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

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Abstract

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. 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.

Keywords

Spatial mental representation, Categorical and Coordinate Spatial Relations, Sketch map, Confirmatory Factor Analysis, Spatial Navigation, Familiar Environments

Introduction

Mental representations of the environment essentially depend on how people encode and store spatial relations between objects (Piccardi, Palmiero, Bocchi, Boccia, & Guariglia, 2019; Piccardi et al., 2018; Lopez, Caffò, & Bosco, 2018). 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 (Landau & Jackendoff, 1993; Laeng, Chabris, & Kosslyn, 2003; 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 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 (Laeng et al., 2003; Baumann et al., 2014). 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). Moreover, 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 the Kosslyn's (1987) distinction between coordinate and categorical spatial relations.

Moreover, 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 is 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 has replicated the hemispheric lateralization effects (e.g., Jager & Postma, 2003; Trojano, Conson, Maffei, & Grossi, 2006; van der Ham & Ruotolo, 2016). Later studies replicated the hemispheric specialization using more realistic stimuli (Saneyoshi, Kaminaga, & Michimata, 2006; van der Ham, Zandvoort, Frijns, Kappelle, & Postma, 2011) and provided additional evidences for a role of the posterior parietal lobe in encoding categorical spatial relations (e.g., Jager & Postma 2003; Baumann & Mattingley, 2014), for instance, in processing landmark sequence (Ciamarelli, Rosembaum, Solcz, Levine, & Moscovitch, 2010). Kessels and colleagues (2004) showed that the right amygdalohippocampectomy patients were impaired on tasks assessing coordinate location information. In similar vein van Asselen and colleagues (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 fronto-parietal network, mainly right sided, that was more involved in the egocentric categorical representations and, a right fronto-parietal circuitry specialized for egocentric coordinate representations. Consequently, categorical and coordinate spatial relations seem to be distinguished at a neural level, as different spatial representations.

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; van der Lubbe et al., 2006), to object location memory tasks (e.g., (Kessels, Postma, & De Haan,1999; 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 (Laeng, 1994; van Asselen et al., 2008). The reported tasks have been employed in studies focusing on visual perception (Hellige & Michimata, 1989; Rybash & Hoyer, 1992; van der Lubbe et al., 2006), spatial memory (Laeng & Peters, 1995; Postma, Izendoorn & De Haan, 1998), mental imagery (Trojano et al., 2002; Palermo, Bureca, Matano, & Guariglia, 2008), and spatial communication (Kemmer & 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 positions as emerging by sketching maps (Evans & Pezdek, 1980; Coluccia, Bosco, & Brandimonte, 2007; Lopez, Caffò, Spano, & Bosco, 2019). 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 figure1) . 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, p. 248), 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, 2017). 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 et al., 2014), or bidimensional regression and his extensions (Freksa, 1992; Gardony et al., 2016; Friedman & Kohler, 2003). 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, a) from a purely formal point of view, and b) from an empirical one.

To do this, firstly, 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 positions and *vice versa*. Secondly, 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).

Insert approximate here figure 1

Method

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 space (Freksa, 1991). As mentioned above, it is possible to separate between qualitative and quantitative features that in turn resemble categorical and coordinate relations. 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 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 figure 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 degrees, the categorical spatial 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 positions and *vice versa*.

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

Insert approximate here figure 2

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.

Participants

One hundred and fifty-three healthy participants, 76 females, between 19 and 30 years of age (age Mean±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 Institutions 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: Mean±SD: 4.60 ± 0.55; female: Mean±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 11.3x12 cm (e.g., De Goede & Postma, 2015), north facing. In order to perform this landmark location task (see Figure 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 figure 4). The landmarks were the entrance of the Student Center, the entrance of the Department of Educational Sciences, Psychology, Communication and the stairs of Salone Affreschi (one of the most well-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 proportional 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 approximatively 6.6 km^2 (see distances in table 1).

Insert approximate here table 1and Figure 3

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.

Insert approximate here Figure 4

Categorical evaluation

In order to measure categorical relations, starting from a sketching area with three landmarks (see figure 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 evaluation

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

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

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 figure 5b).

Insert approximate here Figure 5

Statistical analysis

A series of Confirmatory Factor Analysis (CFA) 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; Mîndrilă, 2010). The model was tested with three commonly used indices: the Satorra–Bentler chi-square (SB $\chi 2$), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA). An acceptable adjustment of the model is determined by values greater than .95 for CFI and less than .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

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=.043; CFI=.94; RMSEA=.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 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=.052; CFI=.98; RMSEA=.084). Moreover, the relative chi-square fit index (Ullman, 2006) for this model reached the recommended cut-off value of less than 2 ($\chi 2$/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 figure 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.

Insert approximate here Table 2 and Table 3

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: 079; category: 0.85), notwithstanding the small number of items (Revelle & Condon, 2018).

