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The roles of categorical and coordinate spatial relations in recognizing buildings

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Abstract Categorical spatial information is considered more useful for recognizing objects, and coordinate spatial information for guiding actions—for example, during navigation or grasping. In contrast with this assumption, we hypothesized that buildings, unlike other categories of objects, require both categorical and coordinate spatial information in order to be recognized. This hypothesis arose from evidence that right-brain-damaged patients have deficits in both coordinate judgments and recognition of buildings and from the fact that buildings are very useful for guiding navigation in urban environments. To test this hypothesis, we assessed 210 healthy college students while they performed four different tasks that required categorical and coordinate judgments and the recognition of common objects and buildings. Our results showed that both categorical and coordinate spatial representations are necessary to recognize a building, whereas only categorical representations are necessary to recognize an object. We discuss our data in view of a recent neural framework for visuospatial processing, suggesting that recognizing buildings may specifically activate the parieto-medial-temporal pathway.

Keywords Landmarks · Human navigation · Allocentric frame · Egocentric frame · Coordinate spatial relations · Categorical spatial relations · Spatial cognition · Imagery

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According to Kosslyn and coworkers (Kosslyn, 1987; Kosslyn, Maljkovic, Hamilton, Horwitz & Thompson, 1995), the brain computes information in both perceptual and imagery domains by referring to two kinds of spatial representations:

- Categorical spatial relations, which specify abstract and general relations between items or between different parts of a complex item (e.g., one item is above/below another one);
- Coordinate spatial relations, which specify metric aspects of the spatial relations between items or between different parts of a complex item (e.g., how distant is one item from another).

Considering the importance of category formation in many linguistic operations, Kosslyn and colleagues (Kosslyn et al., 1989; Kosslyn et al., 1995) suggested that the left-hemisphere specialization for language makes it more suitable for processing categorical information, whereas the prominent role of the right hemisphere in visuospatial and navigational abilities makes it more suitable for processing coordinate information. This pattern of hemispheric specialization has been demonstrated in several studies of the perceptual and imagery domains (Jager & Postma, 2003; Laeng, 1994; Palermo, Bureca, Matano & Guariglia, 2008; Trojano, Conson, Maffei & Grossi, 2006). For example, Laeng (1994) demonstrated that left- and right-hemisphere lesions selectively impair patients' performance in making categorical and coordinate perceptual judgments, respectively. Similarly, in the imagery domain, Palermo et al. (2008a) found that in a population of 34 left- or right-brain-damaged patients, the left-brain-damaged patients were selectively impaired in processing categorical representations, and the right-brain-damaged patients were more impaired in processing the coordinate ones, regardless of whether or not visuospatial neglect was present. In particular, it has been suggested that the right parietal region is predominantly involved in processing coordinate spatial information and that the left parietal region is involved in processing categorical information (Trojano et al., 2006; Trojano et al., 2002).

According to Kosslyn (1994), categorical spatial information is more useful for recognizing objects because it is involved in the invariant representation of an object's shape, whereas coordinate spatial information is necessary to guide actions—for example, during navigation or grasping.

However, contrary to Kosslyn's suggestion, in a previous study carried out in a population of left- and right-brain-damaged patients, we found that patients with right-brain damage (mainly involving the parietal region) were impaired in recognizing the picture of a previously seen building among four alternatives (Palermo, Piccardi, Nori, Giusberti & Guariglia, 2010), and that patients with left-brain damage were not. As the left hemisphere is involved in processing categorical information, and categorical coding is more useful than coordinate coding in recognizing objects, this pattern of results was quite unexpected. Actually, buildings are a special class of stimuli because they can be used as landmarks. Indeed, in a seminal study, Epstein and Kanwisher (1998) demonstrated that a specific area in the parahippocampal cortex (the parahippocampal place area, or PPA) processes scenes of places and buildings. The authors suggested that this occurs because buildings are large and stable structures that define the space around them. Therefore, we suggest that buildings are a special category of items and that, unlike common objects, they are important in defining the geometry of the local space.

O'Craven and Kanwisher (2000) found that the PPA was activated both during the passive viewing of buildings on a university campus and during generation of mental images of them. This suggests that the PPA is involved in the active processing of buildings and that PPA activation might activate a special network involved in attributing a specific identity to a specific building (i.e., "Is this building on my university campus?").

