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RESEARCH ARTICLE

Does spatial cognitive style affect how navigational strategy is planned?

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Abstract
People orient themselves in the environment using three different, hierarchically organized, spatial cognitive styles: landmark, route, and survey. Landmark style is based on a representation encompassing only visual information (terrain features); route style is based on a representation that connects landmarks and routes using an egocentric (body-centred) frame of reference; survey style is based on a global map-like representation that mainly involves an allocentric (world-centred) frame of reference. This study was aimed at investigating whether individual spatial cognitive style affected the way to plan a path when searching for a lost object. Participants with landmark, route, and survey style were assessed with an ecological navigational planning task (the Key Search Task), which required planning a strategy to search for the lost key in a hypothetical wide squared field. Results showed that spatial cognitive styles were associated to different navigational planning strategies, although the time to complete the Key Search Task was comparable across the styles. As revealed by the Key Search Task score, survey style individuals were the best navigational planners, route style individuals were less efficient and landmark style individuals were the least efficient. These results suggest that spatial cognitive style has effects on navigational planning. Implications for clinical settings, such as for developmental topographical disorientation, are discussed.

Keywords Spatial navigation · Planning · Cognitive style · Individual factors · Strategy

Introduction

Spatial navigation is a complex ability we use in everyday life to find our way in the environment; it allows us to plan routes for going back home (Piccardi et al. 2019a), for reaching a novel location as well as for finding an alternative path when jammed in the traffic (Wolbers and Hegarty 2010). People show a great variability in terms of navigation skills. This can be due to external factors, such as the degree of landmark differentiation, for example, emotional landmarks (Palmiero and Piccardi 2017), the degree of visual access to the environment, and the complexity of spatial layout. However, internal factors (personal attributes) such as gender, familiarity, trait of personality, and spatial cognitive styles (Gärling et al.1986; Kitchin 1994; Pazzaglia et al. 2018; Bocchi et al. 2018; Piccardi et al. 2016) are also important. Specifically, spatial cognitive styles reflect the preferred modality for processing environmental information (Kozhevnikov 2007; Kraemer et al. 2009; Paivio and Harshman 1983; Boccia et al. 2017a, b; Tascón et al. 2017). In the field of navigation, three different hierarchically organized spatial cognitive styles (hereafter SCSs; i.e., landmark, route and survey) have been described (Siegel and White 1975; Pazzaglia et al. 2000). The landmark spatial cognitive style (LS) is supported by mental representations including only perceptually salient cues (landmarks, e.g., a church, our best friend's house), not providing any spatial information, but only visual features not linked with others (Siegel and White 1975). Individuals using LS mainly rely on environmental objects when navigating, and their strategies are

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not flexible. They are unable to go beyond the information provided by the setting (i.e., cognitive restructuring) (Boccia et al. 2017a), and are severely affected by the alignment effect (people are better in judging direction when their position in the environment is aligned with the perspective of the learned spatial layout, Nori and Giusberti 2003; Nori et al. 2006). The Route Spatial cognitive style (RS) encodes properties of both landmark and route representations and is predominantly sensorimotor (Siegel and White 1975). Individuals with RS memorize paths and connections among landmarks basing their navigation on body references (e.g., egocentric frames of reference, 'the shop is on my left') and planning a route using a mental list of distances and directions to be followed (Siegel and White 1975; Pazzaglia et al. 2000). The survey spatial cognitive style (SS) involves a global configuration, roughly corresponding to a map-like representation of the environment based on allocentric frames of reference, that is independent from individual's position, such as cardinal points (e.g., North, South, West, East: Siegel and White 1975; Pazzaglia et al. 2000). SS users can easily manipulate their mental map of the environment (Pazzaglia et al. 2000), are better in mental rotations and are also able to flexibly change their navigational strategy (Piccardi et al. 2016).

SS users are more proficient in navigation skills than RS and LS users in reconstructing the navigational field (Boccia et al. 2017a), and are less affected by the alignment effect (i.e., when the perspective of learning and retrieval of an environment does not correspond, there is a cost in speed—we take more time- and in accuracy—we make more mistakes; Warren and Scott 1993; Sholl and Nolin 1997) compared to RS and LS users (Nori and Giusberti 2003; Nori et al. 2006; Verde et al. 2018). In other words, there is an increasing spatial navigation ability ranging from LS to SS. Using a less proficient strategy, LS people more frequently experience the feeling of getting lost. Even though RS individuals are more skilled than LS individuals, they can get lost if a change in a crucial landmark, or a detour, occurs (Nori and Giusberti 2006). Finally, SS individuals are very proficient navigators: they are able to find an alternative shortcut to reach a final destination and to create an interconnected network among different paths without relying on the aid of landmarks (Nori and Piccardi 2011).