Insert approximate here Figure 6

Insert approximate here Table 4

Discussion

The purpose of this study was to examine the possibility that categorical and coordinate spatial information is formally and empirically autonomous in sketch map. To our knowledge this is the first time that categorical and coordinate relationships were analysed employing a very simple version of sketch map, 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 are 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.

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 (.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 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 it 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 & 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) has 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 sketched map should be monitored to understand the timing of picking up from memory and reporting on the sheets coordinate and categorical information. 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, 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.

Authors' contributions AL and AB contributed to the conception, data analysis and drafting the manuscript, AOC and AP to discuss the results and revising the manuscript.

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Conflict of interest statement The authors declare that the study was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical standard All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee (Commissione Etica Locale- nr. 3660-CEL03/17) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Landmarks	Stairs of Salone Affreschi	Entrance of Student Center
Entrance of the Department	128 m	161 m
Stairs of Salone Affreschi		107 m

Table 1. Map of the Campus: distance between landmarks

Distance	*χ2*	*df*	*p*	*χ2/df*	*CFI*	*SRMR*
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

Table 2. x and y Components; df: degrees of freedom; CFI: comparative fit index; RMSEA: root mean square error of approximation

Model	*χ2*	*df*	*p*	*χ2/df*	*CFI*	*SRMR*	*Δχ2*	*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*	100.24	41	<0.001	2.44	0.90	0.133			
Two correlated factors with adjustments*	53.53	40	=0.052	1.34	0.98	0.084	46. 71	1	<0.001

In all the five models one item was deleted (CrdY2) since clearly uncorrelated with latent factor(s)

*Models are adjusted for the same parameters following the Modification Indexes

Table 3. Categorical and Coordinate Components; df: degrees of freedom; CFI: comparative fit index; RMSEA: root mean square error of approximation $\Delta\chi2$; Δdf = differences between models 4 and 5

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

Table 4. Reliability of categorical and coordinate measures


LAGOS
EN125
2KM TO LAGOS
ESPICHE
VILLAS
HOTEL BELLA VISTA
RUA 1 do MAIO
OCEAN CLUB WATERSIDE GARDENS
CLUB COTTAGES
OCEAN CLUB RECEPTION
MIRAGE
OLD ROAD INTO LUZ
BUS
NEW BLOCK
RUA de VAREZA
POST
VILLAS
OCEAN CLUB GARDENS
JESUS STATUE
BIRD STATUE
SCHOOL
APARTMENTS
BAPTISTA SUPERMARKET
CINEMA
WATER FOUNTAIN
RUA DIRETTA
ACE
HOTEL LUZ BAY
RECEPTION
LUZ MEWS
LUNA PARK HOTEL
AVE. dos PESCADORES
COMMERCIAL CENTRE
BANK
CHEMIST
OCEAN CLUB WATERSIDE VILLAGE
RESIDENTS ONLY
QUINTA PARISO
PARK do PRAIA
AUTORENTAL
PROMENADE
LUZ BEACH
CLIFFS
VIEW
FORTELEZA
NOT TO SCALE

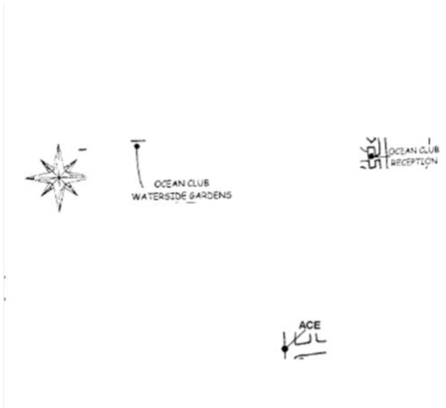
OCEAN CLUB WATERSIDE GARDENS
OCEAN CLUB RECEPTION
ACE

Figure 1. An example of sketch map and details of three landmarks (Illustrations free downloaded from Google Image)

