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The relationship between allocentric and egocentric frames of reference and categorical and coordinate spatial information processing

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We report two experiments on the relationship between allocentric/egocentric frames of reference and categorical/coordinate spatial relations. Jager and Postma (2003) suggest two theoretical possibilities about their relationship: categorical judgements are better when combined with an allocentric reference frame and coordinate judgements with an egocentric reference frame (interaction hypothesis); allocentric/egocentric and categorical/coordinate form independent dimensions (independence hypothesis). Participants saw stimuli comprising two vertical bars (targets), one above and the other below a horizontal bar. They had to judge whether the targets appeared on the same side (*categorical*) or at the same distance (*coordinate*) with respect either to their body-midline (*egocentric*) or to the centre of the horizontal bar (*allocentric*). The results from Experiment 1 showed a facilitation in the allocentric and categorical conditions. In line with the independence hypothesis, no interaction effect emerged. To see whether the results were affected by the visual salience of the stimuli, in Experiment 2 the luminance of the horizontal bar was reduced. As a consequence, a significant interaction effect emerged indicating that categorical judgements were more accurate than coordinate ones, and especially so in the allocentric condition. Furthermore, egocentric judgements were as accurate as allocentric ones with a specific improvement when combined with coordinate spatial relations. The data from Experiment 2 showed that the visual salience of stimuli affected the relationship between allocentric/egocentric and categorical/coordinate dimensions. This suggests that the emergence of a selective interaction between the two dimensions may be modulated by the characteristics of the task.

Keywords: Egocentric/allocentric frames of reference; Categorical/coordinate spatial relations; Visuoperceptual task.

In order to manage a wide range of tasks in everyday life, people have to encode and organize different kinds of spatial information. In some tasks, such as reaching or grasping an object, there is a need to localize the position of objects, and information about metric distance could be used to guide the hand throughout the movement to the target (Kosslyn, Chabris, Marsolek, & Koenig, 1992).

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Instead, in other tasks, such as the recognition of a scene, the use of more abstract nonmetric spatial relations can be sufficient.

In the literature, a distinction between metric and abstract spatial information has been proposed in terms of coordinate and categorical spatial information, respectively (e.g., Kosslyn, 1987, 1994). Coordinate relations specify precise spatial locations of objects or object parts in terms of metric units and exact distances. Categorical relations form general, abstract codes capturing basic relational and invariant spatial information in the visual world such as left/right, above/below. This distinction is supported by computer simulation, behavioural, neurofunctional, and neuropsychological studies (see Jager & Postma, 2003; Postma & Laeng, 2006). In particular, it has been shown that categorical and coordinate representations are subserved by separate neural circuits in the left hemisphere and in the right hemisphere, respectively (Hellige & Michimata, 1989; Kosslyn et al., 1989; Laeng, 1994, 2006; Trojano, Conson, Maffei, & Grossi, 2006; Trojano et al., 2002; van Asselen et al., 2006). According to Kosslyn et al. (1992) coordinate representations specify spatial information in a way that can be used to guide movements. Instead, categorical representations are used in object recognition because of their critical role in supporting an invariant representation of an object's shape (Marr, 1982). In line with this hypothesis, Dijkerman and Milner (1998) showed that the execution of a visuomotor task relied on more precise, metric spatial information than execution of a perceptual matching task.

The distinction between categorical and coordinate spatial information is connected to another important distinction in the field of spatial cognition—that is, between egocentric and allocentric frames of reference (e.g., Kosslyn, 1994; O'Keefe & Nadel, 1978; Paillard, 1991). Egocentric frames of reference define spatial information with respect to the body or parts of the body (e.g., the chair is *one meter* away *from you*, or, the chair is *to your left*), whereas allocentric frames of reference are independent of the viewers' position, and spatial information is referred to external elements such as objects or parts of objects (Kosslyn, 1994) and environmental landmarks (Mou & McNamara, 2002; Shelton & McNamara, 1997; e.g., the chair is *one meter* away from *the table*, or, the chair is *to the left of the table*). Behavioural data in normal subjects have shown that egocentric and allocentric frames of reference are affected selectively by several factors, such as way of learning spatial information (Presson & Hazelrigg, 1984), size (Presson, De Lange, & Hazelrigg, 1989), geometric structure (McNamara, Rump, & Werner, 2003), and degree of familiarity with the environment (Iachini, Ruotolo, & Ruggiero, 2009). Many studies investigating the cerebral organization of spatial processing in patients and healthy adults have suggested that the two frames of reference would engage distinct neural networks (Committeri et al., 2004; Galati et al., 2000; Iachini, Ruggiero, Conson, & Trojano, 2009; Vallar et al., 1999; Zaehle et al., 2007).

According to Milner and Goodale (1995, 2008), the two frames of reference have specific functions in the vision-for-action and vision-for-perception model: egocentric representations would be used by the dorsal stream to programme and control the skilled movements needed to carry out the action, whereas conscious perception would rely on allocentric representations supported by ventral stream. However, Schenk (2006) showed that egocentric and allocentric spatial processing plays a primary role and may be involved in both "action" and "perception", depending on task requirements (see also Ball, Smith, Ellison, & Schenk, 2009).

Central to the present research, we wish to argue that the functional descriptions of categorical/coordinate (Kosslyn, 1987) and allocentric/egocentric (Milner & Goodale, 1995, 2008) distinctions may be intrinsically connected. Allocentric processing provides the observer with a sense of "space constancy", an awareness of relative, categorical locations of objects that is necessary for the recognition of objects or scenes. In turn, metric-coordinate information is used for the egocentric task of performing motor actions towards these objects (Carey, Dijkerman, & Milner, 1998; Jager & Postma, 2003; Kosslyn, 1994; Milner & Goodale, 1995, 2008). Therefore, both egocentric and coordinate representations seem to mainly support the function of guiding movements towards objects, whereas both allocentric and categorical representations appear mostly involved in recognition functions. This raises the interesting question if and how the two dichotomies are related. Jager and Postma (2003) suggest two possibilities. The interaction hypothesis supposes that allocentric processing more or less equates with categorical coding of spatial relations, whereas egocentric processing is close to coordinate coding. In other words, categorical performance should be better with an allocentric reference frame and coordinate performance with an egocentric reference frame. The second possibility—the independence hypothesis—holds that the allocentric/egocentric and the categorical/coordinate distinctions form independent dimensions, which can be fully combined, without showing selective facilitation (Murphy, Carey, & Goodale, 1998). While the former defines the point of reference to anchor a location, the latter specifies the grain of the spatial relation.