What is so special about buildings that there is a specific area in our brain that processes them? Buildings are crucial for human navigation. In fact, due to their location in the environment, buildings can function as landmarks (Lynch, 1960). For instance, if we are visiting a city for the first time, it is easier to return to the parking lot by referring to a salient building such as a museum or a supermarket. Siegel and White (1975) suggested that a landmark is a perceptually salient environmental pattern that helps people orient themselves. Buildings are used as course-maintaining devices, which are usually proximate, in order to maintain navigational direction (Siegel & White, 1975).

According to Farrell (1996), however, a landmark is not only defined by the type of features that allow distinguishing one specific stimulus in the category (e.g., my watch from other watches) but also by metric features related, for example, to its precise spatial position in the environment.

All of this evidence supports the ideas that buildings are a special class of objects due to their usefulness in navigation (Lynch, 1960) and their role in defining the geometry of local space (Epstein & Kanwisher, 1998), and that they are processed by a specific brain area—namely, the PPA—even when they have never been seen during real navigation in the environment (Aguirre, Zarahn & D'Esposito, 1998; Ishai, Ungerleider & Haxby, 2000).

On the basis of this evidence, we hypothesized that buildings are a particular class of stimuli and that, unlike other categories of objects, their recognition is based on the processing of both categorical and coordinate relations.

To test this hypothesis, we submitted a large sample of college students to specific tasks assessing the processing of a simple image according to coordinate and categorical spatial relations (Palermo et al., 2008a) and the processing of a complex image of a building (Palermo et al., 2010) as compared to the processing of complex images of common objects.

A second aim of this article was to analyze the presence of gender differences in recognizing buildings, since contrasting data have been reported in the literature. For example, Tranel, Enekwechi and Manzel (2005) found that men outperformed women in a task in which the participants were required to recognize 65 famous landmarks, such as the Colosseum or the Eiffel Tower. Nori and Piccardi (2010), however, found that gender did not predict the performance in a landmark recognition test, including landmarks of an Italian city (Bologna). It is possible that these differences among studies could be a consequence of different degrees of familiarity with landmarks among participants and of the methods adopted for evaluating familiarity. For example, in the study of Tranel et al. (2005), familiarity was self-evaluated and could have been underestimated or overestimated by the participants because it was quite difficult to evaluate the familiarity of landmarks belonging to a town different from that in which the participants actually lived. Instead, in Nori and Piccardi's study, familiarity corresponded to the years spent in the city in which the landmarks were located.

In the present study, we aimed to evaluate the presence of gender differences per se in building recognition, ruling out the familiarity factor that could be crucial in observing differences among participants. For this reason, we used a set of buildings that had never been seen before by the participants. Specifically, since all of the participants had been exposed to the building to be recognized for the same amount of time (i.e., 10 s), the possible presence of differences among participants should be due to the gender and not to other variables such as different familiarity with the stimuli.

Method and materials

Participants

We enrolled 210 healthy college students recruited at the Department of Psychology of the University of Rome and the Department of Health Sciences of the University of L'Aquila. No participant enrolled in the study had a history of neurological or psychiatric disorders. The sample included 115 women (mean age = 22.62 years, *SD* = 2.53; mean education = 13.37 years, *SD* = 1.33) and 95 men (mean age = 23.35 years, *SD* = 3.14; mean education = 12.73 years, S.D. = 1.75) right-handed (Salmaso & Longoni, 1985).

In accordance with the local ethics committee and the Declaration of Helsinki, all participants gave their written informed consent.

Experimental materials

All participants were presented with the following experimental tasks:

Categorical task (a brief version of the task from Palermo et al., 2008a) The task consisted of 20 items plus an example item; each item included two stimuli and a blank sheet of paper (interstimulus), which were shown in succession (see Fig. 1). The first stimulus, consisting of a sheet of A4 paper with a square frame (side 20 cm) and a circle (radius of 3, 4.7, 5.3, or 7 cm) in the center, was presented for 3 s (measured by means of a mechanical timer). Then a blank sheet of paper was presented for 3 s, followed by the second stimulus, which consisted of the same square frame as the first stimulus and a black square (side 4 mm). The participant's task was to mentally overlap the second and the first stimuli in order to judge whether the black square was inside or outside the circle.

In ten trials, the square was inside the circle, and in ten trials it was outside the circle. The score was either 1 (*correct*) or 0 (*incorrect*).

