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RESEARCH ARTICLE

Frames of reference and categorical and coordinate spatial relations: a hierarchical organisation

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Abstract This research is about the role of categorical and coordinate spatial relations and allocentric and egocentric frames of reference in processing spatial information. To this end, we asked whether spatial information is firstly encoded with respect to a frame of reference or with respect to categorical/coordinate spatial relations. Participants had to judge whether two vertical bars appeared on the same side (*categorical*) or at the same distance (*coordinate*) with respect to the centre of a horizontal bar (*allocentric*) or with respect to their body midline (*egocentric*). The key manipulation was the timing of the instructions: one instruction (reference frame or spatial relation) was given *before* stimulus presentation, the other one *after*. If spatial processing requires egocentric/allocentric encoding before coordinate/categorical encoding, then spatial judgements should be facilitated when the frame of reference is specified in advance. In contrast, if categorical and coordinate dimensions are primary, then a facilitation should appear when the spatial relation is specified in advance. Results showed that participants were more accurate and faster when the reference frame rather than the type of spatial relation was provided before stimulus presentation. Furthermore, a selective facilitation was found for coordinate and categorical judgements after egocentric and allocentric cues, respectively. These results suggest a hierarchical structure of spatial information processing where reference frames play a primary role and selectively interact with subsequent processing of spatial relations.

Keywords Spatial processing · Egocentric/allocentric frames of reference · Categorical/coordinate spatial relations · Instruction timing

Introduction

In order to successfully deal with everyday activities, human beings need to continuously process spatial information. For example, if we want to sit down, we need to know where the chair is with respect to our body. To recognise an object, we may rely on the relationships between the parts of the object (e.g. usually, the handle is not on top of a cup, but on its side). These two kinds of spatial information are encoded by using an egocentric and allocentric frame of reference, respectively (Kosslyn 1994; Milner and Goodale 1995; Paillard 1991). Egocentric frames of reference define spatial information with respect to the observer, whereas allocentric frames of reference are independent of the observers' position and spatial information is referred to external elements such as objects or parts of the objects (Kosslyn 1994; O'Keefe and Nadel 1978; Paillard 1971). The distinction between egocentric and allocentric frames of reference is supported by many behavioural and neurofunctional studies (Committeri et al. 2004; Iachini et al. 2009a, b; Vallar et al. 1999; Zaehle et al. 2007).

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Typically, frames of reference are necessary to organise spatial relations. While frames of reference specify the point where to anchor a location, spatial relations indicate the kind of spatial information. Spatial relations can be coordinate (i.e. metric: the chair is *one metre* from you) or categorical (non-metric, such as left/right, above/below), as first proposed by Kosslyn (1987, see also 1994). Numerous studies have shown that separate neural circuits in the left hemisphere and in the right hemisphere subserve categorical and coordinate spatial processing, respectively (for a review: Jager and Postma 2003; Laeng 1994).

These two dimensions seem to represent different but complementary aspects; we cannot process a metric or abstract spatial relation without specifying a frame of reference (Ruotolo et al. 2011). Furthermore, they have been assigned similar functions in two influential theories. In particular, Kosslyn suggested that coordinate representations specify precise spatial relations in a way that is useful for guiding action (e.g. reaching, grasping, navigating), whereas categorical representations are more useful in perception/recognition tasks because they are involved in a critical aspect of the invariant representation of an object's shape (Kosslyn 1987, 1994; Kosslyn et al. 1992).

Importantly, similar functions are assigned by Milner and Goodale (1995, 2008) to the allocentric/egocentric distinction in their vision-for-action and vision-for-perception model. Their model, as recently highlighted by Schenk and McIntosh (2010), suggests that in order to visually guide an action towards an object, the object's position must be coded egocentrically and its spatial dimensions measured in absolute metrics. In contrast, if the purpose is to recognise an object, the visual system must rely on viewer–invariant relationships (not absolute metrics), thus spatial features should be coded in allocentric frames of reference. However, several studies have shown that egocentric representations can also be used in recognition (Shelton and McNamara 2004) and visual search tasks (Ball et al. 2009; van der Ham et al. 2011) and can interact with allocentric representations during visuo-spatial judgement tasks (Ruotolo et al. 2011). This suggests that there is not a strict relationship between allocentric frames of reference and object/scene recognition because egocentric frames of reference may also play an important role. On the other hand, allocentric representations may also interact with egocentric processing during online grasping control (Heath et al. 2006). Overall, these findings indicate that the use of an egocentric and/or an allocentric frame is not necessarily dependent on task purposes. Furthermore, the distinction between egocentric and allocentric frames of reference seems crucial to interpret several behavioural and neurofunctional findings (Possin 2010; Schenk 2006; Schenk and McIntosh 2010). Contrary to Milner and Goodale's interpretation (1995), some studies about visual illusions suggest that the presence of illusion biases on visuo-perceptual but not visuo-motor performance may depend more on the type of spatial coding used to accomplish the task, that is, egocentric or allocentric, than on the response modality (action-dependent or perception-dependent) required by the task (Bruno et al. 2008; see also Becker et al. 2009; Franz 2001; Wraga et al. 2000).