Notably, the relation between these two spatial distinctions has not yet been examined systematically. Some indirect evidence in support of the interaction hypothesis comes from a study by Iachini and colleagues (Iachini, Ruggiero, et al., 2009) who compared left- and right-parietal brain-damaged patients on an egocentric and allocentric spatial memory task. The results showed that right-patients were dramatically less accurate in judging metric information according to egocentric but not allocentric frames of reference, thereby suggesting a relative specialization of the right hemisphere for egocentric metric information. On the other hand, Carey and colleagues (Carey, Dijkerman, Murphy, Goodale, & Milner, 2006) showed that patient D.F. (Goodale & Milner, 1992), suffering from visual agnosia, performed quite poorly in copying arrays and in pantomiming pointing tasks when she relied on allocentric coordinate but not allocentric categorical coding. Carey and colleagues suggested that their results were consistent with the independence hypothesis.

The goal of the present study was to test the hypotheses regarding the relation between the allocentric/egocentric distinction and the categorical/coordinate distinction. We employed a visuospatial task in two experiments in which categorical and coordinate judgements had to be given with respect to either an allocentric or an egocentric reference frame.

If allocentric/egocentric and categorical/coordinate are interdependent factors, then a significant interaction between the two factors would be expected. In particular, allocentric categorical judgements should be more accurate than allocentric coordinate judgements, and similarly egocentric coordinate judgements should be more accurate than egocentric categorical ones. In contrast, if the two spatial processes are independent, then no significant interaction should emerge.

EXPERIMENT 1

In this experiment, participants saw two white vertical bars (targets), one above and the other below a white horizontal bar. They had to judge whether the two vertical bars appeared at the same distance or not with respect to their body-midline (*ego-centric–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 either with respect to their body-midline (*ego-centric–categorical task*) or with respect to the centre of the horizontal bar (*allocentric–categorical task*).

In this visuospatial judgement task, it is important to control for the influence of allocentric information on the employment of the egocentric reference frame and vice versa. Neggers and colleagues (Neggers, Schölvinck, van der Lubbe, & Postma, 2005; Neggers, van der Lubbe, Ramsey, & Postma, 2006), using a task similar to the one devised here, found that egocentric judgements of a target location were influenced by allocentric irrelevant information but not vice versa. In their studies, participants judged the position of a vertical bar relative to themselves while a task-irrelevant horizontal bar was located at five different positions relative to the target bar. In addition, they had to judge the position of the vertical bar relative to the centre of the horizontal background bar, for different egocentric positions of the target–background ensemble. The results showed that the egocentric judgements were systematically biased by irrelevant allocentric information (positions of the horizontal background). Instead, there was no influence of egocentric target locations on allocentric judgements. Sterken and colleagues (Sterken, Postma, de Haan, & Dingemans, 1999), using a somewhat different task with a larger memory component, showed that an influence of egocentric irrelevant information on allocentric judgements can also occur.

In order to control the possibility of bidirectional interactions between egocentric and allocentric spatial information, we manipulated egocentric and allocentric positions of target bars in order to obtain conditions of alignment (the egocentric and allocentric positions of target bars were the same) and misalignment (the egocentric and allocentric positions of target bars were different). The alignment condition was taken as the baseline against which the effect of the misalignment was measured. If allocentric irrelevant information influences egocentric spatial judgements, then the egocentric performance in the aligned condition would be better than that in the misaligned condition. If egocentric irrelevant information influences the allocentric performance, than allocentric judgements in the aligned condition would be better than those in the misaligned condition.

Method

Participants

Twenty-four students (12 males and 12 females, mean age = 22.75 years, *SD* = 2.66; range: 18–28) from Utrecht University participated in the experiment in exchange for course credit or a small monetary reward. 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. To further avoid reliance on spurious allocentric cues, the edges of the computer screen were masked with black tape. At the end of the experimental session, participants were asked whether they were able to see monitor's edges either before or during experimental trials, and nobody said 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; luminance at the centre of the screen = ~0.0076 cd/m^2). 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.

A pilot experiment was carried out in order to check whether participants were able to maintain their gaze at the centre of the computer for the time requested for each trial. In this study an infrared camera monitoring participants' eye movement was used. Results showed that participants were able to prevent eye movements on 95% of the trials (as also found by Posner, Nissen, & Odgen, 1978). For this reason, we decided not to use an eye tracking system.

Stimuli

The stimuli consisted of two vertical white *target* bars (width: 0.3 mm; length: 2 mm; 24 bits RGB colour coding: 255, 255, 255; luminance 249 cd/m^2), one placed 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; luminance 249 cd/m^2). Participants had to judge whether the two vertical bars appeared at same distance or not (coordinate task) or whether 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 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 Figure 1). For the configurations "DDSS" and "DDDS", the position of the two vertical bars was manipulated in order to obtain five levels of metric difficulty: 2 mm, 4 mm, 8 mm, 10 mm, and 12 mm. For example, a difficulty of 2 mm in DDSS configuration was obtained by placing one of the two vertical bars at 8 mm and the other at 10 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 8 mm on the right and the other at 10 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 2 mm. By following the same logic, metric difficulties of 4, 8, 10, and 12 mm were obtained.

In order to make sure that spatial performance was not affected by artefactual factors such as metric difficulty, the five distances of 2, 4, 8, 10, and 12 mm were kept constant across conditions, in such a way that all judgements were based on the same level of metric difficulty.

Finally, in the SDDS, the two vertical bars were both placed at 2, 4, 8, 10, and 12 mm on opposite sides with respect to the reference point and, of course, the metric difference was zero. These factors—that is, the three distance/side combinations and the five metric levels—gave rise to 15 basic arrangements of stimuli.

Stimuli could be presented in condition of alignment or misalignment between egocentric and allocentric reference frames. For instance, they could appear at the centre of the screen so that the centre of the horizontal bar corresponded

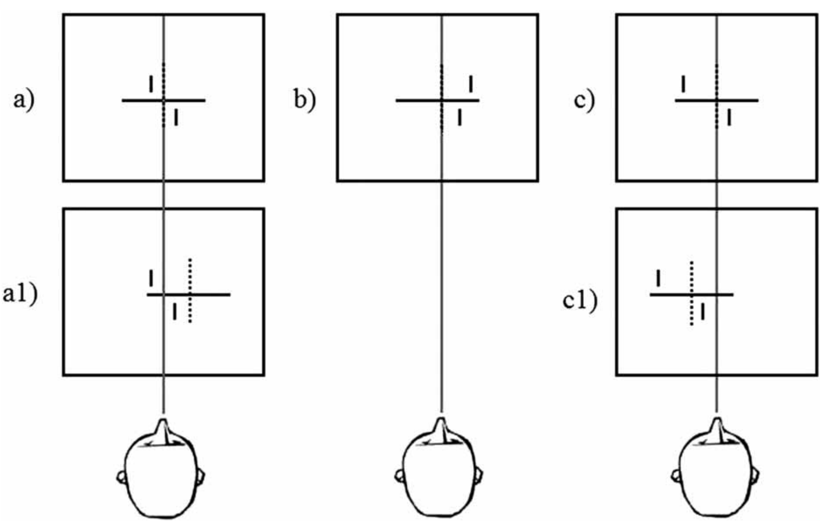

Figure 1. *Examples of stimuli used in the experiments. The grey line indicates the body-midline. The dotted line indicates the centre of the horizontal bar. In the first row the three spatial configurations of the two vertical bars are shown: (a) same distance different sides; (b) different distances same side; (c) different distances different sides. In (a), (b), and (c), examples of alignment between egocentric and allocentric reference frames are shown; in (a1), misalignment is created by displacing only the horizontal bar; in (c1), misalignment is created by displacing the entire stimulus configuration.*