Coordinate task (a brief version of the task from Palermo et al., 2008a) The task consisted of 20 items plus an example item (see Fig. 2). The first stimulus showed a square frame (side 20 cm) with a circle in the center (radius of 2.4, 4.1, 5.3, or 7 cm) and a black square (side 4 mm). This stimulus was presented for 3 s. Then a blank sheet of paper was presented for 3 s, followed by the second stimulus, which consisted of the same square frame as in the first stimulus, which contained only another black square (side 4 mm) in a different position than in the first stimulus. The distance between the two squares and the edge of the circle varied from 0.5 to 3.5 cm; the minimum distance between the squares was equal to 1.0 cm, and the maximum distance was 2.0 cm.

The participant's task was to mentally overlap the second and the first stimuli and to judge whether the black square in the second stimulus was nearer to or farther from the edge of the circle than was the black square of the first stimulus.

In ten trials, the second black square was nearer, and in ten trials the second black square was farther away. The score was either 1 (*correct*) or 0 (*incorrect*).

Building task (Palermo et al., 2010; a modified version of the photo task of Nori & Giusberti, 2006) The task included 20 items, each of which consisted of two stimuli. In each item, the first stimulus was a photo of a building (target). The participants were requested to observe the photo target for 10 s (the presentation time was calculated by means of a mechanical timer). Then they had to generate the previously

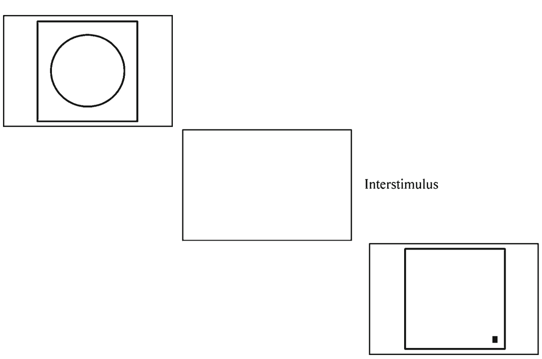

Fig. 1 Example of stimuli used in the categorical task. Participants had to generate an image of the circle seen in the first stimulus and then judge whether the black square was on the inside or the outside of it

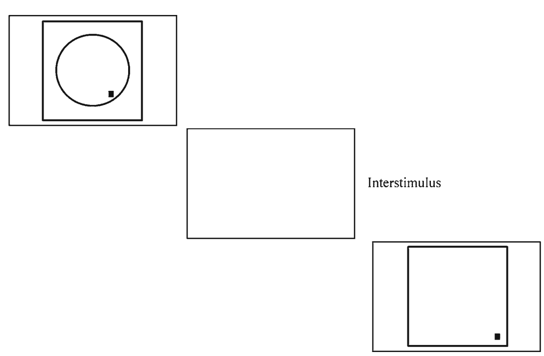

Fig. 2 Example of stimuli used in the coordinate task. Participants had to generate an image of the figure seen in the first stimulus and then judge whether the black square in the second stimulus was nearer or farther from the edge of the circle than was the black square in the first stimulus

seen image with their eyes closed. When the participant was ready, the second stimulus was shown. In the second stimulus, four pictures of buildings were presented (see Figs. 3a and b): the target and three distractors (i.e., incorrect choices among multiple-choice answers). The distractors included a mirror image of the target and two buildings similar to the target, but with different basic visual characteristics (i.e., color) or with modification (or cancellation) of specific elements (such as a window or a roof). This last modification of a building could modify its global shape (see Fig. 3a), such as when elements like the roof or the last floor were manipulated, or not modify its global shape (see Fig. 3b), such as when internal elements (a window or a door) were manipulated. For each item, one could recognize that a building was not the target one in three ways: detecting a categorical modification of the building, detecting a coordinate modification of the building, or detecting both a coordinate and a categorical modification of the building. So, we did not force a priori the ways in which the participants could resolve the task.

For example, if the global shape of the building was not changed, such as when a window was erased, the participants could notice that in the distractor, as compared to the previously seen reference building: (a) the window in the bottom was missing (categorical judgment); (b) the internal metric relation among elements was changed—that is, in the distractor there was 2 cm of distance between the main door and a window, and not 1 cm as in the reference building (coordinate judgment); or (c) there was 2 cm of distance between the main door and the closed window, since the window in the bottom was missing (coordinate plus categorical judgment). In the same way, when the global shape was changed, such as when the last floor was erased, the participant could notice that, relative to the reference building: (a) the distractor was smaller, since the last floor was missing (categorical judgment); (b) in the distractor there was a modification of the metric relations among elements—that is, in the distractor, there was only 2 cm of distance between the main door and the roof, and not 3 cm as in the reference building (coordinate judgment); or (c) in the distractor, there was only 2 cm of distance between the main door and the roof, since the floor below the roof was missing (coordinate plus categorical judgment).

