Cognition and Neurosciences

How to separate coordinate and categorical spatial relation components in integrated spatial representations: A new methodology for analysing sketch maps

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Spatial relations between landmarks can be represented by means of categories and coordinates. In the present research, this paradigm was applied to sketch maps based on information acquired in goal-directed behaviour of exploration of a university campus area. The first aim was to investigate whether categorical and coordinate information can be considered conceptually independent in sketch maps. The second aim was to assess which kind of distance measure served better to represent coordinate information in the present case study, and finally to assess the factorial structure of coordinate and categorical data. Analytic methodology as well as statistical analysis were found to confirm that separating coordinate and categorical components was formally as well as empirically appropriate. A series of confirmatory factor analyses showed the best fit for the model with two correlated components, as well as an acceptable reliability of measures emerged. The two components were moderately correlated. Moreover, the adoption of Manhattan distance seemed to be the most effective method to represent coordinate spatial relations in spatial sketch maps of areas acquired through navigation.

Key words: Spatial mental representation, categorical and coordinate spatial relations, sketch map, confirmatory factor analysis, spatial navigation, familiar environments.

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INTRODUCTION

Mental representations of the environment essentially depend on how people encode and store spatial relations between objects (Lopez, Caffò, & Bosco, 2018; Piccardi, Palmiero, Bocchi, Boccia, & Guariglia, 2019; Piccardi, Palmiero, Bocchi *et al.*, 2018; Lopez, Postma, & Bosco, 2020). Kosslyn (1987) suggested a major distinction between two types of spatial relations. Categorical spatial relations are usually described by recurring to very general spatial labels (Laeng, Chabris, & Kosslyn, 2003; Landau & Jackendoff, 1993; Noordzij, Neggers, Ramsey, & Postma, 2008). Through categorical abstract descriptions, individuals can depict an object and its position as, for example, above or below, on the left or on the right of another object. There is an ongoing debate regarding the possibility that the categorical spatial relations completely overlap with linguistic categories (Kemmerer & Tranel, 2000; Ruotolo, Ruggiero, Raemaekers *et al.*, 2019), such as spatial prepositions, or rather should be separated in visual spatial categories and verbal spatial categories (van der Ham & Postma, 2010). Importantly, correct categorical processing of an object location allows people to perform other relevant tasks such as object identification (e.g., Chabris & Kosslyn, 1998), to capture the general properties of spatial layout (Baumann & Mattingley, 2014), to process and memorize the location of other objects (van der Lubbe, Scholvinck, Kenemans, & Postma, 2006), and to capture important abstract properties about the world (Jager & Postma, 2003). Coordinate spatial relations, in turn, are thought to capture metric distance quantities and refer to precise spatial locations (Baumann & Mattingley, 2014; Laeng *et al.*, 2003). An object could be near to or far from another object, and individuals can mentally represent and judge the exact metric distance between them. Moreover, coordinate representations contain fine-grained metric information and guide actions (Kosslyn *et al.*, 1989; Ruotolo *et al.*, 2019). Recently, van der Ham and colleagues, following Manders (2008), have confirmed a fundamental distinction between qualitative and metric spatial relations. Spatial relations can be considered an important component in geometrical reasoning, claiming the importance of the domain of geometry in the encoding of spatial relations. The authors extended the concept of co-exact and exact Euclid's Elements to categorical and coordinate spatial relations, allowing a comparison between the two processes. Exact relations had metric properties, and co-exact relations consisted of qualitative relations, inferring this distinction as closely related to Kosslyn's (1987) distinction between coordinate and categorical spatial relations.

Furthermore, the hemispheric lateralisation for metric and categorical information seemed compatible with the aforementioned dichotomy. In 1989, Kosslyn and colleagues proposed that the left cerebral hemisphere was mainly engaged categorical processing, whilst the right hemisphere was mainly involved in computing coordinate information. Their participants had to judge whether a dot was on or off a contour of a blob (categorical task), or within 2 mm of the contour of the same image (coordinate task). It is commonly accepted that the left hemisphere is dominant for language, and the right one has a key role in the spatial navigation (Kosslyn, 1987; Kosslyn *et al.*, 1989), and this may, at least partially, substantiate the hemispheric asymmetry regarding the categorical and coordinate encoding of the space. Hellige and

