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"The Role of Visuo-Spatial Working Memory in map learning"

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Index

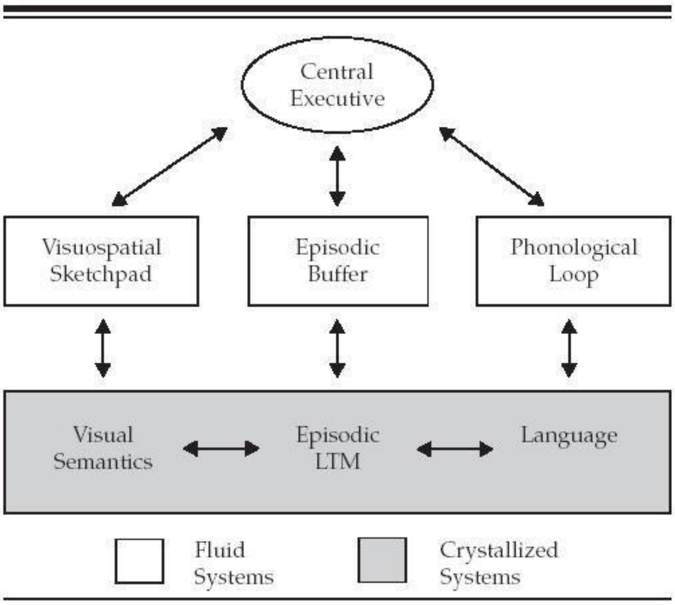
1. PREMISE

The general aim of the present work was to study the relationship between Working Memory and map learning processes, using a dual task paradigm. Theoretical models by Baddeley (2001) and by Thorndyke and Hayes-Roth (1982) were used as frameworks for studying respectively Working Memory and Spatial Knowledge. In the introduction, the two models are discussed (chapter 2 and 3 for Working Memory; chapter 4,5,6,7 for the spatial knowledge). Then, possible links between the two issues are highlighted (chapter 8). In the last part of the introduction (chapter 9), the methodology of the dual task procedure is discussed. While learning a map, experimental participants were asked either to perform a secondary task or not to perform any task (control condition). After the map learning phase, participants were asked to solve three "map-knowledge" tasks, each tapping a different aspects of Spatial Knowledge: Landmark Positioning, Pointing, Route-Finding. Following the dual task approach, four experiments (chapters. 11,12,13,14) were run. Map learning was contrasted with a verbal learning task and two different types of visuospatial interference secondary tasks (4-keys and 9-keys Spatial Tapping) were contrasted with a verbal interference secondary task (Articulatory Suppression). Overall results showed how some aspects of Visuospatial Working Memory are involved in map learning processes, depending on which aspect of Spatial Knowledge is considered and depending on the nature of the secondary tasks.

2. THE REVIEWED MODEL OF BADDELEY'S WORKING MEMORY

According to Baddeley (1986), Working Memory (WM) is a system for the temporary storage and the processing of information, during the execution of cognitive tests. Pioneering studies by Baddeley and Hitch (1974) suggested that working memory differed from Long-Term memory in terms of the amount of retained information and in terms of processes of coding and retrieval of information. The authors developed the hypothesis that a central system coordinates different sub-systems, each one specialized in maintaining and processing different types of information. Specifically, a bulk of experimental results led to the theorization of a tripartite model (fig.1), in which the central system (*Central Executive*) coordinates two slave-systems: the *Phonological Loop* and the *Visuo-Spatial Sketch Pad.* The first system is assumed to be specialized in temporary storage and processing of verbal information, the second one is supposed to maintain and manipulate both visual and spatial information. In the last 20 years, several experimental results confirmed this model. Recently, it has been reviewed (Baddeley, 2002) and a further sub-system called Episodic Buffer was added. A detailed description for each system of the model follows.

Fig. 1. The current model of working memory, revised to incorporate links with LTM by way of both subsystems and the newly proposed Episodic Buffer (Baddeley 2002)



2.1 The Central Executive

The core component of the WM system is the Central Executive. It has the function of coordinating and supervising the slave-systems. Its role consists in selecting strategies and integrating information of different types and sources. Its attentional functions have been emphasised in the last decade. In fact, many similarities exists between the Central Executive and the Supervisory Attentional Subsystem (SAS) of Norman and Shallice (1980), as both the systems are involved in the intentional decisions and in the monitoring of actions. In particular, the SAS is necessary when a new problem occurs. It is a limited-capacity attentional system which is able to combine information from LTM with existing stimuli, in order to plan a novel solution and to ensure that the plan is accomplished. According to the current interpretation (Baddeley, 2002), the Central Executive includes the capacity of focusing, dividing and switching attention.

Focusing attention. Robbins, Anderson, Barker, Bradley, Fearneyhough, Henson, Hudson and Baddeley (1996) examined the effects of tasks that were intended to disrupt activity either of the phonological loop, or of the visuospatial sketchpad, or of the central executive on chess, an activity that seems likely to place heavy demands on the central executive. The performance of novices and experts was compared. *Articulatory Suppression* had no impact on performance, suggesting no role for verbal working memory. Participants were, however, disrupted by a concurrent visuospatial task and even more by the task of generating random digits, which is assumed to place a great demand on the central executive (Baddeley, Emslie, Kolodny, and Duncan, 1998). Performance of both experts and novices differed in overall level but showed the same pattern of sensitivity to visuospatial and central executive disruption, both for remembering a chess position and for choosing the best next move. However, it is unusual to find this pattern of results in all complex tasks. Retrieval from LTM, for example, does not appear to depend heavily on the executive. In a series of experiments, Baddeley, Lewis, Eldridge, and Thomson (1984) imposed a demanding secondary task during the process of learning and/or retrieving lists of words. Although concurrent load had a clear effect on learning, it had little influence on recall accuracy. Craik, Govoni, Naveh-Benjamin, and Anderson (1996) have subsequently replicated this result and have revealed the further interesting feature that, despite being itself unaffected, retrieval does disrupt performance in the secondary task, although the degree of impairment is not sensitive to the level of secondary task demand. In conclusion, the capacity to focus available attentional capacity is clearly an important feature of the Central Executive. It is, however, important to acknowledge that not all tasks, or at least all complex tasks, are heavily dependent on this capacity.

Dividing attention. The second attentional process relying on the Central Executive is dividing attention (Baddeley, 1996). Research in this area has focused on patients with Alzheimer's disease, who, in addition to their marked impairment in episodic LTM, showed attentional deficits (Perry & Hodges, 1999). According to Baddeley, Bressi, Della Sala, Logie and Spinnler (1991), patients with Alzheimer's disease may have central executive impairment. In their study, patients were required to combine tasks which relied mainly on the phonological loop (digit span) and on the visuospatial sketchpad (pursuit tracking). In each case, the level of performance on the individual tests performed alone was equivalent for patients with Alzheimer's disease and for both elderly and young control participants. However, when performed simultaneously, dual-task performance was dramatically impaired in AD but was not affected by age. When the two tasks were performed alone, however, there was no evidence that increasing the level of difficulty differentially affected the patients with Alzheimer's disease (Logie, Della Sala, Wynn, & Baddeley, 2000). These and other studies using both patients with Alzheimer's disease and normal participants appear to argue for a separable executive capacity needed to divide attention (Baddeley, Baddeley, Bucks, & Wilcock, 2001; Bourke, Duncan, & Nimmo-Smith, 1996; Perry & Hodges, 1999).

Switching attention. The third potential executive capacity is that of switching attention, something that is said to be particularly susceptible to frontal lobe damage (Shallice, 1988). After pioneering work by Jersild (1927) and Spector and Biederman, (1976), the topic was largely neglected until revived by an influential paper by Allport, Styles, and Hsieh (1994), whose results suggested that the capacity to switch attention is by no means necessarily one that depends strongly on executive capacity. The question of whether task switching should be regarded as an executive process, or perhaps a range of processes, remains to be decided (see Monsell & Driver, 1999).

2.2 The Phonological Loop

This component is dedicated to the storing and processing of acoustic/verbal information. It is assumed to comprise two components a phonological store (passive) and an articulatory rehearsal (active) component. Memory traces within the store are assumed to decay over a period of about two seconds unless refreshed by rehearsal. These characteristics of the phonological store explain the phonological similarity effect, whereby immediate serial recall of items that are similar in sound (e.g., the letters B, V, G, T, C, D) is poorer than that of dissimilar items (e.g., F, K, Y, W, M, R; Conrad & Hull, 1964). The articulatory rehearsal component was proposed to give an account of the word length effect, whereby immediate serial recall is a direct function of the length of the items being retained (Baddeley, Thomson, & Buchanan, 1975). Hence, a sequence of one-syllable words is much more likely to be recalled correctly than a sequence of four-syllable words. Indeed, the longer is the time for rehearsing (four-syllable words), the greater is the amount of forgetting. Consistent with this view is the fact that when rehearsal is prevented by *Articulatory Suppression* (e.g. the repetition of an irrelevant sound such as the word "*the*") the word length effect disappears (Baddeley et al., 1975).

2.3 The Visuo-Spatial Sketch Pad

A more exhaustive description of this component can be found in the next chapter, "The architecture of the Visuo-Spatial Working Memory". A general description is given here.

The Visuo-Spatial Sketch Pad or Visuo-Spatial Working Memory (VSWM) is assumed to be capable of temporarily maintaining and manipulating visuospatial information, and to play an important role in spatial orientation and in the solution of visuospatial problems. An overview is provided by Logie (1995). The sketchpad is assumed to form an interface between visual and spatial information, accessed either through the senses or from LTM. A good deal of research in recent years has been concerned with the distinction and separation between visual and spatial components. Although it is difficult to find tasks that reflect one or other component in a pure form, there is both behavioural and neuropsychological evidence to suggest an association between spatial WM and the Corsi task, in which the participant attempts to copy a sequence of movements made by the experimenter in tapping an array of blocks. The visual component is better reflected in the pattern span. This involves showing the participant a matrix in which half of the cells are filled and requiring immediate recall or recognition; the size of the matrix is increased to visual span, at which errors begin to occur (Della Sala, Gray, Baddeley, Allamano, &Wilson, 1999). The sketchpad can be disrupted by requiring participants to tap repeatedly a specified pattern of keys or locations, a procedure that impairs the use of visuospatial imagery (Baddeley & Lieberman, 1980). Unattended patterns or visual noise may disrupt the visual component of the system (Logie, 1986; Quinn & McConnell, 1996). Both neuropsychological evidence and functional imaging evidence support the view of the sketchpad as a multicomponent system, with occipital lobe activation presumably reflecting the visual pattern component, parietal regions representing spatial aspects, and frontal activation responsible for coordination and control (Smith & Jonides, 1996). Separating the subcomponents of the sketchpad has proved more difficult than dissecting the phonological loop. However, one feature suggests that future developments may be more rapid. Single-unit recording studies in awake monkeys have allowed the tracing of an active short-term visual memory system that would appear to have considerable similarity to the visuospatial sketchpad and its control processes in humans (Goldman-Rakic, 1996). At the same time, the study of visual attentional processes would appear to provide an extremely promising bridge between work on monkeys and work on the visuospatial sketchpad (Humphreys, Duncan, & Treisman, 1998).

2.4 The Episodic Buffer

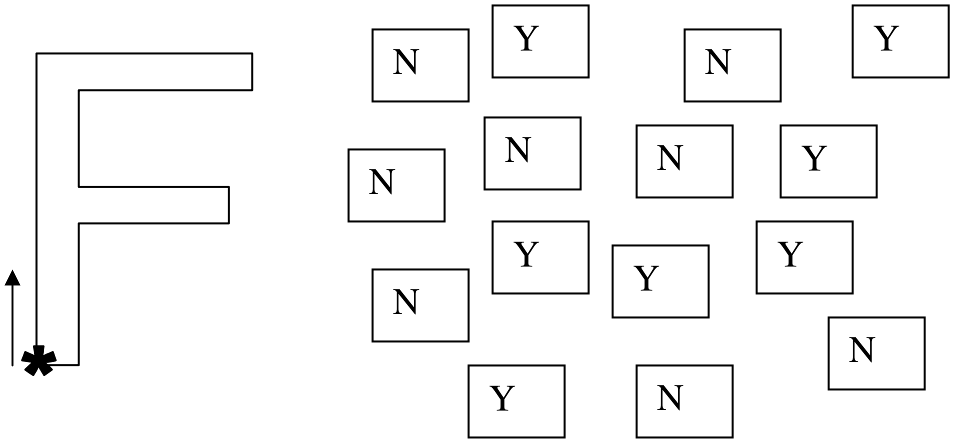
This component of WM has been recently added (Baddeley, 2002) in order to explain how the information coming from Long Term memory can be integrated with the information present in WM. It is supposed to represent a storage system using a multimodal code. It is assumed to be episodic in the sense that it holds integrated episodes or scenes and to be a buffer in providing a limited capacity interface between systems using different codes, that is Long Term memory and Short Term memory and the different sub-components of working memory. Indeed, the tripartite model of Working Memory cannot explain how the information coming from different sub-systems can be integrated. In this sense, the episodic buffer has the role of an interface connecting each working memory sub-systems and, in addiction, Working Memory with Long Term memory. Further details concerning the episodic buffer can be found in Baddeley (2002).

3. VISUOSPATIAL WORKING MEMORY

3.1 Evidences for the existence of visuospatial working memory

In the last 20 years several experiments have demonstrated the existence of a specific system, separated by the Phonological Loop, which is involved in maintaining and processing visuospatial information. Indeed, the more persuasive results stem from experiments using the dual task technique. In 1968, a pioneer study by Brooks already hinted a distinction between spatial and verbal processes. Brooks (1968) required subjects to imagine a block letter (fig. 2) and report, after mentally scanning it, whether successive corners were internal or external to the letter. The experiment showed that visually oriented responses (i.e., pointing to the letters Y or N) took longer than verbal responses (saying "yes" or "no") implying that the visual response task was interfering with the imagery task. In a similar experiment Brooks (1968) asked the subjects to report whether successive words in a sentence were nouns. In this case, verbal responses were slower than visually oriented responses. Brooks' conclusion was that mental imagery is distinct from verbal processes, and shares processing resources with the visual perceptual system.

Fig. 2 Stimulus used by Brooks (1968).



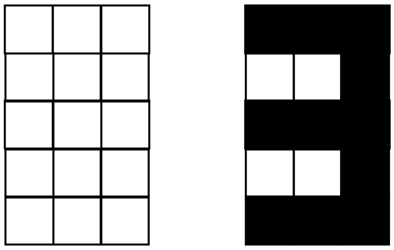
Many other results come from experiments involving selective interference tasks. Indeed, one the first systematic investigation of the visuospatial sketch pad (Baddeley, Grant, Wight and Thomson, 1975) used a version of the imagery technique developed by Brooks (1967) as a memory task that demands storage of visual information. The spatial version of the Brooks task involved asking subjects to visualise a 4 x 4 matrix of squares. The square on the second row and in the second columns was designated as the starting square. The subject's task was to repeat back a sequence of sentences that described movements (up, down, left, right) around the matrix. Participants typically report encoding the sentences as a path through the matrix, and recalling by generating the sentences from their image of the path. However, each subject was instructed to remember the sequence of movements by visualising them in the imagined matrix. The contrasting verbal version of the task consists in using the same sentences as for the visual task, but replacing the words "up", "down", "left", "right" with the words "good", "bad", "slow", "quick".

Again the subjects' task was to repeat the sequence of sentences as presented. However they were instructed to remember the sequence by means of verbal rote rehearsal. In this condition, subjects cannot readily recode the sentences into an imaginable form that can be represented within the matrix, and so are forced to rely on non-visual and predominantly verbal encoding. It seems plausible that the spatial form of the task could be represented in the visuospatial sketchpad, whereas the non-spatial form could not. Baddeley *et. al* (1975) tested this hypothesis by requiring subjects to engage in a visuospatial tracking task during memorization of the instructions in half of the trials. From the results it emerged that memory performance on the spatial and non-spatial forms of the Brooks task were about equivalent in the no tracking conditions. When subjects engaged in this concurrent visuospatial task, however, errors in the spatial memory task increased dramatically, whereas performance on the non-spatial version remained intact. This pattern of selective interference indicates that different components of memory mediate memory for the spatial and non-spatial instructions. The disruptive influence of the tracking task on the spatial memory task is clearly consistent with the view that a memory component specialised for the processing and maintenance of visuospatial material contributes to spatial recall.

The visuospatial sketch pad is thought to provide the medium for the generation and maintenance of information in imaginal form. Imagery mnemonics have also been used to explore the visuospatial sketchpad. The beneficial consequences of using imagery as opposed to rote verbal learning to support the retention of verbal material were well established in the 1970s by researchers such as Paivio (1971) and Bower (1970). Baddeley and Lieberman (1980) reported findings that are consistent with this hypothesis. They instructed subjects to remember lists of unrelated words either by using a rote rehearsal strategy either by using the peg word mnemonic. This mnemonic has been extensively used by researchers interested in the use of imagery in memory, and involves teaching the subjects to associate each of the numbers between one and ten with a rhyming and high imageable word. For example the subject is taught to associate the number *one* with an image of a *bun*, the number *two* with an image of a *shoe,* etc. subjects are then trained to use the images as a way of remembering sequences of items by associating each memory item with an image of the word associated with that word's position in the memory list. So if the first two words in the memory list were *table* and *glass*, the subject would attempt to generate an image incorporating a table with a bun and a glass with a shoe. Once learned, this peg-word technique has been found to provide an extremely effective means of improving memory for unrelated sequences. The involvement of the visuospatial sketch pad in the imagery mnemonic was assessed by comparing the consequences of concurrent visuospatial tracking on memory following either peg word learning or rote learning. It had already been established that spatial recall in the Brooks task was disturbed by concurrent tracking. If imagery also involved the same visuospatial component of working memory, the effectiveness of the peg word mnemonic should have also been reduced during simultaneous tracking. This prediction was supported. In another experiment, Baddeley and Lieberman (1980) found that the pursuit rotor tracking disrupted performance in the imagery condition but not in the rote learning condition. This result was then generalized in a further experiment on a location mnemonic, an alternative imagery technique that involved using images of familiar locations to encode and retrieve memory items.

Using a similar methodology, Logie, Zucco and Baddeley (1990) examined the selective interference in working memory in two experiments. Experiment I contrasted recognition memory span for visual matrix pattern (*visual span*) with that for visually presented letter sequences (*letter span*). In the visual span task a square matrix pattern of increasing complexity was presented to participants. The patterns were made more complex by adding squares to the matrix, two at time. For each pattern, half of the squares were filled at random. After viewing the pattern for two seconds, the screen became blank for two seconds and the pattern reappeared with one of the previously white square changed to a blank square. The subject's task was to point to the position in the matrix pattern, of the changed square. In the letter span task, a random sequence of consonants was presented on the screen. The sequence length was increased by one letter after each group of three trials. Each letter appeared one after the other in the centre of the screen, for three seconds. Participants were asked to memorize the letter sequence in the order in which the letters appeared. There was then a two seconds gap, followed by the same letter sequence, but with one letter replaced by another, different letter. The subject task was to point to the screen whenever they detected the new letter in the sequence. These two span tasks were combined with concurrent arithmetic or a concurrent task which involved the manipulation of visuospatial material, that is the "number matrix task". In this secondary task, subjects were asked to imagine a three by five arrangement of squares (fig. 3). The experimenter then read aloud a sequence of instructions regarding whether each square was to be filled in or left blank, starting with the top left square and working along each row in turn. The resulting pattern of filled and blank squares was in the form of a digit between 0 and 9.

