**Original Research Article**

# Cognitive Impairment Assessment through Visuospatial Memory Can Be Performed with a Modified Walking Corsi Test Using the 'Magic Carpet'

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## Key Words

Corsi test · Complex navigation task · Mild cognitive impairment · Strategies

## Abstract

***Background:*** Subjects with mild cognitive impairment (MCI) have disturbances in their spatial navigation abilities and exhibit early deficits in visuospatial short-term memory. The purpose of the present study was to determine whether a quantitative (span score) and qualitative (evaluating navigation strategies used) analysis of the Corsi test (usual condition and complex navigation task) would be useful to reveal cognitive decline. ***Methods:*** We evaluated the performance of 15 young adults, 21 healthy elderly subjects and 15 subjects with MCI using the electronic version of the Corsi test (the Modified Corsi Block-Tapping Test, MCBT) and the complex navigation task (the Modified Walking Corsi Test, MWCT). The MWCT, which is an adaptation of the Corsi test, assesses spatial memory when the subject walks in a complex environment. We used Richard et al.'s model [Cogn Sci 1993;17:497–529] to investigate problem-solving strategies during the Corsi tests. ***Results:*** The span scores obtained on the MCBT and the MWCT were significantly lower in the healthy elderly subjects (MCBT = 5.0 ± 0.7; MWCT = 4.0 ± 0.7) and the subjects with MCI (MCBT = 4.7 ± 0.8; MWCT = 4.1 ± 0.9) than in the younger adults (MCBT = 6.2 ± 0.6; MWCT = 5.3 ± 1.0). The visuospatial working memory was more impaired in the complex navigation task (MWCT = 4.3 ± 0.9) than in the modified Corsi test (MCBT = 5.3 ± 0.8). Finally, the subjects with greater cognitive impairment were more likely to have inadequate or absence of problem-solving strategies. ***Conclusions:*** Investigating the problem-solving strategies used during the MWCT appears to be a promising way to differentiate between the subjects with MCI and the healthy elderly subjects.

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## Background

The intermediate stage between cognitive health and dementia [1] has been defined as mild cognitive impairment (MCI) and has been widely described in epidemiological and clinical studies. Criteria for MCI require the report of memory problems or other cognitive function, objective cognitive impairment (a test score of 1.5 standard deviation below the age-adjusted mean values), absence of dementia and intact daily functioning. Subjects with MCI seem to be at higher risk for conversion to dementia, particularly Alzheimer's disease [1].

Traditionally, the cognitive evaluation of patients relies on neuropsychological tests. Identifying executive function deficits allows us to detect subjects with MCI [2]. Among the deficits, we observe the presence of alterations of working memory and visuospatial sketchpad [3]. The visuospatial sketchpad includes a visual component and a spatial component [4]. From the neuropsychological approach, a battery of tests is available that specifically explores visual perception abilities (e.g., the Rey-Osterrieth test, Raven's Progressive Matrices, the Trail Making Test part A, and the Clock-Drawing test) and visuospatial memory [e.g., the Corsi Block-Tapping Test (CBT), memory tests with simple or complex environments] [5]. In 2007, Alescio-Lautier et al. [6] observed that the deficits in visuospatial short-term memory are stronger and appear earlier than the deficits related to short-term visual memory in patients with MCI or Alzheimer's disease compared to healthy elderly subjects.

It is acknowledged that visuospatial working memory can be explored using the CBT test [7], which involves the encoding of visual stimuli, the short-term storage of spatial location, the sequence order, and the maintenance of information over time. Age has a significant impact on the completion of this test (i.e., advanced age is associated with lower performance) [8]; regardless of the severity of their disease, the patients with mild and moderate Alzheimer's disease perform worse than the healthy subjects of similar age [9–12]. Despite a significant link between the decrease in the performance on the Corsi test and the development of cognitive problems, few investigations have been conducted in subjects with MCI, and the results are varied [2, 13]. Moreover, it has been suggested that a decrease in visuospatial ability could be a more sensitive indicator of cognitive decline [12, 14] than noticeable deficits in language or speech problems.

Several recent studies have simultaneously attempted to explore visuospatial working memory in the navigation context using an adaptation of the CBT, i.e., the Walking Corsi Test (WalCT) [15–18]. The WalCT, which is a recently developed psychometric tool, evaluates the memory storage of a sequence of places in a defined area. The subject must move to a selection of places based on his memorised location. This spatial navigation task has been studied in healthy older subjects [19], neglect patients [18], patients with epilepsy [20] and brain-injured patients [21]. The studies have shown that these types of patients perform worse on the WalCT test than the healthy controls, but no study has been proposed to evaluate the performance of subjects with MCI. However, several studies that have investigated performance on spatial navigation tasks have shown that, compared to the healthy subjects, the patients with Alzheimer's disease performed worse in routine recognition tasks [22] or an adaptation of the Morris water maze task [23]. The patients with Alzheimer's disease demonstrated a spatial disorientation that is characterised by difficulties in recognising scenery, a path or a road in a real or virtual environment [24]. The loss of visuospatial memory appears early at a stage of MCI and can be observed in navigation tests [5, 22, 23].