The argument of the 'spatial encoding primacy' is also supported by a recent neuropsychological study with patient DF (Schenk 2006). DF suffers from bilateral damage to the ventral stream. Schenk (2006) decoupled the perception/action functions from egocentric/allocentric encodings and, contrary to what was found by Goodale and Milner (1992), showed that DF had a 'normal' performance in both perceptual judgments and motor responses when egocentric encoding was requested, whereas she showed an impairment when allocentric encoding was required.

These studies underscore the important role of spatial encoding, in particular of egocentric and allocentric reference frames, in organising information for different, both perceptual and motor, behavioural purposes. However, it is not clear how egocentric/allocentric and categorical/coordinate dimensions are related; do they have the same or different role in processing spatial information? In other words, is spatial information primarily encoded with respect to a frame of reference or with respect to categorical/coordinate spatial relations?

There are three possibilities: (a) spatial processing requires egocentric/allocentric encoding before coordinate/categorical encoding; (b) categorical/coordinate distinction has a primary role with respect to egocentric/allocentric processing; (c) egocentric/allocentric and categorical/coordinate dimensions have the same role in spatial information processing.

We addressed this issue by using an experimental paradigm similar to that used by Ruotolo and colleagues in a previous study (2011). Participants had to judge whether two vertical bars appeared on the same side (*categorical*) or at the same distance (*coordinate*) with respect to the centre of an horizontal bar (*allocentric*) or with respect to their body midline (*egocentric*). While keeping this same general task design, in the current study, the timing of the instructions was manipulated; in one condition, participants were instructed to encode the stimulus according to one of the two frames of reference (egocentric or allocentric) *before* stimulus presentation, and *after* stimulus presentation, they were asked to give a categorical or a coordinate judgement. In another condition, participants were instructed to encode the categorical or coordinate characteristics of the stimulus *before,* and only *after* stimulus presentation, they were asked to give an egocentric or an allocentric judgement.

If spatial processing requires egocentric/allocentric encoding before coordinate/categorical encoding, then spatial judgements should be facilitated when the frame of reference is specified in advance. In contrast, if categorical and coordinate dimensions are primary, then spatial judgements should be facilitated when the kind of spatial relation is specified in advance. Finally, if the two spatial processes have the same role, then no significant effect of timing of instructions should emerge.

Method

Participants

Forty-eight students (24 men and 24 women, mean age = 22.80, SD = 2.60; range: 18–28) from the Second University of Naples participated in the experiment in exchange for course credit. All participants were right-handed and had a normal or corrected to normal vision.

Apparatus

The experiment took place in a darkened room in order to prevent any interference from allocentric cues. Participants were seated in front of a 17-inch computer screen (1,280 × 768 pixels), at a distance of 50 cm. All participants were asked whether they were able to see the monitor's edges either before or during the experimental trials, and nobody reported they could. A chin rest was used to keep the head still in front of the exact centre of the screen. The stimuli were displayed on a black background (24 bits RGB colour coding: 0, 0, 0). They were generated by a PC, the operating system was Microsoft Windows XP and the software SUPERLAB-Pro 2.0 was used for stimuli presentation. A serial mouse was used to register participants' responses.