Michimata (1989) used a small dot and a horizontal bar to investigate the hemispheric activation. In the categorical task, participants had to answer whether the dot was above or below the bar or further or less 2 cm apart from the bar. Again, the hemispheric specialization was confirmed. A huge number of studies have replicated the hemispheric lateralization effects (e.g., Baciu, Koenig, Vernier, Bedoin, Rubin & Segebarth, 1999; Chabris & Kosslyn, 1998; van der Ham & Ruotolo, 2016; Jager & Postma, 2003; Rybash, J. M. & Hoyer, 1992; Trojano, Conson, Maffei, & Grossi, 2006). Later studies replicated the hemispheric specialization using more realistic stimuli (van der Ham, Zandvoort, Frijns, Kappelle, & Postma, 2011; Saneyoshi, Kaminaga, & Michimata, 2006) and provided additional evidences for a role of the posterior parietal lobe in encoding categorical spatial relations (e.g., Baumann & Mattingley, 2014; Jager & Postma, 2003), for instance, in processing landmark sequence (Ciaramelli, Rosembaum, Solcz, Levine, & Moscovitch, 2010). Kessels *et al.* (2004) showed that the right amygdalohippocampectomy patients were impaired on tasks assessing coordinate location information. In similar vein, van Asselen, Kessels, Kappelle and Postma (2008) showed that patients with a lesion in the left hemisphere performed worse on the category position tasks, and on the contrary individuals with right lesion performed worse on coordinate position tasks. Further research has focalized the attention on the spatial representation resulting from the combination between the categorical and coordinate spatial information and the egocentric and allocentric frame of reference (Ruotolo *et al.*, 2019). The authors showed a higher activation in bilateral occipital and occipito-temporal areas for allocentric–categorical combination and, on the other side, the allocentric–coordinate combination involved bilateral occipital areas, the right supramarginal gyrus and the right inferior frontal gyrus. They also revealed a bilateral frontoparietal network, mainly right sided, that was more involved in the egocentric categorical representations and, a right frontoparietal circuitry specialized for egocentric coordinate representations. Consequently, categorical and coordinate spatial relations seem to be distinguished at a neural level, as different spatial representations (e.g., Committeri, Galati, Paradis, Pizzamiglio, Berthoz & LeBihan, 2004).

Until now, the tasks used to study the categorical and coordinate processing have involved a wide variety of tasks, ranging from the standard dot-bar paradigms (e.g., Hellige & Michimata, 1989; Laeng, Peters, & McCabe, 1998; van der Lubbe *et al.*, 2006), to object location memory tasks (e.g., Ruggiero, Frassinetti, Iavarone, & Iachini, 2014; van Asselen *et al.*, 2008), from recognition of objects under various view points and various positions (e.g., Kosslyn, Chabris, Marsolek & Koening, 1992; Laeng, Shah, & Kosslyn, 1999), to identity matching tasks (e.g., van Asselen *et al.*, 2008; Laeng, 1994). The reported tasks have been employed in studies focusing on visual perception (e.g., Hellige & Michimata, 1989; van der Lubbe *et al.*, 2006; Rybash & Hoyer, 1992), spatial memory (e.g., Laeng & Peters, 1995; Postma, Izendoorn & De Haan, 1998), mental imagery (e.g., Palermo, Bureca, Matano, & Guariglia, 2008; Trojano *et al.*, 2002), and spatial communication (e.g., Kemmerer & Tranel, 2000).

A domain that has yet sparsely been examined is that of spatial relation processing in sketch maps. Undoubtedly, people seem to be able to judge distances and categorical positions as emerging by sketching maps (Coluccia, Bosco, & Brandimonte, 2007; Evans & Pezdek, 1980; Lopez, Caffò, Spano, & Bosco, 2019; Lopez *et al.*, 2020). Sketch maps form a very simple and concise way to represent information regarding the environment. Originally, this graphic schematization of space was described by Lynch (1960) with the use of five key elements: paths, edges, districts, nodes, and, importantly, landmarks – peculiar objects spread in the space in salient positions (see Fig. 1). It is possible to represent graphically the environment drawing it on a sheet of paper in the form of a sketch map, placing certain objects in a specific location, thinking about the spatial configuration in a bird's-eye view (Lopez, Caffò, & Bosco, 2019). Thus, sketch maps – *the internalized reflection and reconstruction of space in thought* – (Hart & Moore, 1973), reflect schematizations that originate in cognitive maps (Wang & Schwering, 2015). Furthermore, sketch mapping is considered a reliable method to represent and externalize collected spatial information (Blades, 1990; Costa & Bonetti, 2018; Lopez *et al.*, 2020. Several authors analysed sketch maps from a quantitative and qualitative point of view (e.g., Wang & Schwering, 2009), such as using the qualitative representations for the alignment of sketch and metric maps (Schwering, Wang, Chipofya, Jan, Li & Broelemann, 2014), or bidimensional regression and his extensions (Freksa, 1992; Friedman & Kohler, 2003; Gardony, Taylor & Brunyé, 2016). These methods were implemented in order to evaluate the participant's accuracy in performing sketch maps, but they did not seem helpful in disentangling categorical and coordinate components of spatial relations in sketch maps.

In the light of the foregoing, the general aim of the present study was to disentangle categorical and coordinate spatial relations applied to sketch maps. In particular, the present study wanted to investigate the validity of the new categorical and coordinate measurement model that separate the computation of categorical from coordinate spatial relations applied to sketch maps: (1) from a purely formal point of view; and (2) from an empirical one.

To do this, first, the study was devoted to investigating if categorical and coordinate information can be thought as conceptually autonomous in sketch maps. More specifically, we aimed to determine whether it is possible to maintain a mental representation of the correct configuration of landmarks in terms of distances irrespective to categorical positions and *vice versa*. Second, different approaches of measuring distances were analysed through confirmative factor analysis (CFA) models, in order to establish which distance measure achieves a better fit with data. Finally, attempting to establish the empirical autonomy of the categorical and coordinate components of spatial relations, a series of CFAs was employed on the corpus of data. The evidence was compared for a single-factor model (i.e., full integration between coordinate and categorical spatial relations) against two bifactorial models: separate but correlated factors (i.e., statistically significant correlation between coordinate and categorical spatial relations) against fully independent factors (i.e., independence between coordinate and categorical spatial relations).