Bearing this in mind, the present study was aimed at investigating, for the first time to our knowledge, the relation between SCS and navigational planning ability. This latter requires an intentional behaviour to imagine, plan and execute a travel plan. From this point of view, human spatial navigation is comparable to a problem-solving situation including the predetermination of a course of actions aimed at achieving a certain goal (e.g., Hayes-Roth and Hayes-Roth 1979; Gärling et al. 1984). According to Gärling et al. (1984) travel plans need to be revised during navigation, either because these plans come to be regarded as unrealistic, or because environmental changes are detected. Indeed, when we walk through an environment, we continually change the perspective, which needs to be updated every time a new orientation (e.g., a turn) is presented.

Navigational planning is a cognitive demanding ability, defined as the capacity of mentally evaluating and selecting the best solution that allows to reach a destination, among many imagined alternative actions (Arleo and Rondi-Reig 2007; Willcutt et al. 2005). Pazzaglia et al. (2018), attempted to address how some individual factors affect the ability of finding a shortcut. They found that shortcut-finding revealed individual differences that were possibly even more marked than those seen in the retracing task, suggesting that studying the implementation of a strategy may provide new perspectives on the study of spatial navigation.

Undoubtedly, navigational planning, differently from other kinds of planning, exposes the individual in a real-world context in which many environmental information are available (Suchman 1987), as well as many different alternative routes to reach a destination (Arleo and Rondi-Reig 2007; Willcutt et al. 2005). For such a reason, navigational planning may be affected by individual differences, such as spatial cognitive styles that may drive the subsequent ideation and the execution of plans. Indeed, if a strategy is not sufficiently flexible or suitable, we can get lost, together with waste of time and energy. It is a common experience that when we are in a hurry and have to visit more than one shop in a mall before returning to the car parking, we generally attempt to save time. In this case, we will choose the shortest route to respond to the specific need of being fast. In a previous study, Bocchi et al. (2017) found that 'good' navigational planners perform better than 'bad' navigational planners (according to the Key Search Task—KST: Wilson et al. 1996) at a maze navigational task, suggesting that good planning skills may affect one's navigational performance. However, that study did not consider individual differences related to the three spatial cognitive styles (LS, RS and SS).

To fill in this gap, our study evaluated spatial cognitive styles by means of a battery of spatial tasks (Spatial Cognitive Style Test—SCST, Nori and Giusberti 2003, 2006) and the navigational planning through the KST. Specifically, we hypothesized that, given that navigational skills were found to improve from landmark to survey style, navigational planning ability would also improve accordingly (i.e., from LS to SS).

Materials and methods

Participants

Ninety-five college students (mean age 26.24 ± 4.55 years; educational level: 13.61 ± 1.31 years; 48 males and 47 females) were recruited. Before taking part in the study, participants filled in a questionnaire in which they self-reported any previous/current neurological or psychiatric disorders. The inclusion criterion was no history of neurological/psychiatric diseases (including substance abuse or dependence). None of the participants was excluded. Participants were divided in three different groups according to their SCSs. Age was comparable among groups [$F_{(2,92)} = 0.80$; $p = 0.45$]. Landmark Spatial Cognitive Style group (LS) was composed by 28 individuals (7 males); Route Spatial Cognitive Style group (RS) was composed by 36 individuals (20 males); Survey Spatial Cognitive Style group (SS) was composed by 31 individuals (21 males).

According to the Declaration of Helsinki, before the assessment and after a full explanation of the protocol and of the non-invasiveness of the study, a written informed consent was obtained from all individual participants included in the study. The study was approved by the local Ethics Committee.

Compliance with ethical standards

At the beginning of each experimental section, the experimenter gave and explained to the participants a leaflet with all the information regarding aim, procedure, risks and advantages of the study. Participants were also informed about their rights, and about the possibility to leave the study at any time they wished. Furthermore, the experimenter invited the participants to express any doubts or questions they might have on the study. After explaining how their personal data would be processed, an informed consent was signed by all individuals included in the study. The Institutional Review Board of the University of L'Aquila, in agreement with the Declaration of Helsinki, approved this study.

Procedure

First, participants were informed about the procedure. The study was conducted in a quiet room where participants were assessed individually. They were asked to sit on a comfortable chair in front of the experimenter. They signed the informed consent and gave the authorization to use their personal data and reported a brief medical history. Afterwards, participants underwent the KST and the SCST battery. The administration order was counterbalanced across subjects. The two tests are described in detail below:

- *The KST* (see Fig. 1) is an easy-to-administer and ecological test. It is one of the subtests of the 'Behavioural Assessment of the Dysexecutive Syndrome' (BADS: Wilson et al. 1996), and it has been recently adopted to assess navigational planning (Bocchi et al. 2017; Carrieri et al. 2018). It consists of an A4-sized piece of paper with the drawing of a 10 × 10 cm empty black square