The participant's task was to identify the target building, and the score was either 1 (*correct*) or 0 (*incorrect*).

Object task The task included 20 items, each consisting of two stimuli. In each item, the first stimulus was a photo of an object (target). The following objects were included in the task: a bomb, a knife, a spoon, a sofa, an apple, a pocket watch, a pot, a dagger, a bunch of grapes, a jug, a guitar, a light bulb, an umbrella, a teddy bear, a chair, a boot, a cup, a tie, an alarm clock, and a table lamp. Participants were requested to observe the photo target for 10 s (the presentation time was calculated by means of a mechanical timer). Then they had to generate the previously seen image with their eyes closed. When the participant was ready, the second stimulus was shown. The second stimulus consisted of a photo of four objects (see Figs. 4a and b): the target and three distractors. The distractors included a mirror image of the target, two objects that differed from the target as to basic visual characteristics (i.e., color) or as to a modification (or cancellation) of specific elements (such as the high heel of a boot or the decorative elements in the handle of a spoon). This last modification of the object could change its global shape (see Fig. 4a), such as when the handle of a cup was modified, or not change its global shape (see Fig. 4b), such as when the internal decorative elements in the handle of a spoon were modified.

For each item, one could recognize that an object was not the target one in three ways: detecting a categorical modification of the object, detecting a coordinate modification of the object, or detecting both a coordinate and a categorical modification of the object. So, we did not force a priori the ways in which the participants could resolve the task. For example, when the global shape of an object was not changed, such as when an element in the decoration of the handle of a spoon was erased, the participants could detect that in the distractor, as compared to the previously seen reference object: (a) the left part of the decoration was missing (categorical judgment); (b) there was a modification in the metric relation among elements—for instance, as compared to the reference object in the distractor, 1.5 cm of distance did not separate the tip of the spoon and the beginning of the decoration, but rather 2 cm (coordinate judgment); or (c) 2 cm of distance separated the tip of the spoon and the beginning of the decoration in the handle, since the left part of the decoration was eliminated (categorical plus coordinate judgment). In the same way, when the global shape was changed, such as when a part of the screw-in base of a lightbulb was erased, the participants could detect that in the distractor, as compared to the reference object: (a) the bottom part of the screw-in base was missing (categorical judgment); (b) there was a modification of the metric relations among elements—for instance, in the distractor only 1.5 cm of distance separated the tungsten filament and the electric contact, not the 2 cm in the reference object (coordinate judgment); or (c) only 1.5 cm of distance separated the tungsten filament and the electric contact, since the bottom part of the screw-in base was missing (coordinate plus categorical judgment).

The participant's task was to identify the target object. The score was either 1 (*correct*) or 0 (*incorrect*).