Coordinate and category: are they formally autonomous?

The way in which humans mentally represent spatial information is a direct mapping of how they perceive and experience the

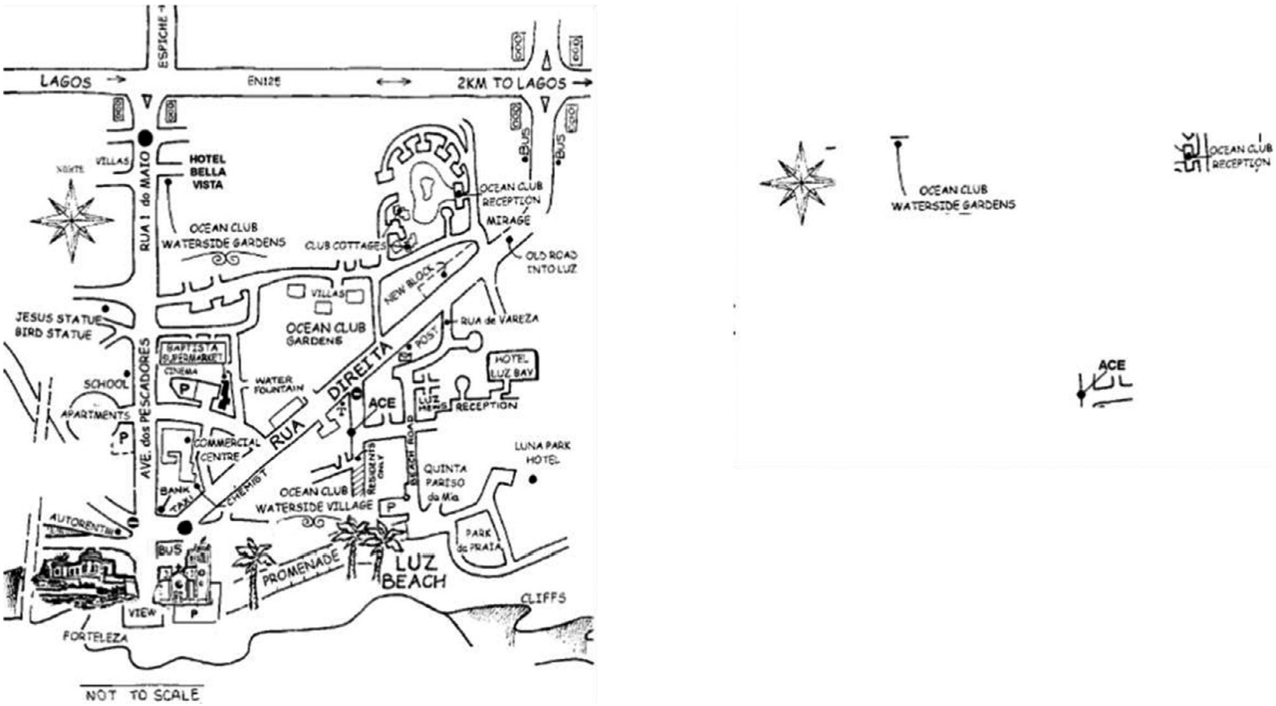

Fig. 1. The left part of the figure represents a sketch map complete of all elements, (i.e., paths, edges, districts, nodes, and landmarks). The right part of the figure represents three landmarks extrapolated from the same map. (Illustrations free downloaded from Google Image).

space (Freksa, 1991). As mentioned above, it is possible to separate between qualitative and quantitative features that in turn resemble categorical and coordinate relations (Landau & Jackendoff, 1993). Then, in order to show the formal autonomy of categorical and coordinate spatial relations, it is possible to adopt a qualitative spatial reasoning, considering categorical spatial relations as positions, and coordinate spatial relations as distances between landmarks.

First, considering categorical positions and distances as a qualitative knowledge about the space (e.g., Ruotolo *et al.*, 2019), it is plausible to use qualitative representations in order to solve problems of spatial reasoning regarding distances between objects/landmarks, not in terms of absolute units but in terms of qualitative ones. By referring to spatial relations through the use of spatial qualitative labels, it is possible to transform the coordinates from *quantitative* to *qualitative*, like in this example: the quantitative assertion "the distance between a and b is 6 cm" and "the distance between b and c is 4 cm," could be reconsidered like "the distance between a and b" is greater than "the distance between b and c," becoming a *relative* concepts regardless of reference units (Frank, 1992). On the other hand, categorical spatial relations are logically eligible to be handled in terms of qualitative spatial labels (Postma & van der Ham, 2016).