Stimuli

The combination of two vertical white *target* bars (width: 0.3 mm; length: 2 mm; 24 bits RGB colour coding: 255, 255, 255) one above and the other below a white horizontal bar (width: 0.3 mm; length: 4.5 cm; 24 bits RGB colour coding: 255, 255, 255) formed the stimuli. Participants judged if the two vertical bars appeared at same distance or not (coordinate task) or if they appeared on the same side or not (categorical task) with respect to egocentric and allocentric reference points. When the vertical bars were referred to the centre of the horizontal bar, they constituted the allocentric positions; when they were referred to the participant's body midline, they were considered the egocentric positions. The combination of 'distance' and 'side' generated three possible spatial configurations of the vertical bars with respect to the reference points. The two vertical bars could be placed at the *Same Distance on Different Sides* (SDDS), at *Different Distances on the Same Side* (DDSS) or *at Different Distances on Different Sides* (DDDS) with respect to the reference point (see Fig. 1). For the configurations 'DDSS' and 'DDDS', the position of the two vertical bars was manipulated in order to obtain three levels of metric difficulty: 2 mm, 4 mm, 8 mm. For example, a difficulty of 4 mm in DDSS configuration was obtained by placing one of the two vertical bars at 4 mm and the other at 8 mm on the same side with respect to the reference point (the centre of the horizontal bar or the body midline), whereas in DDDS configuration, one of the two vertical bars was located at 4 mm on the right and the other at 8 mm on the left with respect to the reference point. So, in all trials, judgements about the position of the two vertical bars were based on a metric difference of 4 mm. By following the same logic, metric difficulties of 2 and 8 mm were obtained. In this way, we could ensure that all judgments were based on the same level of metric difficulty.

Finally, in the SDDS stimuli, the two vertical bars were placed both at 2, 4, and 8 mm on opposite sides with respect to the reference point and, of course, the metric difference was zero. These factors, i.e., the three distance/side combinations and the three metric levels, led to nine basic arrangements of stimuli.

In order to distinguish the two frames reference, either the horizontal bar or the entire configuration was displaced. In the egocentric condition, for each egocentric position of the two vertical bars, the centre of the horizontal bar could appear at 4 or 8 mm, to the right or to the left, with respect to the centre of the screen. This way the target positions with respect to the body midline remained the same, but irrelevant allocentric information, i.e., the centre of the horizontal bar, varied. In the allocentric condition, the entire stimulus configuration could appear at 4 or 8 mm, rightmost or leftmost with respect to the centre of the screen. Therefore, the allocentric positions of the two vertical bars remained the same, but irrelevant egocentric information, i.e., the position of the target with respect to the extension of the body midline varied. We chose the two levels of misalignment, 4 and 8 mm, in order to avoid excessive allocentric facilitation and obtain a comparable level of egocentric and allocentric frames discrimination (see Neggers et al. 2005). In total, nine stimuli were aligned, nine misaligned on the right and nine misaligned on the left. In order to obtain the same number of confirmative (i.e. same distance or same side) and negative (i.e. different distance or different side) responses, nine stimuli of two spatial configurations were presented twice in both the coordinate and categorical tasks. Therefore, for each task, 36 trials were presented (total number = 288 trials).