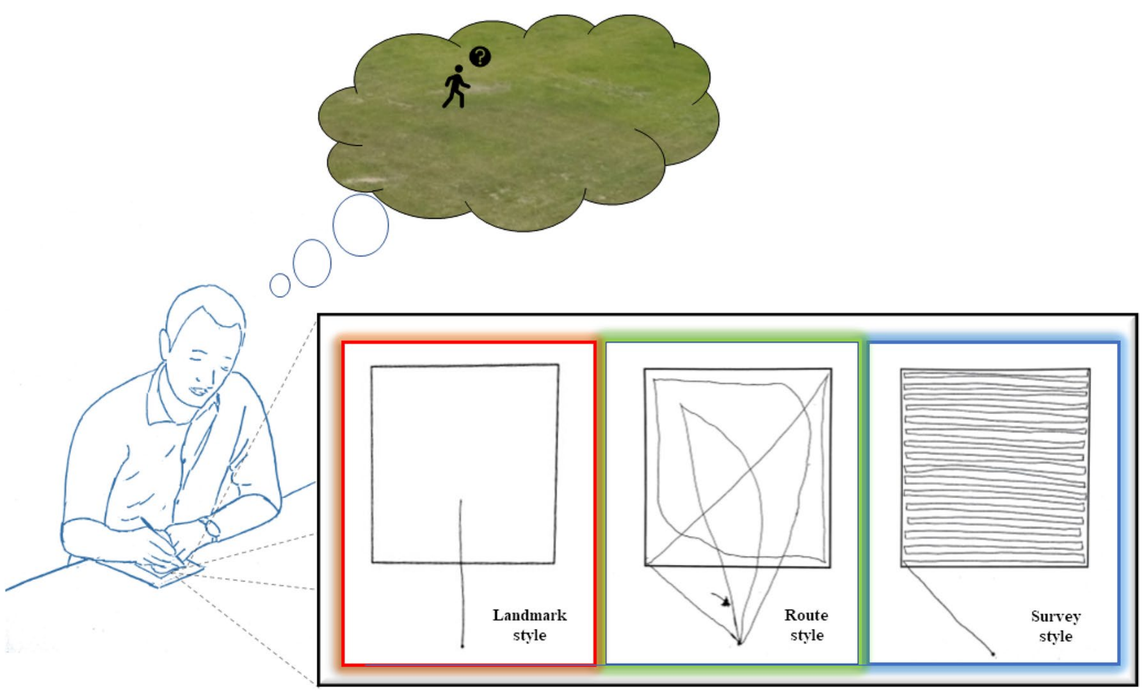

Fig. 1 KST: participants had to image themselves searching their lost keys in a wide field. Concurrently, they had to draw the strategy chosen on an A4 sheet of paper where a 10 × 10 cm square was depicted. On the right, a real example of the KST performance as provided from each spatial cognitive style

in the middle and a small black dot placed 5 cm below the centre of the base of the square. Participants were told to imagine that the square was a large field in which they had lost their keys. They were asked to draw a line (with a marker), starting on the black dot (representing the starting point) to begin the searching of the keys. Participants were required to draw the path they would have followed for being sure to find the keys. They only knew that the lost keys were somewhere in the field, but they did not know exactly where. According to the BADS handbook (Wilson et al. 1996), the KST is evaluated with a total score obtained by summing the score obtained for five variables in which the KST performance can be divided: (1) EN—entry in the field: 3 points if the participant enters in the square within 10 mm from one of the two angles on the square basis, 2 points if the participant enters the squares from any point on the square basis (beyond 10 mm from the angle), 1 point if the participants enters the square from any other point; (2) EX—exit from the field: 3 points if the participant ends his/her pursue within 10 mm from any angle of the square, 2 points if the participant exit from the field in any point along the square basis, 1 point if the participant stops searching along any of the square sides beyond the 10 mm, 0 point if the participant does not ends on the field perimeter or ends in any other point of the field. (3) CL—presence of a continuous line (pen stroke): 1 point if the participant does not rise the pen while tracking the route, or rises the pen but continue tracking from the interruption point as in a continuous line, 0 point if the participant rises the pen from the sheet and then continue tracking the route from a distant point, as if they 'jumped' from a point to another. (4) CO—searching a layout: 5 points if the participant searches the key using one of the efficient systematic configuration often used by people to search a lost object, 3 points if participant uses a 'mixed' configuration resulting from using two or more different configurations together, 0 point if the participant does not use a systematic configuration. (5) FC—field coverage: regardless of the configuration used, 1 point if the participant clearly tries to search all over the field without leaving 'uncovered points', 0 point if the participant does not try to explore the field. The raw score was obtained summing the score reached by the participant in each variable (max 13) and represented the indicator of the KST performance. The time employed to complete the KST was also recorded.

- *SCST* (Nori and Giusberti 2003, 2006) (see Fig. 2) was used to assess the participants' SCSs. It consists of nine subtests, each one composed of 7 items, which were randomly presented. Specifically, the photo task and the figure task underpinned the Landmark spatial cognitive style because they required to recognize buildings or figures without referring to any spatial information. The sequence task, the map description task, the right–left discrimination task and the 2D rotation task underpinned the route cognitive style, because they required an egocentric point of view and a right–left discrimination,