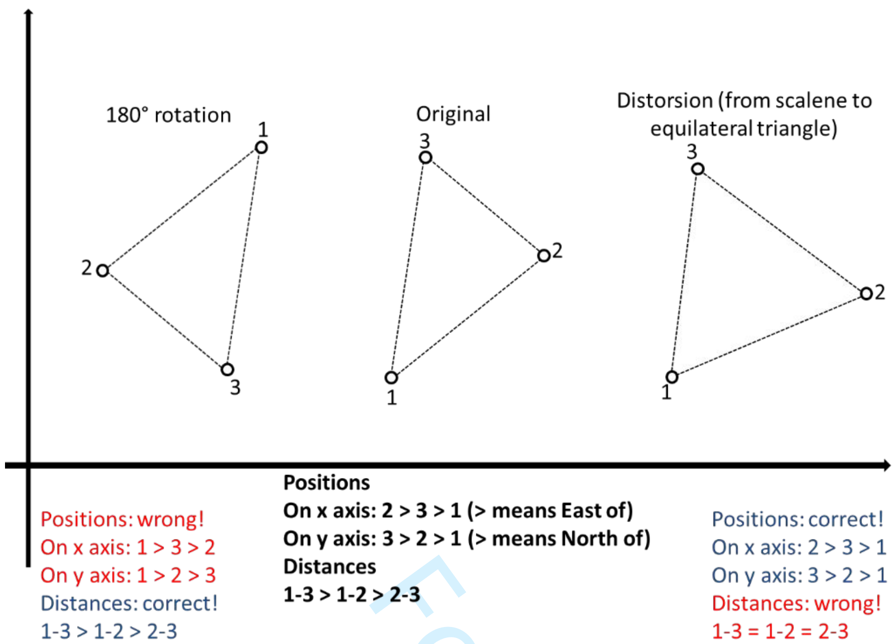
180° rotation
1
2
3
Original
3
2
1
Distorsion (from scalene to equilateral triangle)
3
2
1
Positions: wrong!
On x axis: 1 > 3 > 2
On y axis: 1 > 2 > 3
Distances: correct!
1-3 > 1-2 > 2-3
Positions
On x axis: 2 > 3 > 1 (> means East of)
On y axis: 3 > 2 > 1 (> means North of)
Distances
1-3 > 1-2 > 2-3
Positions: correct!
On x axis: 2 > 3 > 1
On y axis: 3 > 2 > 1
Distances: wrong!
1-3 = 1-2 = 2-3

Figure 2. Hypothetical arrangement of three landmarks

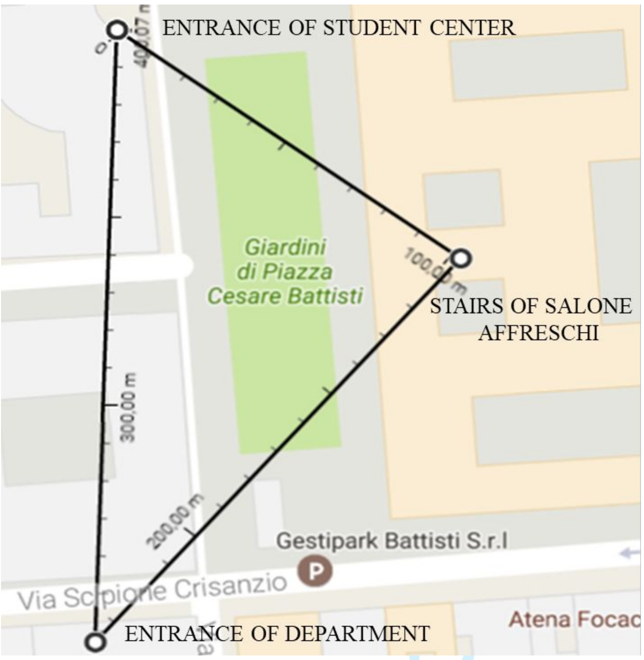
ENTRANCE OF STUDENT CENTER
Giardini
di Piazza
Cesare Battisti
100,00 m
STAIRS OF SALONE
AFFRESCHI
300,00 m
200,00 m
Gestipark Battisti S.r.l
Via Scipione Crisanzio
Atena Focac
ENTRANCE OF DEPARTMENT

Figure 3 The Map of the Campus (Illustrations free downloaded from Google Maps)

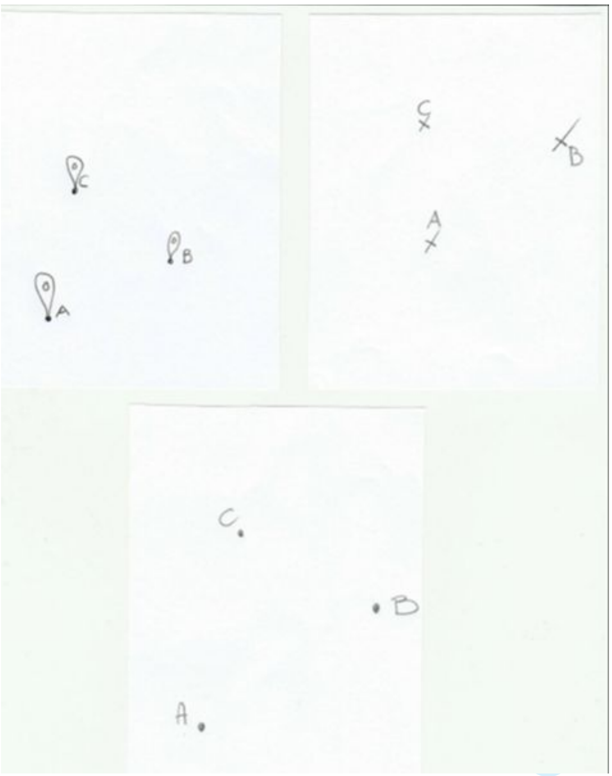
C
B
A
C
B
A
C
B
A

Figure 4. Example of maps drawn by the participants

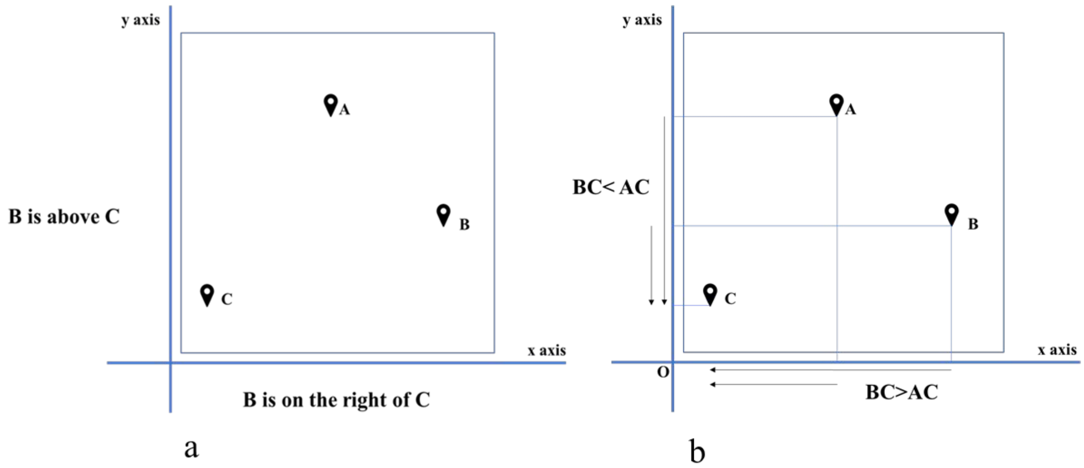
y axis
A
B is above C
B
C
x axis
B is on the right of C
a
y axis
A
BC< AC
B
C
x axis
O
BC>AC
b

Fig.5: a) Categorical measurement model; b) Coordinate measurement model

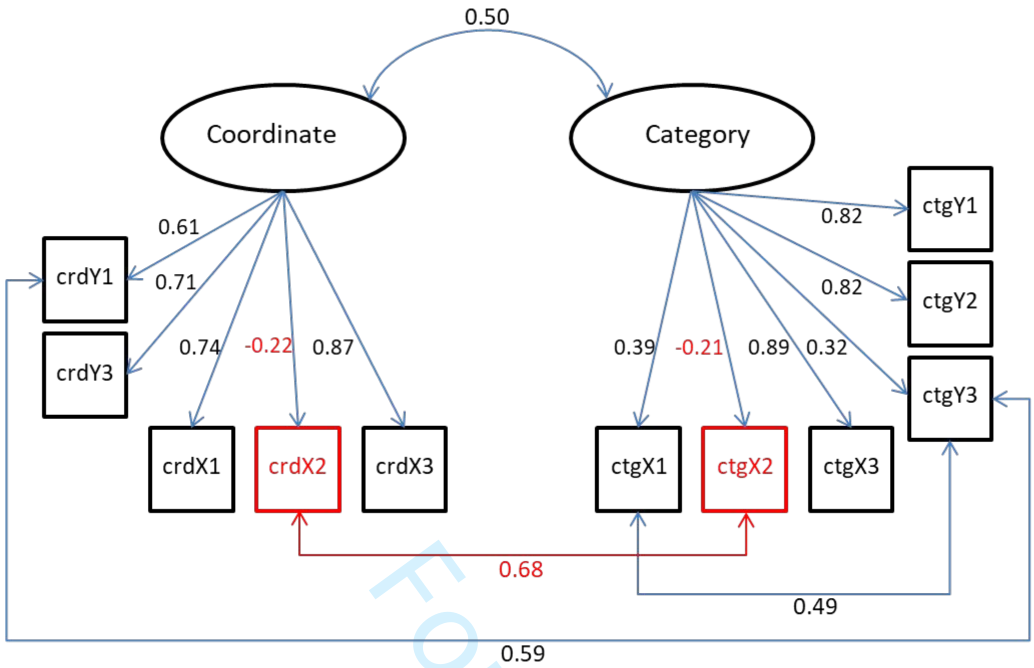
0.50
Coordinate
Category
0.61
0.71
0.74
-0.22
0.87
0.82
0.82
0.39
-0.21
0.89
0.32
crdY1
crdY3
crdX1
crdX2
crdX3
ctgX1
ctgX2
ctgX3
ctgY1
ctgY2
ctgY3
0.68
0.49
0.59

Figure 6. Plot of two-factors correlated model