to the centre of the screen. In this case, egocentric and allocentric points of reference were aligned. In order to distinguish the two reference frames, 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, rightmost or leftmost, with respect to the centre of the screen. In this way the target positions with respect to the body-midline remained the same, but irrelevant allocentric information—that is, the centre of the horizontal bar—varied. Instead, 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—that is, 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 to obtain a comparable level of discrimination of egocentric and allocentric frames (see Neggers et al., 2005). In total, 15 stimuli were aligned, 15 misaligned on the right, and 15 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, 15 stimuli of two spatial configurations were presented twice in both the coordinate and the categorical tasks. Therefore, for each task, 60 trials were presented (total number = 240 trials).

In order to ensure a good balance between task difficulty and task sensitivity, the entire experimental setting and procedure were tested in a pilot study involving 9 participants.

Procedure

The experiment consisted of four tasks organized in four different blocks. In the "egocentric coordinate" task, participants had to judge whether two vertical bars were at the same distance or not with respect to their body midline. In the "egocentric categorical" task, participants had to judge whether the two vertical bars were on the same side or not with respect to their body-midline. In the "allocentric coordinate" task, participants had to judge whether the two vertical bars were at the same distance or not with respect to the centre of the horizontal bar. In the "allocentric categorical" task, participants had to judge whether the two vertical bars were on the same side or not with respect to the centre of the horizontal bar. The presentation of the four blocks was counterbalanced, in order to prevent order effects. For each block, participants performed 60 trials.

A trial started with the presentation of a grey fixation cross (width = 0.3 mm; length: 2 mm) in a grey dotted square (3.5 × 3.5 cm) 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. As soon as the dotted square disappeared, one of the 60 stimuli from a block was presented for 100 ms, and afterwards the screen was blanked for 2 s. During the 2 s, participants had 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. Figure 2 gives an example of the experimental flow. The order of presentation of stimuli was determined by a randomized sequence that was generated before each block. This procedure was very similar to that used by Neggers and colleagues (2005, 2006). The only difference was due to the elimination of the dotted square during stimulus presentation in order to prevent its use as an allocentric reference point. Further, the luminance of both the fixation cross and the dotted square (24 bits colour coding RGB: 63, 63, 63; luminance 17.1 cd/m^2) was much lower than that of the stimuli. This was made to keep attention focused on that portion of space while excluding possible aftereffects due to the high contrast between the dotted square and the background. Indeed, during the pilot study, participants spontaneously reported that stimuli presentation was disturbed by the highly salient dotted square.

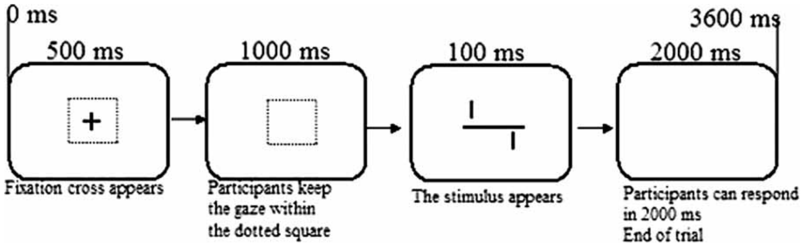

Figure 2. *The figure shows a schematic overview of one trial. At t = 0, the fixation cross is displayed for 500 ms; then the cross disappears, and only the dotted square remains for 1,000 ms. When the square disappears, the to-be-judged stimulus is displayed for 100 ms, after which the participants have 2,000 ms to give their response. After this, a new trial starts.*

The experimental design comprised a two-level within-variable frames of reference (egocentric vs. allocentric) and a two-level within-variable spatial relation type (coordinate vs. categorical). Accuracy (mean number of correct judgements) was the dependent variable (range for each participant for each condition: 0–60).

Results and discussion

Analyses were based on a two-way analysis of variance (ANOVA) for repeated measures with terms for frames of reference and spatial relation type. Bonferroni correction was used to analyse all post hoc effects. The η_p^2 and effect sizes (f) were also reported.

The ANOVA revealed a main effect of the variable frames of reference due to more accurate allocentric ($M = .80$, $SD = .06$) than egocentric ($M = .71$, $SD = .07$) judgements, $F(1, 23) = 29.55$, $p < .0001$, $\eta_p^2 = .56$, $f = 1.13$. There was also a significant main effect of the spatial relation type, $F(1, 23) = 24.73$, $p < .0001$, $\eta_p^2 = .51$, $f = 1.02$, due to categorical judgements ($M = .79$, $SD = .05$) being more accurate than coordinate judgements ($M = .72$, $SD = .06$). Finally, there was no interaction between the two factors, $F(1, 23) = 0.969$, $p = .33$, $\eta_p^2 = .040$, $f = 1.20$ (see Figure 3).

These results appear to be more in line with the hypothesis of independence, as no facilitation for egocentric–coordinate and allocentric–categorical judgements emerged. Admittedly, this conclusion is based on the absence of an interaction effect and on main effects due to the clear prevalence of categorical and allocentric components. One issue to be discussed here concerns the possible impact of procedural features on the performance: the level of difficulty of the various trials and the salience of allocentric components (see Jager & Postma, 2003).

It is crucial to analyse whether task difficulty depends on artefactual factors or on aspects intrinsic to the spatial coding (Dent, 2009). As reported earlier, we controlled that the difficulty of the trials was not due to artefactual factors such as metric difficulty of the required response. However, taking into account the possibility that metric difficulty could selectively affect spatial judgements, we performed a three-way repeated ANOVA with terms for frames of reference, spatial relations type, and metric difficulty (2, 4, 8, 10, and 12 mm). The results showed neither three-way interaction, $F(4, 92) = 0.30$, $p = .8745$, $\eta_p^2 = .013$, $f = 0.11$, nor interaction between frames of reference and metric difficulty, $F(4, 92) = 2.18$, $p = .08$, $\eta_p^2 = .09$, $f = 0.31$. Instead, a significant two-way interaction between spatial relation type and metric difficulty emerged, $F(4, 92) = 15.22$, $p < .0001$, $\eta_p^2 = .40$, $f = 0.81$. Post hoc analysis showed that the interaction was due to categorical judgements being better than coordinate judgements on 2 mm (coordinate, $M = .63$, $SD = .15$; categorical, $M = .84$, $SD = .06$), $F(1, 23) = 99.23$, $p < .0001$, $\eta_p^2 = .81$, $f = 2.1$; and on 4 mm (coordinate, $M = .66$, $SD = .14$; categorical, $M = .78$, $SD = .07$), $F(1, 23) = 21.11$, $p < .0001$, $\eta_p^2 = .48$, $f = 0.95$; whereas no significant differences emerged for 8 mm