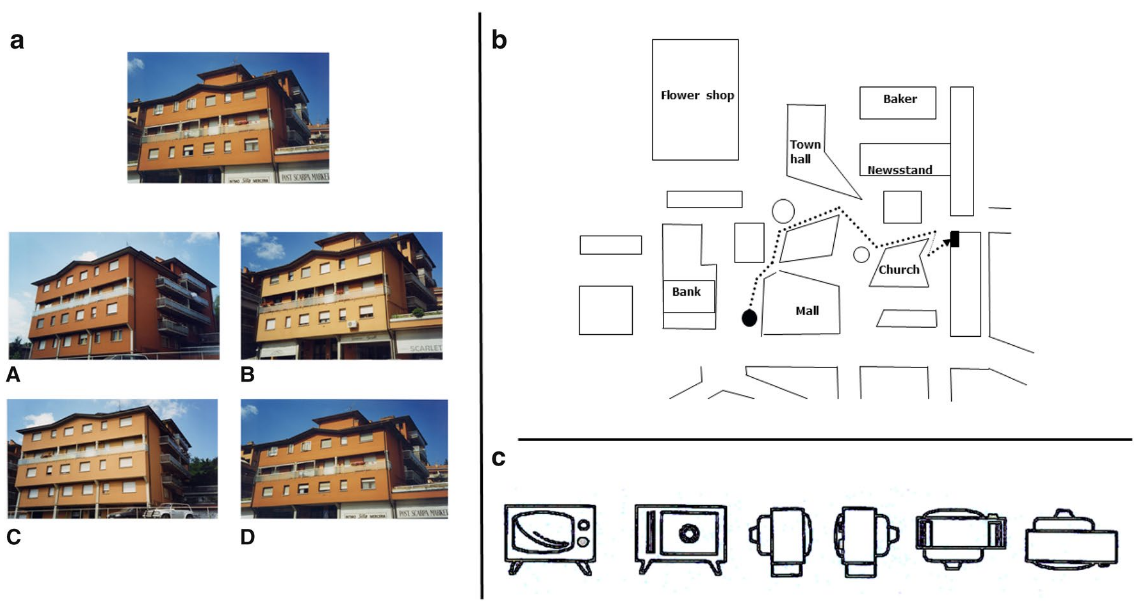

Fig. 2 Three examples from the SCST: **a** photo task (example of landmark tasks) where participants had to recognize the target building among 4 similar buildings; **b** map description task (example of route tasks), where participants had to describe the pathway depicted on the map; **c** 3D rotation task (example of survey tasks), where participants had to mentally rotate the TV target in the direction pointed by a printed arrow and then choose the correct position of the TV among five possibilities

ability considered typical expression of route knowledge. The path task, the 3D rotation task and the sum and straighten task were considered to involve survey knowledge, since they rely on an abstract representation and on an allocentric point of view. The score of each subtest ranged from 0 to 7. Subtests are described in detail below.

Landmark tasks

Photo task

Participants were allowed to study the picture of a building target for 3 s; subsequently, they were instructed to recognize it among photos of four similar buildings (one target and three fillers) (seven trials).

Figure task

Participants were provided with an A4 sheet of paper with drawings of 7 geometrical shapes. They were instructed to study these 7 shapes for 75 s. Participants were allowed to rotate the sheet of paper if they wanted. After that, they were instructed to recognize and mark with a pencil the previously studied shapes among 43 similar shapes fillers.

Route tasks

Sequence task

Participants were asked to study for 15 s a picture representing a navigational scene (a road with landmarks, crossroads, etc.) from a first-person perspective. They were then shown the same picture divided randomly into separate parts (3, 4, and 5), representing a part of the original picture, as in a puzzle. The participants were asked to reorder the parts of the figure as in the original picture (seven trials).

Map description task

Participants were provided with a symbolic map drawn on a A4 sheet of paper, were a pathway was depicted. Participants had to verbally describe the pathway using the following indications: go straight, turn right, turn left. A black dot indicated the starting point and a dotted line indicated the pathway. Participants were asked to imagine they were the black dot and they had to reach the goal (a black square on the upper side of the sheet), following the dotted line pathway and describing it. Specifically, they were instructed to give the correct sequence of the seven right–left turnings (7 points of decision). Participants could rotate the sheet of paper if they wanted to.

Right–left discrimination task

Participants were shown, one at a time, 7 pictures of a schematic hand with different orientation and position. They were asked to identify, without moving their own hands, if each schematic hand was a right or a left hand (seven trials).

2D Rotation task

Participants were shown, one at a time, 7 sheets of paper with a pair of shapes on them (one on the left, one on the right). They were then instructed to indicate if the figure on the right side was a plane rotation of the shape on the left side (seven trials).

Survey tasks

Path task

Participants were shown a path printed on an A4 paper. The path was not linear and had a given systematic configuration. For instance, it could be formed by a straight line and then a left ‘turn’, and again a straight line and a left ‘turn’. Each of the 7 paths started in the lower side of the sheet of paper and went toward the upper side. However, the path was interrupted at a certain point before arriving at the upper side, were three points indicated the possible ending point of the path. Participants had to choose which was the ending point among the three possible alternatives (seven trials).

3D rotation task

Participants were shown, one at a time, 7 sheets of paper with a schematic drawing of a TV. The TV could assume different orientations (frontal, lateral, etc.). Participants had to mentally rotate the TV target in the direction pointed by a printed arrow and then choose the correct position of the TV from among five possibilities (seven trials).