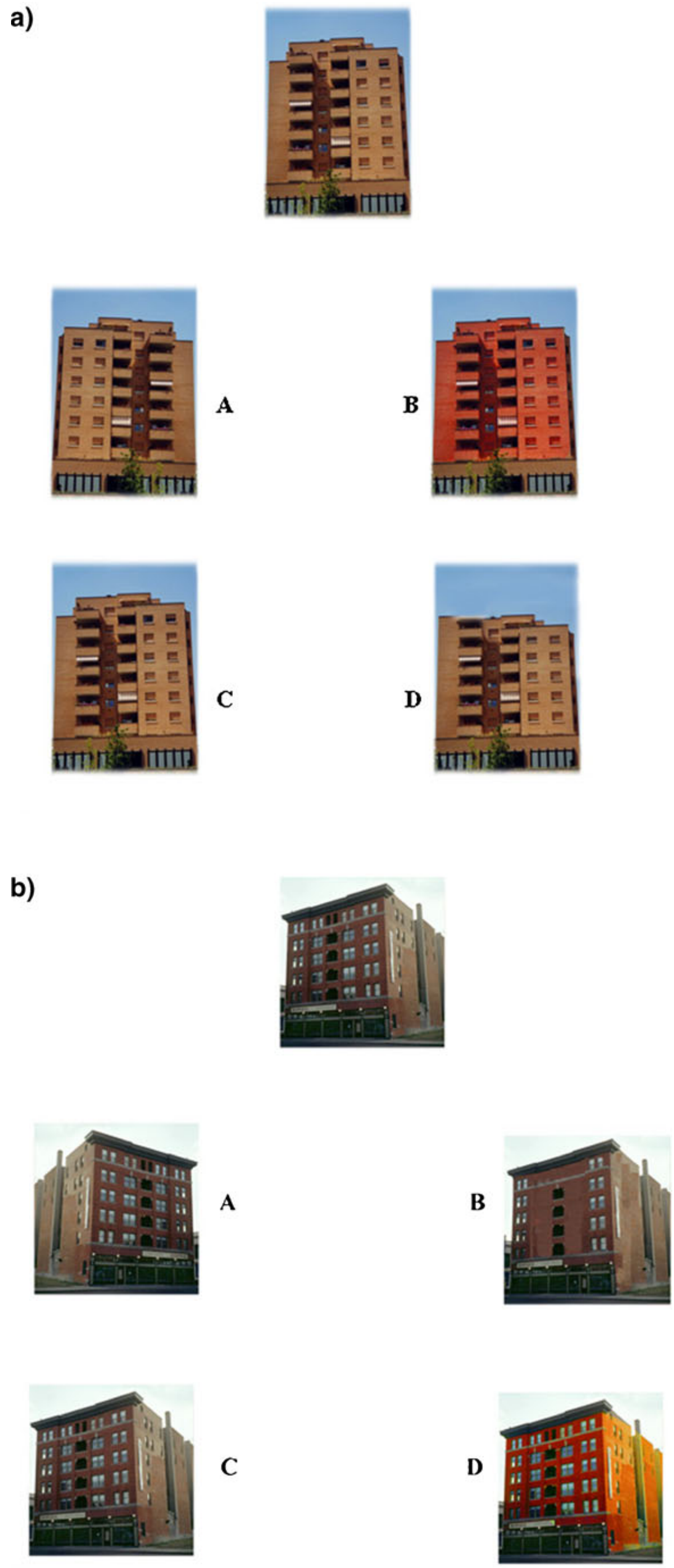

Fig. 3 Examples of building task items. Participants had to recognize the target building (top of each panel), which had been seen for 10 s, among four subsequently presented alternatives (one target and three distractors). The distractors consisted of a mirror image of the target, a building characterized by a modification of some basic visual features, and a building in which some elements were modified or deleted. Distractor "D" in panel (**a**) shows a modification of the global shape of the building. Distractor "B" in panel (**b**) shows a modification of features of the building that do not change the global shape—only internal elements have been modified

Fig. 4 Examples of object task items. Participants had to recognize the target object (top of each panel), seen for 10 s, among four subsequently presented alternatives (one target and three distractors). The distractors consisted of a mirror image of the target, an object characterized by a modification of some basic visual features, and an object in which some elements were modified or deleted. Distractor "C" in panel (**a**) shows a modification of the global shape of the object. Distractor "A" in panel (**b**) shows a modification that does not change the global shape of the object—only internal elements have been modified

Experimental procedure

Each participant was tested individually. Before starting, participants were asked to fill in a questionnaire about their gender, education, predominant hand, and general medical information, so as to exclude participants with neurological and psychiatric disorders or with a drug abuse history. On the questionnaire it was specified that anonymity would be preserved. Then the participants, comfortably seated, completed the experimental tasks. Each stimulus was shown in the center of vision, and the presentation time was calculated by means of a mechanical timer. The presentation of the four tasks was randomized, in order to prevent order effects. The experimental session lasted about an hour. The levels of accuracy for each task (0 to 20 correct answers) were the dependent variables.

Results

For all of the experimental tasks, we recorded the accuracy of each participant (number of correct answers).

To explore the relationship between the ability to process an image according to categorical and coordinate spatial relations and the ability to recognize a building or an object, we performed Pearson correlations on the scores obtained in the four experimental tasks (categorical, coordinate, building, and object tasks).

We found that the ability to recognize a previously seen building (building task) was correlated with both the processing of an image according to coordinate spatial relations (coordinate task: $r = .222$, $p < .001$; see Fig. 5a) and the processing of an image according to categorical spatial relations (categorical task: $r = .219$, $p < .001$; see Fig. 5b). Instead, the ability to recognize a previously seen object (object task) was correlated with the processing of an image according to categorical spatial relations (categorical task: $r = .219$, $p < .001$; see Fig. 5d), but not with the generation of an image according to coordinate spatial relations (coordinate task: $r = .106$, n.s.; see Fig. 5c).