Therefore, another spatial reasoning method could be applied: starting from a hypothetical arrangement of three landmarks, we can do positional (categorical) and distance (coordinate) inferences (see Fig. 2). From the categorical point of view, their original configuration shows the landmark 2 further east of the landmark 1 and 3, and the landmark 3 further north to each other. From the coordinate point of view, the distance between them is different for each couple of landmarks. Applying to the arrangement of points a rotation of 180°, the categorical spatial

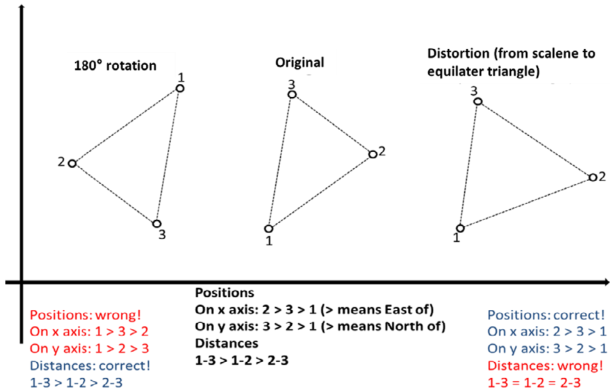

Fig. 2. Hypothetical arrangement of three figures with three landmarks, showing comparisons based on positions and distances for each figure. [Colour figure can be viewed at wileyonlinelibrary.com]

configuration changes while distances between the three points do not. Otherwise, stretching the distances until transforming the scalene having as vertices the three landmarks in an equilateral triangle, the landmarks assumed a different configuration in terms of distances, whereas the categorical information based on relative positions of each landmark to each other could remain unaffected. Consequently, it is possible to suppose that people can depict, in principle, the correct arrangement of landmarks in term of distances disregarding categorical positions and *vice versa*.

Thereby, it is conceivable to claim, potentially, the formal autonomy of categorical and coordinate spatial relations.

Coordinate and category: are they empirically autonomous?

In order to achieve the second and the third aims of the present study – to assess which kind of distance measure was better to represent coordinate information and the empirical autonomy of categorical and coordinate spatial relations – sketching maps regarding the Campus area of a group of university students were analysed.

METHODS

Participants

One hundred and fifty-three healthy participants, 76 females, between 19 and 30 years of age (age $M \pm SD$: 21.07 ± 2.50) took part in the study. All participants were students of the University of Bari from introductory courses in psychology. All participants, blinded to the hypothesis of the study, signed a consent form. The participants were enrolled between November and December 2017. The local Ethical Committee of the Institution approved the study protocol. The mean level of education for the overall sample was 15.2 years (SD = 1.3 years). The whole sample was admitted to the assessment aimed at evaluating the ability to retrieve allocentric spatial information previously learned as an effect of navigation regarding the Campus area.

Materials and procedure

The inclusion criterion for young participants was to be active students for two years, and with a good knowledge of the spatial information related to the campus area. All the participants fulfilled requirements that were set by the researchers regarding level of familiarity with the geographical area investigated (how many times the landmarks had been visited every week on a scale from 1, never, to 7, always; male: $M \pm SD$: 4.60 ± 0.55; female: $M \pm SD$: 3.76 ± 0.54).

Participants had to pinpoint three very familiar landmarks of the Campus area, provided with a "sketching area": an empty box, oriented in portrait format, measuring 11.3 × 12 cm (e.g., De Goede & Postma, 2015), north facing. In order to perform this landmark location task (see Fig. 3), participants had to keep in mind metric (i.e., relative distances) as well as categorical ("A is North/South and East/West of B") spatial relations between landmarks (see Fig. 4). The landmarks were the entrance of the Student Center, the entrance of the Department of Educational

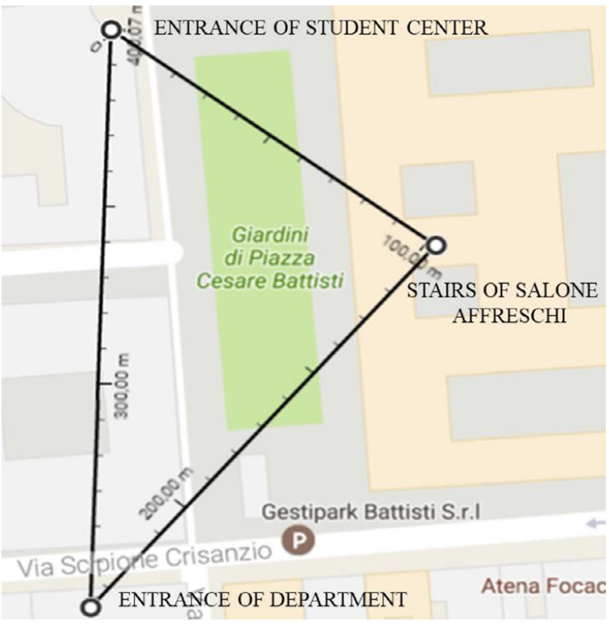

Fig. 3. The map of the Campus Area of the University of Bari with three salient landmarks (i.e., Entrance of the Department, Stairs of Salone Affreschi, Entrance of Student Center – Illustrations free downloaded from Google Maps). [Colour figure can be viewed at wileyonlinelibrary.com]