Sum and straighten task

Participants were presented with a series of segments with a different configuration (straight, L form etc.) printed on a sheet of paper. They had to mentally straighten each segment and then sum the length resulted from the straightened segments. They had to indicate the correct answer choosing among four alternatives (seven trials).

Assessment of the spatial cognitive style

As in Nori and Giusberti (2006), the score of each task was summed with others of the same category to assess the cognitive style (landmark, route and survey tasks). The scores were then divided by the number of tasks in the corresponding category (2 for Landmark style, 4 for Route style and 3 for Survey style). If the number obtained in the landmark tasks was equal to or greater than 80% of the corresponding items and less than 50% of the route and survey items, the participant was supposed to use a landmark cognitive style. If the score was at least 80% of correct answers for the landmark and route tasks but less than 50% of the survey tasks, the participant was supposed to use a route cognitive style. Lastly, if the score was at least 80% of correct answers in each of the three categories of tasks, the participant was supposed to use a survey cognitive style.

Statistical analysis

To investigate if the three groups (LS, RS, SS) differed in the KST score and in the time needed to complete the KST, two separate one-way ANOVAs were carried out. In the first ANOVA, Group (LS, RS, SS) was set as between factor and total score of KST as dependent variable. In the second ANOVA, Group (LS, RS, SS) was set as between factor and time of the KST as dependent variable. The alpha level was set at 0.05. To deeper investigate the differences among the three groups, post-hoc analyses were carried out.

To investigate if the three SCS differed in a specific aspect of KST, [EN—entry in the field, EX—exit from the field, CL—presence of a continuous line, CO—searching of a layout (configuration), FC—field coverage], a MANOVA was carried out with Group (LS, RS, SS) as between factor and sub-scores of the KST (EN—entry in the field, EX—exit from the field, CL—presence of a continuous line, CO—searching of a layout/configuration, FC—field coverage) as dependent variables.

A discriminant analysis was also conducted to investigate the weight of each KST sub-scores on the spatial cognitive style classification. Predictor variables were KST-EN (entry), KST-EX (exit), KST-CO (configuration), KST-CL (continuous line), KST-FC (field coverage).

Results

Groups differed significantly for the KST score [$F_{(2, 92)} = 17.17$; $p < 0.001$; partial $\eta^2 = 0.272$; observed power = 1]. Post-hoc analyses (Bonferroni) showed that SS had a significantly better performance compared to RS ($p = 0.03$) and LS ($p < 0.000$); RS showed a significantly better performance than LS ($p = 0.002$). Regarding time to complete the KST no difference was found among groups [$F_{(2,92)} = 0.65$; $p = 0.52$; partial $\eta^2 = 0.014$; observed power = 0.157]. Means and standard deviations of KST score and KST time are reported in Table 1.

Table 1 Means and standard deviations (in brackets) of the total score of KST (maximum score = 13), and of the time needed to complete the KST for the three groups (spatial cognitive styles: LS, RS, SS)

Group	KST score (Max: 13)	KST time (s)
LS (n.28)	5.28 (3.54)	48.52 36.81)
RS (n.36)	7.86 (2.17)	58.67 (53.35)
SS (n.31)	9.74 (3.05)	59.61 (26.08)

Regarding the MANOVA analysis revealed a significant effect of the variable 'Group' [Lambda Wilks = 0.548, $F_{(10, 176)} = 6.178$, $p < 0.001$; partial $\eta^2 = 0.260$; observed power = 1].

The Univariate ANOVA revealed that all the KST subcomponents showed significant effects surviving the Bonferroni correction ($p < 0.005$): KST-EN [$F_{(2, 92)} = 6.564$, $p = 0.002$; partial $\eta^2 = 0.125$], KST-EX [$F_{(2, 92)} = 11.034$, $p < 0.001$; partial $\eta^2 = 0.193$], KST-CO [$F_{(2, 92)} = 11.247$, $p < 0.001$; partial $\eta^2 = 0.196$], KST-FC [$F_{(2, 92)} = 14.374$, $p < 0.001$; partial $\eta^2 = 0.238$], except for KST-CL [$F_{(2,92)} = 4.419$, $p = 0.015$; partial $\eta^2 = 0.088$].

For discriminant analyses, significant mean differences were observed for all predictors on the dependent variable (group-navigational style). While the log determinants were quite similar, Box's M indicated that the assumption of equality of covariance matrices was violated. However, given that the number of participants per group is homogeneous, this problem is not regarded as serious (Barbaranelli and D'Olimpio 2006). The discriminate function revealed a significant association between groups and predictors, accounting for 45.2% of between group variability. Closer analysis of the structure matrix revealed three significant predictors, namely field coverage (0.817), configuration (0.721) and continuous line (0.451). The cross-validated classification showed that overall 60% of the cases were correctly classified (Figs. 3, 4).