In patients with dementia, the processes involved in wayfinding in a navigation task are similar to those involved in problem-solving tasks [25]. Moving in a complex environment requires several spatio-cognitive stages, such as searching and treating relevant information and organising information in a hierarchical way to accomplish a goal. Therefore, problem-solving processes may be involved during CBT, although the planning stage is absent. In this

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particular CBT task, when one seeks an answer (the solution), one can tackle the problem in various manners (changes in viewpoints, training and memorising strategies). Therefore, the answers can be analysed by evaluating the strategies used.

For the present, the only available method for analysing performance in CBT is the span score. No studies thus far have used a strategy analysis to investigate performance on the CBT or on the WalCT. In this context, such an approach could be of interest for assessing subjects with MCI.

The objectives of this study are two-fold. First, we aimed to determine whether the assessment of visuospatial working memory in the Corsi test and complex navigation task is a good indicator of cognitive impairment in the early stages of a dementing illness. Second, we analysed the different strategies used by subjects in different tests and investigated whether these cognitive strategies were related to cognitive decline. We used a newly designed version of the WalCT, employing the 'Magic Carpet' [26]. We hypothesised that the analysis of the strategies used by the patients in the different Corsi tests will reveal additional information than the Corsi span score in subjects with MCI.

## Methods

### Participants

The present cross-sectional study included 51 subjects, 15 of whom were young subjects (mean, 25.1 years; 12 women, 3 men), 21 healthy older subjects (mean, 73.8 years; 16 women, 5 men) and 15 subjects with MCI (mean, 76.6 years; 12 women, 3 men). All subjects lived in a community dwelling, had not complained about the quality of their gait or balance and were able to walk without assistance. The exclusion criteria included the following: any objective gait disorder due to Parkinson's disease, previous stroke, clinical osteoarthritis in the lower limb joints, myopathy, or neuropathy verified by a formal clinical examination, the presence of depressive symptoms or taking medication. The experiment was undertaken with the written consent of each participant.

We recruited 15 young subjects, the majority of whom were university students, and 21 healthy older participants from noninstitutionalised volunteers aged over 65 years. The elderly healthy controls were free of significant cognitive complaints; however, they were similar to the MCI group in age and gender. All participants in the control group were recruited through mail notifications and other types of announcements.

Most of the participants with MCI were recruited from a memory centre in Paris, France. The participants were diagnosed with MCI according to the Petersen 2004 criteria [1], which included the presence of subjective memory complaints from the patient and family, objective cognitive impairment, preserved general intellectual function, absence of significant functional impairment, and absence of clinical dementia. The MCI sample was divided into three groups: amnestic single domain (aMCI; only memory deficit, n = 6), nonamnestic single domain (naMCI; language, executive function, visuospatial relations, n = 3), and amnestic multiple domain (amMCI; combination of memory deficit and executive dysfunctions, n = 6).

### Cognitive and Physical Test

All subjects underwent a clinical and a neuropsychological evaluation, which was conducted by a trained team. Memory and executive function disorders were diagnosed according to neuropsychological evaluation methods. All volunteers underwent a battery of rapid cognitive impairment tests that were administered by a neuropsychologist and that included the Mini-Mental State Examination [27], the Frontal Assessment Battery [28], the Trail Making Test, part A and part B [29], the Stroop test [30], the Wechsler Adult Intelligence
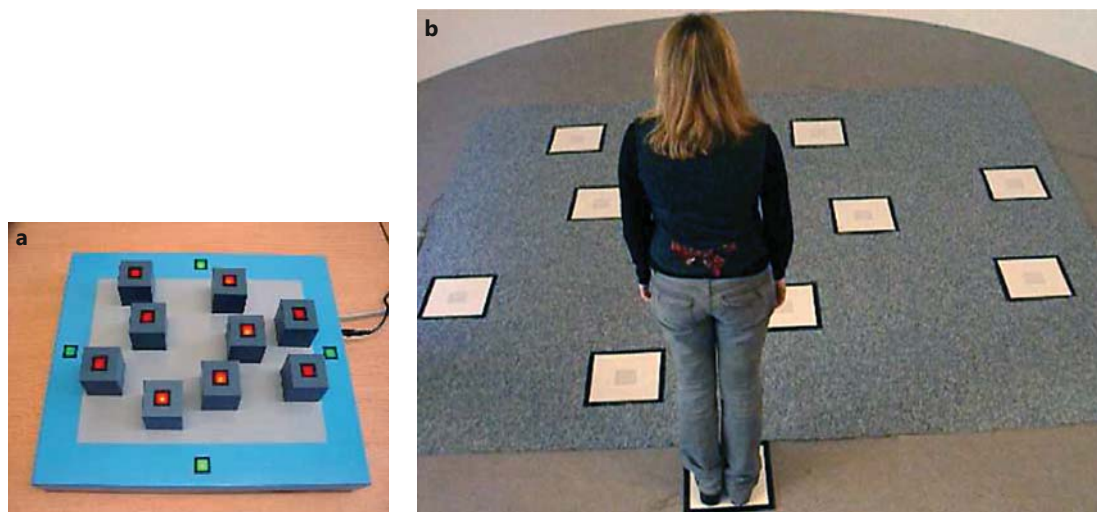
**Fig. 1.** Description of the protocol. **a** MCBT is an electronic version of the CBT. The sequences are controlled by a computer. **b** MWCT is a larger version (3 × 2.5 m; scale 1:10) of the CBT. An electronic version of the CBT was organised in an empty room [15, 20]. The MWCT is controlled by a microcomputer through WLAN connection. Nine white squares (30 × 30 cm) were placed on a grey carpet [26].