Fig. 3 – The visuospatial interference task used by Logie et al. (1990). On the left, the empty imagined matrix 3 x 5 five. On the right, the resulting pattern of filled and blank squares in the form of the digit "3.



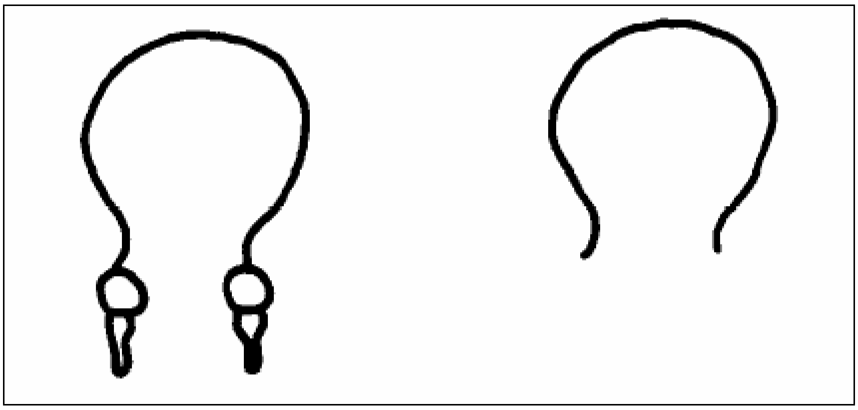
In other words, the participants' task was to generate a visual image of the blank matrix and then mentally fill squares or not as instructed. On completion of a full set of instructions, the subject was required to respond vocally with the digit specified by the resulting pattern. For example, the sequence of instructions: "filled, filled, filled (1^{st} row); unfilled, unfilled, filled (2^{nd} row); filled, filled, filled (3^{rd} row); unfilled, unfilled, filled (4^{th} row); filled, filled, filled (5^{th} row)" will generate the number "3" (fig 3).

Results showed that the concurrent *arithmetic task* substantially disrupted the *letter span task* and it only marginally affected the *visual span task*. The converse was true for the "*number matrix task*", which selectively impaired the *visual span task.*

Experiment II combined the two span tasks with two secondary tasks developed by Brooks (1967) and previously described in Baddeley et al. (1975). The *visual span task* was disrupted by a secondary visuospatial task but not by a secondary verbal task. The converse was true for the *letter span task*. Concurrent arithmetic impairment of Short-Term Visual Memory may reflect a small general processing load, but selective interference due to processing mode may be stronger. This is consistent with a specialized visuospatial mechanism in working memory.

The hypothesis that working memory contains independent verbal and visuospatial components has also received strong empirical support by studies on imagery. In Brandimonte, Hitch and Bishop (1992) the verbal and visual memory are convincingly demonstrated to be dissociable capacities. An imagery manipulation task was used in which subjects were shown a picture of a skipping rope becoming two ice cream cones if the rope is subtracted (fig 4).

Fig 4. *Skipping rope. If the stimulus on the right is subtracted, two ice creams appear.*



In experiment I, recall of the pictures was tested after completion of the subtraction task. Four different learning conditions were contrasted. In the control condition, subjects were given the tasks without being told to remember the stimuli. In each of the three remaining conditions, instructions were given to memorize the sequence of the composite pictures, either before participating in the subtraction task, after training, or while engaging *Articulatory Suppression* prior training. Results showed that recall was better in the control condition than in the non-suppression conditions involving memorization, but at a corresponding level to the condition involving memorization with *Articulatory Suppression*. Thus, when subjects were actively trying to remember the picture sequence, recall was better when engaged in irrelevant articulation than when there was no concurrent task. This counter-intuitive finding of an improvement in recall in a "distractor" condition is explained by Brandimonte, Hitch and Bishop (1992) in terms of the use of phonological recoding. It is suggested that when subjects explicitly attempt to learn the sequence of pictures, they recode the stimuli phonologically and in doing so, fail to rely on the more effective visual codes resulting from imagery transformation. *Articulatory Suppression* prevents subjects from carrying out this phonological recoding, and so forces them to exploit their superior visual memory for the stimuli.

3.2 The architecture of visuo-spatial working memory

The Visuo-Spatial Sketch Pad or Visuospatial Working Memory (VSWM) is a sub-system specialized for the retention and manipulation of visuospatial information. In the last ten years several distinctions have been proposed within the VSWM system.

Dissociation between spatial and visual components of VSWM was supported by research conducted both on brain-damaged and normal individuals. Baddeley and Lieberman (1980) devised two relatively pure concurrent tasks, one of which was spatial only and the other was predominantly visual. The spatial task involved subjects pointing to a moving sound source while blindfolded. The visual task involved the judgment of the brightness of a patch of light. Concurrent blindfolded tracking of the moving sound source selectively disrupted performance in the spatial memory task but did not influence non-spatial memory performance. Conversely the concurrent brightness judgment task impaired the recall of the non-spatial instructions to a greater extent than the spatial instructions. Farah, Levine, and Calvanio (1988) reported the case of a brain-damaged patient who showed a selective impairment in the processing of visual information (i.e. shape and colour), concurrent with an average performance in mental rotation and retention of path in a matrix. Hanley, Young, and Pearson (1991) reported the opposite case of a patient performing normally in visual tasks and showing a very poor performance in spatial tasks.

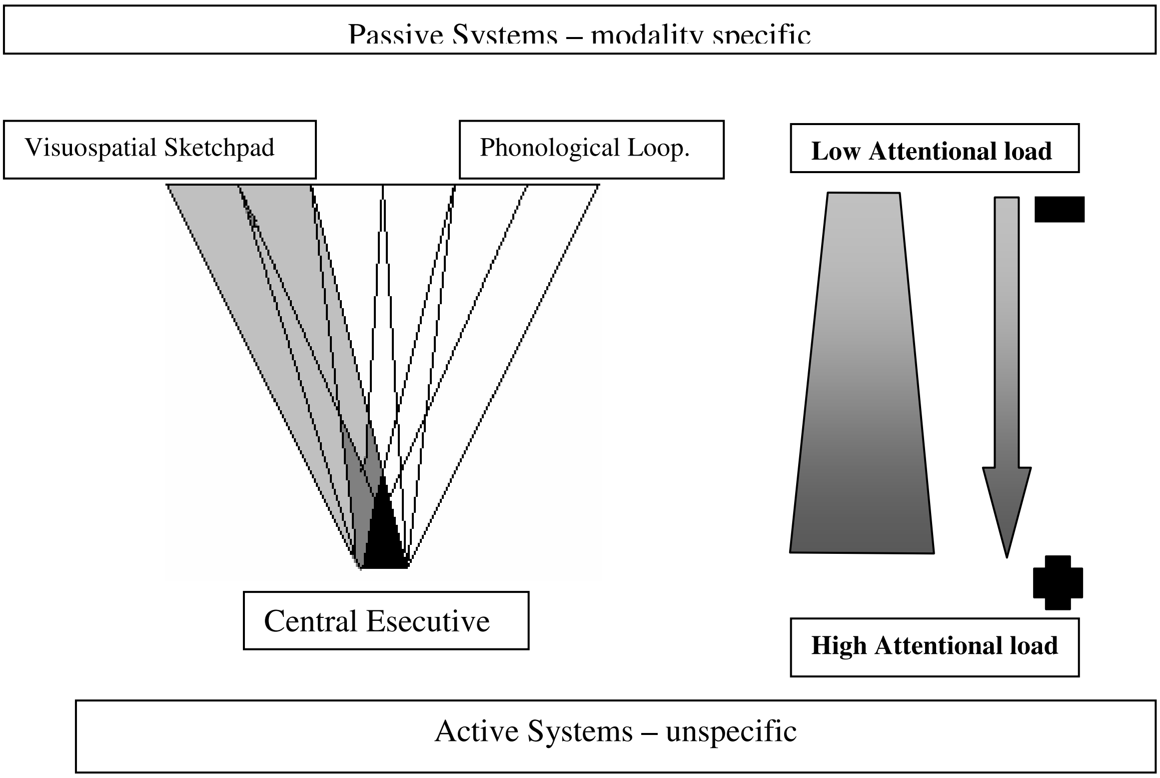
An additional distinction within the VSWM was proposed by Logie and Pearson (1997), involving sequential and simultaneous processes. The authors presented their participants with two different visuospatial tests. One was Corsi's block test (Milner, 1971), in which an experimenter pointed to a growing sequence of blocks arranged on a board. Participants were requested to indicate the same sequence in the correct order, which had just been pointed out by the experimenter. This test is characterised by strong spatial requirements (to remember the absolute and relative position of the blocks) in which the temporal variable is particularly relevant. In fact participants had not only to remember which blocks had been pointed to, but also the exact order of the sequence, in other words the exact route made by the experimenter on the board. In the same experiment, the authors used a different visuospatial test, which required the participants to memorise a matrix pattern in which a number of cells were filled, and to compare this pattern to another given successively. In this case a visuospatial pattern was simultaneously given to the participants, who simply had to match the actual pattern with the one previously memorised. Despite the fact that both the tests required them to remember the positions (in the first case, the positions of the blocks pointed to on the board; in the second case, the positions of the filled cells in the matrix), and so possibly both had spatial requirements, the results showed that the two tasks only moderately correlated with each other and that they had different developmental trends. This type of dissociation was confirmed by clinical studies on individuals who were characterised by low visuospatial ability. For example, Cornoldi, Tressoldi, and Rigoni (1996) found that children with VSWM deficits presented very specific and selective impairments either in Corsi' s block test or in the test that required them to remember the pattern of filled cells in a matrix. These data suggest that the manipulation of the sequential/simultaneous presentation of the visuospatial pattern to be memorised is an important variable, suggesting a differentiation between sequential and simultaneous processes in VSWM.

Logie (1995) proposed the distinction between active and passive components of VSWM. As the Phonological Loop is fractionated in an active system of rehearsal, which reiterates and elaborates the information, and in a passive system, which stores the information, a passive store for retaining the visuospatial information and an active system, which refreshes, scans and manipulates the mental images, is hypothesized. In the Logie (1995)'s model the "visual cache" stores information primarily about visual form and colour and is closely linked to the visual perceptual system, while the inner scribe retains information about movement sequences and is closely linked to the planning and execution of movement.

Similarly, in the Vecchi and Cornoldi (1998)'s model, the passive components are implied in storing and retrieving visuospatial information, while the active components are used for elaborating and manipulating the information. Such a distinction is not rigid as it consists of a continuum from the passive (low level of elaboration and modality specific) to the active (high level of elaboration with high generic attentive load).

Some empirical evidences support this view. Cornoldi (1995) and Vecchi, Monticelli and Cornoldi (1995) found that the passive components of VSWM are less affected than the active components in individuals with a low visuo-spatial ability (Salthouse and Mitchell, 1989; Vecchi, 1998). The passive component seems to operate only when recovering the visuospatial information from LTM, while the active component is involved in all the tasks that require elaborating and processing the visuospatial information. Rather than dissociation, Vecchi and Cornoldi (1998) proposed a continuum of elaboration from the passive to the active components. The passive component does not require central processing of elaboration, while the active component relies on central processing of elaboration and requires a higher load of attentive resources for the integration, modification and manipulation of the information. The two poles of the continuum proposed by Vecchi and Cornoldi (1998) fit within Baddeley's model. On one pole, there are the automatic, inattentive and passive systems which are modality specific (e.g. "phonological store" and "visual cache"); on the other pole there are the active systems (e.g. central executive), which are highly attentional and unspecific (Fig.5).

Fig 5 - Continuum in the structures of Working Memory as proposed by Vecchi and Cornoldi (1998).



The elaboration of the information in working memory does not depend exclusively on the type of information (verbal, visual, spatial), but also on the attentional demand the task requires. Hence, which component will elaborate the information depends on the nature of the task. Studying the active processes of VSWM is problematic because of scarcely adequate experimental procedures (Vecchi & Richardson, 2000). Indeed, many traditional visuospatial tests have been found not to be proper for the investigation of the active-passive components (Vecchi & Richardson, 2000). For instance, the technique of mental rotation or tasks requiring the memory for spatial locations had shown not to be appropriate for the investigation of the active-passive components (Vecchi & Richardson, 2000), because of their scarce ecological validity. To cover this gap, Vecchi and Richardson (2000) devised a Jigsaw Puzzle task, which requires participants to mentally move some section of a fragmented picture, in order to rebuild the complete image. The task can be used with older adults and in the future as a tool for neuropsychological assessment. It possesses good ecological validity and also appears to be sensitive in identifying individual differences (Vecchi & Richardson, 2000). The participants are asked to solve jigsaw puzzles consisting of four, six, or nine pieces without actually touching or moving the pieces in question. Each piece is numbered. The participants are given a prepared response sheet showing the original outline of the completed puzzle, and they are instructed to write down the numbers corresponding to the pieces in the correct spatial positions. Performance is evaluated in terms of the percentage of correct responses as well as in terms of the time needed to solve each of the puzzles. The stimuli were all pictures of inanimate objects chosen from the standardized material constructed by Snodgrass and Vanderwart (1980). To facilitate recognition of the objects as well as to obtain the purest active visuospatial elaboration, all of the stimuli had high values in terms of rated familiarity (as assessed by Snodgrass and Vanderwart, 1980) and image agreement in terms of "how closely each picture resembles people's mental image of the object". This new tasks was recently demonstrated to be a good instrument for assessing the active components of the VSWM (Richardson & Vecchi, 2002; Bosco et al. 2004).

A last distinction within the VSWM involves the "motor component" or "Working Memory for Movements". Temporary memory for movements has been examined systematically in a series of studies by Smyth. In one set of studies, Smyth, Pearson, and Pendleton (1988) asked subjects to watch an experimenter perform a sequence of simple movements such as a forward bend of the head followed by the left arm raised above the head, a step forward onto the right leg, and so on. After presentation of the movement sequence, subjects were required to recall and reproduce the movements in the order of presentation. Smyth et al. reported that subjects could recall a mean of 4.33 movements in sequential order. This was compared with mean verbal spans of 5.12 for these same subjects. Subjects were then asked to perform the movement span and verbal span tasks concurrently with *Articulatory Suppression*, or hand tapping to four switches arranged on a square board, or repeated arm movements. The arm movements involved touching the top of the head with both hands, followed by touching the shoulders, followed by touching the hips, and then returning to the head and repeating the sequence. Smyth *et al.* (1988) found that the repeated arm movement during presentation impaired recall of the movement sequence but not the recall of the verbal sequence. *Articulatory Suppression* was found to disrupt memory for the movement sequence as well as for the verbal sequence. Tapping four switches in a square had no effect on recall of the movement sequence. In further experiments, the authors asked subjects to retain a sequence of locations (Corsi blocks). Performance on the Corsi blocks task was not disrupted by "arm movement suppression", but it was disrupted by tapping a square pattern of four switches. These data point to a distinction between body movements and movements to specified target locations. The distinction was reinforced by later studies which contrasted Corsi block span with memory for series of hand configurations (Smyth & Pendleton, 1989). These results, together with the evidence discussed earlier, lend added sustenance to the idea that a movement component of working memory is linked to the planning and control of movement to targets in space. Since dissociation between spatial and motor WM was suggested (Smyth, *et al.* 1988; Smyth & Pendleton, 1989), many studies confirmed the existence of a mechanism in WM which is specialized for processing information for movements (Quinn & Ralston, 1986; Smyth & Pendleton, 1990; Woodin & Heil, 1996). In Quinn and Ralston (1986), subjects had to move their arms around a square matrix taped to the table. The matrix on the table and the subject's arm were covered, and movements had to be completed without the subject being able to see their arm. This ensured that the concurrent movement task did not involve any visual processing. The authors compared the effects of unseen arm movements that were either compatible with the matrix pattern, or were incompatible. For example, say that the Brooks task involved a series of instructions such as "In the starting square put a 1, in the next square to the right put a 2, in the next square down put a 3" and so on. Compatible concurrent movement would comprise an arm movement to the right, followed by an arm movement down. Incompatible arm movement involved tracing out a boustrepedal pattern, where the arm moved to the right along the top row of the matrix, then down to the next row, moving to the left along that row and so on. Quinn and Ralston found that incompatible movement disrupted recall of the Brooks matrix material, whereas compatible movement did not. They followed up this experiment with a "passive movement" condition where the experimenter held the subject's arm and moved it for them. Even under these conditions, there was a disruptive effect of passive incompatible movement. This finding suggested that the disruption was not due to a general attentional deficit. Overall results show the existence of a particular component of Working Memory, which is specialized for processing the movements.

4. DIFFERENT SOURCES OF ENVIRONMENTAL LEARNING

Several studies attempted to clarify the different aspects of environmental learning. Particularly, the literature focused on four kinds of sources of environmental learning, according to the following categorization: Real environments, Simulated environments, Verbal Descriptions and Maps. All these sources are qualitatively different one another. Each source identifies a different way in which the environment can be experienced and each source can produce different internal representations of the environment.

4.1 Real environments

Spatial learning in real environments was studied in a wood (Malinowski & Gillespie, 2001), in a building (Sadalla & Montello, 1989; Lawton, 1996; Lawton, Charleston & Zieles, 1996), in a maze (Schmitz, 1997) and in a university campus (Kirasic, Allen & Siegel, 1984; Montello & Pick, 1993; Saucier, Green, Leason, MacFadden, Bell & Elias, 2002). All these situations are very ecological and were used especially for assessing spatial orientation. The environment is offered in a three-dimensional perspective within an intra-route view with visual, spatial and kinaesthetic information simultaneously available. When viewing a large-scale world from their normal, within-environment perspective, people must move through the environment to obtain all the information required to develop their spatial knowledge. The process of developing spatial knowledge thus involves integrating the information contained in each visual scene with a range of viewpoint locations, directions and changes, which are controlled by eye, head, and body movements over time (Weatherford, 1985).

In addition, kinaesthetic and vestibular information is also integrated with the visuospatial information. Some experimental evidences support the role of the kinaesthetic and vestibular information in environmental learning. For instance, Rieser, Lockman and Pick (1980) demonstrated that the mere kinaesthetic and vestibular information can be sufficient to structure in mind a detailed spatial representation of the environment. In their experiment, blind people showed an accurate mental representation of a building, developing knowledge both in terms of intra-route view and bird's eye (map-like) perspective.

4.2 Simulated environments

Some examples of spatial orientation in simulated environment are 3-D computer simulations (Moffat, Hampson, & Hatzipantelis, 1998; Waller, Knapp and Hunt, 2001; Lawton & Morrin, 1999; Sandstrom, Kaufman & Huettel, 1998), video recording (O'Laughlin & Brubaker, 1998) and slide sequences (Holding & Holding, 1989). Within simulated environments, it is possible to distinguish between situations that allow interaction with the environment (3-D computer simulations) and others that do not (slides and video recordings). In the first one, "active learning", participants can move themselves and actively decide where to go (Ruddle, Payne and Jones, 1997). In the second one, "passive learning", they are passively shown a static (slides sequence) or dynamic (video recordings) environment. Qualitative and quantitative differences between real and simulated environmental learning exist. Environmental complexity cannot be accurately reproduced in virtual environment, especially in terms of visual details. For example, the materials of the virtual buildings and the type of terrain the subject is walking on are not assessable easily and the shape of the landmarks is regularized (Ruddle, Payne and Jones, 1997). Indeed, all these cues are necessary to build a mental representation of the environment. In addition, hardware distortions and cost limitations typically restrict the field of view in virtual environments to 60°-100 ° at best. Operating with a restricted field of view increases the number of times and the angle to which users must rotate their heads to notice what they are walking past. The lack of peripheral vision has been shown to be important when learning the spatial layout of a room (Alfano & Michel, 1990). In desktop virtual environments, movements are controlled by an abstract interface (mouse, keyboard, etc.) and the information that may be acquired from any single view is affected by the field of view and the presence of and type of cues that facilitate position and direction judgments. Spatial Knowledge formed in a Virtual Environment could be different from one that is formed in the real world. In desktop Virtual Environments, users receive feedback on their rotational and translational movements, which respectively cause changes of direction and position, solely from visual changes in the scene displayed. Visual continuity during these changes in view direction is achieved by constraining the rate at which the view direction is allowed to change. What is more, even if the environment could be offered in a three-dimensional perspective with all the visual details accurately represented, kinaesthetic information is missing. No vestibular or kinaesthetic feedback is provided when users change their view direction, because eye, head, and body rotations are simulated using an abstract interface. Translational movements are also typically controlled by using an abstract interface, and, therefore, users experience no physical locomotion. Other studies have shown that people make significantly greater errors in directional judgments when imagining their body has been rotated than when physically rotating their body

(Presson & Montello, 1994; Rieser, 1989). In sum, simulated sources of spatial learning are less ecological than real environments. Nevertheless, some experimental evidences support the fact that virtual environments still can offer a good representation of the real world. Ruddle, Payne and Jones (1997) investigated differences between real and virtual indoor environmental learning. Participants learned the layout of large-scale "virtual buildings" through extended navigational experience, using the "desk-top" (i.e., non-immersive) virtual environments. Results showed that users who navigate large-scale virtual buildings develop route-finding abilities and some map-like spatial knowledge (direction judgments and relative straight-line distance judgments), which are as accurate as those abilities and spatial knowledge developed by people who work in real buildings.

In Rossano, West, Robertson, Wayne and Chase (1999), two experiments were conducted to investigate the nature of the spatial knowledge obtained from a computer model of a campus environment. A series of tests were administered to assess the spatial knowledge of subjects who learned a campus environment from a map, computer model, or direct experience. Though the "computer model" experimental group had never been on the campus before, 70% of "computer model" subjects were flawless in their ability to navigate from one specific location to another. Computer experience can be equally effective in larger and more open environments. Indeed, many of the computer subjects reported feeling very confident in their ability to find their way around the campus, and also indicated a sense of familiarity (as if they had `been there before') when tested in the actual environment.

4.3 Verbal descriptions

Some studies (Bryant, Tversky, & Franklin, 1992; Denis, 1996; Pazzaglia, Cornoldi, & Longoni, 1994; Perrig & Kintsch, 1985; Taylor & Tversky, 1992a) have found that participants spontaneously construct a spatial mental model as a result of listening to or reading the description of spatial patterns and environments. The literature on spatial descriptions shows that the description of an environment can assume two different main perspectives: intra-route view or bird's eye (map like) view (Tversky, 1981). The intra-route descriptions assume the point of view of a person who is moving through the environment. They are characterised by the use of an intrinsic frame of reference and egocentric terms, such as right, left, front, and back, and have a linear organisation, given by the sequence of landmarks encountered along the route itself. The map-like descriptions provide an overview of the spatial layout, sometimes with a strong hierarchical organisation (Taylor & Tversky, 1992b). An extrinsic frame of reference and canonical terms such as north, south, east, and west are used. In this case, participants are initially provided with the general configuration of the environment and, successively, single items are mentioned and allocated therein. Thus, the comprehension process starts from a more global, visual structure, which is successively filled by local substructures. By contrast, the intra-route descriptions are usually characterised by a linear organisation with the order of items given in the order in which they are encountered along the route. Comprehension of the descriptions requires the implementation of a sequential process, characterised by continuous changes of perspective as a function of proceeding along the route. The type of verbal description of an environment can affect the subsequent mental representation of the environment itself. In Sardone, Bosco, Scalisi and Longoni (1995) participants learned a fictitious environment for 5 or 10 minutes, by reading the verbal description with either an intra-route view or a bird's eye view. Then, subjects were asked to operate some spatial inferences concerning landmarks into the learned environment, starting from some premises. Such premises could be offered with an intra-route view or with a bird's eye view. So they could be with the same view of the learned environment (congruent) or with a view different from the original environmental description (incongruent). Results showed that in some cases, response times were slower for incongruent than for congruent inferences. Unfortunately this effect did not emerge for all the conditions and for long time of learning (10 minutes). However, the results demonstrated that the type of spatial description of the environment affects its consequent mental representation.

4.4 Maps

Environmental learning can also occur by means of a map (Galea & Kimura, 1993; McGuinness & Sparks, 1983; Ward, Newcombe & Overton, 1986; O'Laughlin & Brubaker, 1998; Dabbs, Chang & Strong, 1998; Brown, Lahar and Mosley, 1998; Miller & Santoni, 1986; Coluccia & Martello, 2004). Map learning is a simple and fast way to acquire many details about the environment (Rossano & Moak 1998). Thorndyke and Hayes-Roth (1982) found that subjects who studied a map of a building had an optimal performance in a *Euclidean distance task* and in an *object location task*. Similarly, Hirtle and Hudson (1991) found that subjects who learned the environment from a map are very accurate in straight-line distance and in pointing tasks. They also preferred giving verbal descriptions in terms of cardinal points (for ex. "I go towards the North") and Euclidean distances (for ex. "I turn to right after 300 meters!").

Indeed, individuals who learn from a map, represent the environment in a configurational manner, according to a “bird’s eye” perspective (Taylor & Tversky, 1996). The next chapter will further discuss the map learning issue.

5. LEARNING FORM MAPS

In everyday life, when we move within familiar environments, we usually know the names and the positions of the nearby objects. In unfamiliar environments, maps can help us to acquire familiarity with the surroundings, as they depict all the information (both explicit and implicit) that we need to move through the environment. All streets, pathways, objects and landmarks are considered elements (Thorndyke & Stasz, 1980). Explicit knowledge is referred to labels, shapes and locations of elements in the environment. Implicit knowledge is referred to the information about the spatial relationship between elements like reciprocal positions and distances. All information is simultaneously represented in a map in a concise and symbolic manner. A map could be also defined as a symbolic bidimensional representation of an area enough extended to allow a person to move within (Thorndyke & Stasz, 1980). People usually need to memorize map to find a route, to move from one place to another, to understand the features of an area or finally to know the distances between two objects. Map learning is a constructive process that produces in Long Term Memory a mental representation of the environment depicted (Thorndyke & Stasz, 1980). A typical characteristic of map learning is the presentation of different stimuli all at once. In fact, the to-be-learned information is simultaneously presented on a map (Thorndyke & Stasz, 1980). A map is also quite complex to study, because it requires the learning of many locations, verbal labels, shapes, dimensions, absolute and relative positions of objects, links, routes and colours. For example, a simple red line representing a highway contains information about dimensions, shape, distance, direction, the elements that the road connects and other roads crossing it. A lot of cognitive processes are implicated in map learning and usually learners need to utilize some strategies in order to integrate the spatial and visual information altogether.

Many studies demonstrated that map information could be as a mental image (Kosslyn, Ball, Reiser, 1978, Rossano and Warren, 1989). Otherwise, information acquired from maps could be represented in a more semantic manner (McNamara, Halpin, and Hardy, 1992). For instance, associative links between map elements or spatial categories may be better stored in memory as semantic notions (McNamara, Halpin, and Hardy, 1992). It is not appropriate entering in this long-lasting debated issue here. Probably, both the representational systems (imaginative and semantic) are fundamental in order to elaborate different aspects of the same map (Rossano and Hodgson, 1994). Recall of elements is better performed by semantic strategies, while locations-learning is better performed by visuospatial strategies and imaginative systems. Then, different types of map information can rely on different mental representation (semantic or imaginative): when imaginative learning is adopted, a mental image is stored in memory; on the contrary, when verbal learning is used, semantics rules about map elements are stored (Rossano & Hodgson, 1994).

In the study of Rossano and Morrison (1996) the way of acquiring information from a map is analysed. The authors claim that two main aspects facilitate the learning of a map: the presence of salient elements and the presence of a framework. In accordance with Siegel and White (1975), the authors noticed that the characteristic elements of the environment serve as starting point for acquiring the spatial knowledge. Indeed, Siegel and White (1975) found that the environmental knowledge starts from the salient landmarks. Rossano and Morrison (1996) discuss the facilitating role of the "interpretative framework". Kulhavy, Schwartz and Shaha (1983) found that memory for a map can be improved by the presence of boundary, edges or networks of streets. Such elements give to the map a spatial structure which can help to form in mind a kind of "mental grid" (Kulhavy *et al.*, 1983). Such a grid, in turn, facilitates the learning of the map, as it offers an overall organization that eases the scanning and the partitioning of the map and the positioning of elements. Rossano and Morrison (1996) used an experimental map of a university campus. This map included a main central road and marked perimeter, which were meant to facilitate an "interpretative framework". Results showed that both the peripheral landmarks and the landmark on the main road were better recalled and better positioned.

In sum, both the salient landmarks and a structured framework of roads facilitate the organization and consequently the learning of the map.

5.1 Alignment effect and orientation specificity

When people study a map, they never change their point of view. As opposed to a representation deriving from a direct experience, map information depends on orientation and it is considered an allocentric representation, since the observer is not directly involved (Levine, Marchon & Hanley, 1984).

Presson and Hazelrigg (1984) make a distinction between spatial information that depends on perspective at the moment of acquisition (orientation specific) and spatial information that can be used within different points of view (orientation free).

Many studies (Presson, De Lange & Hazerligg, 1989; Presson & Hazerligg, 1984; Rossano & Warren, 1989; Girando & Pailhous, 1994) confirmed that in map learning information of spatial relations is stored in a specific orientation perspective. This "orientation specificity effect" can be easily demonstrated using a *pointing task*. In this task subjects are instructed to indicate the direction of a target landmark using judgments in terms of angular degrees starting from a hypothetical 0° in front of them. In the "aligned condition" the starting point (0° in front of you) is aligned to the north of the map. In this condition subjects are requested to imagine their position in the same perspective respective to the studied map. On the contrary, in the "misaligned condition" the 0° starting point is misaligned to the north of the map (for ex. 45° degree). In this condition subject are requested to imagine their position in a different perspective respect to studied map. Rossano and Warren (1989) found a big effect size of the alignment effect in the "map learning group", while no significant differences emerged in the "virtual reality group" ("real navigation-like" perspective). Levine *et. al* (1984) found similar effects in "you-are-here maps". A "you-are-here aligned map" was positioned in the same direction as real location; while a "you-are-here contraligned map" was positioned at 180° respecting to the real surroundings. Target location performance was seriously affected by contraligned map in terms of accuracy and time taken. Evans and Pezdek (1980) suggest that spatial information from map leads to an orientation-specific representation and spatial information from real navigation or virtual tour (Rossano & Warren, 1989) lead to an orientation- free representation.

5.2 Distortions in representation of maps

Spatial knowledge is not immune to distortions in representation and "mental short cut" (heuristics). For example the sentences "London is further south than Berlin" and "Rome is further north than Washington" are correct, but they probably disagree with our mental representation. This happens as we normally use heuristics in order to organize our spatial knowledge. Then our mental representations don't mirror perfectly the spatial relation between objects in the real environment. The particular heuristics in the above example is called "part-whole". It is the bias not to estimate spatial relation directly comparing two elements, but on the basis of their high-order hierarchy. For example, we think that London is further north than Berlin, because generally England is further north than Germany, but in reality London is further south than Berlin. Tversky (1981) claimed the existence of at least two different kinds of heuristics in map learning: "rotation" and "alignment". Rotation heuristic is the tendency to rotate the position of target object towards the main reference axis (vertical and horizontal). This phenomenon is due to a spontaneous bias to move the real position of object toward the cardinal points. For example, Italy is thought to extend from north to south, while the real direction is from South-East to North-West. Alignment heuristic is one's tendency to align the objects position one to each other in order to organize a regular structure in the mental representation. For example, Glickson and Avnon (1997) found a bias amongst American people in recalling their own continent in a very regular way. These two heuristics give the impression to be similar but, in rotation heuristic, the whole configuration is translated toward absolute coordinates, while, in alignment heuristic, single map elements are aligned one to each other.

Many other biases have been found in map learning. Streets containing many landmarks are considered longer (Briggs, 1973). Number of turns in a route proportionally affected the estimation of route length (Allen, 1981; Sadalla & Magel, 1980). Very curved paths are estimated to be longer than linear paths (Byrne, 1979). Finally, Tversky (1981) demonstrated that corner formed by two crossing ways are rectified towards 90°.

6. DIFFERENT TYPES OF SPATIAL KNOWLEDGE

Some research (Siegel, Herman, Allen & Kirasic, 1978; Thorndyke & Stasz, 1980) demonstrated that, when we learn by real navigation, the kind of spatial knowledge changes depending on the familiarity with environment. These different types of spatial knowledge can be considered a qualitative development in the spatial representation of the environment, starting from knowledge about routes as far as to an abstract map-similar knowledge (Siegel *et al.* 1979).

Siegel (1981) proposed a developmental model of spatial knowledge. The "landmark knowledge" is the first one to be acquired. Landmark knowledge is the ability to identify salient points of reference. Then you can develop to "route knowledge", the knowledge of landmarks and turns in a temporal sequence about routes. Route knowledge is necessary to reach the most advanced kind of spatial knowledge: "survey knowledge". Survey knowledge is a global understanding of the environment and interrelation between map elements. Such developmental sequence suggests that different types of knowledge are strictly linked. Landmark knowledge predicts route knowledge, which, in turn, is a good predictor of survey knowledge (Anooshian & Young, 1981; Cousins, Siegel & Maxwell, 1983).

Similar theoretical distinction between procedural descriptions and configurational knowledge can be made. Procedural descriptions are referred to knowledge about routes. Such knowledge is likely to emerge by real navigation. Information is sequentially coded and deals with starting point, arrival point, and landmark internal to the route (Thorndyke & Hayes-Roth 1982). Such sequence of actions is a whole of stimuli and rules of actions (Thorndyke, 1981a). Procedural knowledge has many others information, like the sensation of covered distance, the knowledge about time of walking, straight-line location of starting point and particular details of objects met during navigation (Thorndyke and Hayes-Roth 1982).

Exhaustive definition about route and survey knowledge can be found in Bosco and Longoni (1996):

> […] Route knowledge is concerned with complex structures of spatial relations that are acquired and stored in a sequential manner. We can use this knowledge to know how to get from a starting point to an arrival point in the environment and to estimate route distances between landmarks. Survey (or configurational) knowledge is concerned with an immediate representation of the whole environment and reciprocal spatial relation between landmarks. This information is easily acquired by bird's eye viewpoint or by maps. We can use this knowledge and to point to an unseen object in the environment and to estimate Euclidean distances between landmarks […] (Bosco & Longoni, pp. 33-34, 1996).

Moreover, Pazzaglia, Cornoldi and De Beni (2000) give an additional description: "the survey representation is explicitly offered when a place is observed from the bird's eye perspective (i.e. flying on an area) or from a map. The route representation is explicitly offered when sequentially navigating through a maze or path".

Landmark knowledge comes from the familiarization with a reference point. Only the mere position of such reference point is known, but the relative positions between landmarks and the interconnections between landmarks are not. Route knowledge relates to the knowledge of the connections between the landmarks, but nothing is known about the relative positions of the landmarks. In other words, route knowledge allows navigating from a reference point to another one, without knowing the relative positions between the landmarks. Then, the survey (or configurational) knowledge refers to a cognitive map, which implies the knowledge of the reciprocal interrelations between of the landmarks positions. According to the Siegel and White (1975)'s model, the survey knowledge is the most complete. Indeed, from this knowledge information concerning landmarks positions and information concerning routes can be deduced. Initially, Siegel and White (1975) based their studies on the considerations of Piaget concerning the development of the reasoning in children. Hence, the three steps of the evolution of the spatial knowledge were meant to be associated to the development of the human reasoning and, in effect, first experimental evidences confirmed that children progressively developed their spatial representation according to the three types of spatial knowledge (Herman & Siegel, 1978; Cousins *et al*. 1983). However, next research showed that this model can be applied also in the adult life when referring to the acquisition of new spatial information. Hence, when individuals explore a new environment, their spatial knowledge starts form the Landmark Knowledge, then it progresses to the Route Knowledge and, finally, terminates with the Survey Knowledge. The stages for acquiring new spatial knowledge in adults mimic the stages of the development of spatial representation in children.

Such a sequential and progressive development of spatial knowledge was criticized by Anooshian (1996). The author asserts that the three types of spatial knowledge are not necessarily in a sequential and progressive order of development. According to the author, the survey knowledge does not necessarily require the Route Knowledge, which in turn does not inevitably require the formation of the Landmark Knowledge. All these three types of spatial knowledge are alternative and independent from each other. Anooshian (1996) found no correlation between the survey and route components of the spatial knowledge, showing their reciprocal independency. People with very good configurational knowledge did not necessarily show good route knowledge and vice versa. According to Anooshian (1996), information concerning the turns or the sequence of elements along the route can be codified and organized independently from the information concerning positions. Furthermore, Anooshian and Kromer (1986) reported that the well-localized landmarks were different from the landmarks in which the distance estimation was good. In other words, an accurate distance judgment between two landmarks does not necessarily imply the knowledge of the position of these landmarks.

In summary, results demonstrate the existence of qualitatively different and independent types of spatial knowledge, that is, Landmark, Route and Survey Knowledge. Such distinction is valid both for children's development of spatial knowledge and for adults' learning of new environments. The formation of the type of knowledge can be influenced by the source of environmental learning. For instance, a map supports the formation of the survey knowledge, while the real navigation supports the formation of the Route Knowledge. Survey knowledge seems to be the most complete knowledge as it contains information about absolute and relative landmarks positions and routes. Switching from one type of knowledge to another one is possible but it dose not happen spontaneously, and it requires a cognitive effort and intentional processes.

7. RELATIONS BETWEEN THE TYPE OF ENVIRONMENTAL SOURCE AND THE TYPE OF SPATIAL KNOWLEDGE.

Different types of spatial knowledge can also depend on different sources of environmental learning. Thorndyke and Hayes-Roth (1982) compared subjects with more than two years of direct experience of working in a building contrasted to subjects studying a map of the same building. “Map-subjects” performed better than “direct experience subjects” on Euclidean distance tasks and object location task. Map-subjects are thought to pay particular attention to configurational aspects and to construct an allocentric (= object location in relation to the environment) perspective of the surroundings using cardinal points (e.g. “I go towards the North”) and/or Euclidean distances (e.g. “I turn to right after 300 meters!”). On the contrary, “direct experience subjects” performed better in route distance estimation. They are thought to construct an egocentric (=object location in relation to my own body) perspective of the environment (for ex. “I turn to my right, then to my left”). Many results confirmed these findings. Moeser (1988) compared the spatial knowledge of subjects learning a map and subjects with two years of real navigation. The author found that participants with more than two years experience in a building had well-developed route knowledge, but their survey knowledge was less accurate than participants without any direct experience but who studied a map of the same building. Similarly, Lloyd (1989) found that, in landmarks-localization task, subjects with 10 years direct experience in an environment were slower and less accurate than subjects who learned the same environment studying a map for 5 minutes. According to Lloyd

(1989) real navigation-participants were slower and less accurate because, in order to complete the landmarks-localization task, they needed to transform their route knowledge (spontaneously formed from real navigation) in survey knowledge.

Taylor and Tversky (1996) demonstrated that individual learning a map can give verbal descriptions of the environment using both a "route perspective" and a "bird's eye" perspective. When they learned from real navigation, verbal descriptions of the environment were only "route perspective". In Hirtle and Hudson (1991), subjects who learned the environment from a map were more accurate in straight-line distance and pointing tasks than subjects who learned the environment in a route perspective from a slide sequence. In route distance judgment, significant differences did not emerge between the two groups. In the same way, Giraudo and Pailhous (1994) found that participants with direct experience navigation did not improve their performance in repeating an object location task. On the contrary, the more the task was repeated the more the participants with map experience were accurate and fast. In other words, learning form maps yields a significant improvement in locating elements, while no improvement is given by real navigation. Conversely, when the spatial information is acquired by means of real navigation, the formation of Route Knowledge is promoted (Thorndyke and Hayes-Roth, 1982; Rossano, *et al.* 1999). In Rossano *et al.* 's study (1999), participants who learned the environment from direct navigation demonstrated an accurate knowledge concerning how to go from a place to another one and concerning distances estimation in terms of route. Nevertheless, they do not have knowledge about the whole environmental structure. On the contrary, individuals who learn from a map show a good knowledge about the configuration of the environment, but they are less able to use the routes (Rossano, *et al.* 1999).

8. THE ROLE OF VSWM IN ORIENTATION ABILITIES

Previous research on Working Memory showed its important role in different cognitive processes. Verbal Working memory and the elaboration of linguistic information has been extensively studied in the last 20 years. Verbal Working memory was demonstrated to play an essential role in mathematical tasks (Logie & Baddeley, 1987; Logie, Gilhooly & Wynn, 1994), text reading and comprehension (Baddeley *et al.* 1984), in problem solving (Gilhooly, Logie, Wetherick & Wynn, 1993; Saariluoma, 1991) and in learning a new language (Baddeley, Papagno & Vallar, 1988; Gathercole & Baddeley, 1989).

Only recently, researchers directed their attention to the functions that Visuospatial working memory can play in everyday cognitive tasks.

According to Baddeley (1990) VSWM is important for the geographical orientation and for planning spatial tasks. A similar hypothesis was also formulated by Kirasic (1991). Indeed, the author claimed that VSWM can be considered essential for environmental learning.

A body of indirect evidences and direct studies support the hypothesis of an involvement of VSWM in environmental learning.

8.1 Indirect evidences

Some correlational studies hint a relationship between VSWM and environmental learning skills. From a factorial analysis, Allen, Kirasic, Dobson, Long and Beck, (1996) extracted a factor called “Spatial Sequential Memory” and a factor called “Topological Environmental Knowledge”. The factor “Spatial Sequential Memory” is derived from the performance on a *Maze Learning Task* and a *Maze Reversal Task*. In these tasks subjects are instructed to learn for 15’’a pathway shown on a 6 x 6 matrix. In test phase, they are asked to reproduce the same pathway on the 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. The "Topological Environmental Knowledge" is the factorial result of some "environmental learning tasks" performed after the navigation in a real environment, by means of a walk, which occurred through a small city. The environmental learning tasks loading on the "Topological Environmental Knowledge" factor were: "Route Reversal Task", "Scene Recognition and Scene Sequencing Tasks", "Intra-Route Distance Judgment Task" and "Map Placement Task". In the *Route Reversal Task* participants were asked to retrace the walk they had originally taken, starting at the endpoint and finishing at the point of origin. During the task, the experimenter walked just behind the participant and recorded his or her movement. In the *Scene Recognition task* participants had to recognize scenes from the original walk. Participants were shown a series of 50 photographic prints, half of which were from the walk and half of which were from visually similar walks. They were instructed to respond "Yes" or "No" to the question of whether the picture showed a viewpoint from the original walk. The photographs were presented in a random order with regard to the distance from the beginning point of the walk and originals versus foils. The *Scene Sequencing task* was designed to assess participants' temporal-spatial knowledge of the original route. Participants were provided with 25 randomly ordered photographic prints showing scenes from the walk, and were instructed to arrange them in proper temporal sequence starting with the beginning point of the walk. The *Intra-route Distance Judgment task* was designed to assess participants' knowledge of metric distances along the original route. The same 25 photographs used in the scene sequencing task were employed, with the order produced by the participant in the scene sequencing task preserved. Participants produced distance estimates between adjacent scenes. Finally, the *Map Placement Task* was designed to assess participants' configurational knowledge of the area through which the original walk passed. Task materials consisted of the same 25 photographs used in the previous two tasks and a street map of the area in which the route was situated. Participants were shown the photographs one at a time and instructed to mark on the street map with a pencil the exact location depicted in the scene.

Allen *et al.* (1996) found that the "Spatial Sequential Memory" predicted the "Topological Environmental Knowledge". This study suggests that learning of a new environment is supported by VSWM.

It is worth noting that neither the "*Euclidean Distance Judgement*" nor the "*Direction Judgment*" loaded on the "Topological Environmental Knowledge". In the *Euclidean Distance Judgement* and *Direction Judgment* participants were instructed to provide Euclidean distances and direction estimates from one viewpoint to a series of six unseen target Locations along the walk. What is more, these two tasks were not predicted by the Spatial Sequential Memory, showing correlation near to zero between the two *Maze Tasks* and the *Euclidean Distance Judgement*. This result suggests that on the one hand the "Spatial Sequential Memory" is scarcely involved in the learning of the reciprocal interrelations between the landmarks positions (*relative positions*). On the other hand, "Spatial Sequential Memory" predicts the "Route Knowledge" ("Route Reversal Task" and "Intra-Route Distance Judgment Task") and some aspects of the Survey Knowledge like the "*absolute positions"*, namely the position of an object with respect to a structured system of coordinates ("Map Placement Task").

The involvement of VSWM in Route Knowledge was also strongly supported by Pazzaglia and Cornoldi (1999). The authors found that subjects with higher score in the Corsi Block Test had better memory for the verbal description of a route. Twenty two students differentiated for their spatial ability, served as participants. They had been chosen from a sample of 34 undergraduate students. Measures of individual differences in spatial ability were collected using Corsi's block test (Milner, 1971), in which participants have to retain a sequence of targeted movements performed by an experimenter. Participants were defined as a low spatial ability individuals if they had a score equal to or lower than 5 in the Corsi block test. Participants were included in the high spatial ability group if they had a score higher than or equal to 7 in the Corsi block test. A verbal digit span test was also administered and the two groups were matched for verbal span. Next, a spatial text containing the description of an Italian city was given to the participants. The text described how to go from one part of the city to another. During a group session participants were required to read the written description for no more than two minutes. As soon as they had finished reading, they had to write all the relevant information they could remember: they were allowed to recall the information in any order on condition that the correct spatial information was preserved. Results showed that memory performance for the high visuospatial group was significantly better than that for the low group. This result suggests a role of VSWM in learning and processing of new routes, even if the environment is presented in a verbal modality.

Similar results were found by Conte, Cornoldi, Pazzaglia, and Sanavio (1995). In this study, children with higher 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", also were better in a spatial orientation task, which consisted in learning to move, blindfolded, within a room. Results hint to a relationship between environmental learning skills and working memory. Finally, Vanetti and Allen (1968), in a study looking at the communication of environmental knowledge, found that high spatial ability subjects were significantly better at producing effective route descriptions.

A body of studies using dual task methodology, showed the implication of VSWM in memory for movements and spatial navigation. Smyth and Scholey (1994) found that the memory for a sequence of observed arm movements to a series of random block on a table top was disrupted by asking volunteers to perform unrelated arm movements during presentation. These results indicate an overlap in the cognitive resources required for movement memory and those required for movement execution. Some other studies have indicated that these cognitive resources also might be involved in spatial learning. Pazzaglia and Cornoldi (1999), using a selective-interference paradigm, demonstrated that the spatial WM plays an essential role in the processing of route descriptions. Route memory performance was found to be selectively disrupted by a concurrent spatial-sequential task. Two types of matched descriptions of the same environment were made up: descriptions from a route perspective and descriptions that focused on the visual features of the same environments (visual descriptions). The descriptions regarded four different environments: two enclosed environments (a zoo and a sports centre) and two open ones (a farm and a tourist centre). Two concurrent tasks, one visual and one spatial were arranged. For the visual concurrent task, layouts of figures were projected on a computer screen. The layout was either the same as in the previous presentation, or it differed by one figure. The participants' task consisted in detecting when a figure had been changed with respect to the layout immediately preceding it. In the spatial-sequential version of the task, a series of five figures was projected on a computer screen. In the next presentation the figures were presented either in the same order, or the order of presentation changed by reversing two figures. The visual and route descriptions of the environment were auditorily presented to the participants, who were also required to perform the visual or spatial-sequential concurrent task. A free recall task was required at the end of each description. Results showed a significant interaction between the type of description and the version of concurrent task: A selective interference pattern emerged, with route descriptions more disrupted by the concurrent spatial-sequential 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-sequential components of Working Memory are particularly involved in memory for routes. Finally, 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, subjects imagined climbing the routes under control or concurrent spatial tapping conditions. Spatial Tapping, which is supposed to impair the VSWM processing, impaired the performance on "mental climbing" for both routes. Indeed, to mentally complete the routes, subjects under tapping conditions took more time than subjects under control condition. This result suggests that VSWM supports planning and execution of a route.

All the above results suggest the existence of a link between VSWM and learning or representation of the environments.

8.2 Direct evidences

More direct evidences supporting the hypothesis of the involvement of VSWM in environmental learning stem from map learning studies.

Recently, Garden, Cornoldi and Logie (2002) have investigated the role of VSWM in Route Learning in two experiments. The authors, using a dual task methodology, found that Spatial Tapping disrupted route recognition more than *Articulatory Suppression*. In the first experiment, participants learned either route segments from map or non-sense words. The learning phase could include either a concurrent Spatial Tapping task or a concurrent *Articulatory Suppression* task. For the *Route-learning task*, two routes were chosen from the map of a real city (Padova). Each route consisted of 21 segments (marked as red strips) on a monochromatic, schematic map of the city centre. Within each segment, there were always a minimum of two and a maximum of four directions that could be taken, only one of which was indicated for the route to be learned. For the recognition phase, two booklets were prepared (one for each route) containing 21 complete maps. A box along each item showed two, three or four alternative directional choices for each of the 21 segments previously presented. Route one had a total of 11 two-choice segments, 9 three-choice segments and 1 four-choice segment. Route two had 12 two-choice segments, 8 three-choice segments and 1 four- choice segment. All subjects were told that they must try to remember the segments of a route on a map and that the route would be presented as a sequence of individual segments. The 21 experimental segments for one of the routes were presented in sequential order to each subject on a series of printed sheets at a rate of one every two seconds. Each segment was presented on a different printed sheet without indication of the other segments and therefore the subject was required to build an internal representation of the route. Following presentation of the segments there was a blank interval of 90 seconds. After the retention interval, subjects were given a recognition test in which they were shown the segments in the same order as before, but this time for each segment the map showed a choice of two or three alternative directions. Along with the map was a set of two or three boxes, showing a close-up of the relevant map section with the two or three alternative routes marked. Subjects were asked to indicate rapidly by pointing to what they thought was the correct segment. Immediately after the subject's response a new segment was presented.

For the *Nonsense word learning task*, two lists of 21 nonsense words were prepared for the presentation phase. These words were characteristically not easily associable to existing words in Italian. The letters of each nonsense word were then rearranged to form three similar nonsense words, which acted as alternative choices in the recognition phase. Two booklets were constructed for the recognition phase, one for each list. An example of nonsense word from list one was DILUFO and the corresponding recognition set for the word was FOLIDU, LIDUFO, DULIFO, DILUFO. The *nonsense word task* followed the same procedure as employed for route-learning. Each list was presented by means of a series of printed sheets, with one word on each sheet presented at a rate of one every 2 seconds. Following the 90-second retention interval, subjects were shown a series of sheets each containing four items, one of which was identical to an item seen previously (see example above). The task of the subjects was to point to the word which they thought had been seen previously. The sequence of items followed the same order as used at presentation.

One visuospatial and one verbal concurrent tasks were arranged. The *Articulatory Suppression* task involved using a sequence of syllables selected on the basis of being fully monosyllabic when pronounced by Italian speakers: "Ba/Be/Bi/Bo/Bu/Ca/Ce/Ci/Co/Cu". The subjects were instructed to say aloud the sequence of syllables at a rate of one syllable per second, and were given practice in doing so. Suppression commenced immediately prior to and continued throughout presentation of one of the sequences of route segments and the nonsense word lists. Suppression ceased during the 90-second retention interval and then was performed again throughout the recognition phase. The *spatial tapping* (visuospatial concurrent task) involved a custom-made keypad comprising a matrix of 3 x 3 square, black, wooden keys.

The subjects were instructed to tap the nine keys at a rate of one tap per second in a specified pattern which had a forward movement from the top-left square to the bottom-right square, followed by the same sequence of movements in reverse. As with *Articulatory Suppression*, the movement was repeated throughout the presentation and the recognition test, but stopped during the 90-second retention interval. Subjects were asked to tap with their preferred writing hand, and were first given practice in generating taps at the one per second rate. The experimenter monitored subjects closely to ensure that these instructions were followed.

From the map learning task emerged that Spatial Tapping impaired the route recognition performance more than *Articulatory Suppression*. On the contrary, from the non-sense words learning task emerged that *Articulatory Suppression* impaired the words recognition task performance more than Spatial Tapping. The effects of *Articulatory Suppression* on the nonsense word learning confirm previous evidence showing that the articulatory loop is particularly critical in learning new and nonsense words (Papagno, Valentine and Baddeley, 1991). The nature of the recognition task, where the distractors had a similar global form and included the same letters in a different order, required that the subject encoded the phonological-articulatory features of the target words and then during the recognition test examined the phonological-articulatory features of the proposed alternatives. However, in the route-learning task the opposite pattern was found, suggesting that a different component of the working memory system, namely VSWM, may be involved in decisions about different route segments, to a larger extent than the articulatory component.

In a correlational study by Bosco, Vecchi and Longoni (2004), participants were required to study the map of a real environment and to perform a battery of tasks requiring the 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). Eight map-knowledge tasks and four VSWM span tests were arranged for this study.

Map-knowledge tasks: A battery of 8 tests based on a map-learning procedure was designed. A simplified map of the Roman Palatino, an archaeological site open to visitors, was prepared. The map was coloured and included sixteen landmarks. After map-learning phase, participants were asked to perform the 8 map Knowledge tasks, which were built up accordingly to the Siegel and White (1975)'s model of different types of spatial knowledge.

To measure the *Landmark knowledge,* the "Landmark recognition" and the "Landmark surrounding recognition" tasks were made up. *Landmark recognition*: each landmark was presented together with two alternatives modified for small visual details and participants had to identify the correct picture. *Landmark surrounding recognition*: each landmark and its surrounding area of the map were presented together with two alternatives in which only the surroundings were incorrect. Participants had to identify the correct picture.

To measure *Route knowledge,* the "Route recognition", the "Wayfinding" and the "Route distance judgement" tasks were arranged. *Route recognition*: Participants had to identify the correct pathways between two designated landmarks. *Wayfinding*: participants were asked to follow a pathway and finally to indicate the arrival point. *Route distance judgement*: Participants had to identify the longest route-distances between a designated landmark and three alternatives. To measure *Survey knowledge,* the "Map completion task", the "Map section rotation" and the "*Euclidean Distance Judgement*" were made up. *Map completion task:* participants had to locate all the sixteen landmarks in an empty map. *Map section rotation*: Eight experimental stimuli showing the spatial relations among three landmarks were designed. Within each trial, four alternatives were presented each including the same three landmarks in different spatial relations. Performance was evaluated in terms of number of correct trials. *Euclidean Distance Judgement*: Participants had to identify the longest distances between a designated landmark and three alternatives.

Four VSWM span tasks tapping the simultaneous/sequential and the active/passive aspects of VSWM were arranged. In the "Jigsaw Puzzle task" (Richardson & Vecchi, 2002) subjects were simultaneously presented with numbered fragments of a picture of a stated object. Participants had to solve the puzzle, not by moving the pieces but by writing down the corresponding numbers in the correct positions on a response grid. This task is supposed to tap the active and simultaneous components of the VSWM. In the "Mental Pathway task" (Vecchi & Cornoldi, 1999) participants had to follow pathways made of statements of direction (e.g. left, right, forward, and backward) in matrices of different complexity. This task was considered by the authors as an active and sequential task. In the "Visual Pattern test" (Della Sala, Gray, Baddeley and Wilson, 1997) participants were presented with a matrix filled by random black squares only for two seconds and then were asked to reproduce the shown pattern of black squares on a completely blank matrix. This task is supposed to tap the passive and simultaneous components of VSWM. Finally, in the "Corsi span test" (Milner, 1971), a passive and sequential task, the subjects had to reproduce the sequence of positions previously shown by the experimenter on a wooden board comprising nine blocks arranged in random positions.

After a 10 minutes session of map-study, each participant was tested on the eight map-knowledge tasks. In a separated session the subjects' VSWM span was tested using the four tasks previously described.

Multiple regression analyses showed that the VSWM span significantly predicted overall map learning. Namely, the involvement of VSWM was more evident for the two active tasks (Jigsaw Puzzle task and Mental Pathway task) than for the passive tasks (Visual Pattern test and Corsi span test).

Moreover, considering each map-knowledge task separately, it emerged that half of the map tasks (*Landmark Recognition, Landmark Surrounding Recognition, Route Recognition* and *Map Completion Task*) were predicted by the VSWM task. It is worth noting that, three out of the four tasks, which were not predicted by the VSWM task, were tasks about distance estimation (*Euclidean Distance Judgement and Route distance judgement*) and, more in general, tasks requiring the knowledge of the reciprocal landmarks' locations (*Map section rotation*). These results mimic Allen *et al.* (1996)'s results in which learning of the *relative positions* (*Euclidean Distance Judgement* and *Direction Judgment* tasks) was unrelated to VSWM.

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 I, participants studied a map with irregular and complex structure, while in

Experiment II the same participants studied a map with a regular and ordered structure. VSWM was found to predict the orientation abilities for both maps. In accordance with Bosco *et al.* (2004), VSWM predicted the overall map learning. Particularly, the two *Landmark knowledge tasks* and the *Map completion task* were predicted by the active and simultaneous components of VSWM (*Jigsaw Puzzle*) while the *Route recognition task* was predicted by the passive and sequential components of VSWM (*Corsi span test*). Again, the *Euclidean Distance Judgement* and the *Map section rotation* were unrelated to the VSWM span.

In conclusion, all the previously described studies point toward a specific involvement of VSWM in the learning of 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, the relationship between VSWM and all the different aspects of map learning was studied through correlational techniques (Bosco *et al.,* 2004; Coluccia & Martello, 2004). The only study which directly addresses 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 offer a study which, on the one hand, might extends 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 using a different experimental technique: the dual task paradigm. Such a method is explained in more details in the next chapter.

9. THE DUAL TASK PARADIGM

Following Eysenck (1994)'s definition, the dual task paradigm (or concurrent tasks method) is an experimental paradigm in which subjects are asked to execute two tasks at the same time (a primary and a secondary task), which are different in their modality of execution. The idea behind this model is that if the participant is able to perform the two tasks simultaneously, with no reduction in performance at either task, then cognitive resources have successfully been divided. The implication would be that the two tasks require two different processing mechanisms. The usual example is that of the skilled drivers, who can drive and conduct a conversation with a passenger at the same time, with no reduction in either their driving nor in their conversation performance. The methodology was first used by Allport, Antonis and Reynolds (1972), who concluded that two tasks could be performed simultaneously, without reduction in performance, if those tasks used different sensory modalities for input and output. For example, a participant can usually "shadow" a message presented to the ears while sight-reading and playing a piece of music, because two different input modalities (auditory and visual) are being used, as well as two different output modalities (speech and motor). However, it is very difficult even for skilled audio-typists to audio-type at the same time as shadowing, since both tasks involve the same (auditory) input modality. According to Eysenck (1994) the dual-task paradigm stemmed from the necessity of discriminating and isolating single components from the complex cognitive processes. Indeed the execution of a primary task is usually the result of several distinct sub-components. For this reason, it is usually hard to analyse, separate, and differentiate the role of the cognitive processes implied in a primary task. What is more, the variables implied in the primary tasks are hypothetical constructs, which are neither directly observable nor accurately measurable. As it is usually impossible to isolate and differentiate a single cognitive component, hence, a selective interference task (secondary task) is used (Eysenck, 1994). Among all the experimental designs, the dual-task paradigm offered to cognitive psychology one of the most effective tools for studying the composition of the main cognitive processes (Eysenck, 1994). For instance, research on divided and focussed attention systematically used the dual task paradigm (Kahneman, 1973; O'Donnell, 1986; Gopher & Donchin, 1986). When using the dual task paradigm, all the studies on working memory start from the assumption that the cognitive system has a limited capacity of resources (Wickens, 1980). The cognitive tasks employ such resources depending on their characteristics and they compete when loading both on the same resources and when the overall demand exceeds the available capacity of the cognitive system. Consequently, primary and/or secondary tasks performances are impaired.

Since the beginning, several studies on Working Memory successfully applied this paradigm. For instance, using this paradigm, Baddeley and Hitch (1974), successfully investigated the functioning of verbal working memory in various tasks such as learning, recall, reasoning, text reading, text comprehension and semantic memory. Usually, the most common secondary task for the verbal interference is the digit span test, in which subjects are asked to recall an increasing number of digits, or the *Articulatory Suppression task*, in which subjects are asked to say aloud a sequence of non-sense syllables. A typical task for visuospatial interference is the spatial tapping task, in which subjects are asked to continuously tap some keys on a pad, following a specified sequence. Different secondary tasks were used for impairing the central executive. Some examples of these are the "random digit generation" and the "random letter generation" tasks in which participant are instructed to generate random sequences of numbers or letters, without repeating twice the same sequence, and the "mental calculation task", in which participant are requested to mentally calculate the results of some addictions or subtractions.

The dual task paradigm was successfully used to demonstrate the existence of two separate subsystems in the working memory (the phonological loop and the visuospatial sketch-pad). Some examples of the dual task method have already been mentioned in the "*Evidences for the existence of the VSWM*" section.

Thanks to the dual-task paradigm, research on working memory has made sensible progress in the past and it is still developing in the present.

10. AIM AND MAIN HYPOTHESES

The main aim of the present work is to experimentally investigate the role of VSWM in map learning. A dual task paradigm is used to test the general hypothesis that the visuospatial interference task impairs map-learning performance more than the verbal interference task. In order to ensure that results are not due to general demands on the cognitive system or by different levels of task complexity, the same interference tasks will be carried out during a primary verbal task. It is predicted that the primary verbal task performance will be affected more by the verbal interference task than by the visuospatial interference tasks. The visuospatial components of WM might be differently involved in map-learning, depending on the different types of spatial knowledge**.**

11. EXPERIMENT I

11.1 Hypotheses

In Experiment I, two concurrent tasks were executed while learning a map and a list of words (primary tasks). The first concurrent task (Spatial Tapping), which is supposed to selectively impair the VSWM processes, is expected to affect map learning. The second concurrent task (*Articulatory Suppression*), which is supposed to selectively damage verbal WM, is expected to affect learning of a list of words.

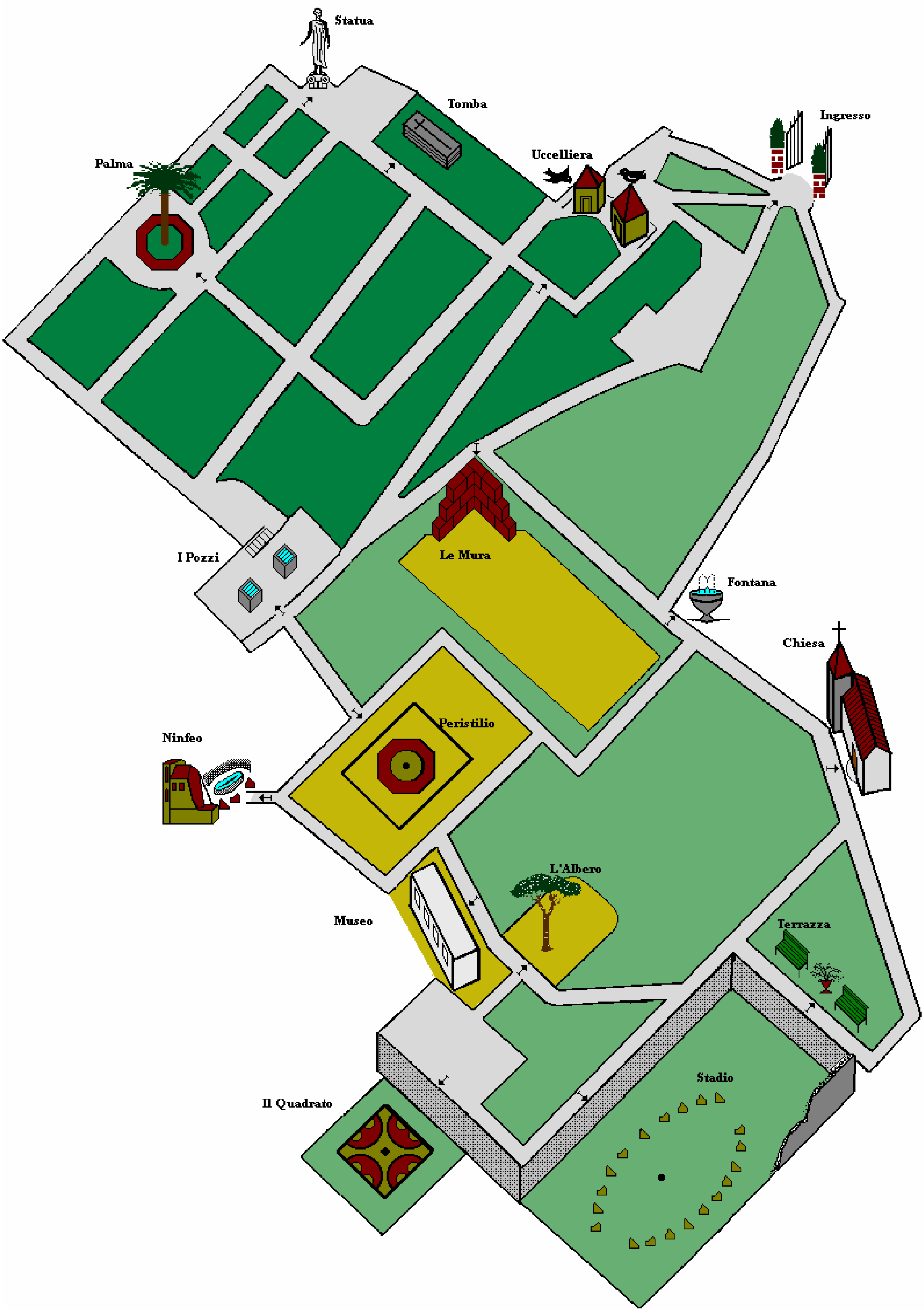
11.2 Method EXP I

11.2.1 Materials

Map

The "Palatin map" (Bosco et al. 2004) was utilized. This map was already successfully used to show the correlation between VSWM and map tasks (Coluccia & Martello, 2004). It depicts 16 landmarks and 12 main routes. To make the map more realistic as possible, some details have to be taken into great consideration. Landmarks should be represented neither in a frontal view, nor from the top, rather they must be offered in ¾ perspective. Landmarks colours are similar to the real world colours. The map-terrain is composed by three different main colours: dark green (intense vegetation), light green (lawn, grass) and yellow-brown (sand, earth, uncultured ground). All the roads and paths are grey. Each landmark must face to the street, because route knowledge is measured by asking the participants to move from one landmark to another landmark using the roads. Some little black arrows point to the landmark in the position it faces to the street.

Fig 6 - "the Palatine Map" used in Experiment I



Map-learning Measures

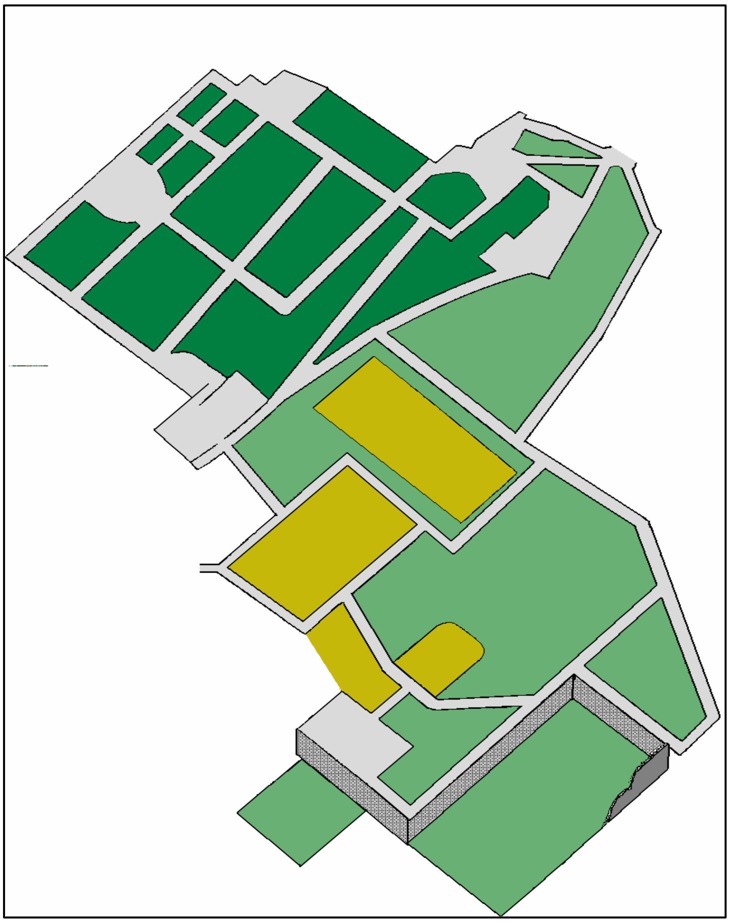
Three tasks tapping different types of spatial knowledge (Landmark, Survey and Route) were chosen from previous studies.

Landmark Positioning Task: This task has been typically employed by previous research (Holding & Holding, 1989; Bosco *et al.* 2004; Coluccia & Martello, 2004) 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) claims that Landmark knowledge is the ability to identify salient points of reference. Only the mere position of such reference point 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 the "Landmark knowledge" in terms of the "knowledge of the *absolute landmark positions*", namely the position of an object with respect to a structured system of coordinates.

Subjects were requested to re-position all the 16 landmarks on a blank map (fig. 7). Two paper-sheets were given to each participant. On the first one, the original map without landmark was shown, while on the second one, all the landmarks were listed. Participants were asked to mark with a cross on the map the exact position of each landmark.

Number of items: 16. Scoring: mean error in millimeters. Error was calculated as the difference between the real position of the landmark and the position pointed by the subject.

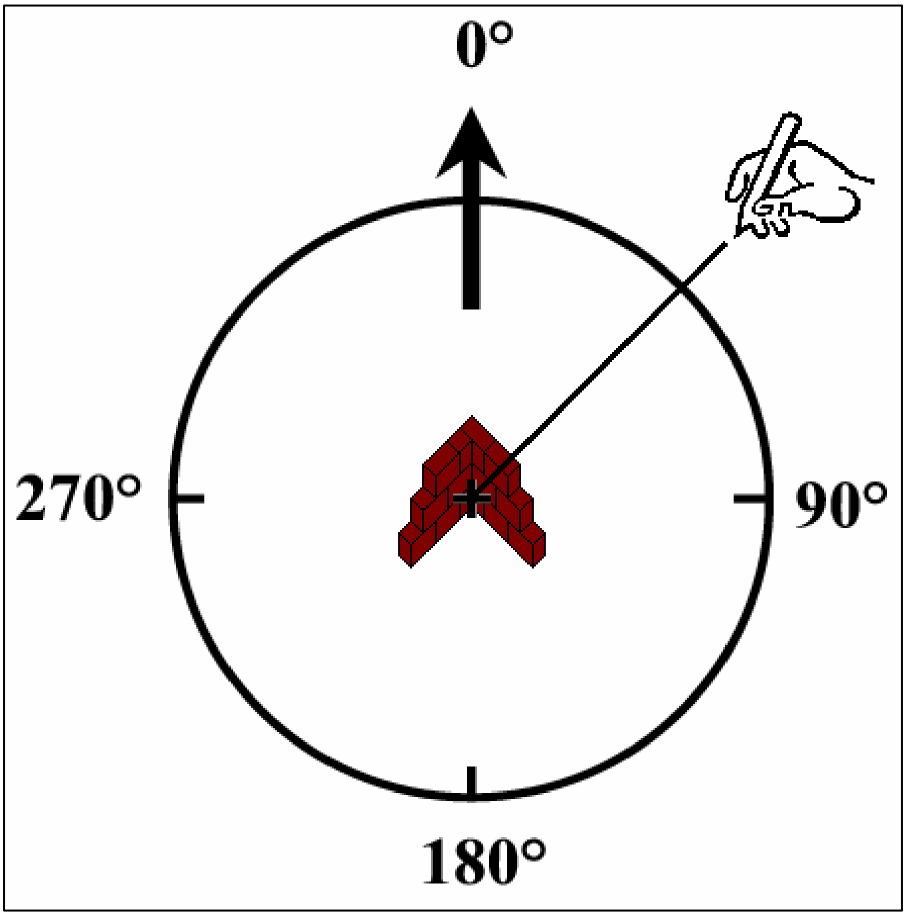
Fig.7 - The empty map used for the Landmark Positioning Task



Pointing Task: Also this task has been typically employed by previous research (Sadalla & Montello, 1989; Kirasic *et al.,* 1984; Holding & Holding, 1989; Montello & Pick 1993; Lawton *et al*., 1996; Lawton, 1996; Lawton & Morrin, 1999; Waller *et al*., 2001) as a good measure of Survey Knowledge. Specifically, this task is supposed to measure a sub-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. Subjects were instructed to indicate direction of a target landmark, starting from another landmark and using judgments in terms of angular degrees.

This task is composed by 8 items. Each item consists of a Landmark positioned at the centre of a circumference. An arrow on the top side of the circumference points from the centre of the circle to the upside of the sheet (which is conventionally the North and indicates 0°). Each item is also accompanied by a written line which states what landmarks to point to. Therefore, each item requires connecting the starting-landmark with the target-landmark. An example of a *Pointing Task* item is illustrated in Fig. 8.

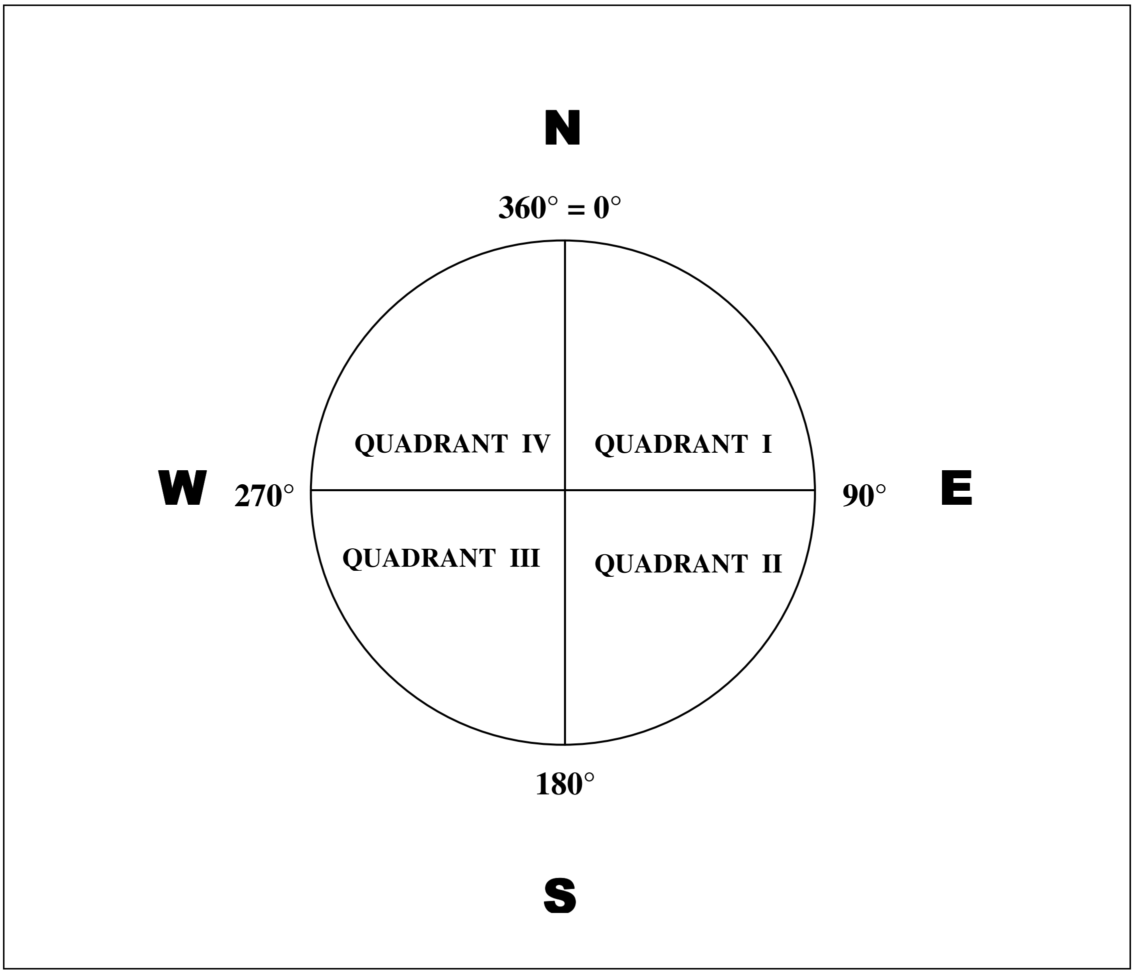
Fig. 8 - An example for the Pointing Task



Starting from the "MURA" point toward the "INGRESSO"

Angular judgements were asked for each different direction in order to tap all the four quadrants of the circle (fig. 9: 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°). As there were 8 items, 2 items for each quadrant were designed.

Fig.9 –The structure used for arranging the Pointing Task's items



Number of items: 8. Scoring: mean error in degree. Error was calculated as the difference between the angular direction and the direction pointed to by the subject.

Route-Finding Task: This task is used to measure Route Knowledge (Ward, et al. 1986; Miller & Santoni, 1986; Schmitz, 1997, Dabbs et al., 1998). Subjects were requested to mentally follow a route description and to indicate the arrival point, selecting the right answer from 3 alternatives. This was an 8 items task. Each item consisted of a route description, which started from a landmark and stopped next to another landmark (arrival point), which 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. An example follows.

You are facing the "Palma", then turn left, go straight-on to the end of the street. Then turn right. On your right you will find

A) MURA B) STATUA C) PERISTILIO

Number of items: 8. Scoring: number of right answers.

The primary verbal task: Non-sense words list

The same primary verbal task of the study of Garden et al (2002) was chosen. For the verbal learning condition (Fig. 10), a list of 28 “three-syllable” nonsense words was used (see Cornoldi, Friso, Miato, Molin, Poli, 1993). Every word had the same number of consonants and vowels and was meaningless for Italian language. The number “28” was about the total number of elements depicted in Palatine Map (16 landmarks + 12 roads). The list of words was simultaneously and visually presented.

Fig. 10 – The "non-sense words" list used for the primary verbal task in Experiment I

FICEGE	**CIDISI**
SESIFE	**LUGOFI**
RAVISE	**LUREDE**
TIGADA	**SANEMI**
RIVEMA	**NOBAMA**
MATADI	**NIBEPA**
ROLERA	**NUGASA**
RENIMI	**NARETO**
VICOCU	**CEPOTA**
DOPOMI	**VIFABE**
POREBO	**MEDELA**
REBAGA	**PETIRA**
MEFOGA	**GECICE**
FARANA	**SIGATO**

Verbal learning: Non-sense words recognition task

Subjects were requested to mark from 4 alternatives the word that was present in the studied list. The wrong alternatives were anagrams of the original words. Scoring: Number of right answers. An example of the recall list is shown in Fig 11.

Fig. 11 – The recall list for the non-sense words recognition task

1.	SAMINE	MISANE	NESAMI	SANEMI
2.	GOLUFI	GOFILU	LUGOFI	FILUGO
3.	ROLERA	RORELA	LORERA	LORARE
4.	GAREBA	BAREGA	REBAGA	GABERA
5.	TIGADA	DITAGA	TIDAGA	DIGATA
6.	SESIFE	FESESI	SEFESI	SIFESE
7.	……	…..	…..	…..

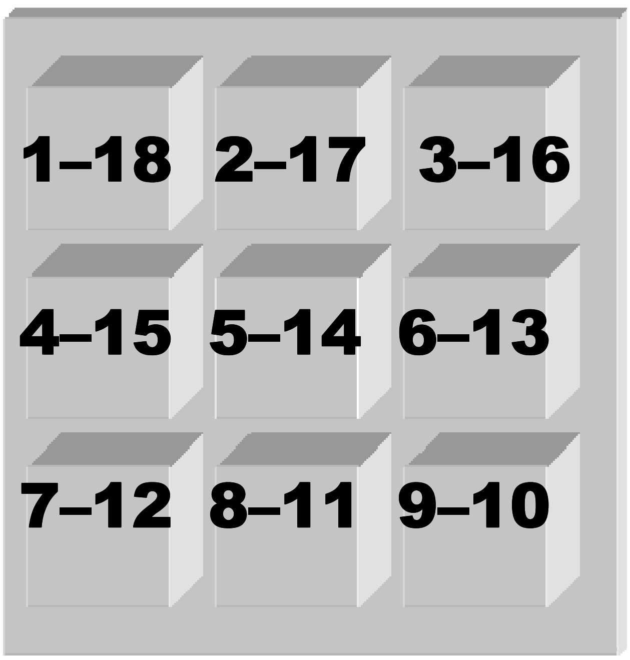
Number of items: 28. Scoring: number of right answers.

Concurrent tasks

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

Spatial tapping: the subjects were instructed to continuously tap the 9 raised corners of a 3x3 wooden pad, *at the rate of* one tap per second, following a specified patter (fig.12) which have forward movement from the top-left square to the bottom right square, followed by the same sequence of movement in reverse.

Fig.12 – Schematic representation of the wooden pad used for the 9-keys spatial tapping task. The numbers show the ordered series of taps required to complete a full sequence.



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 did a mistake (wrong sequence of tap or syllable) the experimenter warned the subject 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 neither during the delay nor during the test phase.

11.2.2 Procedure

Ninety-six volunteers (48 males and 48 females), aged from 19 to 30, took part in Experiment I. Thirty-two participants (group 1) performed the map learning (5' minutes) without interference. Then they performed the primary verbal memory task (5' minutes) without interference. A second group of 32 participants (group 2) performed the map learning task in a Spatial Tapping condition. Then, half of them performed the primary verbal memory task with *Articulatory Suppression*, and the other half performed the same verbal memory task with tapping. A third group of 32 participants (group 3) performed the map learning task under *Articulatory Suppression*. Then, half of them performed the primary verbal memory task with

Articulatory Suppression, and the other half performed the same verbal memory task with tapping. Concurrent tasks were executed only during the learning phases. Each learning phase lasted 5 minutes. After the learning phase, the map or the list of words was hidden and the participants observed a fixation point for 90” (delay interval). Then the participants performed the three map learning tasks (Landmark Positioning, Pointing and Route Finding), if they had previously studied the map, or the Verbal learning task (Non-sense words recognition), if they had previously studied the list of words. Gender and order of presentation of map / list of words were counterbalanced.

11.3 Results EXP I

<u>Landmark positioning task</u>

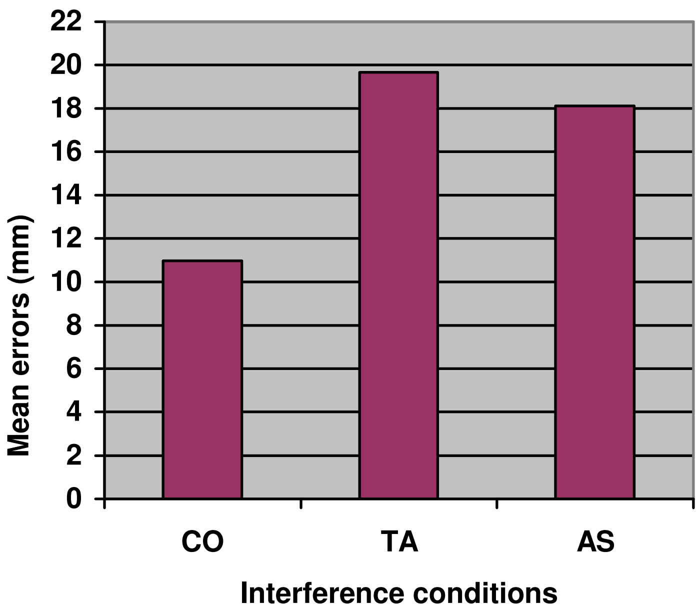
Descriptive Statistics

Tab I reports the descriptive statistics for *Landmark Positioning Task* grouped by the type of interference task (TA= Spatial Tapping, AS= *Articulatory Suppression*, CO=Control). Scores are reported as mean errors in millimetres. Performance levels for each condition are shown in Fig. 13.

Tab I. Landmark Positioning (mean error)

	Ss	Mean	Std.Dev.	Std.Err
CO	32	10,98	12,25	2,16
TA	32	19,67	16,78	2,96
AS	32	18,10	13,13	2,32

Fig.13 – Landmark Positioning Task. Mean error in millimetres for the control, tapping and Articulatory Suppression conditions.



ANOVA

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 emerged ($F_{(2,93)}$= 3.41, *MSE* = 201.49, $p < .05$), Post-hoc analysis showed a significant difference between the Control and Tapping conditions, but no differences between Control and Articulatory Suppression. Corresponding p-level values are reported in tab II.

Tab II - Landmark Positioning Task - Probabilities for Post Hoc Tukey's test

	CO	TA	AS
CO		**0,04**	0,12
TA	**0,04**		0,90
AS	0,12	0,90	

p level values are reported. Significant values are marked for p < .05

Pointing Task

Descriptive Statistics

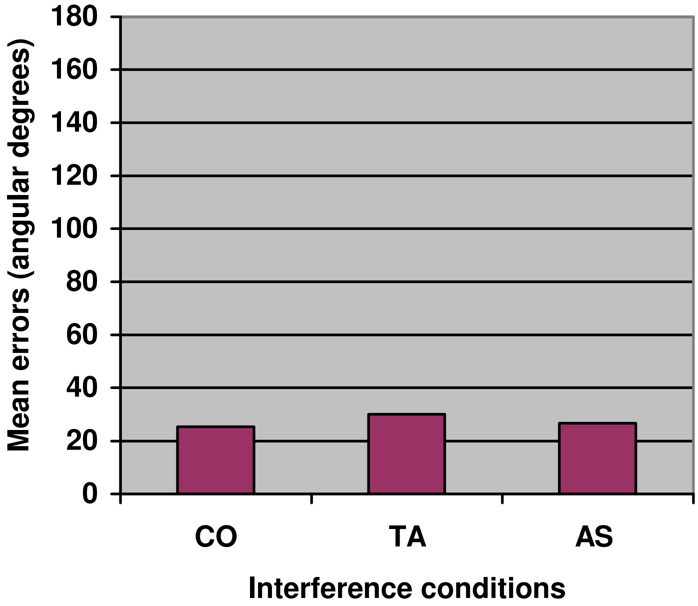
Tab. III reports the descriptive statistics for the *Pointing Task* grouped by the type of interference task (TA= Spatial Tapping, AS= *Articulatory Suppression*, CO=Control)

Scores are reported as mean errors in angular degrees. Performance levels for each condition are shown in Fig. 14

Tab III Pointing Task (Mean Error)

	Ss	Mean	Std.Dev.	Std.Err
CO	32	25.41	9.94	1.76
TA	32	30.07	18.20	3.22
AS	32	26.66	10.62	1.88

Fig.14 – Pointing Task. Mean error in angular degrees for the control, tapping and Articulatory Suppression conditions.



ANOVA

A one-way ANOVA with Pointing as a dependent variable and type of interference task as a three-level factor (Control, Spatial Tapping, *Articulatory Suppression*) was performed. As no significant effects emerged ($F_{(2,93)}$= 1.03, *MSE* = 181,00), post-hoc analyses were not run.

<u>Route-Finding task</u>

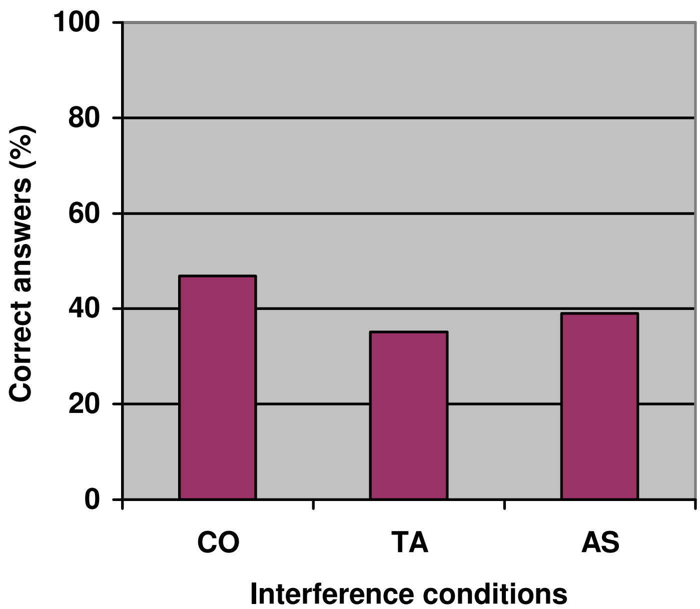
Descriptive Statistics

Tab IV reports the descriptive statistics for *Route-Finding Task* grouped by the type of interference task (TA= Spatial Tapping, AS= *Articulatory Suppression*, CO=Control). Scores are reported as percentage of right answers. Performance levels for each condition are shown in Fig. 15

Tab IV - Route task (% of Right answers)

Ss	Mean	Std.Dev.	Std.Err	
CO	32	46.88	17.96	3.18
TA	32	35.16	16.63	2.94
AS	32	39.06	17.89	3.16

Fig.15 – Route-Finding Task. Percentage of right answers for the control, tapping and Articulatory Suppression conditions.



ANOVA

A 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 performed. As a significant effect emerged ($F_{(2,93)} = 3.72$; MSE = 306.4; $p < .05$), post-hoc analysis was run. A significant difference was found between Control and Tapping conditions, but no differences between Control and *Articulatory Suppression* emerged. Corresponding p-level values are reported in tab V.

Tab V – Route-Finding Task - Probabilities for Post Hoc Tukey test

	CO	TA	AS
CO		**0,02**	0,18
TA	**0,02**		0,65
AS	0,18	0,65	

p level values are reported. Significant values are marked for $p < .05$

Non-sense words recognition task

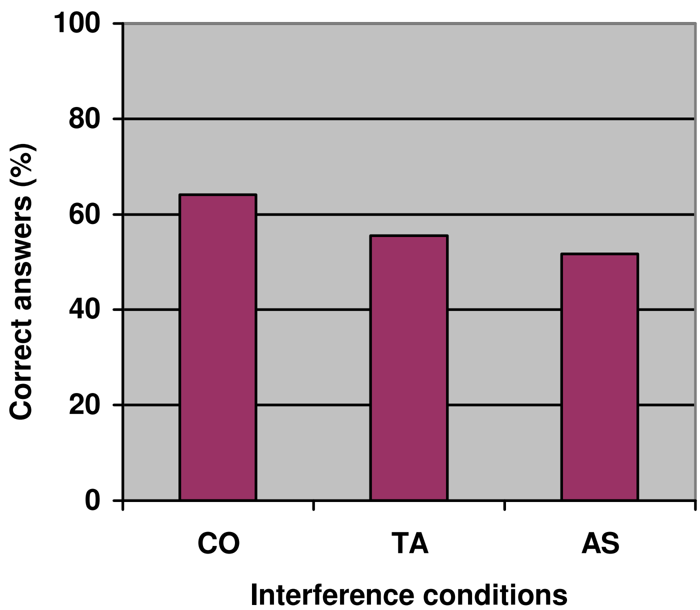
Descriptive Statistics

Tab VI shows the descriptive statistics for the "Non-sense words recognition task" grouped by the type of interference task (TA= Spatial Tapping, AS= *Articulatory Suppression*, CO=Control). Scores are reported as percentage of right answers. Performance levels for each condition are shown in Fig. 16

Tab VI Non-sense words recognition task (% of Right answers)

	Ss	Mean	Std.Dev.	Std.Err
CO	32	64,06	14,68	2,60
TA	32	55,47	15,10	2,67
AS	32	51,67	11,90	2,10

Fig.16 – Non-sense words recognition task. Percentage of right answers for the control, tapping and Articulatory Suppression conditions.



ANOVA

A one-way ANOVA with "Non-sense words recognition task" 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

($F_{(2,93)}$ = 6.61; *MSE* = 195.00; p< .01), post-hoc analysis was run. A significant difference was found between Control and *Articulatory Suppression* conditions. Unexpectedly, the difference was also significant between Control and Tapping conditions. Corresponding p-level values are reported in tab *VII*

Tab VII – Non-sense words learning task - Probabilities for Post Hoc Tukey test

	CO	TA	AS
CO		**0,04**	**0,001**
TA	**0,04**		0,52
AS	**0,001**	0,52	

p level values are reported. Significant values are marked for p < .05

11.4 Discussion (EXP I)

In accordance with the hypotheses, results showed that *Articulatory Suppression* affected the primary verbal task but not the map learning task. The Spatial Tapping Task significantly interfered with some aspects of map learning. In particular, learning of the "*absolute landmarks' positions*" and Route Knowledge were impaired by the concurrent tapping task, while the *Pointing Task* remained unaffected. Possibly, VSWM is not particularly involved in the learning of reciprocal landmarks positions.

Unexpectedly, the Spatial Tapping Task impaired performance in the primary verbal task too.

12. EXPERIMENT II

As the Spatial Tapping task interfered with the word learning task, three sub-hypotheses were generated:

1. **Non-sense words learning is a proper verbal task. The 9-keys Tapping task is a general demanding task, which loads on the central executive and VSWM is not implied in map learning.**
2. **The 9-keys Tapping task is selective. There are some spatial components in the non-sense word learning task. Indeed, words are visually and simultaneously presented and spatial strategies might have been used: e.g. FIGECE is top-left, SIGATO is down-right.**
3. ***Both* the 9-keys Tapping task is too demanding *and* the non-sense word task has spatial components.**

12.1 Hypothesis EXP II

In order to test the first hypothesis, Experiment II was conducted. In this experiment, the 9 keys spatial tapping task was replaced by a 4 keys spatial tapping task, which is supposed to be less demanding. If the 4-k tapping task does not affect map learning, then the interference which was found in Experiment I was probably due to a general disruptive effect. If even the 4-k tapping task affects map learning, then the interference which was found in experiment I was probably due to the specific characteristics of the primary verbal task. For example, the modality of presentation (visual and simultaneous) could have supported some spatial strategies.

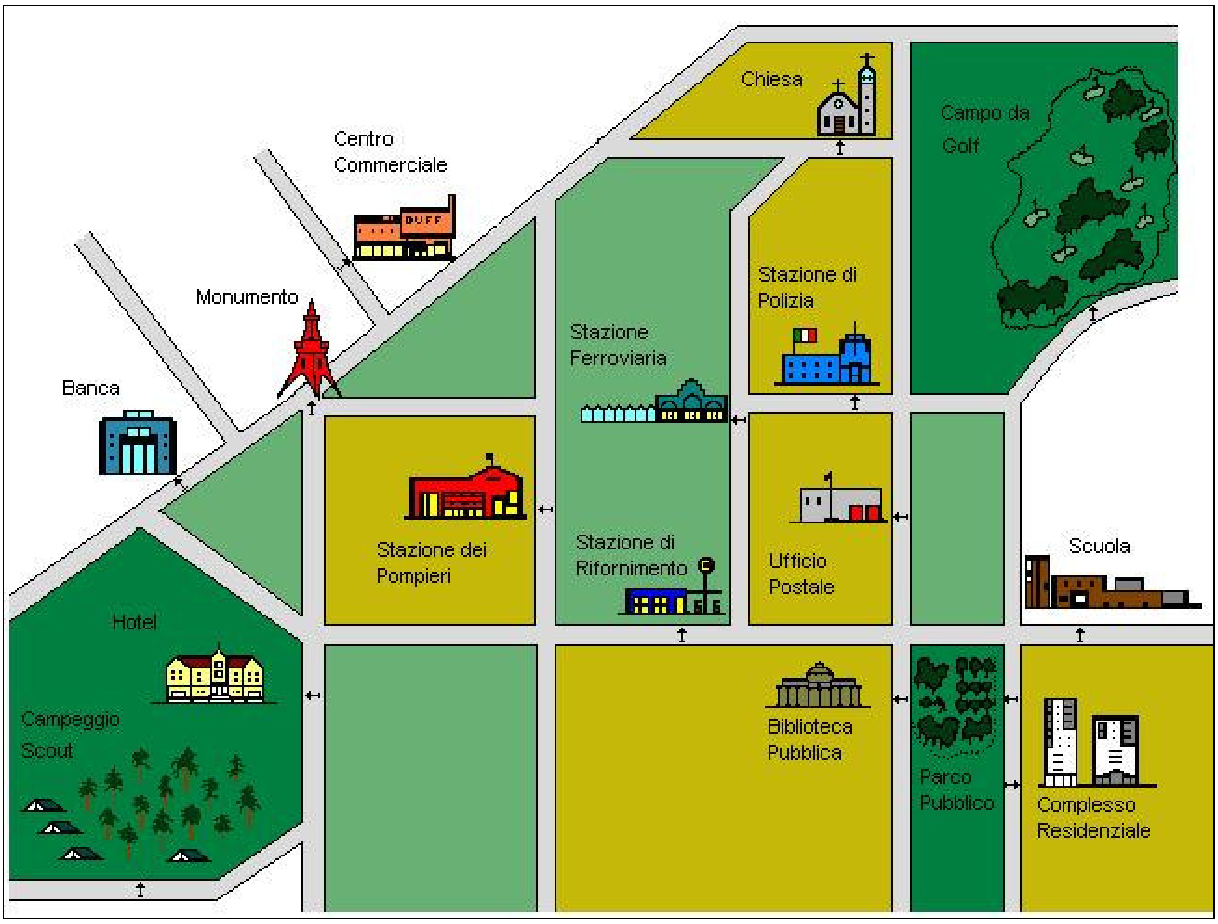
12.2 Method

12.2.1 Materials

Maps

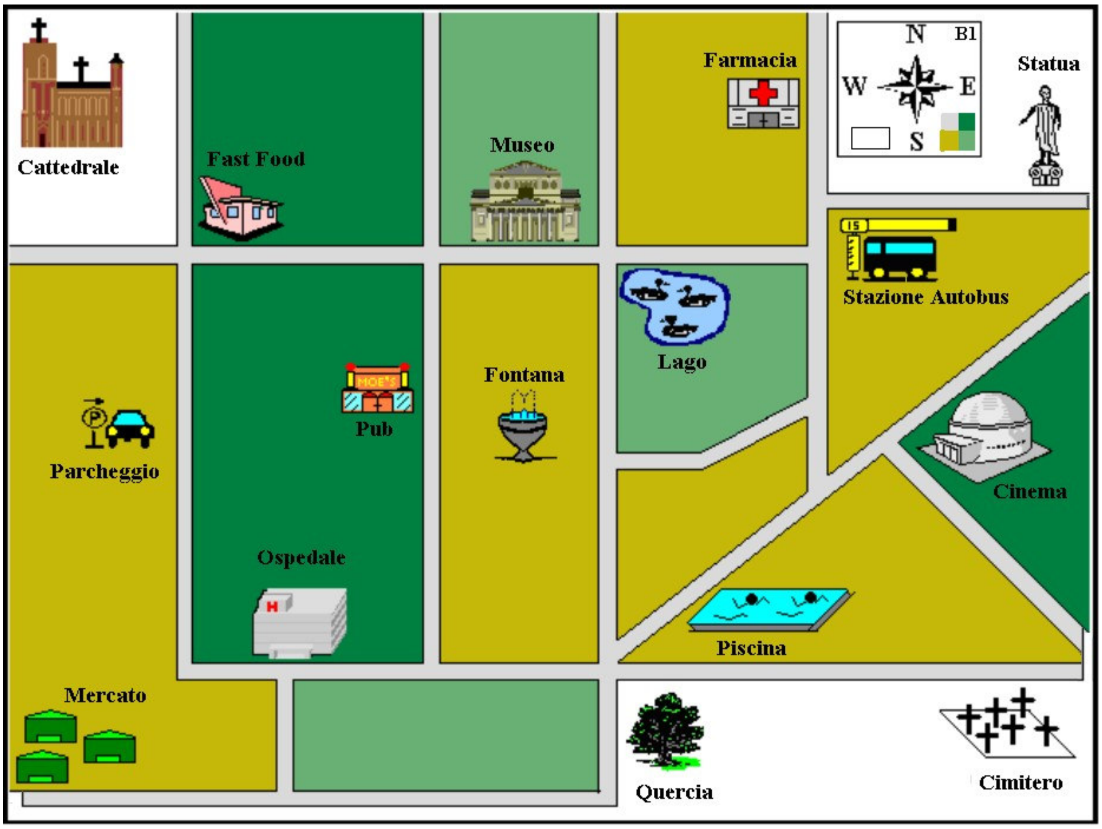
The “TOWN map” (adapted from Thorndyke & Stasz, 1980) was utilized as Map A. This map was already successfully used to show the correlation between VSWM and map tasks (Coluccia & Martello, 2004). It depicts 16 landmarks and 12 routes (see Fig.17).

Fig.17 - the "Town Map" (map A) used in Experiment II



The Palatine map of Experiment I was replaced by the Town map. If the spatial tapping task affects performance also in the Town map, it can be concluded that results do not depend on the specific characteristics of the used map. Then, in order to further extend results to different maps and in order to carry out a within subject design, a second map (MAP B) was used. Map B (fig. 18) was constructed using the same main colours and the same number of landmark and routes.

Fig.18 – the " Map B", based on the map A.



Map-learning Measures

All the tasks of Experiment I were used, except for the *Pointing Task*. As the *Pointing Task* was unaffected by a high-interference tapping task (9-keys), it is not reasonable to expect that a low-loading tapping task (4-keys) can impair the performance on the *Pointing Task*.

Landmark Positioning Task: Subjects are requested to re-position all the 16 landmarks on a blank map. This was the same task as Experiment I.

Number of items: 16. Scoring: mean error in millimetres.

Route-Finding Task: subjects were requested to mentally follow a route on the map and to indicate the arrival point, selecting the right answer from 4 alternatives.

Each item consisted of a sequence of written instructions. This task was very similar to the *"Route-Finding Task"* used in Experiment I. Only few changes were made to enhance the comprehension of the task. Some new rules were applied for structuring the new items:

1. Any reference to landmarks in the written instructions was avoided. A landmark was mentioned exclusively with reference to the starting point. Landmarks present within the route were not mentioned. The starting point was depicted in order to avoid misunderstandings. Within the icon depicting the starting point, a little black arrow pointed to the direction of the landmark, in order to represent the starting position and direction.
2. Each item contained 4 alternatives instead of three (see Experiment I).
3. Each item was composed by the same number of turns.
4. If a landmark was used as a starting point in an item, it could not be used as the arrival point in the remaining items.
5. Instructions within each item were given either in terms of cardinal points (fig. 20) or in terms of left-right sequences of turns (fig. 19).

Number of items: 8. *Scoring*: Number of right answers.

Fig.19 – Route task. an example of an item in which the instructions are given in terms of left-right sequences of turns.

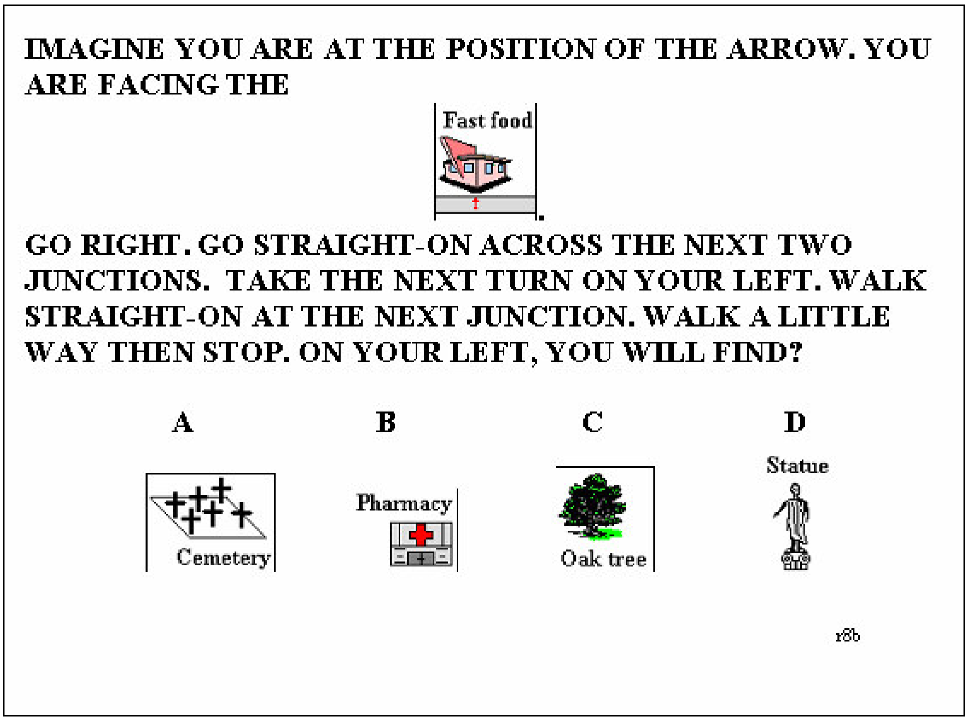
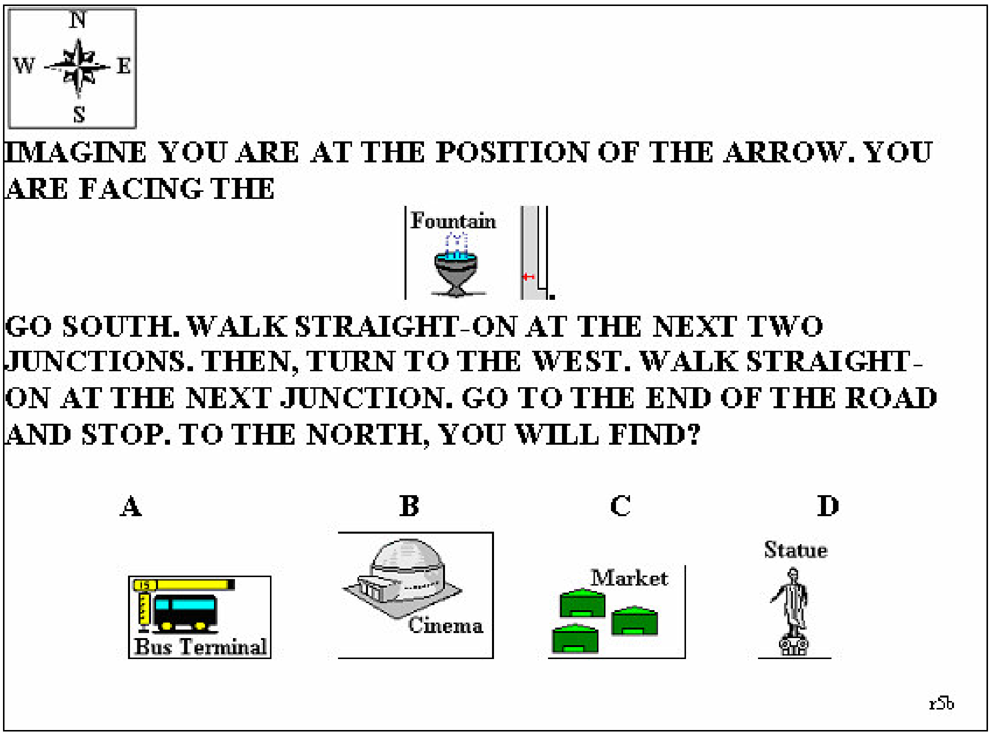


Fig.20 – Route task. An example of an item in which the instructions are given in terms of cardinal points.

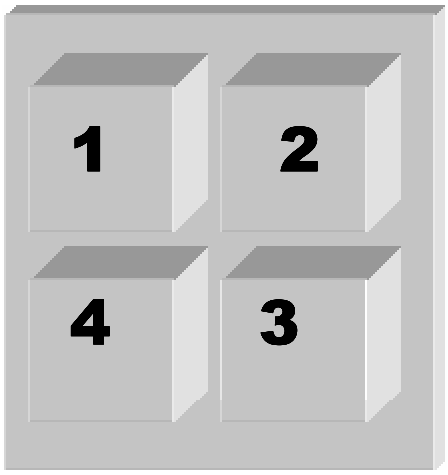


Concurrent task

Spatial tapping: subjects were requested to continuously tap the four raised corners of a 2x2 pad, one per second, in a clockwise direction (fig. 21).

Before each learning phase, participants had 1 minute for practicing the secondary task. During the practice, only the secondary task was executed without the primary task.

Fig.21 – Schematic representation of the wooden pad used for the 4-keys spatial tapping task. The numbers show the ordered series of taps required to complete a full sequence.



12.2.2 Procedure

24 subjects, who did not participate in Experiment I, studied for 5 minutes a first map (**A or B**), while performing or not the tapping task. after 5 minutes, the map was hidden and participants executed some arithmetic tasks (30''). Then, they performed the *Landmark Positioning Task* and the *Route-Finding Task*. Afterwards, the same subjects studied for 5 minutes a second map (**B or A**), while performing or not the tapping task. Again, after 5 minutes, the map was hidden and subjects executed some arithmetic tasks (30''). Then they performed the *Landmark Positioning* and the *Route-Finding Task*.

The order of presentations of control / tapping conditions and maps (A/B) were counterbalanced using four different groups of 6 participants. Each group was composed by 3 males and 3 females:

Group 1: map A, tapping – map B, control

Group 2: map B, tapping – map A, control

Group 3: map A, control – map B, tapping

Group 4: map B, control– map A, tapping

After performing the task in the first map, subjects knew the kind of tasks that they were expected to do in the second map. Knowing the tasks could facilitate their performance with the second map, despite of the first one. In order to reduce sequence effect, in addition to counterbalancing, a practice map with an example for

Landmark Positioning Task and *Route-Finding Task* was given before starting with the real experiment.

The fixation point (which in Experiment I subjects were asked to observe for 90”), was replaced by arithmetic tasks in order to avoid any possible rehearsal during delay. Indeed, one might ague that during the 90” of blank interval in Experiment I, participants could have rehearsed the map and/or the list of words.

The concurrent spatial tapping task was executed only during map learning.

12.3 Results EXP II

Landmark positioning task

Descriptive Statistics

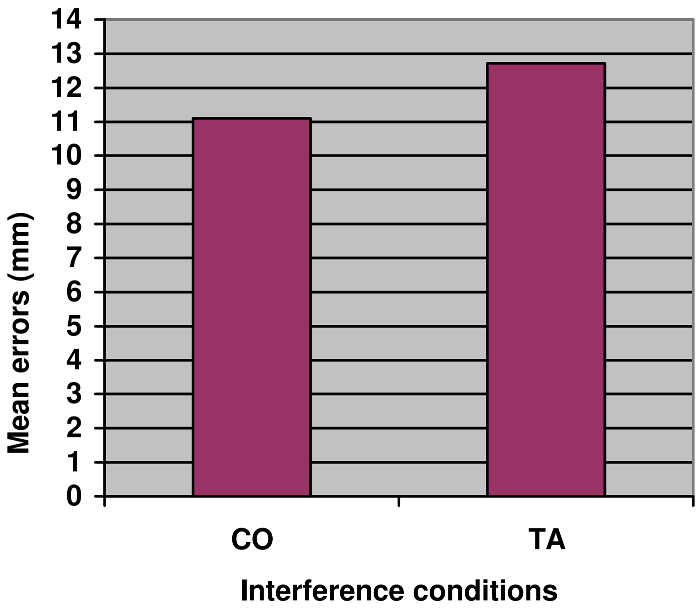
Tab VIII reports the descriptive statistics for the *Landmark Positioning Task* grouped by the presence of interference task (TA= Spatial Tapping, CO=Control). Scores are reported as mean error in millimetres. Performance levels for each condition are shown in Fig 22.

Tab VIII - Landmark Positioning (Mean Error)

	Ss	Mean	Std.Dev.	Std.Err
CO	24	11.11	3.04	0.62

TA	24	12.72	3.60	0.73

Fig.22 – Landmark Positioning Task. Mean error in millimetres for the control and tapping conditions.



ANOVA

A one-way ANOVA with Landmark Positioning as a dependent variable and presence of the interference task as a two level within-factor (Control vs Spatial Tapping) was performed. A significant difference was found between Control and Tapping conditions ($F_{(1,23)}= 6.51$, *MSE* = 4.77, $p < .05$), with mean errors higher in the Tapping condition than in the Control condition.

<u>Route-Finding task</u>

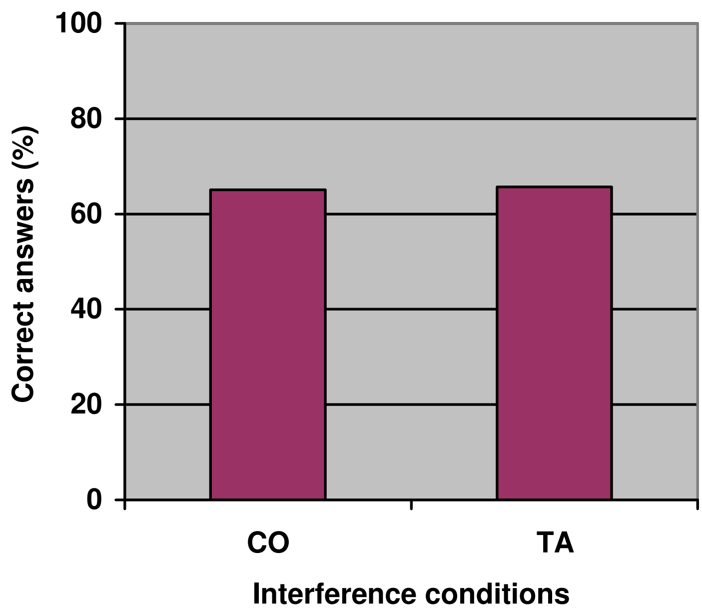
Descriptive Statistics

Tab IX reports the descriptive statistics for the *Route-Finding Task* grouped by the presence of interference task (TA= Spatial Tapping, CO=Control). Scores are reported in percentage of right answers. Performance levels for each condition are shown in Fig 23.

Tab IX - Route-finding (% of right answers)

	Ss	Mean	Std.Dev.	Std.Err
CO	24	65.10	20.84	4.25
TA	24	65.63	24.24	4.95

Fig. 23 – Route-Finding Task. Percentage of right answers for the control and tapping conditions.



ANOVA

A one-way ANOVA with Route-finding as a dependent variable and presence of interference task as a two level within-factor (Control vs Spatial Tapping) was performed. No Significant difference was found between Control and Tapping conditions ($F_{(1,23)} = 0.0074$, $MSE = 438.04$).

12.4 Discussion (EXP II)

Results showed that some aspects of map learning are affected even by a low loading spatial tapping. Indeed, the 4-key Spatial Tapping significantly interfered with learning of landmarks positions. However, the Spatial Tapping Task did not impair performance on learning the routes. Possibly, this task is less sensitive to interference and therefore it can be affected only by a highly interfering tapping task. Nevertheless, it has not been demonstrated yet that the 4-key tapping task is a selective task. In other words, it is still not known whether the 4-key tapping task has a selective effect on map learning or it also impair word learning. Experiment III was designed to verify this hypothesis.

13.EXPERIMENT III

A primary verbal task, in which the visuospatial components are attenuated, is supposed to be unaffected by the 4-key tapping task. Therefore, a new verbal task, that is the “Paired-associated words learning” task (Duyck, Szmalec, Kemps & Vandierendonck 2003), was designed with sequential and oral presentation. Moreover, subjects answered orally and only words with low imageability were selected.

13.1 Hypothesis

If the 4-key tapping task does not affect the new verbal task, in which any possible spatial aspect is carefully avoided, then it can be considered a selective interference task.

13.2 Method EXP III

13.2.1 Materials

The new primary verbal task: Paired-Associated Words Learning

The “Paired-associated words learning” task (Duyck *et al.* 2003) consists in learning the association between the 1st and the 2nd word of each pair. Care was taken to avoid any visual or spatial component: A) Words were sequentially and auditorially presented through the headphones. B) Subjects answered orally. C) 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. Fig. 24 shows the word-pairs lists used in Experiment III.

Fig. 24. The list of associate words (list A and B)

LIST A

FAVOLA	BUGIA
TENEBRA	VERTIGINE
SCANDALO	COLLERA
ANNO	PATTUGLIA
BRANDELLO	SINTOMO
CLERO	LITIGIO
BESTIA	POLPA
LATO	CRONACA
INTERESSE	ERNIA
QUESTIONE	FAMA
TURNO	VITTIMA
OCCIDENTE	RATA
DRAMMA	PROSA
PERICOLO	SCIROCCO
CARCASSA	ORIGINE
STAGIONE	STRAGE

LIST B

SILLABA	DETTAGLIO
RAPA	RAFFICA
DEMONIO	NORMA
ATRIO	FASCINO
PATTO	CARATTERE
ASMA	CAPRICCIO
RITMO	GAZZA
CANAPA	INTESTINO
NUORA	PAROLA
INDAGINE	INQUILINO
ARTE	INNO
VIZIO	MODA
GARBO	CLIMA
STRATO	VELENO
AUTUNNO	MESTIERE
GLOBO	VANTAGGIO

LIST C

MERCE	VALVOLA
CARRIERA	AGIO
TARIFFA	AGGUATO
CATEGORIA	TRAGEDIA
ARNESE	GARA
COLPA	CAPARRA
ANGOSCIA	MANZO
BRIVIDO	SCRUPOLO
FASE	DOGANA
SEDE	TORDO
PREDA	EPISODIO
FASTIDIO	CODICE
ZONA	PROVERBIO
LITRO	RESIDUO
LUSSO	STAFFA
BOIA	NAZIONE

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.

Number of items: 16 pairs of words. *Scoring*: Number of correct words.

Concurrent tasks

*Articulatory Suppression***:** subjects 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: subjects were requested to continuously tap the four raised corners of a 2x2 pad, one per second, in a clockwise direction. This was the same task as used in Experiment II.

Before each learning phase, participants had 2 minutes for practicing the secondary task. During the practice, only the secondary task was executed without the primary task.

Pilot study:

A pilot study with 10 subjects was run in order to set the level of difficulty of the lists of words and the efficacy of *Articulatory Suppression*. A control and an *Articulatory Suppression* conditions were included in the pilot study. Six different lists of words were structured and the three lists with the highest effect of *Articulatory Suppression* were selected. This procedure in the pilot study allowed to exclude the lists of words that were not "properly verbal" and to select only the lists in which verbal strategies are essential. Such a precaution was taken to be sure that the material was authentically verbal.

13.2.2 Procedure

Thirty-six subjects studied the three lists of 16 words-pair (list A, list B, list C), either in a control condition, while performing the Spatial Tapping Task, or while performing the *Articulatory Suppression* task. All the subjects were asked to study the three lists of words and to perform a different interference task for each list (Control, Tapping, Art. 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’ 48’’. Then, subjects were requested to perform some calculations for 30”. After that, they performed the cued recall task. Gender, order of presentation of lists and interference conditions were fully counterbalanced.

The concurrent tasks were executed only during the word learning phase, but not during the recall phase.

13.3 Results EXP III

Paired-Associated Words Learning task

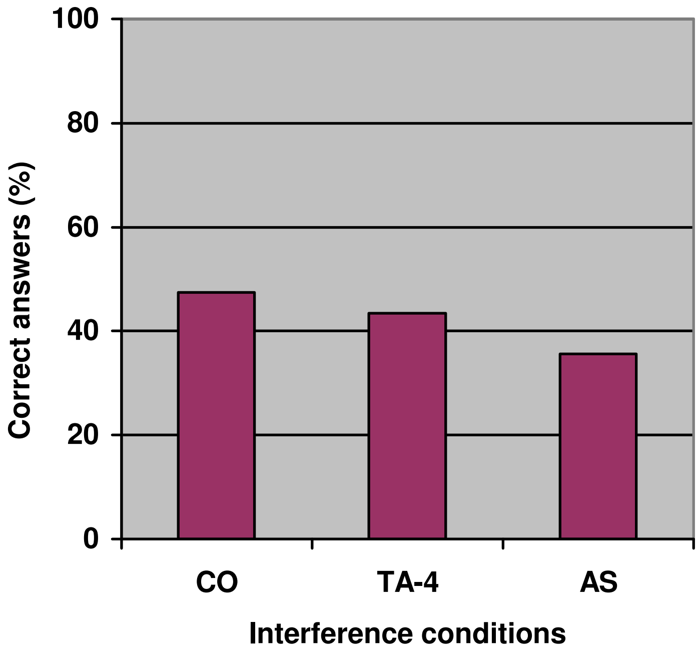
Descriptive statistics

Tab X shows the descriptive statistics for the “Paired-Associated Words Learning” task grouped by the type of interference task (TA-4= 4-keys Spatial Tapping, AS= *Articulatory Suppression*, CO=Control). Scores are reported as percentage of right answers. Performance levels for each condition are shown in Fig 25.

Tab X - Paired-Associated Words Learning task (% of Right answers)

Ss	Mean	Std.Dev.	Std.Err	
CO	36	47,40	27,11	4,52
TA-4	36	43,40	24,68	4,11
AS	36	35,59	23,71	3,95

Fig.25 – Paired-Associated Words Learning task. Percentage of right answers for the control, tapping and Articulatory Suppression conditions.



ANOVA

A one-way 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 of type of interference emerged ($F_{(2,70)} = 4.95$; $MSE = 262.40$; $p < .01$), post-hoc analyses were run. A significant difference was found between Control and *Articulatory Suppression* condition, but not between Control and Tapping conditions. Corresponding p-level values are reported in tab XI.

Tab XI - *Paired-Associated Words Learning task. Probabilities for Post Hoc Tukey test.*

	CO	TA-4	AS
CO		0.55	**0.01**
TA-4	0.55		0.11
AS	**0.01**	0.11	

p level values are reported. Significant values are marked for p < .05

13.4 Discussion (EXP III)

Results of Experiment III showed no effect of the 4-keys tapping task on the *paired-associated words learning*. This result can be interpreted as indicating that the 4-keys 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. As in Experiment I, the effect of the 9 keys-Spatial Tapping task was found in a "Nonsense words learning" task, two explanations seem plausible: either the 9-keys tapping task is too demanding or there are some spatial components in the verbal memory task used. Given that a 4-keys tapping task showed an effect on Landmark Positioning (Experiment II) and its interference is selective (Experiment III), it is possible to conclude that VSWM is involved in the learning of Landmark positions. Overall results hint to the conclusion that the effect of the 9-keys tapping which was found in Experiment I is not due to a general loading on attentional resources. Mostly plausibly, in Experiment I some spatial components were present in the non-sense word learning task (the non-words were visually and simultaneously presented) and some spatial strategies might have been used for learning them. However, selectivity of the 9–keys tapping task is not yet demonstrated. Experiment IV is aimed at directly testing whether a 9-keys tapping task affects a verbal memory task, in which any possible spatial aspect is carefully avoided. In Experiment IV, the same primary task used in Experiment III was combined with a concurrent 9-keys tapping task.

14. EXPERIMENT IV

As the Spatial tapping selectively impaired learning of landmark positions while it did not affect the *paired-associated words learning* task, the hypotheses that VSWM is not implied in map learning and that the *non-sense word learning* task contains spatial components can be excluded. Hypotheses 2 (The 9-keys Tapping is selective) and 3 (The 9-keys Tapping is not selective) were then tested in Experiment IV.

14.1 Hypothesis EXP IV

If the "high-interference" (9-keys) Spatial Tapping impairs the "Paired-associated words learning" task, then the 9-keys Tapping is a general demanding task and hypothesis 3 is confirmed. If the 9-keys Tapping does not impair the "Paired-associated words learning" task, then the 9-keys Tapping is a selective task with high spatial interference and hypothesis 2 is confirmed.

14.2 Method EXP IV

14.2.1 Materials

Primary verbal task: Paired-associated words learning task

This was the same task as in Experiment III. It consisted in learning the association between the first and the second word of a pair of words. During recall only the first word of each pair was presented, and the subjects were asked to recall the second word. Three similar lists (list a, list b and list c) each of 16 pairs of unrelated words were played at the rate of one pair every 6 seconds. Only words with low imageability were included in the list.

Cued recall

The same task as in Experiment III was used. Only the first word of each pair was played from a tape at the rate of one pair every 6 seconds. Subjects were requested to recall the second word of each pair.

Number of items: 16 pairs of words. *Scoring*: Number of correct words.

Concurrent tasks

*Articulatory Suppression***:** subjects 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.

9-keys spatial tapping: subjects were requested to continuously tap the 9 raised corners of a 3x3 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.

14.2.2 Procedure

36 participants studied the LIST A, B and C, either in a control condition, while performing the 9-keys Spatial Tapping Task, or while performing the *Articulatory Suppression* task. All the subjects studied the three lists of words and were asked to perform a different interference task for each list (Control, Tapping 9-k, Art. Suppression).

During the study phase, each pair was randomly played for a total of three times in a different order. Then, subjects were requested to perform some calculations for 30". After that, they performed the cued recall task. Gender, order of presentation of lists and interference conditions were counterbalanced as in Experiment III.

14.3 Results EXP IV:

Paired-Associated Words Learning task

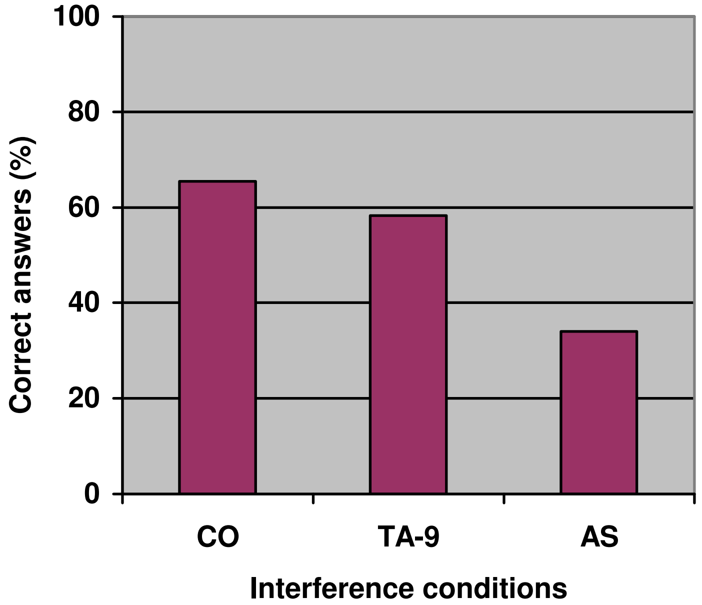
Descriptive statistics

Tab XII shows the descriptive statistics for the "Paired-Associated Words Learning" task grouped by the type of interference task (TA-9= 9-keys Spatial Tapping, AS= *Articulatory Suppression*, CO=Control). Scores are reported as percentage of right answers. Performance levels for each condition are shown in Fig 26.

Tab XII Paired-Associated Words Learning task (% of right answers)

	Ss	Mean	Std.Dev.	Std.Err
CO	36	65,45	24,07	4,01
TA-9	36	58,33	24,04	4,01
AS	36	34,03	26,20	4,37

Fig.26 – Paired-Associated Words Learning task. Percentage of right answers for the control, tapping and Articulatory Suppression conditions.



ANOVA

A one-way 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; *MSE* = 253.50; p< .0001), post-hoc analyses were run. A significant difference was found between Control and *Articulatory Suppression* condition and between Tapping and *Articulatory Suppression*, but not between Control and Tapping conditions. Corresponding p-level values are reported in tab XII.

Tab XII – Paired-Associated Words Learning task.Probabilities for Post Hoc Tukey test

	CO	TA	AS
CO		0.15	**0.0001**
TA	0.15		**0.0001**
AS	**0.0001**	**0.0001**	

p level values are reported. Significant values are marked for p < .05

14.4 Discussion (EXP IV)

Performance on the primary verbal task was impaired by *Articulatory Suppression* but it was unaffected by the 9-keys Tapping task. This result demonstrates that the 9-keys Tapping task is a selective task. The tapping effect, found in Experiment I on map learning, is not due to the complexity of the secondary task but to the visuospatial nature of the non-sense word learning task when visually and simultaneously presented. Hypothesis 2 can therefore be confirmed.

15. SUMMARY OF RESULTS

Tab XIV shows an overview of results. Overall, learning of landmarks locations is impaired by any kind of spatial tapping task, but it is never impaired by *Articulatory Suppression*. This means that learning the *absolute positions* of the landmarks requires visuospatial but the verbal working memory. Learning the *relative positions* of landmarks (*Pointing Task*) seems to be unaffected by any type of interference: neither 9-keys *Spatial Tapping*, nor *Articulatory Suppression* impaired this task. It is reasonable to conclude that the *Pointing Task* is not impaired by the 4-keys *Spatial Tapping*, because it is a less demanding secondary task. Learning the routes seems to require VSWM only partially. Indeed, only a selective task with high spatial interference (9-keys tapping) was found to affect performance on this task. A possible interpretation is that Route Learning is supported by both active and passive subsystems of working memory. Hence, it might be that the 4-key tapping impaired only the active components of WM, preserving the passive processes, while the 9-keys tapping impaired both the active and passive sub-systems. Therefore, only the passive component of WM could not be able to support the processes of routes learning. An alternative hypothesis is that the 9-keys tapping impairs a hypothetical “motor component” of VSWM, namely the "Working Memory for Movements" component (Smyth & Pendleton, 1989). On the contrary, the 4-key Spatial Tapping does not load on the motor component. Hence, only the motor aspects of the VSWM seem to be involved in Route Learning.

Tab XIV. Summary results of the effect of 4-keys tapping, 9-keys tapping and Articulatory Suppression on map learning and on two verbal control tasks.

	TAP-9	**TAP-4**	**Art. Suppr.**
LANDMARK POSITIONING	*	*	**No**
POINTING	**No**	**?**	**No**
ROUTE-FINDING	*	**No**	**No**
1st VERBAL task (spatial components)	*	**?**	*
2nd VERBAL task (Paired Assoc. Words)	**No**	**No**	*

Concerning the verbal tasks, it emerges that, when words are visually and simultaneously presented (**1st VERBAL task),** WVSM is involved. Nevertheless, when words are sequentially and auditorially presented (**2nd VERBAL task**), no types of spatial tapping (neither 4 nor 9 keys) impair word learning performance, while *Articulatory Suppression* does so.

16. GENERAL DISCUSSION

The present study was aimed at testing the general hypothesis that the VSWM is implied in map learning. Results confirmed that VSWM is involved in map learning depending on which type of map-knowledge is considered. On the one hand, VSWM seems irrelevant for learning the "relative positions" between landmarks (*Pointing Task*). Indeed, neither the 4-k nor the 9-k Tapping task affected pointing performance. On the other hand, both the 4-k and the 9-k Tapping tasks impaired performance in the *Landmark Positioning Task*. It seems that VSWM plays an essential role 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 definition of landmark knowledge is accepted, it can be said that VSMW is fundamental for the formation of Landmark Knowledge and irrelevant for Survey Knowledge. Otherwise, if 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 in "*Survey Knowledge for Absolute Positions"* and "*Survey Knowledge for Relative Positions"*. Hence, it is possible to conclude that VSWM is engaged only in learning the "*absolute positions*" component of Survey Knowledge, while it is not involved in the "*relative positions*" component.

These results are 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 Judgement was unrelated to VSWM. Moreover, both the *Direction judgment* (Allen *et al.,* 1996) and the *Map Section Rotation* (Bosco *et al.*, 2004; Coluccia & Martello, 2004) were found to be unrelated to VSWM as well. Similarly it was found that the *Pointing Task* is unaffected by visuospatial interference. It can be concluded that VSWM is scarcely involved in the learning of the reciprocal interrelations between the landmarks positions (*relative positions*).

Again, in accordance with our 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 the VSWM. Similarly, it was found that performance in the *Landmark Positioning Task* is impaired by visuospatial interference. Hence, it is possible to conclude that 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 unexpected. To our knowledge, previous studies (Allen *et al.,* 1996; Bosco *et al.*, 2004; Coluccia & Martello, 2004) did not directly address this issue, as they merely conclude that two kinds of knowledge emerged, without any reference to the causes of the differential involvement of VSWM. Further research is therefore needed to understand the meaning of this pattern of results and, above all, to understand why VSWM is not involved in learning the *relative positions between landmarks*. Probably, investigating the sub-components of VSWM could help to 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.

Concerning the relationship between Route Knowledge and VSWM, at this stage of research, it is hard to draw a clear conclusion. Nevertheless, on the basis of the present results, some hypotheses can be formulated. It was found that the 9-key tapping affected Route Learning, while the 4-key tapping did not. The *Route Reversal Task* (Allen et al., 1996) and the *Route recognition task* (Bosco *et al.*, 2004; Coluccia & Martello, 2004) were found to be correlated to VSWM. Consistently with our study, Garden *et al* (2002) found that VSWM is involved in Route Knowledge, by using a 9-key tapping. However, the authors did not run experiments using a 4-key tapping task. What it is not clear at present is why only the 9-key tapping task affected Route Learning, whereas the 4-key tapping task did not.

A first elementary explanation is that VSWM is definitely involved in Route Learning but the *Route-Finding Task* is less sensitive than the *Landmark Positioning Task* and therefore it needs a higher degree of spatial interference. Indeed, only a marked disturb of VSWM can produce some interference with Route Learning, which is unaffected by a low load of spatial interference. Both our results and previous literature (Garden *et al*. 2002) showed that the selective task with high spatial interference (9-k Tap) affected Route Learning.

However, two alternative explanations, based on the structural differences of the two spatial tapping tasks, are also possible. Indeed, if the 9-key tapping task affects the Route Learning and the 4-key tapping task does not, it is reasonable to seek the cause of such a pattern of results in the structural differences between the two kinds of spatial tapping tasks. To execute the 4-key tapping task, all the taps must occur in a clockwise direction and this direction never changes. Quite the opposite, the 9-key tapping task requires the subjects to continuously change the direction of tapping from the left to the right and then from the right to the left.

This demanding shift of sequence could heavily load the sequential component of VSWM. Hence, it might be hypothesized that the 9-key (but not the 4-key) Spatial Tapping affects "Sequential Working Memory". It is worth noting that performances in the *Route Reversal Task* (Allen et al., 1996) and in the *Route recognition task* (Bosco *et al.*, 2004; Coluccia & Martello, 2004) were predicted by the passive and sequential components of VSWM (*Corsi span test*, *Maze Learning Task).* Indeed, both the Corsi span test and the Maze Learning Task are passive and sequential tasks: The Corsi Task requires coping (passive task) a sequence (sequential task) of movements made by the experimenter. The Maze Learning Task requires reproducing (passive task) a previously seen pathway (sequential task) on a matrix.

A second alternative hypothesis, also based on the structural differences of the two tasks, is that the continuous shift of direction and the total amounts of taps in the 9-key version could heavily load the motor component of VSWM. Hence, it might be hypothesized that the 9-key (but not the 4-key) Spatial Tapping task affects "Working Memory for Movements" (Smyth *et al.*, 1988). It seems reasonable that such a motor sub-component could be particularly involved in Route Learning. In fact, post-experimental reports show that subjects usually imagine themselves walking inside the map, moving along the streets and rotating their body toward left and toward right, when turns are required. Moreover, non-systematic observations revealed that, while executing the *Route-Finding Task*, some participants actually rotate their body on the chair.

Therefore, it seems plausible that the 4-key tapping task does not affect Route Learning because the motor component of working memory is not impaired. Conversely, the 9-key tapping task would impair Route Learning because working memory for movements is disrupted.

In any case, the present study argues for a fundamental role of VSWM in route-learning processes. Little is known about the processes of route-executing. By using a selective task with high spatial interference (9-key tapping), 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 is not clear whether VSWM is involved in the learning of routes, in the mental execution of a route, or in both of them. As in our study interference occurred only during the learning phase, it can be argued that a high spatial interference task affects Route Learning. However, the present result does not exclude that VSWM is also involved in route execution.

17. CONCLUSIONS

The present work shed some new light on the complex cognitive components underlying spatial learning processes. Additionally, it confirmed and extended some previous results about the role of VSWM in map learning. Further studies are 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 specific role of

“Working Memory for Movements” could be also investigated in mental navigation processes.

Further studies could explore 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, trying to understand the elaboration and organization of spatial information can help both the enhancement of instruments for orientation and the understanding of human cognition.

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