Discussion

In the present study, we tested the hypothesis that spatial cognitive style can affect the way an individual plans a route, influencing the choice of the navigational strategy in which they are more confident. We expected that individuals with a more efficient navigational style (i.e., Survey Style) would show a better navigational planning. To test this hypothesis, we asked individuals with different SCSs to perform a task requiring planning and to navigate a pathway on a sheet of paper to search for a lost object in a wide empty field. This task involved the implementation of a navigational strategy to cover all the available space to maximize the chance to find the lost object. Results confirmed our hypothesis on the

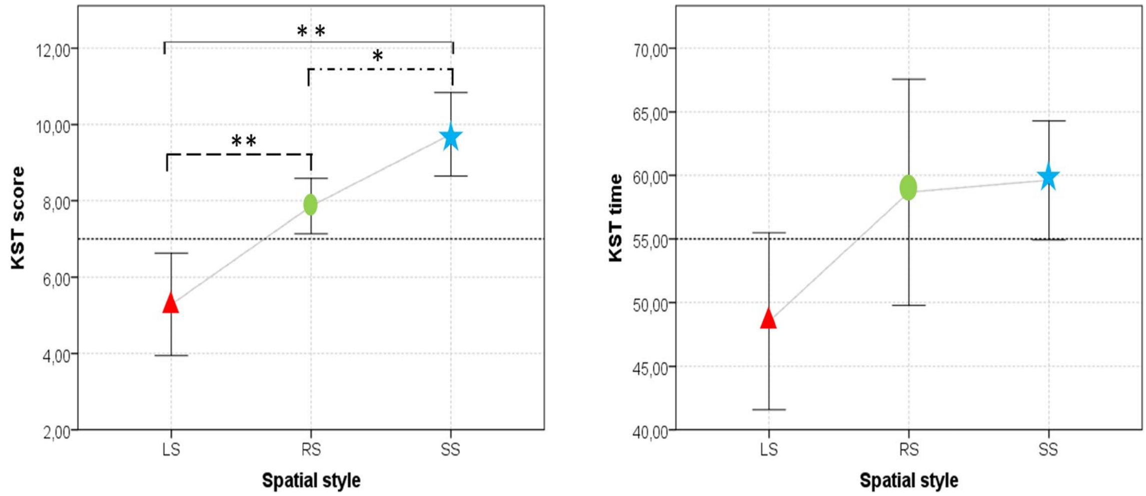

Fig. 3 Plot on the left shows the trend of the three groups (LS, RS, SS) on the KST general score (obtained summing the score of EN—entry, EX—exit, CL—continuous line, FC—field coverage, CO—configuration). SS obtained the higher score, while LS obtained the lower score. Plot on the right shows the trend of the three groups (LS, RS, SS) on KST Time. No differences emerged for time needed to complete the KST. In each graph, Landmark group is marked with a red triangle, Route group is marked with a green circle, and survey group is marked with a blue star. Significant differences have been marked with one ($p < 0.05$) or two ($p < 0.01$) asterisks

different level of efficiency in the three SCSs. Analyses on the single components of the scoring of the KST showed that all the KST components were significantly different among groups, except for KST continuous line.

Generally speaking, the trend of the score of the sub-components reflected the total score trend. Indeed, the SS group was significantly better in all task components. Nevertheless, some interesting differences occurred. In the configuration score (CO), which is probably the most relevant for succeeding in the KST, the SS group did not perform significantly better than RS. Both were able to implement an efficient configuration, compared to LS. Indeed, the survey style users differed from route and landmark style users for the modalities of entering (EN) and exiting (EX) the field. In this case, the maximum score is obtained when the participant enters or exits within 10 mm from an angle of the square (see methods for details). This suggests, according to the features of their cognitive style, that SS individuals were able to take advantage from an allocentric frame of reference (e.g., the geometrical configuration of the environment), rather than using an egocentric frame of reference (e.g., the own body position). Interestingly, LS and RS individuals did not differ on these components. Regarding the Continuous line (CL), although the analyses showed no significant differences among groups, some speculations can be done. For CL, one point is attributed if the participant does not interrupt the tracking of the route, while 0 point is given if the route is interrupted in a point and then continued in a distant point. Certainly, if a person searches for a lost object in a field without reference points, it is mandatory to follow an itinerary and be aware of where they already searched and where to go next. The best way of doing this is by trying to maintain a continuous route, without going to a point, exiting from the field and then re-entering from another point of the field, because in such a case, some part of the field can remain uncovered. Given that the KST explicitly requires the subject to image of actually performing the task, interrupting the line is comparable to a 'jump' from a place to another of the field. SS had a higher score on continuous line, therefore, they did not image searching the keys starting in a point and then stopping and keeping the search in a point far from the previous. Conversely, LS individuals generally had a lower score of continuous line, as they did not follow a continuous route but 'jumped' from a point to another point of the field, reflecting a lack of a strategy to search the lost keys. For the Field Coverage (FC) only LS individuals did not cover an acceptable part of the field, probably due to a weak planning strategy.

In general, this evidence implies that SCSs support different navigational abilities of planning. Therefore, each SCSs show a peculiar ability to plan a strategy for a goal-directed navigation. Since the navigational planning ability requires both mental imagery and cognitive flexibility (Bocchi et al. 2017; Carrieri et al. 2018), the different features of SCSs exhibited in the KST can be the result of their increasingly higher level of these abilities (e.g., Piccardi et al. 2017; Pazzaglia and De Beni 2006; Nori et al. 2012; Verde et al. 2018). Specifically, environmental mental imagery and cognitive flexibility offer to SS individuals different possible solutions to solve the KST and to choose the best strategy according to the context. As the field of the KST does not have any reference point, the best way to perform the task is

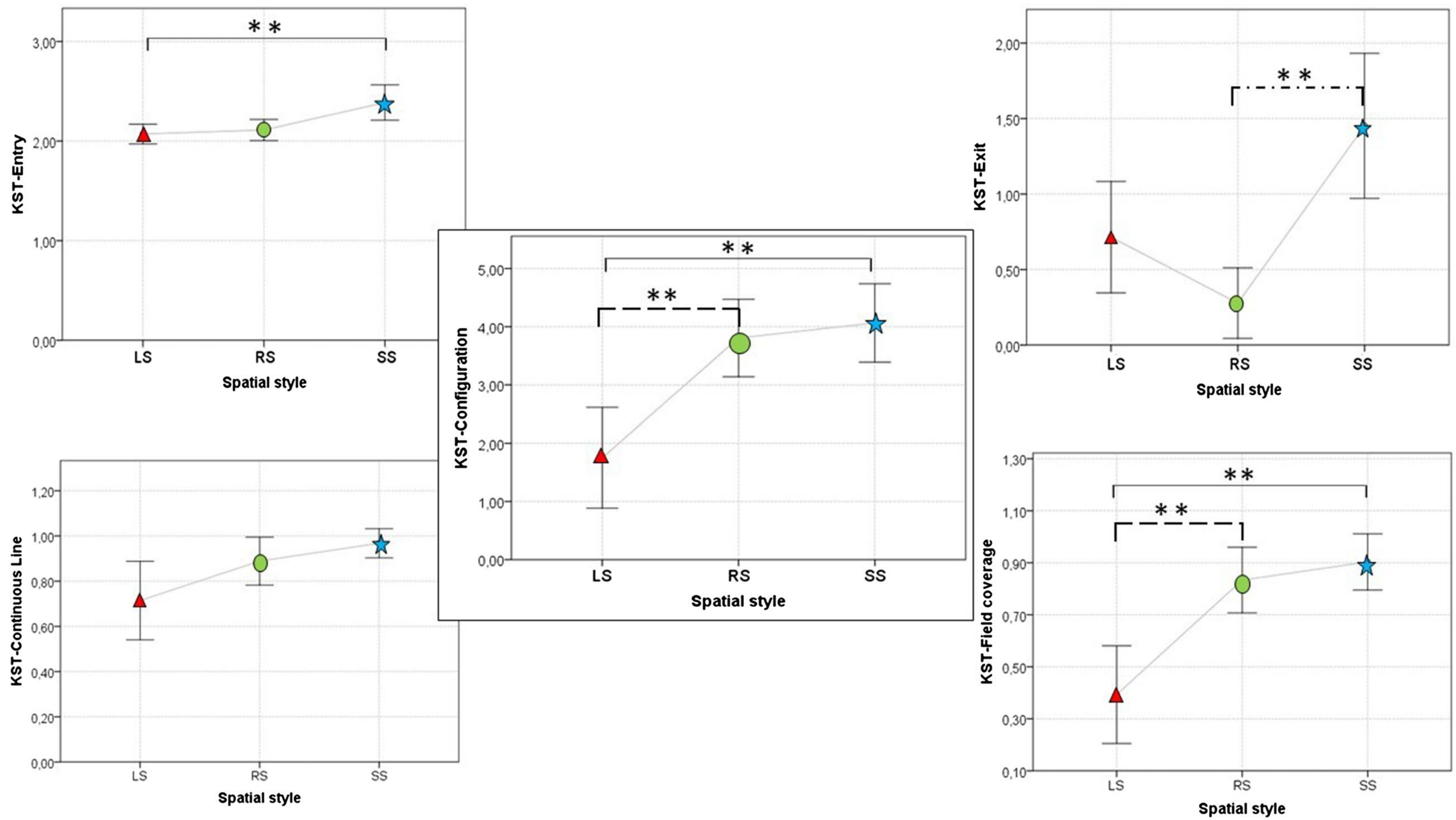

Fig. 4 Plots show the trend of the three groups (LS, RS, SS) on each KST component (EN—entry, EX—exit, CL—continuous line, FC—field coverage, CO—configuration). In each graph, Landmark group is marked with a red triangle, Route group is marked with a green circle, and Survey group is marked with a blue star. SS obtained the higher scores in each of the KST components. RS always obtained a better performance than LS except for EX—exit from the field. LS obtained the worst scores in each component. Significant differences have been marked with one ($p<0.005$) or two ($p<0.001$) asterisks

using an organized searching strategy, that is a 'configuration' to search all over the field while keeping track of the places already explored (Wilson et al. 1996). Interestingly, the poor performance of RS and LS individuals cannot be explained by temporal constraints because no time limit was given to the task and the examiner did not invite the participants to be as fast as possible, but only to be accurate. SS individuals spent their time implementing an accurate strategy, while LS individuals spent their same amount of time using a disorganized strategy.