Scale [31] and the Dubois' 5-word test [32]. Mood and depression were assessed using the Geriatric Depression Scale [33].

Finally, the participants were asked to perform spontaneous walking for 10 m in a standardised environment on an 8-meter electronic walkway (GAITRite®; CIR Systems, Inc., Sparta, N.J., USA). The purpose of this test was to evaluate the walking abilities of the subjects.

*Experimental Tasks and Procedures*
Electronic Version of the CBT – The Modified Corsi Block-Tapping Test
The CBT is a classic test that is used to rapidly assess visuospatial memory. The test involves nine wooden blocks (3 × 3 cm) that are randomly distributed on a board with a dimension of 25 × 30 cm. First described by Milner [34] and developed by Corsi [7], this test requires the patient to press on a series of blocks. First, the action sequence is shown to the patient; subsequently, the patient must recall the sequence and immediately repeat it in the same order. There are several computerised versions of the Corsi test [35, 36]. Both the traditional and computerised versions of this test provide similar outcomes [37]. In this test, the examiner first presents a short series (i.e., starting with a 2-block sequence) and gradually increases the length of the sequence if the patient's response is correct. In the present study, we used a modified CBT (MCBT) that was developed by the Collège de France, Paris (an electronic version is available) (fig. 1). The MCBT uses the same protocol developed by Milner in 1971 [34]; however, the board and cubes are plastic, and the sequences are shown on a computer. The blocks are illuminated every 1,500 ms, and the end of the sequence is marked by a tone, at which time the subject is asked to reproduce the sequence.

After the first three simple sequences have been presented, if at least two of them have been reproduced correctly, the next level is administered (i.e., a 3-block sequence). When two trials out of three at the same level have not been correctly reproduced, the test stops [20, 38]. The score, which is the length of the last sequence correctly reproduced, is recorded. This quantitative measure is called the span.

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Modified Walking Corsi Test Using the 'Magic Carpet'

In the present study, the experimental conditions were similar to those described by Piccardi et al. [15] on the classical walking Corsi, except that we used an electronic version. The technology used is a wireless 'Magic Carpet', which is a set of tiles that are lit by a computer allowing a large variety of possible combinations of sequences. This experimental set-up was developed at the Collège de France [26] (fig. 1). The Modified Walking Corsi Test (MWCT) was performed in an empty room with a dimension of 4 × 5 m; the walls were covered with curtains that served to hide external references (e.g., doors and windows). The magic carpet is composed of nine white panels (30 × 30 cm) that are placed on a grey carpet with a dimension of 250 × 300 cm, using a layout similar to the CBT on a larger scale (scale 10:1). Each panel is equipped with force sensors, and the panels are connected to a computer work-station to record the subject's responses. To repeat the sequence, the subject walked directly on the magic carpet panels after hearing a tone. This process was filmed to study the movement strategies used by the subjects as they walked and navigated in the environment.

In the MWCT, the experimental conditions (e.g., instructions and scoring) were the same as those in the MCBT, including the starting position. In the test proposed by Piccardi et al. [15], the patient and the examiner had the same starting point in the WalCT, which is not the case in the CBT.

The order of the successive tests (i.e., MCBT and MWCT) was counterbalanced among the subjects in each group. The patients did not show any problems in understanding the instructions.

Cognitive Strategies Assessed from the Trajectory Errors

Although the span score is the same as the score obtained in the CBT test [7], we have identified ways to obtain additional information. We can consider the Corsi task to be a 'simple' problem-solving activity because the subject must remember a sequence of movements by storing the illuminated blocks one by one and then reconstituting the sequence. This task is 'simple' because it does not require the planning stages of a complex problem-solving activity (e.g., the Tower of Hanoi). In this context, the model published by Richard et al. [39] could be an elegant way to analyse the sequences of movements performed by the subject. The basic idea is that an individual will try to find the best compromise to solve a problem under a set of constraints. The subject will try to respect all constraints, but in certain cases called 'deadlocks', he will decide not to consider one constraint. Usually, he decides not to follow the constraint that he considers to be less important or the one that is the most restrictive.

The different steps involved in successful information processing in the test require the adequate storage and recall of the parameters of locomotor trajectories (i.e., choosing the correct direction, the precise localisation of the blocks and the correct number of blocks). If these three criteria are correctly met, the visuospatial pathway is successfully reproduced by the motor or the locomotor trajectory. The analysis of different categories of trajectory errors was based on the trajectories performed by the subjects when they failed twice in one trial level. The errors were noted and described to determine the constraints that were not respected by the subjects.

We have identified five strategies (with different types of errors): (S1) *Localisation* (one wrong block is shown); (S2) *inversion* (two blocks are shown in the wrong order); (S3) *approximation* (sequences with several errors but with a general configuration similar to the shown sequence); (S4) *random sequence* (sequences presented without any logic), and (S5) *incomplete sequence* (sequences with too many or not enough blocks) (fig. 2).