We also performed a standard multiple regression analysis to investigate the degree to which each of the mental imagery skills contributed to predicting participants' performance in recognizing landmarks and objects. The regression

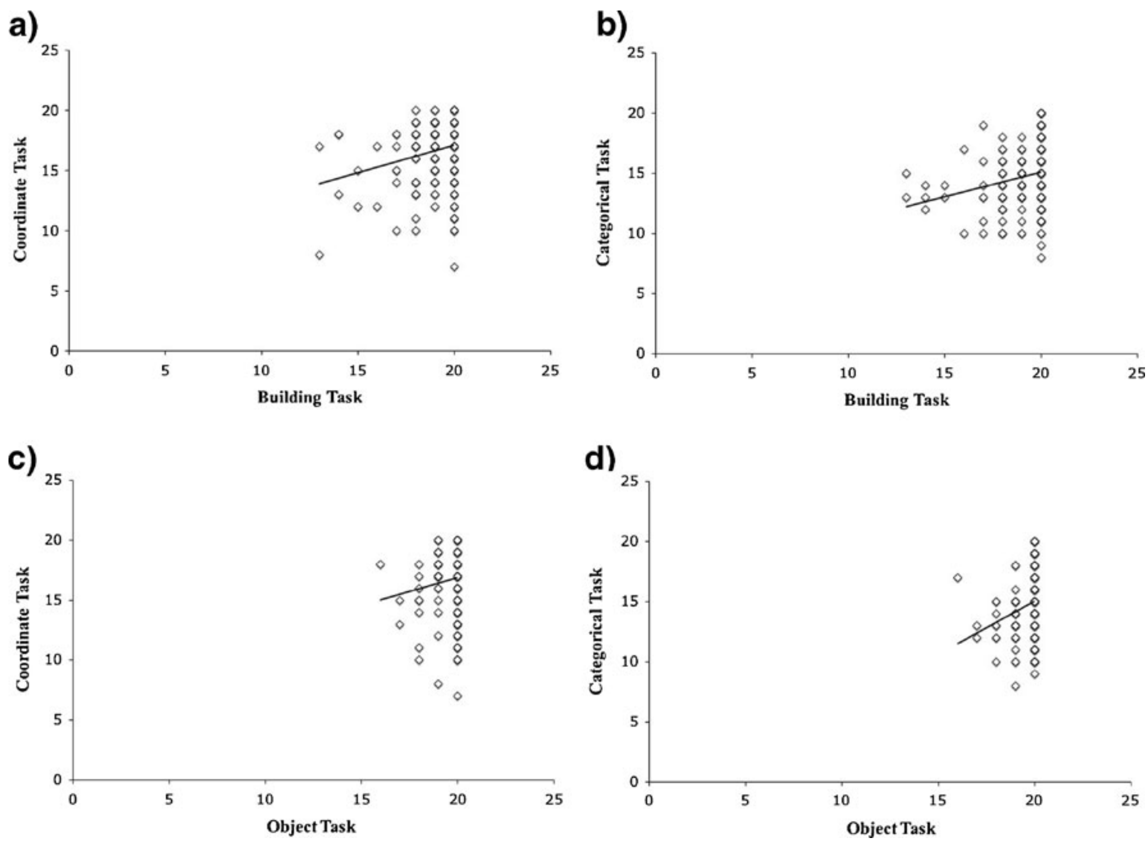

Fig. 5 Correlations among tasks. (**a**) A statistically significant correlation between the building task (number of correct answers) and the coordinate task (number of correct answers). (**b**) A statistically significant correlation between the building task (number of correct answers) and the categorical task (number of correct answers). (**c**) A nonsignificant correlation between the object task (number of correct answers) and the coordinate task (number of correct answers). (**d**) A statistically significant correlation between the object task (number of correct answers) and the categorical task (number of correct answers)

analysis with the building task as dependent variable and the categorical task and the coordinate task as independent variables revealed that both tasks predicted the ability to recognize a building [$R = .28$, $R^2 = .078$; $F(2, 207) = 8.76$, $p < .001$; for the coordinate task, $\beta = .18$, $t(207) = 2.58$, $p < .01$; for the categorical task, $\beta = .17$, $t(207) = 2.52$, $p < .05$].