The discriminant function analyses showed that KST subcomponents that can discriminate among spatial styles were: field coverage, configuration and continuous line. Interestingly, these components are close to each other: a configuration is not possible if the continuous line is not maintained, and a configuration is considered efficient only if the participants make a clear attempt to cover all the field. Therefore, this result confirms that configuration is the most important index of KST, which best mirrors the strategy used by participants. Moreover, the discriminant function derived from the data suggested that KST components allows to correctly classify the spatial cognitive style features in 60% of the cases, suggesting that the performance obtained by a participant in the KST can be useful to discriminate among spatial styles.

It should be pointed out that other processes are involved in navigational planning (Byrne et al. 2007; Mullally and Maguire 2014). For example, memory workload itself can affect navigational planning, leading to rely more on heuristics when planning a pathway (Wiener et al. 2009). Moreover, proficiency in different memory systems (visuo-spatial, episodic) can affect the way a navigational task is solved. People with high visuo-spatial working memory (VSWM) prefer memorizing the spatial relationship between landmarks (Nori et al. 2009). As they compare their mental spatial representation with the external environment, this process could be considered an online updating of spatial information. Indeed, when we navigate we continually have to change our perspective, updating it at a new orientation every time (e.g., a turn). Moreover, the moving reference frame itself results in an additional load on the spatial component of VSWM. Episodic memory, which allows to learn and recall first-person experiences (Tulving 1972) can also affect navigational planning. In particular, the constructive nature of episodic memory allows to imagine or simulate experiences that might occur in one's personal future (called episodic future thinking) (Schacter et al. 2017), a key process for route planning, in which past experience can be used to build new routes and to simulate possible routes. According to this link between episodic memory/route planning, several neural models linking prefrontal cortex to deeper structures have been proposed. The dynamic neural model of Byrne et al. (2007) accounted for the interaction between long- and short-term memory processes in encoding, retrieval, mental imagery and planning, explaining how egocentric and allocentric mental representations of the environment can combine to ensure a good navigational planning ability. Martinet et al. (2011) proposed a model where hippocampal formation would send representations of the spatial context to the PFC that processes such representations according to the current situation. More evidence indicates that the interaction between hippocampus and PFC plays a role in other aspects of navigation, such as coding the reward of reaching the goal (Howard et al. 2014), strategy application (Dahmani and Bohbot 2015) and solving the detour problems in navigation (Boccia et al. 2014; Spiers and Gilbert 2015).

Taken together, these findings suggest that functional and neural interactions between planning and memory are fundamental in navigational planning and that the proficiency of episodic memory can be responsible for navigational planning performance. As a consequence, future research should take into account the close relationship between episodic memory navigational planning ability and spatial cognitive style.

Considering that a different percentage of gender was present in each group, one may advance that gender differences may have affected the results of this study. However, as reported by Nori and Giusberti (2003), Nori et al. (2006) and Nori and Piccardi (2011), when cognitive style is considered, gender differences disappeared in solving spatial problems. Therefore, we are inclined to believe that the nonhomogeneous distribution of males and females within the three cognitive styles do not affect performance (see also Piccardi et al. 2016).

Although more studies are necessary, a good competence on travel planning may explain why SS individuals can easily find an alternative route and LS individuals do not. In this sense, our findings are important to better understand the individual factors that account for spatial navigation ability and the wide variability shown by humans in navigation (Wolbers and Hegarty 2010). Finally, the present study has implications for spatial navigation disorders observed in healthy elderly individuals (Iaria et al. 2009; Kirasic 1991; Wilkniss et al. 1997; Piccardi et al. 2015) and in patients with Alzheimer's Disease or Mild Cognitive Impairment (Bianchini et al. 2014; Boccia et al. 2016, 2019), as well as in individuals with Developmental Topographical Disorientation (DTD), a neurodevelopment disorder affecting the ability to develop an adequate navigational competence throughout the lifespan (Nemmi et al. 2015; Iaria et al. 2009; Bianchini et al. 2010, 2014; Palermo et al. 2014a, b; Iaria and Barton 2010; Piccardi et al. 2019b). In particular, in DTD, impairments in navigational planning can also be detected, suggesting the importance to address navigational aspects of executive functions in the rehabilitation of navigational disorders. Moreover, considering the importance of spatial navigation abilities in daily life, and the evidence that disorders such as DTD or Alzheimer's Disease are widely diffused in the population, a fast and easy neuropsychological screening of spatial abilities becomes necessary to allow an accurate and well-timed diagnosis and intervention. Considering the easiness and speed of the KST administration, the results of this study suggest that KST could potentially be a good screening tool for navigational strategies planning ability.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 declaration of Helsinki and its later amendments, or with comparable ethical standards.

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