Presumably, the errors in the responses of the subjects suggest that they eliminate some constraints (e.g., localisation, direction, or number of blocks). If the constraints are too strong,
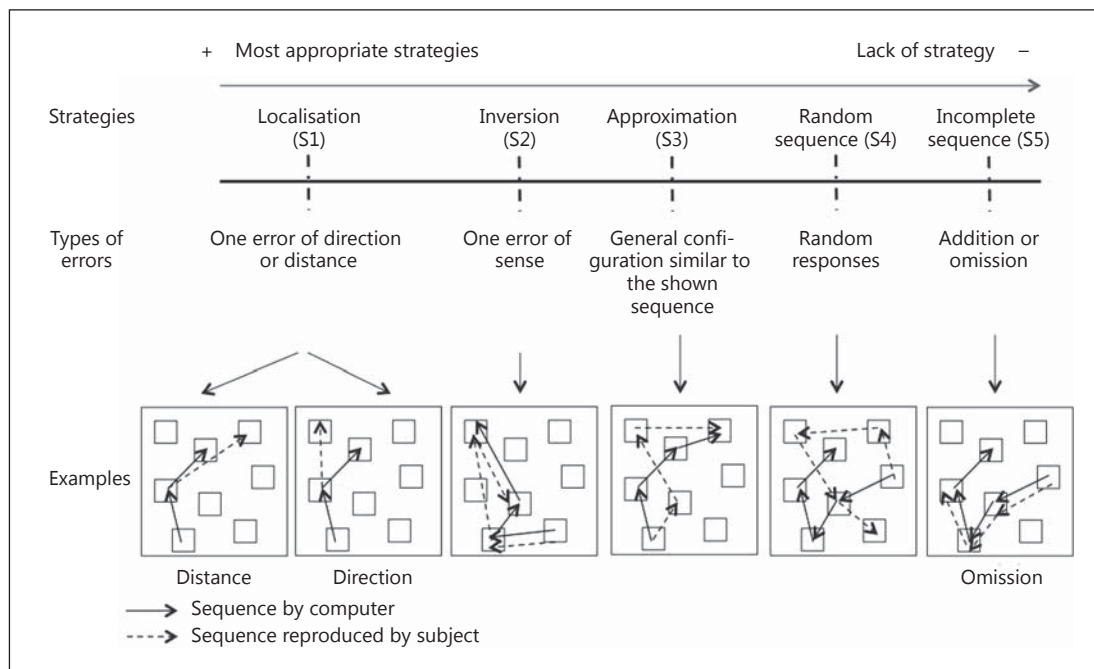
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**Fig. 2.** Analyses of the various strategies used in the Corsi test, according to the mistakes that were made.

the subjects begin to neglect the precise localisation of each block and adopt a less suitable strategy, which makes their response approximate. Finally, a lack of strategy forces the subjects to abandon all constraints (random response) or to show an incorrect number of blocks (fig. 2). This method of analysis can be presented as a graduated scale that ranges from the lack of a strategy to the most appropriate strategies.

### Statistics

The span scores were analysed using a factorial ANOVA (3 × 2) with three groups (young subjects, healthy elderly and MCI subjects) and two conditions (MCBT and MWCT). The differences in cognitive performance and gait were analysed using a one-way ANOVA. Correlations between functional capacity (walking speed) and performance on the MCBT and MWCT tests were evaluated using the Spearman test.

Finally, the strategies were studied in two stages. First, we used a binary code (0 or 1) to show whether one strategy had been employed (1) or not (0). Subsequently, we compared the two groups of subjects (healthy elderly subjects vs. MCI patients) for each test (MCBT and MWCT) using the Mann-Whitney test. The statistical analyses were performed using the Statistica version 9 (Statsoft Inc., Tulsa, Okla., USA) software, and significant difference was set at $p < 0.05$.

## Results

### Cognitive and Physical Tests

The results of the different cognitive tests revealed a pronounced memory deficit (Dubois' 5-word test), impaired global executive function (Frontal Assessment Battery), mental inhibition (Stroop test) and especially impaired mental flexibility (Trail Making Test) in subjects

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**Table 1.** Demographic and clinical characteristics of the study participants

| Characteristics | MCI (n = 15) | OH (n = 21) | YH (n = 15) | p |
|---|---|---|---|---|
| Age, years | 76.6±5.9 | 73.7±6.9 | 25.1±2.3*, # | <0.00001 |
| Male, n | 3 | 5 | 3 | |
| *Cognitive test* | | | | |
| MMSE | 27.8±1.5 | 28.5±0.9 | 28.3±1.0 | 0.18 |
| FAB | 15.4±1.7 | 17.0±0.6* | 17.5±0.8* | <0.00001 |
| WAIS (digit span forward and backward) | 99.8±9.6 | 99.1±10.1 | 96.6±10.3 | 0.64 |
| Stroop test | 1.4±4.7 | 7.9±6.7* | 5.7±4.7* | <0.0001 |
| TMT (part A) | 43.9±4.5 | 35.6±8.3* | 17.6±10.8*, # | <0.00001 |
| TMT (part B) | 102.8±6.5 | 73.1±14.5* | 33.7±39.4*, # | <0.00001 |
| ΔTMT, s | 58.8±39.6 | 37.6±14.3* | 16.1±6.7*, # | <0.00001 |
| Dubois' 5-word test (of 10) | 9.3±1.6 | 10.0* | 10.0* | <0.04 |
| Dubois' 5-word test (of 20) | 16.8±0.7 | 19.2±0.5* | 19.5±3.1* | <0.0001 |
| Clock-Drawing test | 6.2±0.9 | 6.6±0.6 | 6.7±0.6 | 0.09 |
| Mini-GDS | 0.4±0.5 | 0.2±0.4 | 0.1±0.1 | 0.16 |
| *Physical test* | | | | |
| Gait speed, cm/s | 108.5±16.1 | 117.6±20.4 | 125.8±15.3* | <0.01 |

