interesting that the body-specific interfering effect was present at the -75 SOA, i.e., before the motor program was prepared.

General discussion

Eye contact is a hallmark of interpersonal interactions. A considerable number of studies focused on the role of gaze perception in modulating social attention (Nummenmaa and Calder 2009). However, also non-facial body parts may play an important role in human communication at both implicit and explicit levels. Hands, e.g., are likely to modulate the reflexive shifts of joint attention. Studies of visuo-spatial attentional shifts have linked pointing and saccadic responses to exogenous and endogenous cuing, respectively (Sheliga et al. 1995, 1997).

In the present study, the analysis of saccadic and hand-pointing responses allowed us to compare the attention-catching power of directional gaze, hand and arrow distracters presented before, simultaneously or after a cue signaling actions to be performed with eyes or hand. We found clear interferential effects, seemingly in the absence of any voluntary control, on the subject's performance, when the directional instruction provided by the imperative signal was incongruent with the one provided by the three different types of distracters. This is in keeping with mount-

ing evidence indicating that reflexive attention is not only triggered just by peripheral cues but also by central signals (Driver et al. 1999; Hommel et al. 2001; Tipples 2002; Bonato et al. 2008a, b; Stevens et al. 2008). Importantly, a specific relationship between shifts of attention and distracting stimuli with social valence, namely gaze and hands, was found in our study. This result extends previous reports showing that viewing sudden directional gaze or pointing movements in a given individual seems to reflexively and rapidly attract the onlooker's attention towards the same direction even when orienting is not relevant or is even detrimental to the task (Driver et al. 1999; Friesen et al. 2005; Ricciardelli et al. 2002, 2009; Langton et al. 1996, 2000). Physiological studies reported reflexive attentional shifts during hand movement preparation and responses (Eimer et al. 2005; Foster and Eimer 2007; Hagler et al. 2007). It has been demonstrated that visuo-spatial attention is primed by action processing of simultaneously presented objects or visual distractors in pointing and reaching tasks (Castiello 1996; Keulen et al. 2002; Sailer et al. 2002; Tipper et al. 1992). Our results show that the specific interfering effect of social stimuli may change in different circumstances, such as, e.g., when different effectors are used to make an overt response. Thus, an entirely novel result of the present research is that the social modulation of reflexive attention does not reflect mere spatial codes but is also mapped according to effector-specific reference systems. Indeed, our Study 1 shows that a distracting gaze impaired saccadic performance significantly more than distracting biological-social (hand) or non-biological stimuli (arrows). By contrast, Study 2 shows that a distracting hand impaired pointing performance significantly more than distracting gaze or arrows. The distracter-specific effects are selectively reflected in accuracy and RTs in the saccadic and hand pointing, respectively, is likely due to genuine physiological differences between these two types of movements. Saccades, e.g., are inherently ballistic in nature and much faster than hand-pointing movements. In contrast, hand-pointing movements are much less ballistic and may vary along a higher number of degrees of freedom. Thus, it may not be surprise that ongoing corrections, typically encountered in incongruent trials, are more frequent in the hand pointing than in the saccadic task.

At any rate, the higher interference of social cues does not occur according to mere coding of a given position in space but it is influenced by the relation between the body part depicted in the distracter and the body part that performs the action requested by the experimental task. This pattern of results may suggest that the construction of joint attention contexts, which sculpt the most salient interpersonal interactions (Tomasello and Haberl 2003), is much more dynamic than previously believed. Indeed, within the social domain, the degree of interference produced by a

given stimulus is not stable but it depends on the relationship with the effector used for performing in a given task. It is worth noting that the interfering effect of social stimuli mainly occurred when the distracting stimulus preceded the instruction to move. This indicates that the detrimental effect is due to interference with ongoing action programs in accordance with premotor theories of attention (Rizzolatti et al. 1987) that, however, do not make specific predictions about the possibility that socially driven shifts of visuo-spatial attention are mapped according to body-part specific reference frames. The phenomena reported in the present study may be reminiscent of behavioral studies that show how visuo-motor priming may end up in automatic imitation (Heyes et al. 2005). In a similar vein, a facilitation of hand grasping performance during observation of a hand in a congruent but not in an incongruent position (Craighero et al. 2002) was found. Moreover, observing another person making incongruent movements has a significant interference effect on movement execution that was not found during observation of a robotic arm making incongruent movements (Kilner et al. 2003). The close link between specific visual stimuli and specific motor actions is also suggested by neurophysiological studies on the motor mirroring of observed hand actions (Fadiga et al. 1995; Romani et al. 2005; Urgesi et al. 2006). The notion that a similar mirror system may exist also for the oculomotor domain is supported by the finding that similar, mainly fronto-parietal and temporal, cortical regions are recruited during execution and observation of eye movements (Grosbras et al. 2005). The reflexive shifts of attention underlying our effects might have been triggered by a fast and automatic spatial-directional coding of the imperative signal. Previous studies demonstrate that spatial codes derived from perceived gaze direction induce spatial compatibility and Simon effects (Ansorge 2003; Zorzi et al. 2003). However, to the best of our knowledge, no studies on the specific effect of perceived hand direction have so far been performed. In view of this, the role of spatial coding in modulating body-part specific shifts of attention may be an important topic for future research. The specific behavioral association between distracting and acting body parts found in the present study makes possible data-driven exploration of the neural underpinnings of this body-part specific mapping. Indeed, neurophysiological and neuroimaging techniques can be used to explore whether specific nodes of the fronto-parietal network involved in body-part specific triggering of visuo-spatial attention play a specific role during saccadic and pointing tasks. Both these types of studies are currently performed in our laboratory.

Overall, in keeping with previous research (Driver et al. 1999; Friesen et al. 2005; Quadflieg et al. 2004; Ricciardelli et al. 2002), our two experiments indicate that reflexive attention is socially modulated. However, we significantly

extend previous knowledge by showing that reflexive shifts of visuo-spatial attention are modulated by social body stimuli through a sensorimotor mirroring process that takes place according to body-part specific reference frames.

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