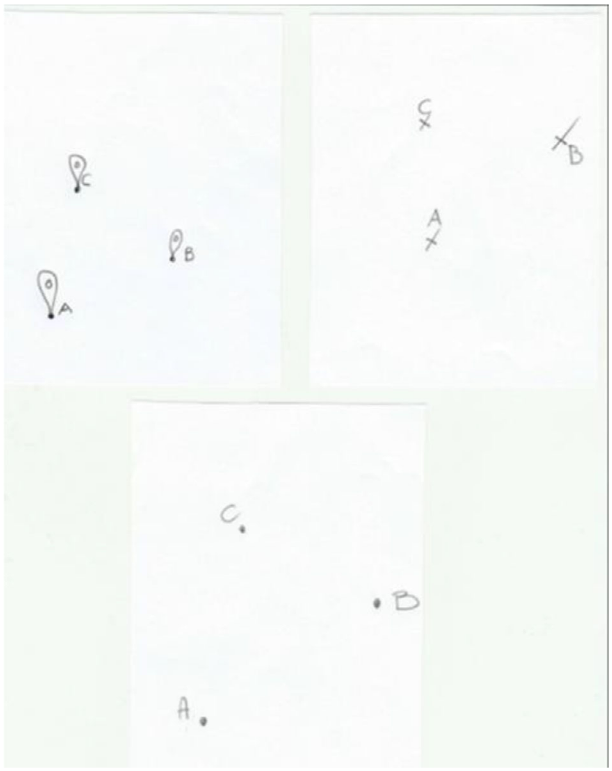

Fig. 4. Examples of map drawn by the participants, with three landmarks reported for each map.
[Colour figure can be viewed at wileyonlinelibrary.com]

Sciences, Psychology, Communication and the stairs of Salone Affreschi (one of the most known halls of the University). Participants were given the following instructions: "Think of the spatial relationships between the landmarks. Draw in the box below three crosses, corresponding to the landmarks. You can use the full box. Please, label them, taking care to respect their distances and their correct positions." The selection of these landmarks was the result of a rating on the level of knowledge of students regarding the locations. Moreover, we chose them for their memorability and spatial configuration. The intended area is approximately 6.6 km^2 (see distances in Table 1).

The entire procedure was made clear to the participants beforehand. Participants were assessed individually in a well-lit and quiet room without disturbances. Data were collected in a single session. The whole assessment lasted a maximum of ten minutes.

Categorical scoring

In order to measure categorical relations, starting from a sketching area with three landmarks (see Fig. 5a) for each couple of landmarks, categorical judgements could be obtained comparing positions, separately, on x (e.g., B is on the right of C) and y axes (e.g., B is above C). For each correct categorical spatial relation, one point was assigned (maximum six points, three comparisons for each axis). This measurement model is an extension of the classical method to evaluate categorical spatial relation (e.g., Hellige & Michimata, 1989), applied to sketch maps.

Coordinate scoring

Coordinate judgements could be obtained comparing each couple of distances between landmarks. The most common straight-line distance between two points in Euclidean space is called Euclidean distance. According to the Euclidean distance formula, the shortest distance between two landmarks (namely, A and B) in the plane with coordinates (x_A, y_A) and (x_B, y_B) is given by:

Table 1. *Distances in meters between landmarks of the campus area*

Landmarks	Stairs of Salone Affreschi	Entrance of student center
Entrance of the department	128 m	161 m
stairs of Salone Affreschi		107 m

$$AB = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}.$$

Another way to measure distance is the sum of the absolute differences of Cartesian coordinates between two points in the plane: the Manhattan distance. For two landmarks (again, A and B) in the plane with coordinates (x_A, y_A) and (x_B, y_B), the formula is:

$$AB = |x_A - x_B| + |y_A - y_B|.$$

Moreover, the axial components of Manhattan distance can be considered separately:

$$AB_x = |x_A - x_B|,$$
$$AB_y = |y_A - y_B|.$$

A maximum of three points could be collected by the participants for Euclidean and Manhattan distance, while a maximum of six points (i.e., three comparisons for each axis) could be collected by the participants on axial components of Manhattan distance (see Fig. 5b). In conclusion, we assigned one point if the comparison between two distances was correct. Therefore, we obtained two desirable advantages: (1) the same metric/measure unit for coordinate and categorical relations; and (2) binary data allowed to adopt the same estimation method in confirmatory factor analysis for coordinate and categorical items.