The regression analysis with the object task as dependent variable and the categorical and coordinate tasks as independent variables revealed that only the categorical task predicted the ability to recognize an object [$R = .23$, $R^2 = .05$; $F(2, 207) = 5.52$, $p < .01$; for the coordinate task, $\beta = .05$, $t(207) = 0.76$, n.s.; for the categorical task, $\beta = .21$, $t(207) = 2.93$, $p < .01$].

To detect differences among the tasks, we performed paired *t* tests on the means of the building and object tasks, and on the means of the categorical and coordinate tasks. The building task ($M = 19.24$, $SD = 1.32$) was revealed to be more difficult than the object task ($M = 19.74$, $SD = 0.62$) [$t(1, 209) = -5.52$, $p < .001$]. Similarly, a statistically significant difference was found between the categorical task ($M = 14.8$, $SD = 2.4$) and the coordinate task ($M = 16.7$, $SD = 2.7$) [$t(1, 209) = 9$, $p < .001$].

Finally, to verify whether gender differences had a role in the building and object tasks, we performed a 2 × 2 mixed ANOVA (Gender × Task) in which gender was considered as the independent variable and performance at the building and object tasks as the dependent variable. A nonsignificant main effect emerged for gender [$F(1, 208) = 0.02$, n.s.], a significant main effect for task [$F(1, 208) = 29.46$, $p < .001$; for the building task, $M = 19.24$, $SD = 1.32$; for the object task, $M = 19.74$, $SD = 0.62$] and a nonsignificant Gender × Task interaction [$F(1, 208) = 0.34$, n.s.].

Discussion

The aim of the present study was to determine which types of spatial relations allow for identifying buildings and other types of visual stimuli.

Before discussing our main goal, we would like to briefly discuss our finding of the absence of a gender difference in object and building recognition. Indeed, this means that the basic process of identifying buildings is not affected by gender. In our study, all of the participants had been exposed to the set of buildings for the same amount of time (10 s), and thus there were no differences in familiarity with the stimuli among the participants. For this reason, as was suggested by previous studies (Iachini, Ruotolo & Ruggiero, 2009; Nori & Piccardi, 2010), we think that, when individuals have the same level of familiarity with landmarks, gender differences among female and male participants disappear. This evidence is in line with studies of human navigation that have found a male advantage when participants had to learn sophisticated mental representations of new environments or use Euclidean information (see, e.g., Cánovas, García & Cimadevilla, 2011; Palermo, Iaria & Guariglia, 2008b; Saucier et al., 2002), but not when landmark information was sufficient to solve the task (see Saucier et al., 2002).

Regarding the main aim of this study, on the basis of Kosslyn's (1994) findings, we should have found that the ability to process buildings is related to the ability to perform the categorical but not the coordinate task, because our participants only had to recognize a previously seen building, not act on it. Indeed, categorical information should be more useful in perceptual recognition, because it is involved in processing the invariant representation of an object's shape, whereas coordinate spatial information is needed to guide actions, such as navigating or grasping (Kosslyn, 1994). However, the metric relations between the parts of a building—for example, the metric relations between the roof and the main door—should be important for recognizing this kind of item, and by definition this should require the processing of coordinate information. Indeed, there is no doubt that to recognize a specific building in an urban neighborhood in which the features of the buildings are very similar, it is necessary to perceive that a specific building is 2 m higher than the closer buildings or that the balcony on the first floor is about 10 m long.

The data from the present study suggest that identifying buildings could require both categorical and coordinate processing, whereas identifying common objects could require only categorical processing. We hypothesized that the involvement of both categorical and coordinate spatial relations in the recognition of buildings could also explain why we found that it is more difficult to identify a specific building than a specific object. However, caution should be taken before drawing definitive conclusions, since our correlations between tasks were moderate. This evidence could be attribute to the fact that other variables, such as other perceptual and visuospatial skills not evaluated by our experimental tasks, could be mainly involved in building and object recognition.

For example, the recognition of objects or buildings in our tasks could have required some degree of mental rotation skills in order to detect, for example, that one distractor was a mirror image. Moreover, it should be interesting to deeply analyze which perceptual factors may activate mostly action-oriented or perception/recognition components.