Values are mean ± SD except where indicated otherwise. YH = Healthy young subject; OH = healthy older subject; MMSE = Mini-Mental State Examination; FAB = Frontal Assessment Battery; WAIS = Wechsler Adult Intelligence Scale; TMT = Trail Making Test; GDS = Geriatric Depression Scale. * p < 0.001 compared with MCI; # p < 0.001 compared with OH.

with MCI relative to healthy elderly subjects and young subjects (p < 0.05 for each test) (table 1). Other cognitive functions, including global cognitive efficiency (Mini-Mental State Examination), intelligence (Wechsler Adult Intelligence Scale) and visuoconstructive abilities, were well preserved in normal ageing and pathological states. There was also a decrease in the Trail Making Test performance for healthy elderly subjects relative to the younger subjects (p < 0.05).

Finally, a significant difference (p < 0.05) was found in walking speed between the healthy older adults and the young adult subjects with MCI but not between the healthy elderly group and the group with MCI (table 1). No differences in anthropometric variables (i.e., size of shoes, weight, and height) were noticed among the different groups of subjects. There was no correlation between walking speed and performance on the MCBT (r = 0.19, p < 0.05). However, a positive and significant correlation was revealed between the MWCT performance and walking speed (r = 0.32, p < 0.05).

*Quantitative Analysis – Span Score*

The visuospatial working memory was more impaired in the complex navigation task (MWCT = 4.3 ± 0.9) than in the Corsi test (MCBT = 5.3 ± 0.8). The MWCT showed a significant difference ($F_{1, 49}$ = 21.7, p < 0.001), with better performance on the MCBT than on the MWCT for young subjects (MCBT = 6.2 ± 0.6 vs. MWCT = 5.3 ± 1.0), for the elderly (MCBT = 5.0 ± 0.7 vs. MWCT = 4.0 ± 0.7) and for subjects with MCI (MCBT = 4.7 ± 0.8 vs. MWCT = 4.1 ± 0.9) (fig. 3).

We also found a significant effect when we compared individual performance ($F_{2, 48}$ = 26.4, p < 0.001). The young subjects performed better than the healthy elderly subjects and the subjects with MCI both on the MCBT and MWCT. However, there was no significant difference between the two groups of older subjects on the MCBT or the MWCT (similar

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**Fig. 3.** Impact of the complex navigation task on the visuospatial working memory of the subjects in each group. OH = Healthy older subject; YH = healthy young subject. ANOVA with a plan of 3 × 2 factors was used. * Significant difference, p < 0.05.
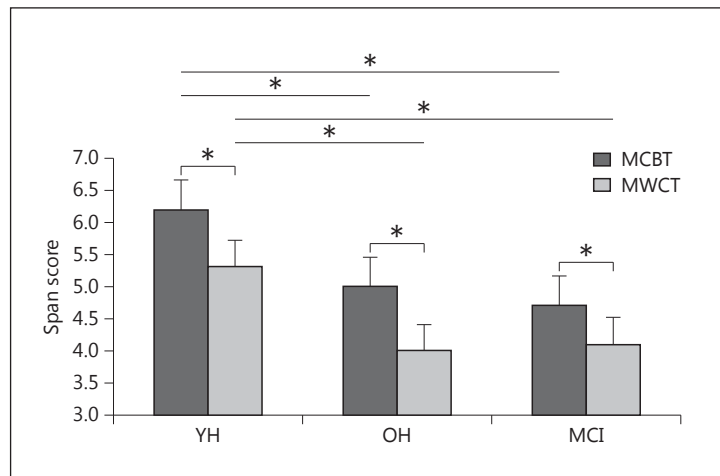


**Fig. 4.** Behavioural profiles in problem solving at the latest stage of the Corsi test. The mean score was calculated during the subject's last and unsuccessful trial series (span + 1), as the mean number of times a strategy was used. **a** Strategies during MCBT. **b** Strategies during MWCT. OH = Healthy older subject. Statistics were performed using the Mann-Whitney test. * Significant difference, p < 0.05.
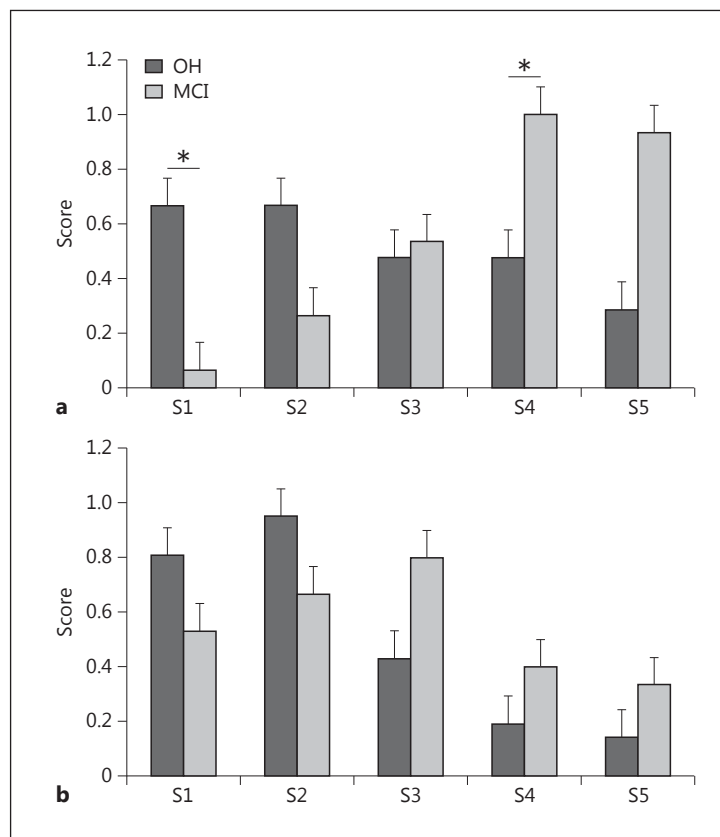
conclusions were drawn using the ANOVA with our three groups of subjects and using nonparametric statistics when only the two groups of elderly subjects were considered) (fig. 3). However, the span score analysis did not present any interaction among the groups of subjects ($F_{2, 48} = 0.51$, p = 0.59).

*Qualitative Analysis – Cognitive Strategies*
Problem-solving strategies were investigated because 90% of the results demonstrated a span score of 4 for the MCBT and 5 for the MWCT. In the qualitative analysis, we observed

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different behavioural patterns in visuospatial processing between the healthy elderly subjects and the subjects with MCI in the MWCT (fig. 4). During spatial navigation, the behavioural profiles were specific in each group. The strategy S1 (localisation) was used significantly more often in the healthy elderly than in the subjects with MCI ($p = 0.005$), and the strategy S4 (random sequence) was used significantly more often in the subjects with MCI than in the healthy elderly subjects ($p = 0.02$). The patients with MCI demonstrated a lack of strategies (random sequence), whereas the healthy elderly subjects appeared to use the most appropriate strategies (localisation). In contrast, the analysis of strategies used on the MCBT showed no difference between the two groups.

## Discussion

Visuospatial memory, which plays a basic role in daily life, is required for orientation and spatial localisation and for using a navigation map. In the present study, we were especially interested in the early deficits in visuospatial memory that occur in subjects with MCI. We have shown a significant impact of ageing in the performances obtained in the Corsi tests in traditional and navigation conditions. Cognitive impairment did not demonstrate such an impact. Moreover, the strategy analysis was able to reveal differences in problem solving in subjects with MCI and healthy elderly subjects, especially in the navigation task (MWCT).

We can speculate whether the performances obtained in the two kinds of Corsi tests (traditional and navigation) that we used are connected to similar or different memory systems. Several studies have supported the idea that performance on the CBT and WalCT relies on different memory systems [15, 20]. This hypothesis is consistent with the literature; we know that visuospatial memory is not an individualised structure. The model proposed by Piccardi et al. [15] has one spatial memory system for objects that are close to the subject (peripersonal/reaching memory system) and another system for spatial navigation purposes (spatial navigation). In the present study, the performance on the MWCT was lower than that on the MCBT. Our results and the findings of recent studies in the literature suggested that there are two memory systems for processing visuospatial information: one for peripersonal/reaching memory that addresses objects that are close to the subject and another process that involves spatial navigation. However, our data are in conflict with the results obtained by Piccardi et al. [15], which show that the span score is more important on the WalCT than on the CBT in young subjects. They introduced the hypothesis that the difference in the performance on these two tests was related to enriched and diversified sensory integration (visual, vestibular, and proprioceptive) that occurs during the navigation task and facilitates the processing of mnesic memory processes. We attribute the discrepancies in the results of these two studies to the specific methodological conditions used in our tests. Our subjects were assessed similarly in the MCBT and the MWCT, in contrast to the study by Piccardi et al. [15], where the sequences were produced by the experimenter and not by a computer. Thus, we assume that seeing the experimenter perform the sequence on the mat allows the patient to mentally simulate the action by activating different sensory inputs; such processes were impossible in our MWCT. Additionally, we can explain the discrepancy between the results on the MWCT and the MCBT by the complex navigation sequence because our subjects had to update their spatial map at each step/block of the sequence on the MWCT. Memorising the sequence is achieved by spatially mapping the environment from a particular point of view, whereas repetition alters the subject's own spatial references and changes the subject's perspective. A recent study using the magic carpet has shown the impact of perspective changes on learning a sequence by using visuospatial working memory [26].

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In the present study, we investigated the effect of healthy and pathological ageing on the performances in two kinds of Corsi tests. A recent study demonstrated that performance on the CBT and the WalCT begins to degrade at the age of 47 years [19]. Using the span score, we were able to show an effect of ageing on spatial short-term memory based on the performance in our two tests. The decrease in performance seems to be not only connected to the navigation task difficulty but also to the decrease in the working memory capacity because of ageing.

Several studies have shown a performance decrease in patients in the early-to-moderate stages of dementia compared to healthy subjects of similar age [9–12]. However, the information on the capabilities of patients with MCI is lacking. We expected to find impaired performance in the group with MCI, since the deterioration of the prefrontal cortex over time [40] results in cognitive difficulty in completing complex tasks that require executive functions, such as those tasks in the CBT. Nevertheless, we were unable to detect any differences in performance between the healthy elderly subjects and the patients with MCI in the performance of MCBT.

With the additional cognitive deficits present in older subjects with MCI, we considered that we would detect marked performance difficulty in subjects with MCI relative to healthy elderly subjects, especially on the spatial navigation task (i.e., on the MWCT). Disorders of spatial orientation (topographical disorientation) and spatial memory deficits have been shown to represent an early sign of degenerative dementia [5]. Our data showed that the two groups of elderly subjects did not differ in their performance on the MWCT, which suggests that visuospatial navigation working memory was not affected in the stage of MCI. However, the subjects with dementia disorders present an important topographical orientation impairment [24, 41], i.e., an impairment in the allocentric and egocentric systems during spatial navigation [23, 42] that affects their ability to create and use a spatial map. The navigation deficits observed in these patients are likely related to the brain damage that occurs in the early stages of Alzheimer's disease [43]. Additionally, many studies have highlighted changes in egocentric and allocentric navigation performed by patients with MCI relative to healthy elderly subjects [22, 23, 42, 44]. One explanation for our results could be provided by the heterogeneity of our group of patients (6 aMCI, 3 naMCI, 6 amMCI), which would increase the variability in the responses and therefore mask problems in the working memory. Laczo et al. [42] showed that patients with aMCI have a deficit in encoding and consolidating memories that are associated with hippocampal damage. The performance of subjects with aMCI is similar to that of subjects with Alzheimer's disease, whereas the memory performance of subjects with naMCI is similar to that of healthy elderly subjects [43]. These authors concluded that the deficits are likely to be related to neuropathological disease processes that affect the neuronal navigation circuits.

We observed striking changes in the way that our subjects with MCI responded to the tests when they analysed their behaviour and strategies. The MCBT and the MWCT rely on different cognitive functions, including encoding capabilities, planning strategies and memorisation. Among these functions, we were particularly interested in the types of strategies used to solve the Corsi test. We have established a graduated scale that ranges from the lack of a strategy to the use of the most appropriate strategies (fig. 2). There was no significant difference in the strategies used between the groups of older subjects in the performance on MCBT, but there were significant differences in the strategies used between the groups of older subjects in the performance on MWCT. Although the elderly appear to achieve the same performance (measured by the span score), studying the strategies reveals pronounced deficits in subjects with MCI. The errors of the healthy elderly subjects were primarily related to localisation, which are associated to an attention deficit. Elderly subjects are known to present such deficits [45]. In addition, the strategies used by the subjects with MCI during the tests were unsuitable and reflect their early deficits in spatial memory [5, 43]. Thus, we assume that cognitive

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DOI: 10.1159/000356727 | © 2014 S. Karger AG, Basel
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impairment can be evaluated in the elderly by studying their behaviour and the type of strategy that they used in our test. Analysing such strategies could be a relevant way to differentiate between the subjects with MCI and the healthy elderly subjects. The sudden loss of all information on the MWCT could be related to an early alteration of neuronal circuits that are involved in human navigation [43]. Consequently, the evaluation of navigation skills in the MWCT can help to identify MCI subjects. The dual task test has recently been shown to be relevant to detect patients at risk for developing dementia [46]. The test, which was used in the present study, evaluated navigation skills that can be rapidly performed; it is also computerised and therefore evaluator independent.

Finally, we wanted to test the relationship that may exist between motor performance and visuospatial working memory. It is likely that the deficits shown on the MWCT depend on decreased walking speed, which increases locomotion time in the elderly. Therefore, the subjects have more time to forget the end of the sequence. When we evaluated the subjects' spontaneous walking for 10 m and their working memory capacity in their performance in MWCT, we observed a significant correlation between their motor performance but not in their performance in MCBT. Thus, the differences observed between the young subjects and the MCI subjects seem to be related to motor deficits. Differences in gait speed may explain cognitive impairment in the MCI group [47]. We hypothesise that the decrease in MWCT performance with pathological ageing is primarily caused by cognitive impairment and motor deficits.

However, limitations of the present study are the rather small number of included subjects and the disparity between women and men in all studied groups. Several studies have shown that gender strongly influences spatial navigation performance, especially on the WalCT [15, 19, 48]. Additionally, our group of subjects with MCI was heterogeneous and not large enough to permit subgroup analyses. Unfortunately, our subjects were not checked by MRI or by specific biomarkers to explore the state of their health.

In the future, it will be interesting to explore how patients with dementia perform on the MWCT to determine whether the information on topographical disorientation can be extracted. It would also be important to investigate whether this test has a predictive value on the onset of dementia or cognitive decline.

## Conclusion

Brain and cognitive impairment associated with ageing creates difficulty in correctly performing tasks that require visuospatial working memory. Although these deficits were more pronounced during the navigation task, it is clear that the span scores on the MCBT and the MWCT do not identify early cognitive decline in subjects with MCI. However, studying the strategies that subjects use to solve problems on the Corsi tests and on the spatial navigation tests is a novel approach to differentiate between the cognitive performance in healthy elderly subjects and the cognitive performance in subjects with MCI. This assessment appears to be a valuable tool for measuring the state of the neural circuits involved in spatial navigation. Identifying the strategies used in these tests could be a useful marker for identifying subjects at risk for developing dementia.

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## References

1. Petersen RC: Mild cognitive impairment as a diagnostic entity. J Intern Med 2004;256:183–194.
2. Traykov L, Raoux N, Latour F, Gallo L, Hanon O, Baudic S, Bayle C, Wenisch E, Remy P, Rigaud AS: Executive functions deficit in mild cognitive impairment. Cogn Behav Neurol 2007;20:219–224.
3. Huntley JD, Howard RJ: Working memory in early Alzheimer's disease: a neuropsychological review. Int J Geriatr Psychiatry 2010;25:121–132.
4. Logie RH: Visuo-Spatial Working Memory. Hove, Erlbaum, 1995.
5. Iachini I, Iavarone A, Senese VP, Ruotolo F, Ruggiero G: Visuospatial memory in healthy elderly, AD and MCI: a review. Curr Aging Sci 2009;2:43–59.
6. Alescio-Lautier B, Michel BF, Herrera C, Elahmadi A, Chambon C, Touzet C, Paban V: Visual and visuospatial short-term memory in mild cognitive impairment and Alzheimer disease: role of attention. Neuropsychologia 2007;45:1948–1960.
7. Corsi PM: Human memory and the medial temporal region of the brain. Diss Abstr Int 1972;34:819B.
8. Rowe G, Hasher L, Turcotte J: Age differences in visuospatial working memory. Psychol Aging 2008;23:79–84.
9. Trojano L, Chiacchio L, De Luca G, Fragassi NA, Grossi D: Effect of testing procedure on Corsi's block-tapping task in normal subjects and Alzheimer-type dementia. Percept Mot Skills 1994;78:859–863.
10. Grossi D, Becker JT, Smith C, Trojano L: Memory for visuospatial patterns in Alzheimer's disease. Psychol Med 1993;23:65–70.
11. Vecchi T, Saveriano V, Paciaroni L: Storage and processing working memory functions in Alzheimer-type dementia. Behav Neurol 1998;11:227–231.
12. Baudic S, Barba GD, Thibaudet MC, Smagghe A, Remy P, Traykov L: Executive function deficits in early Alzheimer's disease and their relations with episodic memory. Arch Clin Neuropsychol 2006;21:15–21.
13. Haller S, Missonnier P, Herrmann FR, Rodriguez C, Deiber MP, Nguyen D, Gold G, Lovblad KO, Giannakopoulos P: Individual classification of mild cognitive impairment subtypes by support vector machine analysis of white matter DTI. AJNR Am J Neuroradiol 2013;34:283–291.
14. Buccione I, Perri R, Carlesimo GA, Fadda L, Serra L, Scalmana S, Caltagirone C: Cognitive and behavioural predictors of progression rates in Alzheimer's disease. Eur J Neurol 2007;14:440–446.
15. Piccardi L, Iaria G, Ricci M, Bianchini F, Zompanti L, Guariglia C: Walking in the Corsi test: which type of memory do you need? Neurosci Lett 2008;432:127–131.
16. Piccardi L, Bianchini F, Iasevoli L, Giannone G, Guariglia C: Sex differences in a landmark environmental re-orientation task only during the learning phase. Neurosci Lett 2011;503:181–185.
17. Bianchini F, Incoccia C, Palermo L, Piccardi L, Zompanti L, Sabatini U, Peran P, Guariglia C: Developmental topographical disorientation in a healthy subject. Neuropsychologia 2010;48:1563–1573.
18. De Nigris A, Piccardi L, Bianchini F, Palermo L, Incoccia C, Guariglia C: Role of visuo-spatial working memory in path integration disorders in neglect. Cortex 2013, Epub ahead of print.
19. Piccardi L, Bianchini F, Argento O, De Nigris A, Maialetti A, Palermo L, Guariglia C: The Walking Corsi Test (WalCT): standardization of the topographical memory test in an Italian population. Neurol Sci 2013;34:971–978.
20. Piccardi L, Berthoz A, Baulac M, Denos M, Dupont S, Samson S, Guariglia C: Different spatial memory systems are involved in small- and large-scale environments: evidence from patients with temporal lobe epilepsy. Exp Brain Res 2010;206:171–177.
21. Piccardi L, Iaria G, Bianchini F, Zompanti L, Guariglia C: Dissociated deficits of visuo-spatial memory in near space and navigational space: evidence from brain-damaged patients and healthy older participants. Neuropsychol Dev Cogn B Aging Neuropsychol Cogn 2011;18:362–384.
22. deIpolyi AR, Rankin KP, Mucke L, Miller BL, Gorno-Tempini ML: Spatial cognition and the human navigation network in AD and MCI. Neurology 2007;69:986–997.
23. Hort J, Laczo J, Vyhnalek M, Bojar M, Bures J, Vlcek K: Spatial navigation deficit in amnestic mild cognitive impairment. Proc Natl Acad Sci USA 2007;104:4042–4047.
24. Monacelli AM, Cushman LA, