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Learning from Maps: The Role of Visuo-spatial Working Memory

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SUMMARY

The involvement of visuo-spatial working memory (VSWM) in map learning was tested. While learning a map, participants were asked either to perform or abstain from a secondary interference task. Learning of the map was assessed by means of three different tasks (landmark positioning, pointing, route finding), each tapping a different type of spatial knowledge, namely, relative position knowledge, absolute position knowledge and route knowledge. Results showed that VSWM supports learning of absolute landmark positions but not learning of relative landmark positions. Moreover, VSWM appears to be involved in route learning. Copyright © 2007 John Wiley & Sons, Ltd.

Nowadays, travels to unfamiliar places and movements within unknown locations are getting always more frequent and acquaintance of the new environment is required to happen hastily. Since travelling is getting everyday easier and quicker, the achievement of a rapid and detailed knowledge of the surroundings is a crucial need in our life.

Spatial orientation is a crucial ability for everyday life. When people navigate through a real environment, they might learn about the spatial configuration of the environment by means of different tools. Maps are among the most used tools helpful for exploring unfamiliar surroundings. Indeed, people commonly use maps to find their way in a novel environment.

Maps support spatial learning as they present spatial information as an allocentric representation of the environment. Since maps are useful tools for navigation, research on spatial cognition and cognitive science in general have devoted increasing attention to the study of map learning processes. In fact, while on the one hand map learning research may help to understand the cognitive processes underlying the organisation and the elaboration of spatial information, on the other hand it may help to develop and enhance human navigation.

Recently, researchers directed their attention to the functions that visuo-spatial working memory (VSWM) can play in everyday cognitive tasks. According to Baddeley (1990), VSWM is important for geographical orientation and for planning spatial tasks. A similar hypothesis was also formulated by Kirasic (1991) who claimed that VSWM could be considered essential for environmental learning. A body of indirect evidence and direct studies support the hypothesis of an involvement of VSWM in environmental learning.

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Some correlational studies hint to a relationship between VSWM and environmental learning skills. Pazzaglia and Cornoldi (1999) found that participants with higher scores in the Corsi Block Test had better memory for the verbal description of a route than participants with lower scores. This result suggests a role of VSWM in learning and processing of new routes, even when the environment is presented in a verbal modality.

Similar results were found by Conte, Cornoldi, Pazzaglia, and Sanavio (1995). In that study, children with a high score in VSWM tests, as measured by the task of 'reproducing the exact position of some cells in a matrix' and the task of 'following a pathway in a matrix', were also good in a spatial orientation task, which consisted of learning to move blindfolded within a room. Results hint to a relationship between environmental learning skills and working memory. Finally, Vanetti and Allen (1988) in a pioneer study looking at the communication of environmental knowledge, found that the participants with high spatial ability were significantly better at producing effective route descriptions.

On the basis of a factorial analysis, Allen, Kirasic, Dobson, Long, and Beck, (1996) extracted two factors labelled 'spatial sequential memory' and 'topological environmental knowledge'. On the factor labelled 'spatial sequential memory' loaded a *maze learning task* and a *maze reversal task*. In these tasks, participants were asked to reproduce a previously studied pathway of a 6×6 matrix, beginning either from the starting point (maze learning task) or from the ending point (maze reversal task). Even if these two tasks are not properly VSWM span tests, they could be considered as approximately measuring VSWM.

On the factor labelled 'topological environmental knowledge' loaded several 'environmental learning tasks' (two tapping route knowledge: 'route reversal task' and 'intra-route distance judgment task' and two tapping survey knowledge: 'scene recognition and scene sequencing tasks' and 'map placement task'). The tasks were performed after navigation in a real environment, by means of a walk through a small city. Interestingly, the authors found that the 'spatial sequential memory' predicted the 'topological environmental knowledge'. Therefore, this study seems to suggest that VSWM is related to performance in environmental learning tasks.

However, it is worth noting that neither an 'Euclidean distance judgement' task nor a 'direction judgment' task was predicted by the 'spatial sequential memory' factor, showing correlations near to zero. In these tasks, participants were asked to provide Euclidean distances (Euclidean distance judgement) and direction estimates (direction judgment) from one viewpoint to a series of six unseen target locations along the walk. These two tasks did not load on the factor labelled 'topological environmental knowledge', suggesting the hypothesis of two potentially separable forms of survey knowledge: one type of survey knowledge might refer to the reciprocal interrelations between landmark positions (from now on 'relative positions knowledge') as required, for instance, by distance and direction judgment tasks. A second type of survey knowledge might refer to the position of an object with respect to a structured system of coordinates (from now on 'absolute positions knowledge', as, for instance, in the 'scene recognition and scene sequencing tasks' and 'map placement task'). Within such a distinction, 'spatial sequential memory', on the one hand, would be scarcely involved in learning *relative positions* while, on the other hand, it would support the learning of *absolute positions* and of 'route knowledge'.

In addition, a body of studies using the dual task methodology seems to suggest the involvement of VSWM in spatial navigation (Pazzaglia & Cornoldi, 1999; Smyth & Scholey, 1994; Smyth & Waller, 1998). For example, Smyth and Scholey (1994) found that memory for a sequence of observed arm movements towards a series of random block on a

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table top was disrupted by asking volunteers to perform unrelated arm movements during presentation. These results indicate an overlap between the cognitive resources required for movement memory and those required for movement execution.

Pazzaglia and Cornoldi (1999), using a selective-interference paradigm, demonstrated that spatial WM plays an essential role in processing route descriptions. Route memory performance was found to be selectively disrupted by a concurrent spatial task. Two types of matched descriptions of the same environment were made up: descriptions from a route perspective ('route descriptions') and descriptions that focused on the visual features of the same environments ('visual descriptions'). A free recall task was required at the end of each description. Two concurrent tasks, one visual and one spatial were arranged. A selective interference pattern of results emerged, with 'route descriptions' more disrupted by the concurrent spatial task than by the visual task. Visual descriptions of the same environment were equally disrupted by the two concurrent tasks. These results suggest that the spatial components of 'working memory' are particularly involved in memory for routes.

In a study by Smyth and Waller (1998), professional climbers were trained on two routes of a climbing wall, one vertical and one horizontal. After training, participants imagined climbing the routes under control or concurrent spatial tapping conditions. Spatial tapping, which is supposed to affect VSWM, impaired performance on 'mental climbing' for both routes. Indeed, to mentally complete the routes, participants under tapping conditions took more time than participants under control condition. This result suggests that VSWM supports planning and execution of a route.

All the above-mentioned indirect evidences seem to suggest the existence of a link between VSWM and the learning and/or the representation of an environment.

More direct evidence supporting the hypothesis of an involvement of VSWM in environmental learning stems from map learning studies. To date, only three studies addressed this issue: two studies used a correlational technique and the third one employed a dual task methodology.

In the first correlational study by Bosco, Longoni, and Vecchi (2004), participants were required to study the map of a real environment and to perform a battery of tasks requiring knowledge of the studied map (map-knowledge tasks). The authors found that VSWM predicted performance in some map-knowledge tasks (landmark recognition task, landmark's surrounding recognition task, map completion task and route recognition task). In this study, four VSWM span tests and a battery of eight map-knowledge tasks were arranged according to Siegel and White's (1975) model of different types of spatial knowledge. Therefore, there were two landmark knowledge tasks (the 'landmark recognition' and the 'landmark surrounding recognition' tasks), three *route knowledge tasks* (the 'route recognition', the 'wayfinding' and the 'route distance judgement' tasks), and three *survey knowledge tasks* ('map completion task', the 'map section rotation' and the 'Euclidean distance judgement').

Four VSWM span tasks were arranged: the 'jigsaw puzzle task' (Richardson & Vecchi, 2002), the 'mental pathway task' (Vecchi & Cornoldi, 1999), the 'visual pattern test' (Della Sala, Gray, Baddeley, & Wilson, 1997), and the 'Corsi span test' (Milner, 1971).

Multiple regression analyses showed that the VSWM span significantly predicted overall map learning. In particular, considering each map-knowledge task separately, it is worth noting that the tasks which were not predicted by VSWM (Euclidean distance judgement and route distance judgement, and map section rotation) were tasks requiring the knowledge of the reciprocal landmarks locations (relative positions knowledge). These

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results mimic Allen et al.'s(1996) results in which learning of the *relative positions* was unrelated to VSWM.

In a second correlational study, Coluccia and Martello (2004) studied the relation between VSWM and map learning extending previous results by Bosco et al. (2004) to different types of maps. Indeed, two structurally different maps were compared on the same map-knowledge tasks and on the same VSWM span tasks used by Bosco et al. (2004). In Experiment 1, participants studied a map with an irregular and complex structure, while in Experiment 2 the same participants studied a map with a regular and ordered structure. VSWM was found to predict orientation abilities for both maps. In accordance with Bosco et al.'s (2004) study, VSWM predicted the overall map learning performance and, more specifically, the two *landmark knowledge tasks*, the *map completion task* and the *route recognition task*. Again, the *Euclidean distance judgement* and the *map section rotation* (*relative positions knowledge*) were unrelated to the VSWM span.

Using a dual task methodology, Garden, Cornoldi, and Logie (2002) investigated the role of VSWM in a specific aspect of spatial knowledge, namely, 'route learning'. The authors found that spatial tapping disrupted route recognition more than articulatory suppression. In the first experiment, participants learned either route segments from a map (map learning task) or non-sense words (verbal learning task). The learning phase could include either a concurrent 9 keys spatial tapping task or a concurrent 10 syllables articulatory suppression task or a control condition (without concurrent tasks). From the map learning task emerged that both concurrent tasks impaired control performance. However, spatial tapping impaired route recognition performance more than articulatory suppression did. On the contrary, from the verbal learning task emerged that non-sense word recognition performance was impaired more by articulatory suppression than by spatial tapping. The effects of articulatory suppression on non-sense word learning confirm previous evidence showing that the articulatory loop is particularly critical when learning new words (Papagno, Valentine, & Baddeley, 1991). Such a pattern of results indicates that VSWM is involved in route learning.

To sum up, the above studies seem to point towards a specific involvement of VSWM in learning new environments. Nevertheless, such a relationship, which is much more evident in map learning, seems to depend on the type of spatial knowledge. So far, only the studies that employed correlational techniques covered multiple aspects of map learning (Bosco et al., 2004; Coluccia & Martello, 2004). Conversely, the only study which directly addressed this issue using a dual task technique (Garden et al., 2002) did not consider all the different aspects of map learning, being restricted to the study of route knowledge. Therefore, the main aim of the present work is to provide a study which, on the one hand, might extend the results of Garden et al. (2002) to other types of environmental knowledge and, on the other hand, might lend support to previous correlational results, by using a dual task paradigm, the assumption being that these kinds of studies would greatly benefit from additional experimental evidence.

The general hypothesis was that the spatial interference task would impair map learning performance more than the verbal interference task. More specific predictions about the involvement of spatial WM for each type of spatial knowledge can be grouped in two classes. On the one hand, from the results of Allen et al. (1996), Bosco et al., 2004 and Coluccia and Martello, 2004, it might be argued that the spatial WM would not necessarily be involved in 'relative positions knowledge' (as required for example in a pointing task), while it is reasonable to expect an involvement of WM in 'absolute positions knowledge' (as required in a landmark positioning task) and in route knowledge (as shown by Garden

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et al., 2002). On the other hand, the learning of both *absolute* and *relative positions* might rely on the same spatial representation (e.g. a survey perspective) and they might be equally disrupted by a concurrent spatial tapping task.

EXPERIMENT 1

In Experiment 1, two different concurrent tasks were executed while learning a map. The first concurrent task (spatial tapping), which is supposed to selectively engage the spatial component of VSWM, was expected to affect map learning. The second concurrent task (articulatory suppression), which is supposed to selectively engage verbal WM, was expected not to affect map learning.

Method

Materials

The map. The 'Palatin map' (Bosco et al., 2004) was utilised (see Figure 1). This map was already successfully used to demonstrate the existence of a correlation between VSWM and map tasks (Coluccia & Martello, 2004). It depicts 16 landmarks and 12 main routes.

What follows is a literal translation (as same as next quoted instructions) of the instructions for map learning from Italian into English: 'You are going to perform an experiment about map learning. I will give you a map. You have to study it carefully within 5 minutes, well enough to draw it. The map is a town plan showing the roads and 16 landmarks. Pay attention to the landmarks, their position on the map and to all the roads connecting them. After learning the map for 5 minutes, the map will be taken away and you will be asked to perform some tasks that require knowledge of the map you have learned. Please ask the experimenter if you have any questions'.

Map learning measures. Three tasks tapping different types of spatial knowledge were chosen from previous studies.

Landmark positioning task: This task has been typically employed by previous research (Bosco et al., 2004; Coluccia & Martello, 2004; Holding & Holding, 1989) as a good measure of survey knowledge. However, according to the strict definition given by Siegel (1981), it can also be considered a landmark knowledge task. Indeed, Siegel (1981) argues that landmark knowledge is the ability to identify salient points of reference. Only the mere position of such reference points is known, but the relative positions between landmarks and the interconnections between landmarks are not (Siegel, 1981). The terms of this debate will not be discussed here and this task will be considered as measuring 'landmark knowledge' in terms of 'knowledge of absolute positions', namely the position of an object with respect to a structured system of coordinates.

Participants were requested to re-position all the 16 landmarks on a blank map. Two paper-sheets were given to each participant. On the first one, the original map without landmarks was shown, while on the second one, names of all the landmarks were listed. Participants were asked to mark the exact position of each landmark on the map with a cross. Error was calculated as the difference between the real position of the landmark and the position marked by the participant. As the landmarks were not points in space but objects extended in space, participants were told to centre the X at the centre of the

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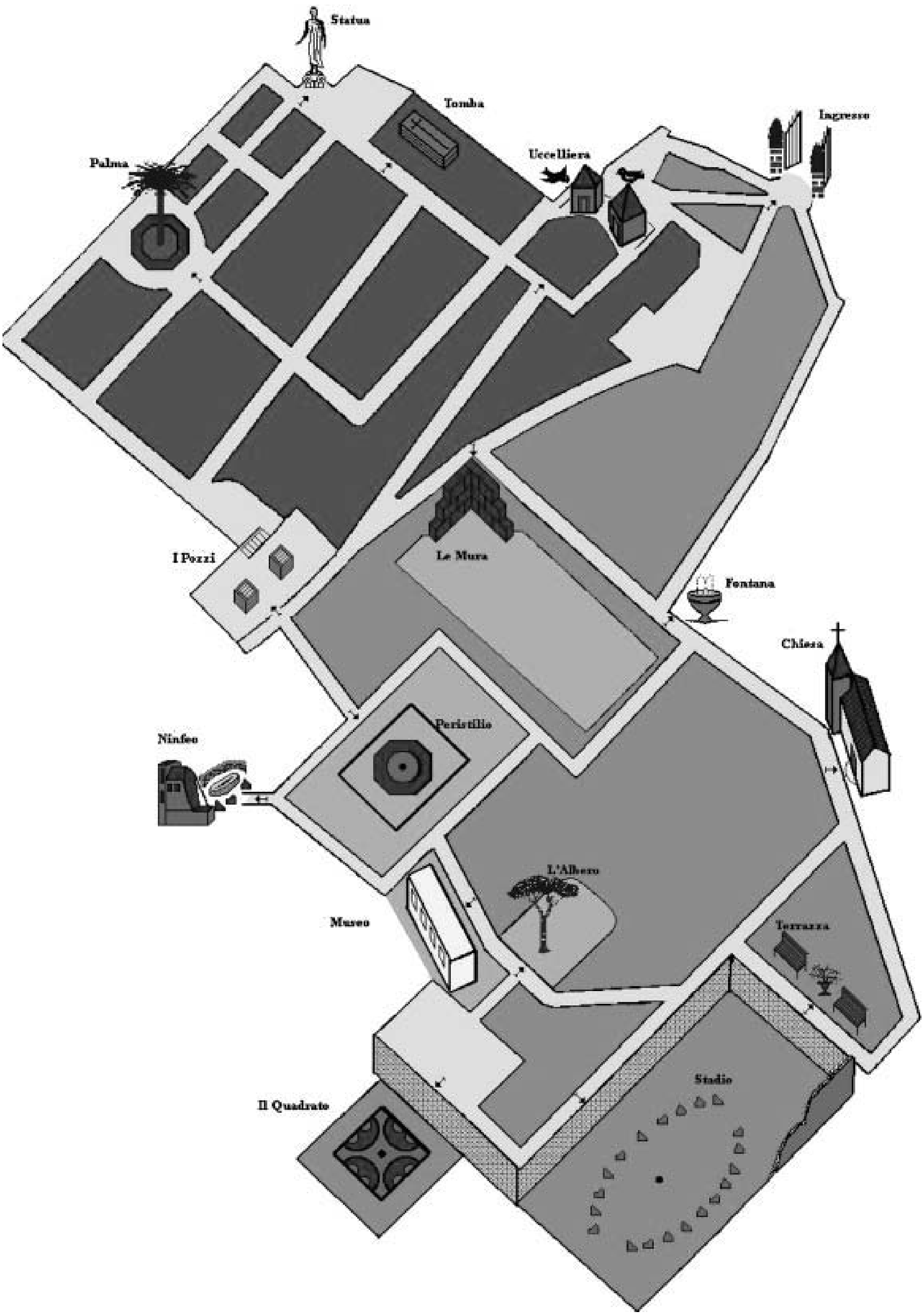

Figure 1. The 'Palatine map' used in Experiment 1

landmark's location. Final score was given by the mean error in millimetres of all the landmarks.

Instructions for landmark positioning task (from Italian into English): 'Now I will show you the same map from which all landmarks have been removed. Please, indicate the

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correct location of each landmark, by drawing a cross in the exact position corresponding to the centre of the landmark. Beside each cross, put the corresponding name of the landmark. Try to be as accurate and quick as you can'.

Pointing task: This task too has been typically employed by previous research (Holding & Holding, 1989; Kirasic, Allen, & Siegel, 1984; Lawton, 1996; Lawton, Charleston & Zieles, 1996; Lawton & Morrin, 1999; Montello & Pick, 1993; Sadalla & Montello, 1989; Waller, Knapp & Hunt, 2001) as a good measure of survey knowledge. Specifically, this task is supposed to measure an aspect of survey knowledge, that is, the 'knowledge of the relative positions', namely the reciprocal positions between objects or the position of an object with respect to another. Participants were instructed to indicate the direction of a target landmark, starting from another landmark and using judgments in terms of angular degrees. In other words, participants had to trace an arrow from the centre to the diameter going towards the direction where the landmark to be pointed out was supposed to be. Participants were given instructions to imagine themselves at a starting landmark, facing the north of the map (the map was conventionally aligned to the North).

This task was composed of eight items. Each item consisted of a landmark positioned at the centre of a circumference. An arrow on the topside of the circumference starting from the centre of the circle pointed to the upside of the sheet (which is conventionally the North and indicates 0°). Each item was also accompanied by a written line which stated what landmarks to point to. Therefore, each item required connecting the starting landmark with the target landmark.

Angular judgments were asked for each different direction in order to tap all the four quadrants of the circle, as shown in Figure 2 (North-east direction: quadrant I = from 0° to 90°; South-east direction: quadrant II = 90°–180°; South-west direction: quadrant III = 180°–270°; North-west direction: quadrant IV = 270°–360°).

Error was calculated as the difference between the angular direction and the direction pointed to by the participant. The final score was given by the mean error in degree of all the items.