Keeping in mind this limit, it should be underlined that our data are consistent with the idea that for identifying buildings, not only categorical spatial relations (such as that the main door is to the right of a balcony), but also coordinate spatial relations (such as the specific distance between a window and a door) need to be processed. Such an idea is suggested by the observation that right-parietal lesions specifically affect the ability to identify previously unknown buildings, as well as the ability to process coordinate relations (Palermo et al., 2008a; Palermo et al., 2010). Because the right parietal regions are involved in processing coordinate information (Trojano et al., 2006; Trojano et al., 2002), and because, as we have demonstrated here, coordinate coding is necessary to process this kind of stimuli, the specific deficit of right-brain-damaged patients in recognizing buildings can be better interpreted as a deficit in processing coordinate relations rather than as a more general visuo-perceptual impairment.

The present data also support the idea that buildings are a special type of visual stimuli. Indeed, buildings are the most frequent type of landmark in urban environments, and their identity is specified not only by their appearance but also by some spatial and metric information specific to that building (Farrell, 1996). When an Italian who has never visited Paris is shown a picture of the Eiffel Tower taken from the Trocadero, he or she is able to identify the tower, but when the same picture is shown to a Parisian, he or she also has information about the distance from his or her vantage point, the river, and his or her home. Thus, we can expect that showing a familiar building to participants will activate coordinate information in those who use those buildings as landmarks.

Note that in our task we purposely used buildings that the participants had never seen in their real environment; thus, the buildings did not act as true landmarks—that is, as crucial objects for orientation in the environment. Indeed, although it is obvious that when a landmark is used to direct navigation in the environment, coordinate information has to be processed, it is less evident why a picture of a previously unknown building should require coordinate coding for it to be recognized among other buildings.

Thus, the relationship that we found between the abilities to identify buildings and to process coordinate relations cannot be justified in terms of eliciting navigational metric information by viewing a landmark. Instead, it seems that buildings, unlike other types of visual stimuli, require the processing of coordinate features just to identify specific elements.

Neuroimaging studies support the idea that buildings are a special class of objects. In fact, a specific area (PPA) was found to be involved in perceiving and imagining buildings, even when they had never been seen in the real environment (Aguirre et al., 1998; Epstein & Kanwisher, 1998; Ishai et al., 2000), and thus never been used as landmarks. Recent reports have shown that the PPA receives spatial (and metric) information directly from the dorsal "where" pathway (Kravitz, Saleem, Baker & Mishkin, 2011), which, according to Kosslyn (1994), is involved in processing coordinate relations.

The original distinction between categorical and coordinate spatial information may remind one of the distinction between allocentric and egocentric frames of reference (e.g., Kosslyn, 1994; O'Keefe & Nadel, 1978; Paillard, 1991). Following a classical point of view, these two frames of reference have, respectively, specific functions in vision-for-perception and vision-for-action (Milner & Goodale, 1995, 2008). In other words, allocentric processing is closer to categorical coding of spatial relations and is necessary for visual perception and recognition, whereas egocentric processing is closer to coordinate coding and is necessary for actions (Ruotolo, Iachini, Postma & van der Ham, 2011). As was suggested by Ruotolo et al., (2011) however, the use of an egocentric and/or an allocentric frame (and, by inference, the use of coordinate and categorical coding) does not necessarily depend on the task purposes. Indeed, some studies have shown that egocentric representations can also be used in recognition (Shelton & McNamara, 2004) and in visual search tasks (Ball, Smith, Ellison & Schenk, 2009; van der Ham, van Zandvoort, Frijns, Kappelle & Postma, 2011), suggesting that frames of reference can work in parallel. Therefore, we can hypothesize that because buildings are crucial for navigation, they can elicit the activation of both a vision-for-perception network and an "acting" brain network specifically developed for navigation, even when they are not being used in navigation. In other words, since buildings are mostly used to navigate through the environment in daily life, they can elicit a coordinate coding even when they have to be recognized for a different purpose, as in our task. Kravitz et al. (2011) described a new neural framework for visuospatial processing that distinguishes three pathways emerging from the dorsal stream: a parieto-prefrontal pathway, a parieto-premotor pathway, and a parieto-medial-temporal pathway, which respectively mainly support spatial working memory, visually guided action, and spatial navigation. Buildings might specifically activate this parieto-medial-temporal pathway.

In conclusion, we suggest that buildings are a special class of items that require the processing of both categorical and coordinate information. This is strictly related to their specific features and functions, because due to their structure, they can define the spatial layout of the environment, and due to their location in the environment and their function as landmarks, they are deeply involved in human navigation.

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