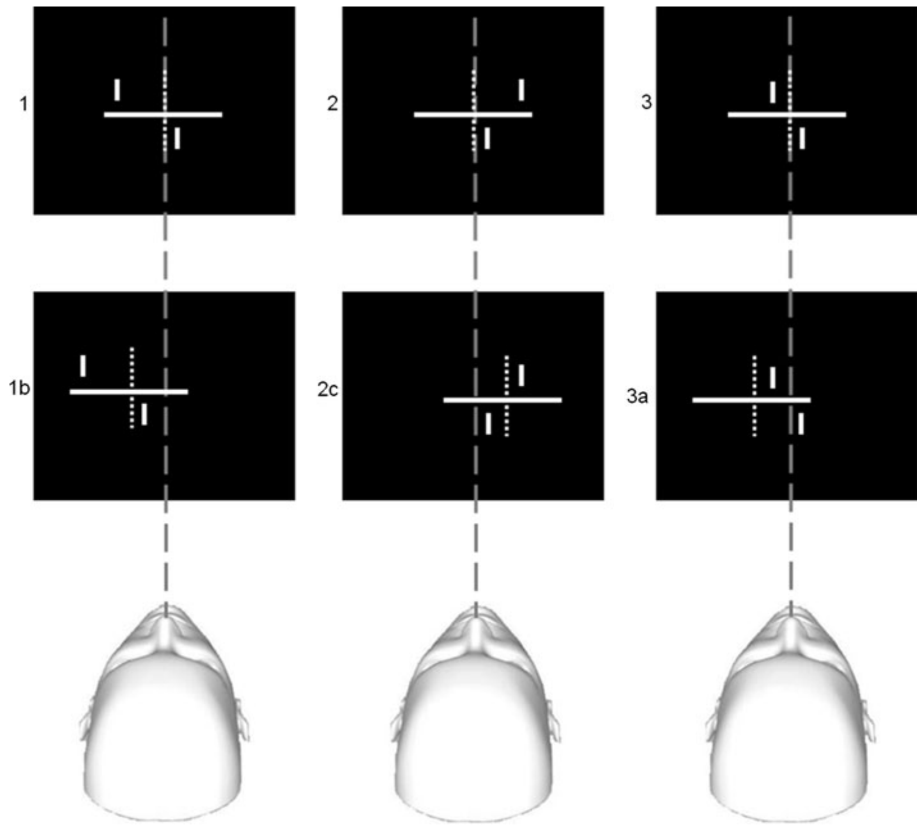

Fig. 1 Examples of stimuli used in the experiment. The *dotted grey lines* indicate the body midline. The *white dotted lines* indicate the centre of the *horizontal bar*. In the first row, the three spatial configurations of the two *vertical bars* are shown: *1* Different Distances Different Sides; *2* Different Distances Same Side; *3* Same Distance Different Sides. In *1*, *2* and *3* examples of alignment between egocentric and allocentric reference frames are shown. In *1b*, *2c* and *3a* examples of misalignment between egocentric and allocentric reference frames are shown; in *1b,* misalignment is created by displacing the entire stimulus configuration; in *2c,* misalignment is created by displacing only the *horizontal bar*; in *3a,* misalignment is created by displacing only the *horizontal bar*

Procedure

Participants saw two white vertical bars (targets), one above and the other below a white horizontal bar. They had to judge if the two vertical bars appeared at the same distance or not with respect to their body midline (*egocentric-coordinate task*) or with respect to the centre of the horizontal bar (*allocentric-coordinate task*). Moreover, they had to decide whether the two vertical bars were on the same side or not with respect to either their body midline (*egocentric-categorical task*) or with respect to the centre of the horizontal bar (*allocentric-categorical task*). However, information about what kind of spatial relation and what kind of frame of reference to use for the spatial judgements was given in two separate moments with respect to stimulus presentation. In the 'Frames of reference before (FoRb)' condition, participants were asked to encode the stimulus according to one of the two frames of reference (egocentric or allocentric) *before* stimulus presentation and *after* stimulus presentation, they were asked to give a categorical or a coordinate judgement. Instead, in the 'Spatial relations before (SRb)' condition, participants were asked to encode the categorical or coordinate characteristics of the stimulus *before* stimulus presentation and only *after* stimulus presentation, they were asked to give an egocentric or an allocentric judgement. The experiment consisted of eight different tasks. During the experimental session, there was a 10-s pause after every 36 trials. A trial in the FoRb condition started with the auditory presentation of the word 'Corpo' ('body' in English) if participants had to encode the relationship between the two vertical bars with respect to their body midline or with the word 'Barra' ('bar' in English) if they had to encode the relationship between the two vertical bars with respect to the centre of the horizontal bar. Afterwards, a grey fixation cross (width = 0.3 mm; length: 2 mm) in a grey dotted square (3.5 × 3.5 cm) was presented at the centre of the screen. Participants were instructed to fixate the fixation cross for 500 ms; next, the cross disappeared and they had to maintain ocular fixation within the dotted square for 1.000 ms. This was inserted in order to avoid the scope of attention being differently primed in each frame of reference condition (Okubo et al. 2010; Laeng et al. 2011). Participants knew that the area of presentation of the stimuli was limited to that indicated by the dotted square, that is, the centre of the screen. As soon as the dotted square disappeared, one of the stimuli was presented for 100 ms. Afterwards, the screen was blank and the word 'Distanza' ('distance' in English) was auditory presented if a coordinate judgment had to be expressed. Instead, in case of a categorical judgement, the word 'Lato' ('side' in English) was provided. Participants had 2 s to press the right (affirmative answer) or left (negative answer) button of the mouse to give the response. If they failed to respond within 2 s, a text was presented on the screen indicating that they did not respond in time. The duration of all auditory cues was 500 ms. All the cues were given in Italian. Figure 2 gives an example of the experimental flow for both 'FoRb' and 'SRb' conditions.

Before the experimental session, there was a training session. Participants were explained the different tasks and performed 20 trials in which a feedback was given. The presentation of all the 288 trials was randomised for each participant.

The experimental design comprised a 2-level within variable Frames of reference (Egocentric vs. Allocentric), a 2-level within variable Spatial relations (Coordinate vs. Categorical) and a 2-level within variable Instructions timing (FoRb vs. SRb). Accuracy (mean number of correct judgements) and Response Time (in milliseconds) were the dependent variables.

Results

Analyses were based on 3-way Anovas for repeated measures with terms for 'Frames of reference' (egocentric, allocentric), 'Spatial Relations' (categorical, coordinate) and 'Instructions Timing' (FoRb, SRb) variable. The Scheffe's test was used to analyse post hoc effects.

For accuracy, the ANOVA revealed a main effect of the variable 'Frames of Reference' due to allocentric judgments ($M = .77$; $SD = .05$) being more accurate than egocentric judgments ($M = .66$; $SD = .03$), $F(1, 47) = 202.02$, $P < .0001$, $\eta_p^2 = .81$. A main effect of 'Spatial Relations' was also found, $F(1, 47) = 98.79$, $P < .0001$, $\eta_p^2 = .67$. This effect was due to categorical ($M = .76$; $SD = .06$) being better than coordinate judgments ($M = .66$; $SD = .04$). Furthermore, the main effect of the variable 'Instructions Timing' appeared: $F(1, 47) = 51.67$, $P < .0001$, $\eta_p^2 = .52$. Participants performed significantly better when the instructions about the frames of reference were given *before* ($M = .74$; $SD = .04$) instead of *after* ($M = .69$; $SD = .04$) stimulus presentation.

No significant 2-way interaction was found (Frames of reference × Spatial Relations: $F(1, 47) = 1.20$; $P = .28$, $\eta_p^2 = .025$; Frames of reference × Instructions Timing: $F(1, 47) = .36$; $P = .55$, $\eta_p^2 = .0075$; Spatial Relations × Instructions Timing: $F(1, 47) = 1.36$; $P = .21$, $\eta_p^2 = .034$) but a 3-way interaction appeared: $F(1, 47) = 4.85$; $P < .05$, $\eta_p^2 = .09$. The post hoc analysis revealed

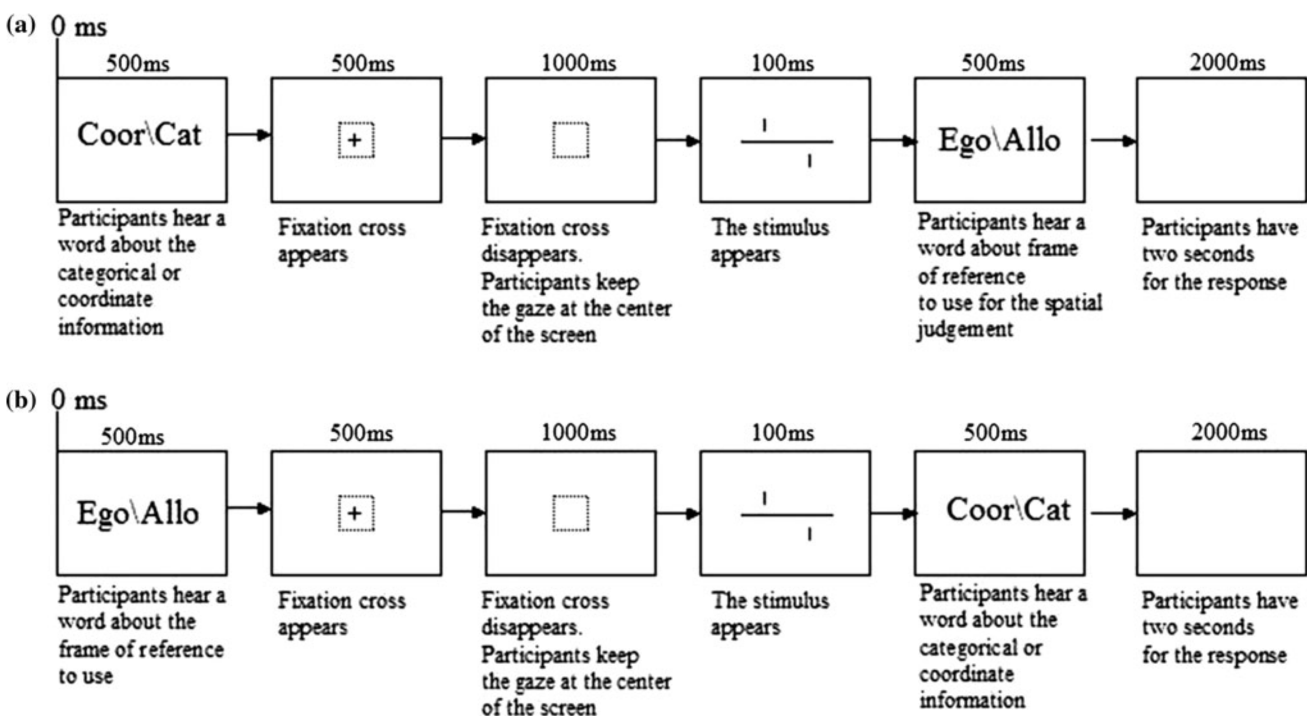

Fig. 2 This figure depicts a schematic overview of two trials of the experiment. **a** Condition 'SRb'. At $t = 0$ ms, participants hear the word 'Distanza' ('distance' in English) if they have to encode coordinate relations, or the word 'Lato' ('side' in English) if they have to encode categorical relations; at $t = 500$ ms, the fixation cross is displayed; when the cross disappears, only the *dotted square* remains for 1,000 ms, then the to be judged stimulus is displayed for 100 ms, after which the participants can hear the word 'Corpo' ('body' in English) for egocentric judgement or the word 'Barra' ('bar' in English) for allocentric judgment. After the second word, participants have 2 s for the response; **b** Condition 'FoRb'. In this condition, participants hear the word about the frame of reference before stimulus presentation and the word about the spatial relation after stimulus presentation

that the variable 'Instructions Timing' influenced the relationship between Frames of reference and Spatial relations. In the 'SRb' condition, allocentric categorical judgements ($M = .79$; SD = .12) were more accurate than all other judgements (Ps < .0001; allocentric coordinate: $M = .71$; SD = .08; egocentric categorical: $M = .70$; SD = .04; egocentric coordinate: $M = .57$; SD = .08), whereas the egocentric coordinate judgements were the least accurate (Ps < .01). The same pattern appeared in the 'FoRb' condition: allocentric categorical ($M = .86$; SD = .09) were the most accurate judgements (Ps < .001; allocentric coordinate: $M = .73$; SD = .08; egocentric categorical: $M = .75$; SD = .04; egocentric coordinate: $M = .63$; SD = .08), egocentric coordinate were the least accurate judgements (Ps < .0001). However, as shown in Fig. 3, the coordinate performance improved when an egocentric frame of reference was specified before than after stimulus presentation, $F(1, 47) = 9.92$, $P < .005$, $\eta_p^2 = .17$, whereas the categorical performance improved when the allocentric frame was given before stimulus presentation: $F(1, 47) = 23.53$, $P < .0001$, $\eta_p^2 = .33$. No other significant differences were found.

For response latency (ms), the Anova revealed a main effect of 'Frames of reference', $F(1, 47) = 11.68$, $P < .001$, $\eta_p^2 = .20$. This effect was due to allocentric judgements ($M = 913.5$; SD = 97.65) being faster than egocentric ones ($M = 948.3$; SD = 102.5). A main effect of 'Spatial relations' was also found, $F(1, 47) = 33.28$, $P < .0001$, $\eta_p^2 = .41$, due to categorical judgements ($M = 903.4$; SD = 102.6) being faster than coordinate judgements ($M = 958.4$; SD = 95.9). In line with the previous results, a main effect of the 'Instructions timings' was also found, $F(1, 47) = 14.25$, $P < .0005$, $\eta_p^2 = .23$. Participants were faster when the frames of reference were given before ($M = 913.7$; SD = 88.4) than after the presentation of the stimulus ($M = 948.13$; SD = 108.3).

A 2-way interaction between coordinate and categorical spatial processing and instructions timing emerged, $F(1, 47) = 5.28$, $P < .05$, $\eta_p^2 = .10$ (see Fig. 4). The post hoc analysis revealed that the presentation of the instructions about the frames of reference before or after the stimulus did not influence the categorical performance ($F < 1$), but the coordinate performance, $F(1, 47) = 17.76$, $P < .0001$, $\eta_p^2 = .27$. Coordinate judgments were significantly faster when the instructions about the frames of reference were given before ($M = 930.74$; SD = 99.41) the presentation of the stimulus than after ($M = 986$; SD = 112.42). Finally, categorical judgements were faster than coordinate ones, either when the frame of reference was presented before the stimulus (categorical FoRb: $M = 896.61$; SD = 91.24), $F(1, 47) = 10.86$, $P < .005$, $\eta_p^2 = .19$ or after it (categorical SRb: $M = 930.74$; SD = 99.41), $F(1, 47) = 24.1$, $P < .0001$, $\eta_p^2 = .34$.

In order to verify whether artifactual procedural features, such as the level of difficulty of the various trials and the alignment/misalignment between egocentric and allocentric frames of reference could have influenced the pattern of results further analyses were carried out. Taking into account the possibility that metric difficulty could selectively affect spatial judgements, we performed a four-way repeated ANOVA with terms for frames of reference, spatial relations type, instructions timing and metric

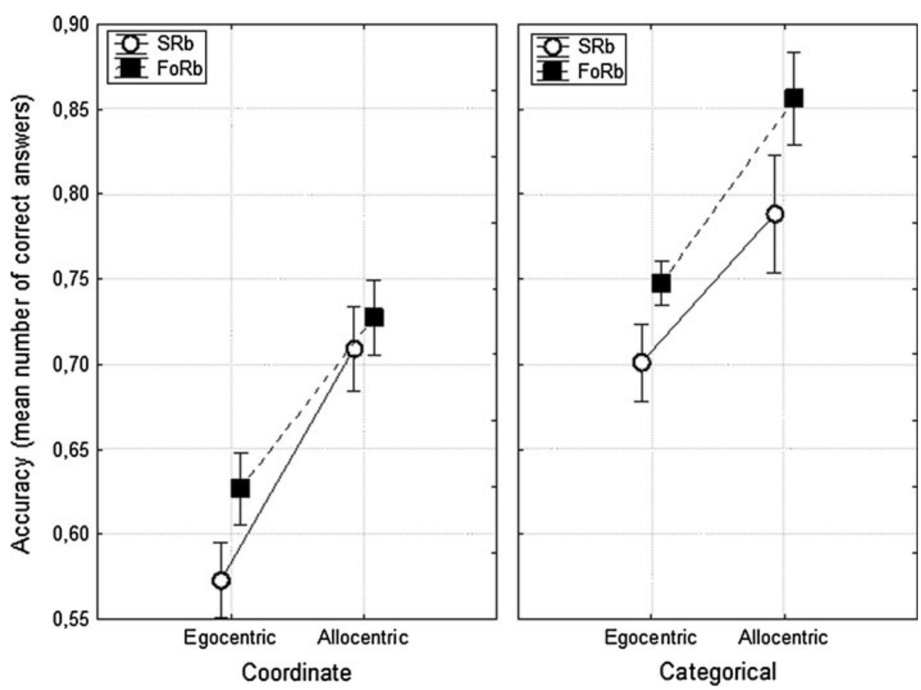

Fig. 3 Mean accuracy for categorical and coordinate spatial judgements as a function of egocentric and allocentric frames of reference and timing conditions

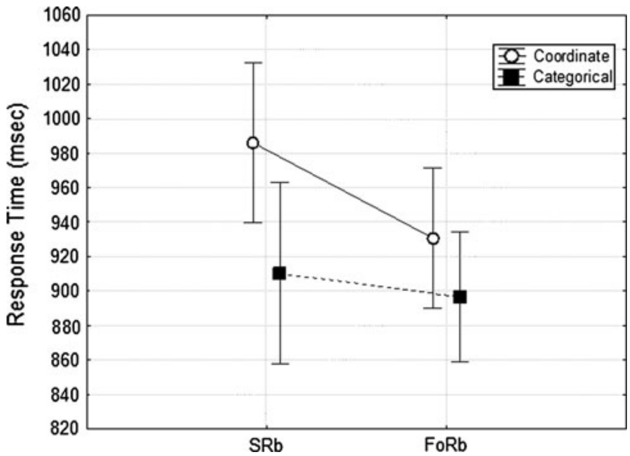

Fig. 4 Mean response time for categorical and coordinate spatial judgements as a function of timing conditions

difficulty (2, 4, and 8 mm). With regard to accuracy, results did not show a main effect of difficulty levels ($F < 1$). Furthermore, the absence of any significant interaction effect involving the variable 'metric difficulty' (Ps $> .19$) indicated that the levels of difficulty of the tasks did not influence the pattern of results previously found. The same pattern of results was found for response latency.

Some studies showed that in condition of misalignment, irrelevant allocentric information can influence egocentric visuo-spatial judgements (Neggers et al. 2005, 2006) and viceversa (Sterken et al. 1999; Ruotolo et al. 2011). To see whether this influence was present also in this study, a four-way ANOVA for repeated measures with terms for frames of reference, spatial relations type, instructions timing and alignment (aligned/misaligned) was carried out. Results showed neither four or three-way interaction effects (in all cases $P > .19$), but only the main effect of the variable 'Alignment': $F(1, 47) = 27.44$, $P < .0001$, $\eta_p^2 = .36$. The effect reflects that the judgments in the aligned condition ($M = .76$; SD $= .08$) were more accurate than in the misaligned condition ($M = .70$; SD $= .06$). The same pattern of results appeared for the response time. These results indicated that although the influence of irrelevant information on egocentric and allocentric judgments appeared in misalignment conditions, it did not affect the relationship between frames of reference and spatial relations.

Discussion

The research reported here was focused on the role of allocentric/egocentric frames of reference with respect to categorical/coordinate spatial relations in organising spatial information. Participants made spatial judgements that combined one type of reference frame with one type of spatial relation. Overall, the results indicate that pre-cueing participants with a frame of reference leads to more accurate and faster spatial judgments than pre-cueing participants with spatial relations. The improvement was particularly evident for categorical judgements when the stimulus had to be encoded according to an allocentric reference frame and for coordinate judgements when an egocentric frame was specified before stimulus presentation. It is important to point out that this effect was not influenced by the difficulty of the task or the conditions of alignment/misalignment between the two frames of reference. Moreover, in any case, spatial judgments did not improve when spatial relations cues were given before stimulus presentation. Therefore, it seems that for spatial information to be processed efficiently, the first necessary operation is to encode it according to frames of reference. This suggests that spatial information processing could be considered to be organised in a hierarchical fashion, with frames of reference having a primary role with respect to categorical/coordinate spatial relations. However, it is important to highlight that this interpretation is limited to visuo-perceptual organisation of spatial information, given the current experimental design. Nevertheless, this finding can be considered as a further support to studies that show a 'primacy' of reference frames in several tasks addressing visual illusion effects and perception/action dissociations (Becker et al. 2009; Heath et al. 2006; Schenk 2006; Wraga et al. 2000). Furthermore, it seems in line with recent proposals suggesting that visual spatial cognition is organised according to egocentric–allocentric frames of reference (e.g. Possin 2010).

The results also showed that coordinate judgments improved particularly when an egocentric frame was given before stimulus presentation, whereas categorical judgments improved particularly when an allocentric frame was required. This gives some insight into the relationship between the two spatial distinctions. In line with Jager and Postma (2003) and Ruotolo et al. (2011), the selective facilitation for the egocentric/coordinate and allocentric/categorical combinations would suggest that frames of reference and spatial relations form interactive dimensions. One possibility is that the pattern of facilitation might be the expression of the functional link between frames of reference and spatial relations. The models proposed by Kosslyn (1994) and Milner and Goodale (1995) would suggest that coordinate spatial information specified according to egocentric frames of reference are necessary to guide actions, whereas allocentric categorical information are more useful to recognise scenes or objects. In other words, allocentric processing would be closer to categorical coding of spatial relations, whereas egocentric processing would be closer to coordinate coding.

Our data are partially in line with this interpretation. Even though an advantage of allocentric categorical over allocentric coordinate judgments appeared, an advantage of egocentric categorical over egocentric coordinate judgments also emerged. More specifically, participants performed worse in egocentric coordinate tasks than in all other tasks, although a small improvement was observed when the egocentric frame was indicated before stimulus presentation. Instead, the results clearly speak in favour of the combination allocentric and categorical whose related judgements were the most accurate and fastest. As suggested by Ruotolo et al. (2011), this could be due to the fact that the task used in this research, based on 2-D stimuli and requiring non-visually driven motor response modality, might have enhanced perceptual/recognition components and hence favoured allocentric and categorical judgments. In turn, the characteristics of the task could have limited the emergence of the interaction between egocentric and coordinate components. For example, Ruotolo et al. (2011) showed that it was sufficient to reduce the luminance of the horizontal bar with respect to the two vertical bars to determine an improvement of coordinate judgments particularly when combined with an egocentric frame of reference. Therefore, in our experiment, the two vertical bars (target bars) and the horizontal bar (that is the allocentric cue) had the same luminance that could have stressed the allocentric relations to the detriment of the egocentric ones and, in turn, could have masked the interaction with coordinate components.

In sum, although the appearance of a selective facilitation suggests particular links between egocentric coordinate and allocentric categorical, the general pattern of results, in line with our hypotheses, suggests that egocentric and allocentric frames of reference have a primary role with respect to categorical and coordinate spatial relations in processing spatial information; when spatial information is primarily processed and organised according to a frame of reference, spatial performance is generally more accurate and faster. This would confirm the importance of the kind of spatial encoding in visuo-spatial information processing (Ball et al. 2009; Bruno 2001; Schenk 2006). Moreover, these data shed light on the relationship between the two kinds of spatial encoding (Jager and Postma 2003). Indeed, the presence of a hierarchical organisation between the two dimensions seems to suggest that they can be considered as different but not independent processes because egocentric and allocentric frames of reference may interact with coordinate and categorical spatial relations. However, future studies should investigate the possible influence of task characteristics such as kinds of stimuli (2D/3D), response modalities (verbal/motor) and temporal parameters (immediate/delayed response) on the relationship between egocentric/allocentric frames of reference and coordinate/categorical spatial relations.

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