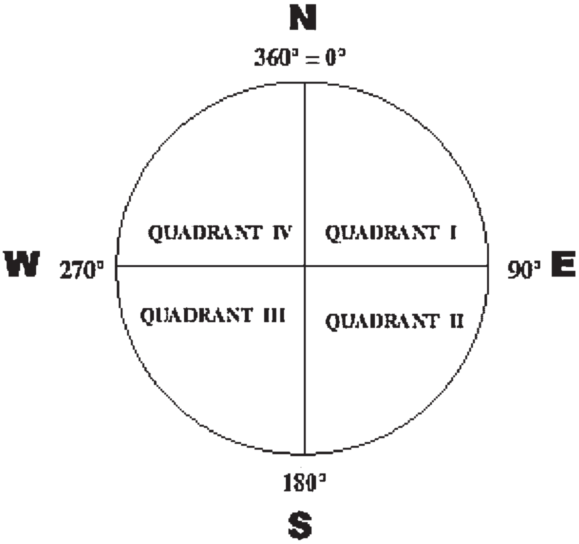

Figure 2. The structure used for arranging the pointing task's items

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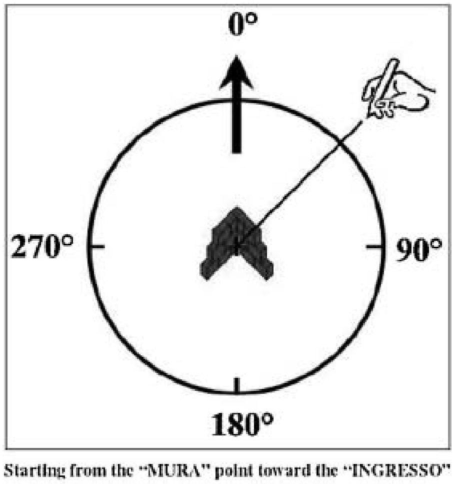

Figure 3. A trial item for the pointing task

Instructions for pointing task (from Italian into English): 'Now you will be shown a circle with a landmark in the middle. Imagine yourself in the position of the landmark in the centre of the circle facing towards the North of the map (angular degree: 0°). From this position point directly towards another target landmark, by tracing a line which starts from the centre of the circle and crosses its circumference in the direction of the target landmark. Try to be as accurate and quick as possible. Please have a look at the following example: (Figure 3 was given as an example).

Example: Imagine yourself in the position of MURA facing to 0°. Now point towards INGRESSO. Trace a line which starts from MURA and goes to the direction of INGRESSO crossing the circumference. Please, when tracing the line pay attention to its angular direction'.

Route finding task: This task was used to measure route knowledge (Dabbs, Chang, & Strong, 1998; Miller & Santoni, 1986; Schmitz, 1997; Ward, Newcombe, & Overton, 1986). Participants were requested to mentally follow a route description and to indicate the arrival point, selecting the right answer from three alternatives. This was an 8-item task. Each item consisted of a description of a route, which started from a landmark and stopped next to another landmark (arrival point). The starting point of each landmark was indicated by a black arrow on the map. The arrival point was not explicitly told to the participants. After reading the description, participants were asked to select the arrival point of the route, choosing between three alternatives. The final score was given by the percentage of right answers. Figure 4 shows an example of a route finding item.

IMAGINE YOU ARE FACING THE PALM, AT THE POSITION OF THE ARROW. GO RIGHT. WALK STRAIGHT-ON TO THE END OF THE ROAD AND THEN TURN LEFT. ON YOUR RIGHT YOU WILL FIND…

MUSEO – STATUA - TOMBA

Figure 4. An item from the route finding task

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Instructions for route finding task (from Italian into English): 'You will be asked to imagine yourself facing towards a starting landmark, at the location of the arrow. You will then read instructions to move away from the starting point along a specified route. To follow a route, move within the direction specified along the roads of the map. The instructions will tell you what direction to take at each road junction (turn left, turn right, turn north, turn west, go straight). You will finish at a point that is close to another landmark, which lies in the direction indicated from your final position. Indicate which of the three landmarks is the closest to you. Try to be as accurate and quick as possible'.

Concurrent tasks. The same interference tasks used by Garden et al. (2002) were used.

Spatial tapping: The participants were instructed to continuously tap the nine raised keys of a 3×3 wooden pad, at the rate of one tap per second, following a specified pattern which included forward movements from the top-left square to the bottom right square, followed by the same sequence of movements in reverse (boustrophedon sequence). Numbers in Figure 5 indicate the order of the sequence of keys to tap. The board was hidden from the participant's view.

Articulatory suppression: Participants were asked to say aloud the sequence of non-sense syllables: BA-BE-BI-BO-BU-DA-DE-DI-DO-DU at the rate of one syllable per second. The experimenter monitored the secondary task performance. Verbal feedback was given to modulate the one-per-second rhythm. If the participants made a mistake (wrong sequence of tap or syllable) the experimenter warned them to start over.

Before each learning phase, participants had 2 minutes for practicing each secondary task. During the practice, only the secondary task was executed without the primary task. Both interference tasks were executed only during the learning phase and never during the delay or during the test phase.

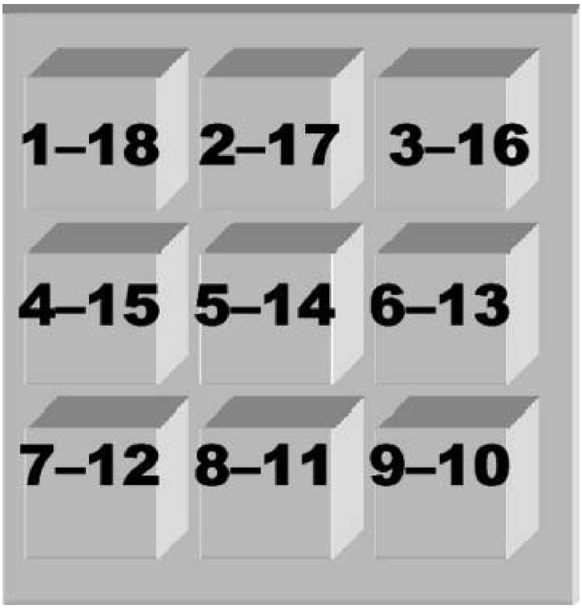

Figure 5. The spatial tapping task board (numbers indicates how to tap the sequence)

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Participants and procedure

Ninety-six volunteers (48 males and 48 females), aged from 19 to 30, took part in Experiment 1. Thirty-two participants (control group) performed the map learning (5 minutes) without interference. A second group of 32 participants (Group 2) performed the map learning task under a spatial tapping condition. A third group of 32 participants (Group 3) performed the map learning task under articulatory suppression. Concurrent tasks were executed only during the learning phases. Each learning phase lasted 5 minutes. After the learning phase, there was a delay interval of 90 seconds. During delay, the map was hidden and participants were asked to perform some arithmetic tasks in order to avoid any possible rehearsal. Such a delay was useful to avoid any recency effect on the subsequent map learning tasks.