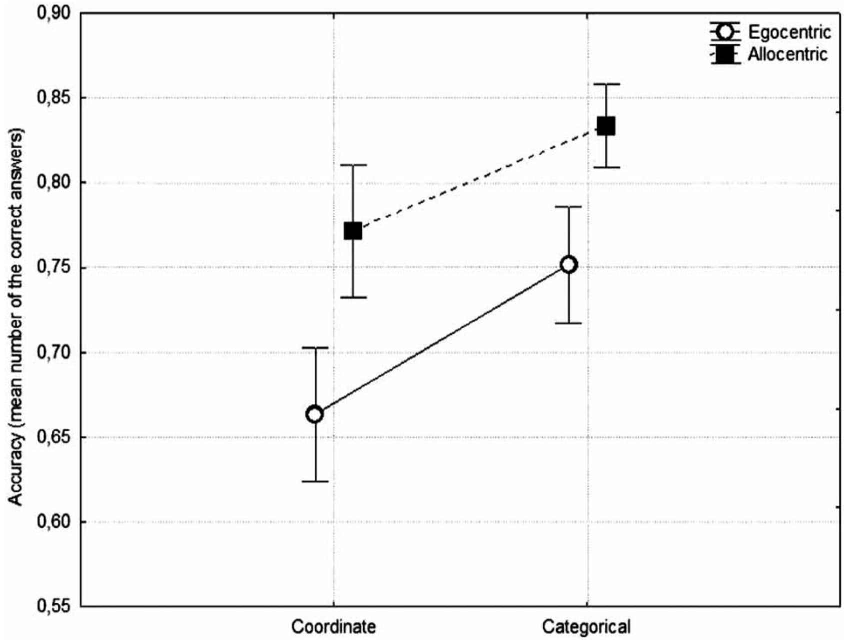

Figure 3. *Experiment 1. Mean accuracy for categorical and coordinate spatial judgements as a function of egocentric and allocentric frames of reference.*

(coordinate, $M = .79$, $SD = .09$; categorical, $M = .82$, $SD = .11$); $F(1, 23) = 1.97$, $p = .17$, $\eta_p^2 = .08$, $f = 0.29$; 10 mm (coordinate, $M = .78$, $SD = .11$; categorical, $M = .76$, $SD = .13$), $F(1, 23) = 0.24$, $p = .70$, $\eta_p^2 = .09$, $f = 0.31$; and 12 mm (coordinate, $M = .79$, $SD = .12$; categorical, $M = .76$, $SD = .08$), $F(1, 23) = 1.34$, $p = .26$, $\eta_p^2 = .06$, $f = 0.24$.

A post hoc power analysis with G*Power 3 software (Faul, Erdfelder, Lang, & Buchner, 2007) was carried out in order to assess the power of the three-way ANOVA design for repeated measures that we used. The results showed a very high global power of .98 (Cohen, 1988, 1992). Therefore, it can be assumed that the nonsignificant results we found reveal very small or no differences (Lenth, 2007).

In the literature, it is well known that categorical judgements are easier than coordinate ones (Bruyer, Scailquin, & Coibion, 1997; Kosslyn et al., 1989; Parrot, Doyon, Démonet, & Cardebat, 1999). One way to manage this intrinsic difficulty is to make categorical judgements as difficult as coordinate ones. Therefore, a second ANOVA was carried out that compared the four kinds of spatial judgements by excluding the 2 and 4 mm conditions and collapsing together 8, 10, and 12 mm conditions. The ANOVA showed that even if the categorical advantage on coordinate judgements disappeared (coordinate, $M = .79$, $SD = .11$; categorical, $M = .78$, $SD = .11$), $F(1, 23) = 0.43$, $p = .52$, $\eta_p^2 = .02$, $f = 0.13$, both the allocentric advantage on egocentric judgements, $F(1, 23) = 33.27$, $p < .0001$, $\eta_p^2 = .59$, $f = 1.20$, and the absence of an interaction effect, $F(1, 23) = 0.23$, $p = .64$, $\eta_p^2 = .009$, $f = 0.09$, were confirmed.

As regards the predominance of allocentric components, the analysis of the aligned/misaligned conditions was performed. If egocentric judgements in the misaligned condition were worse than those in the aligned condition, it would mean that the allocentric component was indeed preponderant in the task. The cross-check would be given by the absence of a similar effect in allocentric judgements. In order to check this possibility, a two-way ANOVA for repeated measures with terms for frames of reference (egocentric/allocentric) and alignment (aligned/misaligned) was carried out. The mean accuracy for aligned/misaligned and egocentric/allocentric judgements was computed for each subject. The results showed a significant two-way interaction between the two factors, $F(1, 23) = 11.11$, $p < .005$, $\eta_p^2 = .33$, $f = 0.70$. The post hoc analysis revealed that egocentric aligned judgements ($M = .78$, $SD = .09$) were better than egocentric misaligned judgements ($M = .67$, $SD = .08$), $F(1, 23) = 42.28$, $p < .0001$, $\eta_p^2 = .65$, $f = 1.37$. Although at the threshold of statistical significance, allocentric aligned judgements ($M = .83$, $SD = .08$) were better than allocentric misaligned judgements ($M = .79$, $SD = .06$), $F(1, 23) = 7.25$, $p = .013$, $\eta_p^2 = .24$, $f = 0.56$. These results showed that the influence of allocentric irrelevant information on the egocentric task was much stronger than the influence of egocentric irrelevant information on allocentric judgements. This could be due to the fact that the horizontal bar was highly salient and could have stressed the allocentric component to the detriment of the egocentric component and, in turn, could have masked any interaction effect. This factor was controlled in Experiment 2.

EXPERIMENT 2

Experiment 1 seems more supportive of the independence hypothesis, which claims that allocentric/egocentric and the categorical/coordinate distinctions form independent dimensions without showing selective facilitation. However, a further demonstration of the independence of the two spatial distinctions is needed. We have already speculated that the salience of the allocentric information may have played an important role. Interestingly, Neggers and colleagues (2005) found that by increasing the background bar luminance, irrelevant allocentric information linearly influenced egocentric perception. This finding suggests that the reduction of the horizontal bar intensity might mitigate the influence of the allocentric components and make the task more sensitive to the egocentric components. In order to check this possibility, a second experiment was carried out. Experiment 2 was identical to Experiment 1, except that the horizontal background bar had a lower luminance with respect to the two vertical bars, thus emphasizing the egocentric position of the vertical bars.