Statistical analysis

A series of confirmatory factor analyses (CFAs) was conducted to test the goodness of fit of the distance comparison based on the Euclidean, Manhattan, and the axial components of Manhattan distances. Moreover, a series CFAs were conducted to test the goodness of fit of five models on the latent structure of the categorical and coordinate components: one general latent component (i.e., the hypothesis is that coordinate and categorical judgements are not independent in the sketch maps), two correlated and two not correlated latent components (i.e., the hypothesis is that coordinate and categorical judgements are to some extent/completely independent in the sketch maps). Moreover, two adjusted models were also performed based on the one general latent component and on the two correlated latent components. Analyses were performed with R software and the Lavaan package for structural equation modeling (Rossel, 2012). In order to select the most appropriate CFA estimation method, the assumption of normality was checked as suggested by Finney and DiStefano (2006). Mardia's (1974) multivariate kurtosis indicated a lack of normality of the data. The diagonally weighted least squares (DWLS) estimator was selected because of its robustness with ordinal data, small samples, and even in cases of violations of normality (Forero *et al.*, 2009; Mindrila, 2010). The model was tested with three commonly used indices: the Satorra–Bentler Chi-square (SB χ^2), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA). An acceptable adjustment of the model is determined by values >0.95 for CFI and <0.08 for RMSEA (Hu & Bentler, 1999). Moreover, Kuder-Richardson 20 (KR 20) was calculated to measure the internal consistency of categorical and coordinate components. The squared multiple correlation (smc) was calculated using Guttman's lambda 6 coefficient.

RESULTS

CFA on distances

Preliminary analyses revealed no gender differences associated with variables included in the CFAs.

As shown in Table 2, CFA revealed which models provide an acceptable fit to the data. The x and y components achieved the best sequence of fit parameters ($\chi^2_{(9)} = 17.37$, $p = 0.043$; CFI = 0.94; RMSEA = 0.072) suggesting that the x and y axis components of Manhattan distance seemed to be the best way to represent coordinate information. In the subsequent analyses, the axial components of Manhattan distance were adopted as measure of coordinate spatial relations.

CFA on categorical and coordinate components

As shown in Table 3, CFA revealed which models provide an acceptable fit to the data on categorical and coordinate spatial

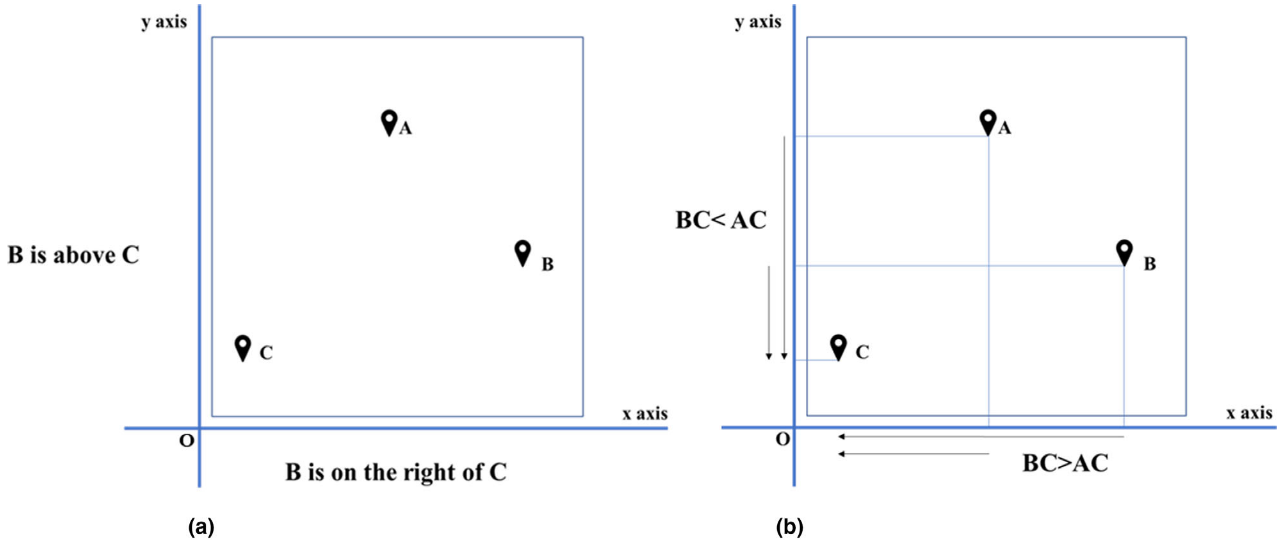

Fig. 5. (a) Categorical scoring; (b) Coordinate scoring, on positions and distances of three landmarks respectively, for x and y axes. [Colour figure can be viewed at wileyonlinelibrary.com]

relations. Both for the categorical and coordinate components, six comparisons were analysed: three for categorical and coordinate spatial relations on the x axis (for category: ctgX1, ctgX2, ctgX3; for coordinate: crdX1, crdX2, crdX3) and on the y axis, (for category: ctgY1, ctgY2, ctgY3; for coordinate: crdY1, crdY2, crdY3) respectively.

Two correlated latent components formed the best fitting model ($\chi^2_{(40)} = 53.53$; $p = 0.052$; CFI = 0.98; RMSEA = 0.084). Moreover, the relative chi-square fit index (Ullman, 2006) for this model reached the recommended cut-off value of < 2 (χ^2/df = 1.34); and the $\Delta\chi^2$ between the model with two correlated latent components and the model with one general latent component was significant, showing that the former showed a significant better fit than the latter model's one. Factor loadings are presented in Fig. 6. Two items presented negative factor loading (for category ctgX2; for coordinate crdX2), and one (crdY2) showed to be unrelated to both factors. These three items were deleted from the subsequent analysis of internal consistency.