After delay, participants performed the three map learning tasks (landmark positioning, pointing and route finding). Gender and order of presentation of map tasks were counterbalanced. Participants had not previous specialised experience of maps or geography.

Results

Means and standard deviations are reported in Table 1. A one-way ANOVA with landmark positioning as a dependent variable and type of interference task as a three-level factor (control, spatial tapping, articulatory suppression) was performed. As a significant effect of 'type of interference' emerged ($F(2,93) = 3.41$, $p < .05$), *post hoc* analyses were run. A Dunnett test showed a significant difference between the control and tapping conditions ($p < .05$), but no differences between control and articulatory suppression.

A second one-way ANOVA with mean errors in angular degrees (pointing) as a dependent variable and type of interference task as a three-level factor (control, spatial tapping, articulatory suppression) was performed. No significant effects emerged ($F(2,93) = 1.03$). As expected, *post hoc* analyses (Dunnett test) did not show any significant difference.

A third one-way ANOVA with route finding as a dependent variable and type of interference task as a three-level factor (control, spatial tapping, articulatory suppression) was run. A significant effect emerged ($F(2,93) = 3.72$; $p < .05$) and *post hoc* analyses (Dunnett test) were run. A significant difference was found between control and tapping conditions ($p < 0.05$), but no differences between control and articulatory suppression emerged.

The pattern of correlations among the three dependent measures is rather complex. On the one hand, pointing and landmark positioning performances are highly correlated ($r = 0.69$ with $p < .001$). On the other hand, landmark positioning but not pointing

Table 1. Control, spatial tapping and articulatory suppression performance on map learning (landmark positioning, pointing, route finding)

		LP(err)		PO (err)		RF(%)	
	N	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	32	10.98	12.26	25.41	9.94	46.88	17.96
Tapping	32	19.68	16.78	30.07	18.20	35.16	16.63
Art. suppr.	32	18.11	13.14	26.66	10.62	39.06	17.89

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performance, correlates with route finding performance ($r = -0.29$; $p < .01$). This suggests that even if the two survey tasks are strongly related, they do not relate with the route task in the same way. Therefore, it is reasonable to hypothesise that pointing and landmark positioning share a common process in the sense that they rely on the same spatial representation but, at the same time, the two tasks once again show opposite results.

One might argue that the results in the pointing task are due to such procedural limits as order effects of task execution. However, the order of presentation of the tasks was counterbalanced and specific analyses showed no position effects.

Discussion

The spatial tapping task significantly interfered with some aspects of map learning. In particular, learning of the 'absolute positions' and route knowledge were impaired by the concurrent tapping task. Conversely, there was not a significant effect of articulatory suppression on map learning. However, one might argue that articulatory suppression might have somewhat affected map learning. Indeed, the means in the spatial tapping and articulatory conditions are not very far to one another in value. This could be due to the fact that, when learning a map, to some extent, verbal strategies might be also employed either to learn the name of the landmarks or to apply the label to some portion of the map (to label the configuration). For example, a portion of route might be codified as a 'L' letter or the shape of a route or a block may resemble to a common object and therefore it can receive great benefit from labelling. However, what is interesting in the present study is the result showing how spatial tapping impairs map learning performance. For this reason, it is now important to verify whether the execution of the tapping task selectively affects map learning or indiscriminately affects any type of learning (i.e. a verbal learning task). Indeed, one might argue that the spatial tapping task used here (with a high number of keys and a complex boustrophedon sequence) was just a general demanding task, which loaded on the central executive. Although this can be ruled out since the pointing task was not affected by tapping, a primary verbal learning task can be used as a further control.

EXPERIMENT 2

In order to test whether the tapping task is a general demanding task or not, Experiment 2 was conducted. In this experiment, a primary verbal task was executed while performing the same tapping task as in Experiment 1. If the tapping task does not affect the verbal task, then it can be considered a selective interference task. If the tapping task does affect the primary verbal task, then it can be considered a general demanding task and the interference found in Experiment 1 are not due to a selective interference.

Method

Materials

Primary verbal task (paired-associated words learning). The 'paired-associated words learning' task (Duyck, Szmalec, Kemps, & Vandierendonck, 2003), consisted in learning the association between the 1st and the 2nd word of each pair. Words were sequentially and auditorially presented through the headphones. Participants answered orally. Only words with low imageability were used.