Method

Participants

Twenty-four students (12 males and 12 females, age mean = 23.58 years, $SD = 3.34$; range: 18−30) from Utrecht University participated in the experiment in exchange for course credit or a small monetary reward. All participants were right-handed and had a normal or corrected-to-normal vision.

Stimuli and procedure

Stimuli and procedure were the same as those in Experiment 1. The only variation concerned the luminance of the horizontal bar: It was reduced with respect to Experiment 1 (24 bits colour coding RGB: 63, 63, 63; luminance 17.1 cd/m^2).

Results and discussion

The model of data analysis was the same as that in Experiment 1. The ANOVA revealed a main effect of the variable spatial relation type due to more accurate categorical ($M = .81$, $SD = .06$) than coordinate ($M = .73$, $SD = .07$) judgements, $F(1, 23) = 44.98$, $p < .001$, $\eta_p^2 = .66$, $f = 1.40$. In contrast with Experiment 1, there was no main effect of the variable frames of reference, $F(1, 23) = 0.015$, $p = .89$, $\eta_p^2 = .006$, $f = 0.08$, as shown by related means: egocentric judgements = .77, $SD = .14$; allocentric judgements = .76, $SD = .15$.

A significant two-way interaction between frames of reference and spatial relation type was found, $F(1, 23) = 6.01$, $p < .05$, $\eta_p^2 = .21$, $f = 0.51$. The post hoc analysis showed that categorical judgements ($M = .81$, $SD = .07$) were more accurate than coordinate judgements ($M = .71$, *SD* = .08) in the allocentric condition, $F(1, 23) = 36.66$, $p < .0001$, $\eta_p^2 = .62$, $f = 1.26$. Similarly, categorical judgements ($M = .79$, $SD = .06$) were more accurate than coordinate judgements ($M = .74$, $SD = .08$) in the egocentric condition, $F(1, 23) = 11.38$, $p < .005$, $\eta_p^2 = .33$, $f = 0.70$. We might argue, then, that the significant interaction was due to the fact that the difference between categorical and coordinate judgements was stronger in the allocentric than in the egocentric condition, as it is clearly visible in Figure 4. Instead, no significant difference between egocentric and allocentric frames emerged when combined either with coordinate judgements, $F(1, 23) = 2.66$, $p = .116$, $\eta_p^2 = .103$, $f = 0.10$, or with categorical judgements, $F(1, 23) = 1.11$, $p = .30$, $\eta_p^2 = .046$, $f = 0.22$. It is worth noticing that the least accurate judgements now were the allocentric coordinate ones, whereas in Experiment 1 the egocentric coordinate judgements were the least accurate.

To control the possible effect of metric difficulty also in this case, a three-way repeated measure ANOVA with terms for frames of reference, spatial relation type, and metric difficulty (5 levels) was carried out. The results showed neither a three-way interaction, $F(4, 92) = 2.12$, $p = .08$, $\eta_p^2 = .084$, $f = 0.30$, nor an interaction between frames of reference and metric difficulty, $F(4, 92) = 2.07$, $p = .09$, $\eta_p^2 = .083$, $f = 0.30$. As for Experiment 1, an interaction between spatial relation type and metric difficulty, $F(4, 92) = 27.25$, $p < .0001$, $\eta_p^2 = .54$, $f = 1.08$, emerged. Post hoc analysis revealed that the 2 mm and 4 mm of metric difficulty facilitated categorical judgements rather than coordinate ones: 2 mm categorical, $M = .85$, $SD = .09$; 2 mm coordinate, $M = .64$, $SD = .14$); $F(1, 23) = 128.43$, $p < .0001$, $\eta_p^2 = .85$, $f = 2.38$; 4 mm categorical, $M = .78$, $SD = .13$; 4 mm coordinate, $M = .58$, $SD = .12$; $F(1,23) = 75.42$, $p < .0001$, $\eta_p^2 = .77$, $f = 1.83$. Instead, no significant differences emerged for 8 mm (coordinate, $M = .83$, $SD = .08$; categorical, $M = .85$, $SD = .09$); $F(1, 23) = 1.32$, $p = .26$, $\eta_p^2 = .054$, $f = 0.24$; 10 mm (coordinate, $M = .80$, $SD = .10$; categorical, $M = .75$, $SD = .12$); $F(1, 23) = 3.04$, $p = .09$, $\eta_p^2 = .12$, $f = 0.36$; and 12 mm (coordinate, $M = .81$,

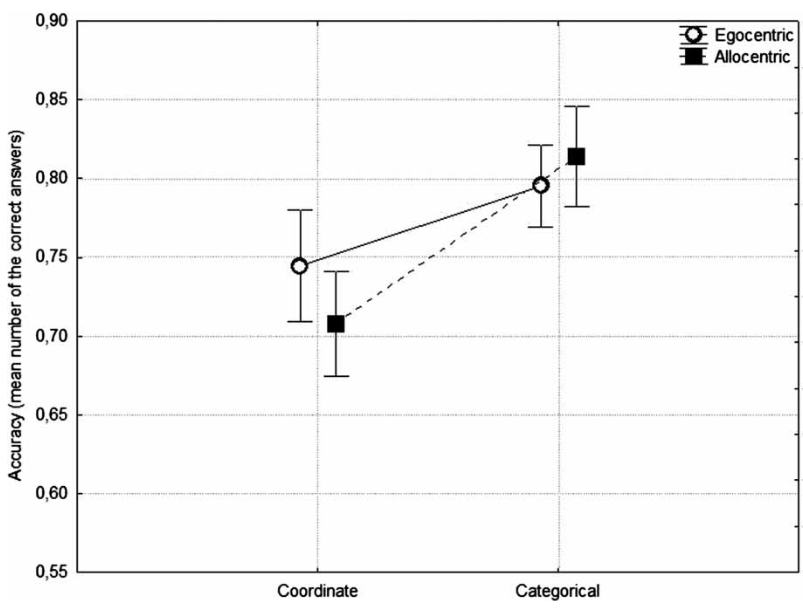

Figure 4. *Experiment 2. Mean accuracy for categorical and coordinate spatial judgements as a function of egocentric and allocentric frames of reference.*

SD = .12; categorical, *M* = .79, *SD* = .08); $F(1, 23) = 0.57$, $p = .45$, $\eta_p^2 = .024$, $f = 0.16$. As for Experiment 1, a post hoc power analysis showed that the global power of the three-way design was very high: .98.

Further, an ANOVA without 2 mm and 4 mm levels of difficulty was performed. The results showed no main effects of frames of reference (egocentric, *M* = .79, *SD* = .13; allocentric, *M* = .81, *SD* = .13), $F(1, 23) = 1.73$, $p = .20$, $\eta_p^2 = .07$, $f = 0.27$; and spatial relations (coordinate, *M* = .80, *SD* = .12; categorical, *M* = .80, *SD* = .13), $F(1, 23) = 0.00$, $p = .98$, $\eta_p^2 = .000012$, $f = 0.0034$; but an interaction between frames of reference and spatial relation type, $F(1, 23) = 6.42$, $p = .018$, $\eta_p^2 = .22$, $f = 0.53$. The related means were: egocentric–coordinate, *M* = .81, *SD* = .11; egocentric–categorical, *M* = .77, *SD* = .07; allocentric–coordinate, *M* = .79, *SD* = .08; allocentric–categorical, *M* = .83, *SD* = .08. The post hoc analysis showed that the interaction was due to categorical judgements being better when combined with an allocentric rather than an egocentric frame of reference, $F(1, 23) = 10.26$, $p = .003$, $\eta_p^2 = .32$, $f = 0.69$. Further, it is important to notice that allocentric categorical judgements were tendentially better than allocentric coordinate ones, $F(1, 23) = 3.01$, $p = .078$, $\eta_p^2 = .12$, $f = 0.35$, but did not differ from egocentric coordinate ones, $F(1, 23) = 0.64$, $p = .43$, $\eta_p^2 = .027$, $f = 0.17$. Finally, there was no significant difference between allocentric coordinate and egocentric coordinate judgements, $F(1, 23) = 0.32$, $p = .58$, $\eta_p^2 = .014$, $f = 0.12$, and between egocentric categorical and egocentric coordinate judgements, $F(1, 23) = 2.38$, $p = .14$, $\eta_p^2 = .093$, $f = 0.32$. This analysis confirms the association between allocentric and categorical components, suggesting that although the metric difficulty of the task can have influenced some aspects of the performance (the egocentric categorical facilitation over egocentric coordinate judgements), it does not explain the whole pattern of results, such as the strong allocentric–categorical association. This suggests that the experimental manipulations were sensitive to the different kinds of spatial coding.

A comparison between aligned and misaligned trials for Experiment 2 was also performed. A two-way ANOVA for repeated measures with terms for frames of reference (egocentric/allocentric) and alignment (aligned/misaligned) was carried out. Results showed only the main effect of alignment, $F(1, 23) = 121.95$, $p < .0001$, $\eta_p^2 = .84$, $f = 2.29$, due to misaligned judgements (*M* = .72, *SD* = .05) being worse than aligned judgements (*M* = .85, *SD* = .06). No interaction between the two factors emerged, $F(1, 23) = 0.03$, $p = .86$, $\eta_p^2 = .0013$, $f = 0.04$. This could be due to a strong influence of egocentric irrelevant information on allocentric judgements. Indeed, egocentric aligned judgements (*M* = .85, *SD* = .07) were more accurate than egocentric misaligned judgements (*M* = .72, *SD* = .08), $F(1, 23) = 57.05$, $p < .0001$, $\eta_p^2 = .71$, $f = 1.56$, and allocentric aligned (*M* = .85, *SD* = .08) were better than allocentric misaligned (*M* = .72; *SD* = .07), $F(1, 23) = 66.92$, $p < .0001$, $\eta_p^2 = .74$, $f = 1.69$.

Overall, the pattern of results indicated that the reduction of the luminance of the horizontal bar influenced the relation between the two factors by increasing the egocentric performance to the detriment of the allocentric one. In order to clarify this point, Experiments 1 and 2 were crossed in a three-way ANOVA for mixed designs with terms for frames of reference (within), spatial relation type (within), and luminance (between: high/low).

The ANOVA revealed a significant interaction between luminance and frames of reference, $F(1, 46) = 18.41$, $p < .0001$, $\eta_p^2 = .29$, $f = 0.64$. Post hoc analysis showed that egocentric judgements were better in the low (*M* = .77, *SD* = .06) than in the high luminance condition (*M* = .71, *SD* = .07), $F(1, 46) = 9.9$, $p < .005$, $\eta_p^2 = .18$, $f = 0.47$.

A three-way interaction between luminance, frames of reference, and spatial relation type was also found, $F(1, 46) = 5.53$, $p < .05$, $\eta_p^2 = .11$, $f = 0.35$. Post hoc analysis showed that egocentric coordinate judgements were better in the low (*M* = .74, *SD* = .02) than in the high (*M* = .66, *SD* = .02) luminance condition,

$F(1, 23) = 10.39$, $p = .003$, $\eta_p^2 = .18$, $f = 0.47$. Further, in the high luminance condition, allocentric categorical judgements ($M = .83$, $SD = .02$) were more accurate than all other judgements ($ps < .05$), whereas egocentric coordinate judgements were the least accurate ($ps < .0001$; see Figure 5).

The same analysis was performed without the 2-mm and 4-mm levels of metric difficulty. A similar pattern of results emerged. Indeed, the ANOVA revealed a significant interaction between luminance and frames of reference, $F(1, 46) = 13.58$, $p < .0005$, $\eta_p^2 = .23$, $f = 0.55$. Post hoc analysis showed that egocentric judgements were better in the low ($M = .79$, $SD = .06$) than in the high luminance condition ($M = .72$, $SD = .07$), $F(1, 46) = 8.09$, $p < .005$, $\eta_p^2 = .15$, $f = 0.42$. A three-way interaction between luminance, frames of reference, and spatial relation type was also found, $F(1, 46) = 4.17$, $p < .05$, $\eta_p^2 = .08$, $f = 0.29$. Post hoc analysis showed that egocentric coordinate judgements were better in the low ($M = .81$, $SD = .11$) than in the high ($M = .71$, $SD = .12$) luminance condition, $F(1, 23) = 1.46$, $p = .004$, $\eta_p^2 = .16$, $f = 0.43$. Further, in both high and low luminance conditions, categorical judgements were more accurate when combined with an allocentric (high, $M = .83$, $SD = .07$; low, $M = .83$, $SD = .08$) rather than with an egocentric frame of reference (high, $M = .73$, $SD = .10$; low, $M = .77$, $SD = .07$; $ps < .004$).

This pattern of results suggests a privileged association between allocentric and categorical components. Furthermore, when egocentric components acquire relevance, a facilitation for egocentric coordinate association also appears.

Overall, it seems that allocentric components were stronger in Experiment 1 whereas egocentric components gained more relevance in Experiment 2. The analysis of aligned/misaligned conditions should confirm a strong bidirectional influence between egocentric and allocentric information in the last experiment but not in Experiment 1. To this end, a three-way ANOVA for mixed design with terms for frames of reference, alignment, and luminance was performed. The results showed a significant interaction between the three factors, $F(1, 46) = 5.61$, $p < .05$, $\eta_p^2 = .11$, $f = 0.35$. The post hoc analysis confirmed that in the high luminance condition, egocentric aligned judgements ($M = .78$, $SD = .09$) were better than egocentric misaligned judgements ($M = .67$, $SD = .08$), $F(1, 23) = 42.28$, $p < .0001$, $\eta_p^2 = .65$, $f = 0.94$, whereas there was no significant

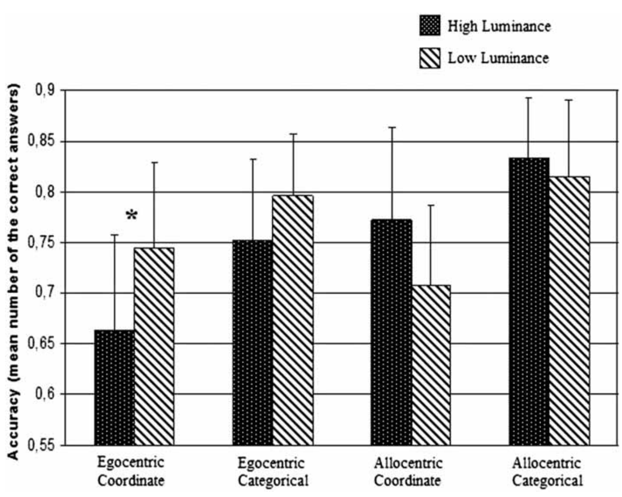

Figure 5. *Mean accuracy for coordinate and categorical judgements as a function of the frames of reference and of the luminance of the horizontal bar.* $^*p < .0001$.

difference between allocentric aligned ($M = .83$, $SD = .08$) and allocentric misaligned judgements ($M = .79$, $SD = .06$), $F(1, 23) = 7.25$, $p = .013$, $\eta_p^2 = .24$, $f = 0.56$. This indicates that egocentric irrelevant information did not influence the allocentric performance when allocentric spatial relations were salient. Instead, in the low luminance condition, allocentric aligned judgements ($M = .85$, $SD = .08$) were significantly better than allocentric misaligned ones ($M = .72$, $SD = .07$), $F(1, 23) = 66.23$, $p < .0001$, $\eta_p^2 = .74$, $f = 1.69$, thereby showing that egocentric irrelevant information strongly influenced allocentric spatial judgements. Further, egocentric aligned judgements ($M = .86$, $SD = .07$) were significantly better than egocentric misaligned ones ($M = .73$, $SD = .08$), $F(1, 23) = 57.1$, $p < .0001$, $\eta_p^2 = .71$, $f = 1.56$. Overall, these results confirmed that in the low luminance condition there was a strong bidirectional influence between allocentric and egocentric cues.

In sum, the spatial relations between the targets and the horizontal bar were highly salient in the high luminance condition, and allocentric irrelevant information strongly influenced egocentric judgements. Instead, when the salience of the spatial relations between stimuli decreased (low luminance condition), participants relied more on their body as a frame of reference, and, as a consequence, egocentric irrelevant information clearly influenced allocentric judgements.

GENERAL DISCUSSION

The research reported here investigated the relationship between reference frame processing and spatial relation coding. In two experiments, participants had to judge the position of two vertical bars placed above and below a horizontal bar, in relation either to their body midline (egocentric reference frame) or to the centre of the horizontal bar (allocentric reference frame). Moreover, they had to make distance judgements (coordinate spatial relation) or relative categorical judgements. Two hypotheses were tested: according to the interaction hypothesis, allocentric processing of categorical relations should be more accurate than allocentric processing of coordinate relations, whereas the opposite pattern should appear for egocentric processing. Instead, according to the independence hypothesis, no selective facilitation should appear. In Experiment 1, the two vertical bars and the horizontal bar had the same luminance. The results showed that participants were more accurate in judging categorical and allocentric than coordinate and egocentric spatial relations. When controlling for metric difficulty, the categorical advantage disappeared but the strong allocentric advantage was confirmed. However, no interaction between the two distinctions emerged. The analysis of the conditions where the centre of the horizontal bar corresponded to the body midline (alignment between frames of reference) or where the centre of the horizontal bar was displaced with respect to the body midline (misalignment between frames of reference) revealed a strong influence of irrelevant, allocentric information on egocentric judgements and a weaker influence of egocentric irrelevant information on allocentric judgements.

Further insight in the relation between the two spatial distinctions followed from a manipulation of the visual strength of the allocentric reference frame. Arguably, the allocentric preponderance found in Experiment 1 might be due to the highly salient allocentric information (i.e., the horizontal bar). Therefore, in Experiment 2, the luminance of the horizontal bar was reduced. This manipulation had a negative effect on the allocentric performance but a positive effect on egocentric judgements. Consequently, no main effect of reference frame occurred. Most importantly, there now was an interaction between the type of reference frame and the type of spatial relation. Although categorical judgements were more accurate than coordinate judgements with both egocentric and allocentric reference frames, the difference between the two types of spatial relations was stronger when combined with allocentric information. Although still significant, the difference was instead mitigated in the egocentric condition. Furthermore, the reduction of luminance specifically improved egocentric coordinate judgements.

The improvement of the egocentric component was also confirmed by the analysis of misaligned and aligned conditions. The results showed a strong bidirectional interaction between egocentric and allocentric information, confirming that the influence of egocentric irrelevant information on allocentric judgements was much stronger than in the first experiment.

In general, the pattern of results was confirmed when metric difficulty of categorical and coordinate tasks was equated. The only difference was due to the fact that allocentric categorical judgements were not only tendentially better than allocentric coordinate ones but also more accurate than egocentric categorical ones.

Taken as a whole, the results of the two experiments show a prevalence of categorical and allocentric components, with the coordinate/egocentric association becoming more important when the salience of the main allocentric reference (the horizontal bar) was reduced. In this case, a significant interaction emerged, although it only partially supported the interaction hypothesis. Indeed, the expected advantage for categorical/allocentric over coordinate/allocentric judgements emerged. However, a facilitation for categorical/egocentric over coordinate/egocentric judgements also emerged. This advantage could be explained by a relative categorical facilitation over coordinate judgements. As proposed by Kosslyn (1994), representations of metric spatial relations are qualitatively distinct from representations of categorical spatial relations. A metric representation is "dense"; that is, an infinite number of intermediate cases fall between any two relations. In contrast, a categorical relation is discrete; there is no range of intermediate values between on and off or between above and below. Further, in some cases, a categorical spatial relation can subsume a range of coordinates. For example, when one specifies a spatial relation, such as "two inches from", one is specifying a particular kind of category: It contains only one member. For this reason, Bruyer and colleagues (1997) argued that categorical judgements as implemented in most tasks are almost by definition easier than coordinate judgements: The categorical computation would be fast and easy at the cost of precision, while the contrary applies to the coordinate coding. On the same line, Parrot and colleagues (1999) suggested that categorization represents a general strategy that can be viewed as a fundamental cognitive operation by which information is summarized into overlearned categories that reduce processing costs in terms of speed and efficiency. Therefore, it is difficult to consider categorical processing and easiness separately. Conversely, coordination implies a complex episode-dependent processing that does not rely on a priori organization of information. This issue has recently been addressed by Dent (2009), who claimed that categorical relations are an intrinsic property of the representation of spatial configurations. Indeed, he found a robust categorical advantage in a positional change task (usually defined as a coordinate task by Postma and De Haan, 1996). The categorical advantage on coordinate performance has been found in a large number of studies (Jager & Postma, 2003).

Given the relative easiness of categorical processing as compared to coordinate processing, it is crucial to control the level of metric difficulty required by the relative judgements. For this reason, in the literature, categorical judgements are often made more difficult than coordinate ones (Bruyer et al., 1997). In our research, a different strategy was chosen: The level of metric difficulty was taken as a factor together with frames of reference and spatial relation types. This comparison showed that the general pattern of results remained unchanged for both experiments. Indeed, the advantage for categorical judgements when combined with an allocentric frame was confirmed. This suggests that difficulty of the trials per se affects performance in a general quantitative manner but not qualitatively.

The hypothesis of interaction derives from the notion that frames of reference and types of spatial relations may be functionally linked. According to Kosslyn (1994) and Milner and Goodale (1995), coordinate spatial information specified according to egocentric frames of reference would be necessary to guide actions, whereas allocentric categorical information is more useful to recognize scenes or objects. This would suggest that categorical/allocentric and coordinate/egocentric should be easier than coordinate/allocentric and categorical/egocentric judgements, respectively. It is important to note that the interaction hypothesis does not predict whether this general pattern should emerge independently of the purpose and the characteristics of the task at hand. Several studies have shown that characteristics of the task such as luminance of stimuli (e.g., Sergent, 1991; see also Neggers et al., 2005), response modality (verbal vs. motor), and dimension of stimuli (2-D vs. 3-D objects) can influence spatial information processing.

For example, studies about visual illusions highlight the importance of response modality in processing spatial information. In particular, studies supporting the dual visual stream model (Milner & Goodale, 1995) suggest that visual illusions have a strong influence on spatial judgements requiring vision for perception such as verbal or key press responses, but not on spatial judgements requiring vision for action, such as motor responses (e.g., Aglioti, DeSouza, & Goodale, 1995; Bridgeman, Gemmer, Forsman, & Huemer, 2000). However, data showing that even action does not resist visual illusions are reported (Franz, 2001; Franz, Gegenfurtner, Bülthoff, & Fahle, 2000). In recent meta-analytical works, it is suggested that the influence of visual illusions on action is mitigated or even absent only when motor responses are expressed by pointing judgements (not grasping) that require visual control within an egocentrically defined space (Bruno, Bernardis, & Gentilucci, 2008; Bruno & Franz, 2009).

Beyond these controversies, this literature suggests that the response modality used in our task could have led participants to focus their attention more on the spatial relations between the elements of the stimulus rather than on action-related components. Other studies have demonstrated that egocentric visual information, particularly when head/eye-centred, is crucial to guide the hand towards visible locations in space (Thaler & Todd, 2009). More specifically, the use of binocular cues, and consequently of "disparity matching" information, would provide information about relative distance that, in turn, can be used to guide the hand continuously to a target (Bingham, Bradley, Bailey, & Vinner, 2001; Melmoth & Grant, 2006; Mon-Williams & Dijkerman, 1999; Saunders & Knill, 2003, 2004, 2005). Although this process might not require explicit computation of metric information, its use could be implied to the extent that reliance on distance is necessary.

Finally, a growing body of data suggests that just seeing actual three-dimensional, manipulable objects, but not nonmanipulable objects, may activate pragmatic components (for a review see Borghi, 2005; Iachini, Borghi, & Senese, 2008) and motor-related areas (Chao & Martin, 2000; Grafton, Fadiga, Arbib, & Rizzolatti, 1997).

This large body of evidence would suggest that perceptual and recognition tasks favour allocentric and categorical representations, whereas egocentric and coordinate information is more useful in action-oriented tasks (Becker, Ansorge, & Turatto, 2009; Neggers et al., 2005; see also Schenk & McIntosh, 2010). Therefore, the characteristics of the task used in our experiments—that is, spatial response modality and 2-D nonmanipulable stimuli—are such that perception/recognition factors are highlighted to the detriment of action-oriented factors. Future studies should systematically investigate the factors that may activate mostly action-oriented or perception/recognition components.

Although the task used here favoured allocentric and categorical components, it is important to notice the improvement of coordinate judgements in combination with egocentric frames when the salience of allocentric components was reduced. This could suggest the presence of a latent association between coordinate and egocentric dimensions even in a non-action-oriented task. The presence of a strong bidirectional influence between egocentric and allocentric information confirmed the relevant role of egocentric components in Experiment 2, in line with Sterken and colleagues (1999). According to Milner and Goodale (1995), egocentric information is not relevant for typical perceptual tasks. This has been supported by a series of experiments about visual illusions (Bridgeman et al., 2000; Westwood, Heat, & Roy, 2000). In contrast, other works have found that egocentric information is relevant even when the test required the perception and the recognition of a spatial arrangement (e.g., Ball et al., 2009; Schenk, 2006; Sterken et al., 1999). Our findings are more in line with these last works and with a more complex visual streams organization than the initial Milner and Goodale model (Gallese, 2007; Rizzolatti & Matelli, 2003).

The fact that Neggers and colleagues (2005) did not find a bidirectional interaction could be due to a procedural factor. Indeed, they measured the probability that irrelevant allocentric and egocentric information had influenced participants' egocentric and allocentric judgements, respectively, concluding that a unidirectional influence of allocentric on egocentric frame is statistically more likely than a bidirectional influence. However, in their study, there was no control condition against which to compare the possible influence of irrelevant information. Instead, a baseline where spatial frames are congruent gives the opportunity of a more sensitive measure of such effects.

In sum, the pattern of data from Experiments 1 and 2 suggests that allocentric/egocentric and categorical/coordinate dimensions represent distinct, but not completely independent, factors whose interaction can be modulated by the characteristics of the task. More specifically, the task used in this experiment favoured categorical judgements when combined with an allocentric rather than an egocentric frame of reference. Further, allocentric categorical judgements were better than allocentric coordinate ones. It is important to highlight that the strong combination between allocentric and categorical dimension can not be accounted for by the task difficulty. These findings confirm the relevant role of allocentric and categorical components in perceptual and recognition tasks, as suggested by Milner and Goodale (1995, 2008) and Kosslyn (1994), respectively. However, the fact that egocentric judgements, in particular when coordinate, improved and influenced allocentric judgements when the luminance of the horizontal bar was reduced, reveals that egocentric components have a role not only in action but also in perceptual tasks. This trend also underscores the possibility that frames of reference have a primary role in organizing spatial information in both perceptual and action tasks (Ball et al., 2009; Heath, Rival, Neely, & Krigolson, 2006; Schenk, 2006).

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