Reliability of latent components

The internal consistency for categorical and coordinate components was assessed through the Kuder-Richardson 20. KR20 values were 0.82 for each component (see Table 4). Also, the Guttman's lambda 6 coefficients showed a good reliability (coordinate: 0.79; category: 0.85), notwithstanding the small number of items (Revelle & Condon, 2019).

DISCUSSION

The purpose of this study was to examine the possibility that categorical and coordinate spatial information is formally and empirically autonomous in sketch maps. To our knowledge, this is the first time that categorical and coordinate relationships were analysed employing a very simple version of sketch maps, with only three landmarks. Overall, the results showed the formal independence of categorical and coordinate components, and the empirical independence, although the two components were also moderately correlated.

More specifically, categorical and coordinate spatial relations seemed to be independently detectable from a formal point of view. Using abstract qualitative spatial reasoning, it was suggested that someone can rearrange perfectly a spatial configuration on the basis of categorical information regardless of the coordinate information, and *vice versa.*

Moreover, the present study showed that the best fitting measure of coordinate information is the axial components of Manhattan distance. A possible explanation is that humans move in the urban environment performing sequences of horizontal and vertical paths to reach landmarks. They are able to build integrated representation of the space, combining information from vertical and horizontal directions (e.g., Tversky, 2005) as in the case of urban spaces based on *castrum romanum* (Boone, & Modarres, 2009). The castrum system, with its regular layout, provides a simple and well-organized framework of landmark positions, recognizable in most cities as well as in the geographical area of the present study.

Table 2. *CFAs on Distances estimated with different methods (i.e., Euclidean, Manhattan, x and y Components of Manhattan)*

Distance	χ^2	df	p	χ^2/df	CFI	RMSEA
Euclidean	33.39	1	<0.001	33.39	0.379	0.184
Manhattan	23.88	1	<0.001	23.88	0.543	0.155
x and y components	17.37	9	=0.043	1.93	0.942	0.072

Notes: df = degrees of freedom; CFI = comparative fit index; RMSEA = root mean square error of approximation.

Furthermore, in order to test the goodness of fit of five models regarding the latent structure of coordinate and categorical components derived from sketch maps, results showed an adequate fit for the model of two correlated components and an adequate reliability of measures. The correlation between the latent components was identified as moderate (0.50), indicating that they are related but not collinear, and probably, measuring different aspects of the same spatial relations. Thereby, the best fit for the model of two components could help to support the brain differentiation involved in the categorical and coordinate process (Kosslyn, 1987). The aforementioned moderate correlation from empirical data would seem to be in contradiction with the idea of a formal independence between categorical and coordinate components. This is not the case. Formal and theoretical independence does not imply total independence in practice. Indeed, the participants drawing a map based on incidental knowledge, must necessarily adopt a *global* approach that takes into account categorical positions and distances, as well. Thus, coordinate and categorical estimations, produced concurrently and by the same respondents, are more likely to be correlated with each other. Nonetheless, a single-factor solution – supporting the notion of a unique system that processes both information – does not fit the data as well as the solution to two correlated factors. This result accords well with what has been argued further on. Moreover, categorical spatial relations are considered mainly abstract, and the coordinate one essentially metric. Some researchers state that representations and cognitive processes involved in categorical spatial relation processing can be considered verbal as well as spatial (e.g., van der Ham & Borst, 2011). Probably, the moderate correlation is due to the use of a task completely based on a spatial process, and not on verbal approach (Borst & Kosslyn, 2010). As suggested by van der Ham and Borst (2011), when articulatory suppression was made in categorical and coordinate tasks, performance was not affected, indicating that neither categorical nor coordinate spatial relation processing relies substantially on verbal coding.

Finally, the internal consistency was adequate, notwithstanding the small number of items measuring the two components. The deleted items concerned categorical and coordinate information that participants failed to discriminate. Our results indicated that a difference of 10–20 meters of the walkable area (10–15% of the length of the target area) had not been discriminated accurately, generating mix-up results.

This study cannot be generalized to every kind of spatial information: the factor structure of categorical and coordinate measurements has been tested on data regarding a walkable area: the local university campus. This task is based on spatial information derived from ongoing exploration of the environment (Tversky, 2000). Other research is needed to generalize the results. Moreover, the ongoing process leading to the final

Table 3. *CFAs on categorical and coordinate spatial relations*

Model	χ^2	df	p	χ^2/df	CFI	RMSEA	$\Delta\chi^2$	Δdf	p
One factor	228.36	44	<0.001	5.19	0.70	0.161			
Two uncorrelated factors	339.87	44	<0.001	7.72	0.52	0.199			
Two correlated factors	197.01	43	<0.001	4.58	0.75	0.136			
One factor with adjustments[a]	100.24	41	<0.001	2.44	0.90	0.133	46.71	1	<0.001
Two correlated factors with adjustments[a]	53.53	40	=0.052	1.34	0.98	0.084			

Notes: In all the five models one item was deleted (CrdY2) since clearly uncorrelated with latent factor(s). df = degrees of freedom; CFI = comparative fit index; RMSEA = root mean square error of approximation. [a]Models are adjusted for the same parameters following the Modification Indexes.

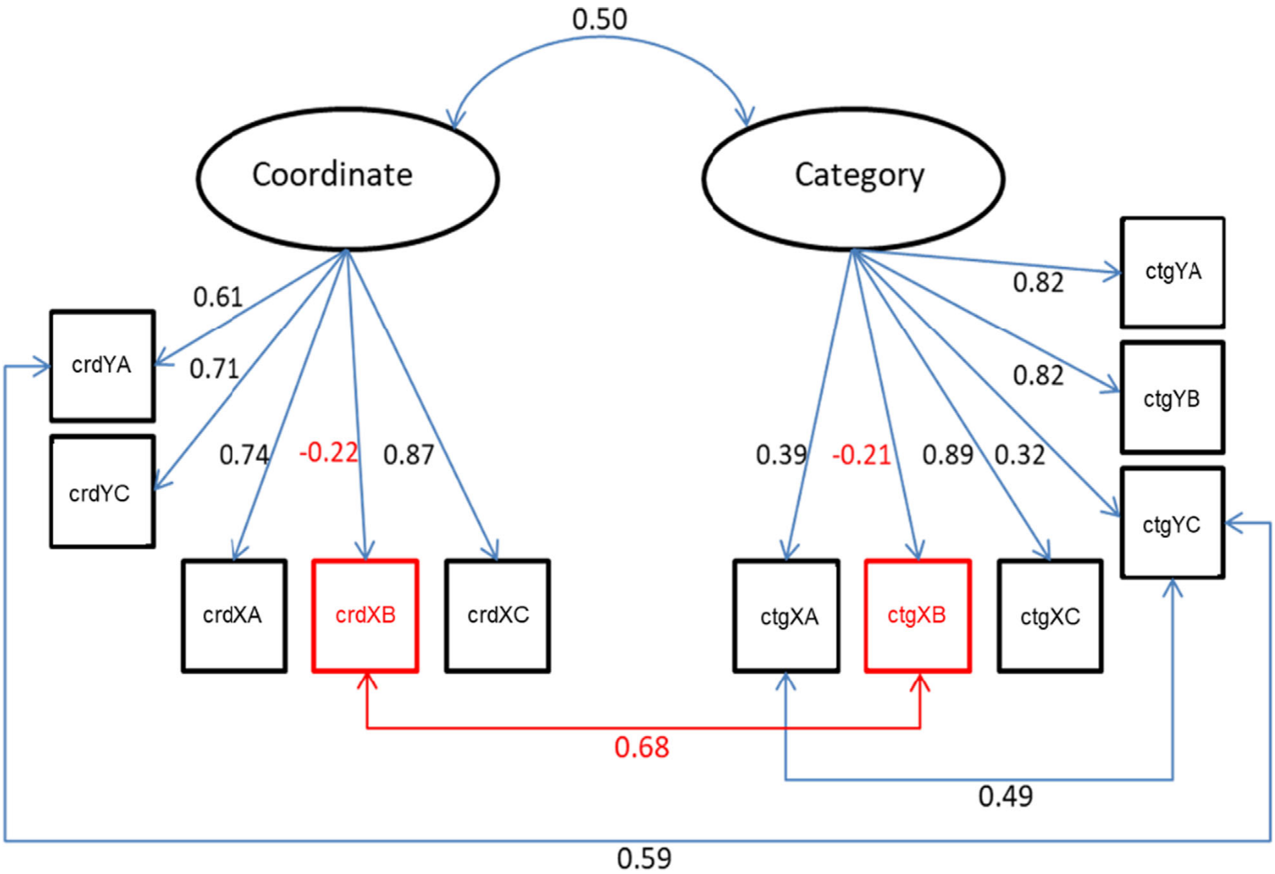

Fig. 6. Path diagram of the best fitting model, namely the two-factors correlated model. [Colour figure can be viewed at wileyonlinelibrary.com]

Table 4. *Reliability of categorical and coordinate factors*

Component	Item(s) eliminated	Nr Items final version	KR-20	95% CI	Std. Alpha	Guttman (smc)
Coordinate	crdX2, crdY2	4	0.82	0.78–0.87	0.83	0.79
Category	ctgX2	5	0.82	0.78–0.87	0.83	0.85

sketched map should be monitored to understand the timing of picking up from memory and reporting on the sheets coordinate and categorical information.

This method is easily suitable for relatively few landmarks; indeed, the number of comparisons increases rapidly with the increase of the number of items.

Despite these limitations, the application of the categorical and coordinate dichotomy to sketch maps seems a helpful paradigm studying the development of mental representations of categorical and coordinate spatial relations along the lifespan, and how they can be combined with egocentric and allocentric frame of reference.

CONCLUSIONS

In conclusion, in the light of the present literature, the method to separate coordinate and categorical components in integrated external representation of spatial information seems to be appropriate formally as well as empirically, providing an effective approach to decode independently positional and metric spatial information as derived by freely sketched maps. We can argue that all the urban areas hampering to reach a target following a direct and linear path, are suitably analysed according to the present method. Categorical and coordinate spatial relations can be measured and evaluated separately, supporting the hemispheric lateralization for metric and categorical information.

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