In the verbal learning condition, three lists (List A, List B and List C), each of 16 pairs of unrelated words, were played from a tape *at the rate of* one pair every 6 seconds. The level of imageability for each word was stated on the basis of the 'psycholinguistic norms for 626 Italian nouns' (Barca, Burani, & Arduino, 2002). Word pairs were neither semantically nor phonologically associated.

Verbal learning measure (cued recall of paired-associated words). During recall, only the 1st word of each pair was presented (at the rate of one every 6 second) and the participants were requested to recall the 2nd word of each pair. There were 16 pairs of words for a total of 16 items. The score was given by the percentage of correctly recalled words.

Concurrent tasks. Concurrent tasks were the same as Experiment 1.

Articulatory suppression: Participants were requested to continuously say aloud the sequence of syllables BA-BE-BI-BO-BU-DA-DE-DI-DO-DU, at the rate of one syllable per second.

Spatial tapping: Participants were requested to continuously tap the nine raised keys of a 3×3 pad, one per second, following a direction from the top left to the bottom right and then from the bottom right to the top left.

Participants had 2 minutes for practicing the secondary tasks. During the practice, only the secondary task was executed without any other task.

Participants and procedure

None of the participants who took part in Experiment 1 had taken part in Experiment 2. Thirty-six volunteers, aged from 19 to 27, studied three lists of 16 word-pairs (List A, List B, List C), in a control condition, while performing the spatial tapping task, or while performing the articulatory suppression task. All the participants were asked to study the three lists of words and to perform a different interference task for each list (control, tapping, articulatory suppression). During the study phase, a tape played the words at the rate of one pair every 6 seconds. Each list was repeated three times, any time with a different order. Therefore, each list was studied for 4 minutes 48 seconds, which is more or less the same time as map learning. Then, there was a delay interval of 90 seconds in which participants were asked to perform some arithmetic tasks. After that, they performed the cued recall task. Gender, order of presentation of lists and interference conditions were counterbalanced.

The concurrent tasks were executed only during the word learning phase, but neither during delay nor during recall.

Results

Means and standard deviations are reported in Table 2. A within-subjects ANOVA with number of correctly recalled words as a dependent variable and type of interference task as a three-level factor (control, spatial tapping, articulatory suppression) was performed. As a significant effect emerged ($F_{(2,70)} = 38.56$; $p < .0001$), *post hoc* analyses (Dunnett test) were run. A significant difference was found between control and articulatory suppression conditions ($p < .001$), but not between control and tapping conditions.

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Table 2. Control, spatial tapping, and articulatory suppression performance on paired associated words learning.

		Words (%)	
	N	*M*	*SD*
Control	36	65.45	24.07
Tapping	36	58.33	24.04
Art. suppr.	36	34.03	26.20

Performance on the primary verbal task was impaired by articulatory suppression, but it was unaffected by the tapping task. This result demonstrates that the tapping task is not a general demanding task which loads on the central executive. Therefore, the spatial tapping task is a selective task.

As the spatial tapping task was demonstrated to be a selective task, the tapping effect, found in Experiment 1 on map learning, was not due to the complexity itself of the secondary task, but to the selective spatial interference in working memory.

Results of Experiment 2 showed no effect of the spatial tapping task on the paired, associated word learning. This result can be interpreted as indicating that the spatial tapping task is a selective task. According to Baddeley's model, the concurrent spatial tapping task is supposed not to impair performance on the primary verbal task.

Overall, results from this experiment hint to the conclusion that the effect of the spatial tapping which was found in Experiment 1 is not due to a general loading on attentional resources.

GENERAL DISCUSSION

To sum up, both learning of landmark locations and learning the routes are impaired by spatial tapping task but not by articulatory suppression. This means that learning the routes and the *absolute positions* of the landmarks requires the visuo-spatial but not the verbal working memory.

Concerning the verbal control task, an opposite pattern of results emerges. Indeed, articulatory suppression impairs word learning performance, while spatial tapping does not. Such a pattern of results fit with the predictions from Baddeley's (1990) model (two distinct working memory sub-systems elaborate verbal and visuo-spatial information).

The present study was also aimed at testing specific effects of VSWM in different types of map-knowledge. Results on absolute position (landmark positioning) and route knowledge are quite clear, while results on relative positions (pointing) are hard to interpret. On the one hand, the high correlation between the pointing task and landmark positioning task seems to suggest that these two tasks rely on the same representation (e.g. survey). On the other hand, the two tasks differently relate to the route task: pointing does not correlate to route finding, while landmark positioning does. In addition, both route finding and landmark positioning are affected by spatial tapping. Conversely, learning the *relative positions* of landmarks (pointing task) seems unaffected by spatial tapping. This

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could suggest that VSWM is not particularly involved in the learning of reciprocal landmark positions.

It seems that VSWM plays a role only for the learning of the 'absolute positions', that is the positions of landmark with reference to a structured system of coordinates. Such a pre-existing structured system, in which landmarks are located, is represented by the empty map, which is given in the *landmark positioning task*. Therefore, if the strict definition of landmark knowledge is accepted (only the mere position of landmarks is known, but the relative positions between landmarks and the interconnections between landmarks are not. Siegel, 1981), it might be concluded that VSWM is fundamental for landmark knowledge, whereas it would not be particularly relevant for survey knowledge. Alternatively, if also the *landmark positioning task* is considered as a survey task, just like the *pointing task*, then it can be argued that *survey knowledge* is not a unitary knowledge and it can be divided into 'survey knowledge for absolute positions' and 'survey knowledge for relative positions'. Hence, it is possible to conjecture that VSWM is engaged only in learning the 'absolute positions' component of survey knowledge, while it is not involved in learning the 'relative positions' component. These results seem consistent with Allen et al. (1996), Bosco et al. (2004) and with Coluccia and Martello (2004). Indeed, all these studies found that the *Euclidean distance judgment* was unrelated to VSWM. Moreover, both the *direction judgment* (Allen et al., 1996) and the *map section rotation* 0(Bosco et al., 2004; Coluccia & Martello, 2004) were found to be unrelated to VSWM as well. Again, in accordance with the present study, the learning of the position of a landmark with respect to a structured system of coordinates (absolute positions) was found to be related to VSWM. In fact, performances in the *landmark surrounding recognition*, the *map completion task* (Bosco et al., 2004; Coluccia & Martello, 2004) and the *map placement task* (Allen et al., 1996) were predicted by VSWM. Similarly, it was found that performance in the *landmark positioning task* is impaired by visuo-spatial interference. Hence, it seems reasonable to conclude that, in the realm of map learning, VSWM is involved in the learning of the absolute position of a landmark.

However, it is not clear why VSWM should be differentially involved in these two types of spatial knowledge. Indeed, while the relationship between *absolute positions* and VSWM is not surprising, the lack of a correlation between the *relative positions* and VSWM is hard to understand. Indeed, assuming that relative and absolute positions call for different types of knowledge is hard because these two measures highly correlate with one another. To my knowledge, previous studies (Allen et al., 1996; Bosco et al., 2004) did not directly address this issue.

However, at the present status of knowledge, only mere speculations can be made. Further research is therefore needed to understand why VSWM would not be involved in learning the *relative positions between landmarks*. Plausibly, investigating the components of VSWM could help understand this lack of relationship. For instance, it might be that the spatial and the visual components of WM are differentially implied in learning the *relative positions* and the *absolute positions*. However, further experiments are required to directly investigate this hypothesis. To start with, the present research has raised the questions and provided initial answers.

Concerning the relationship between route knowledge and VSWM, results from Garden et al. (2002) were confirmed and extended. By using a tapping task, Garden et al. (2002) found that VSWM was involved in route knowledge. As their participants executed the concurrent task both in the learning and in the recall phases, it was not clear whether VSWM is involved in the learning of routes, in the mental execution of a route, or both. As in the present study, interference occurred only during the learning phase, it can be argued that tapping task affects route learning. However, the present result does not exclude that VSWM is also involved in route execution. The new finding in comparison to Garden et al. (2002) consists in the fact that, when learning from a map, VSWM is clearly demonstrated to be involved in route learning. This was left ambiguous in previous results.

CONCLUDING REMARKS

The present work sheds some new light on the complex cognitive components underlying spatial learning processes, as limited to map learning. Additionally, it extended previous results about the role of VSWM in map learning (Garden et al., 2002) and confirmed previous correlational studies (Bosco et al., 2004; Coluccia & Martello, 2004) by using a different technique of investigation.

The novelty of the current study as compared to other studies consists in the fact that, for the first time, VSWM is explicitly demonstrated to have a role during the learning of a map. As already mentioned, Garden et al.'s (2002) study did not allow full understanding of whether VSWM was involved in learning the map or in executing the task. Such an ambiguity represents the limit of the correlational studies by Bosco et al. (2004) and Coluccia & Martello (2004) as well. Indeed, the fact that VSWM span correlates with map tasks performance does not let us know whether VSWM is essential during the learning phase or during the execution of the tasks. Given that, in the present study, the spatial interference task was performed only during the map learning phase, it can be concluded that VSWM is essential for learning a map. However, this new finding does not exclude the possibility that VSWM is also important during the execution of map tasks. Further research might directly address this issue. What seems important here is to emphasise the distinction between learning processes and execution processes. Such a distinction was not considered in previous studies.

Further studies are also needed to explore exhaustively the function of VSWM in spatial learning. For instance, research might separately investigate the role of the visual and the spatial components of working memory in map learning. Moreover, the differential role of spatial and sequential components of working memory could also be investigated in mental navigation processes.

However, it is worth noting that the present results are confined to map learning processes and to the learning of one single map. To extend the present study, current ongoing research is focusing on testing different maps. However, it would also be interesting if further research explored environmental learning in the real world or by means of computer-simulations. Indeed, one of the most interesting challenges of map learning studies is to identify the theoretical basis to understand the complex processes of human navigation.

Nevertheless, the study of map learning itself should not be disregarded. Maps are useful instruments for navigation. Trying to understand the mechanisms underlying the map learning process and, more in general, the elaboration and organisation of spatial information can help both the enhancement of instruments for orientation and the comprehension of human cognition.

The present work also sheds light on the cognitive processes implied in map learning and, more in general, in spatial orientation. Spatial orientation is a crucial activity for everyday life. Maps are useful tools, often used for getting oriented in new and unfamiliar places. Studying the processes of map learning may allow a better understanding of how to improve our learning abilities during acquisition of new environments. In addition, it may promote the development of several applications devoted to the enhancement of our spatial orientation abilities within unfamiliar locations.

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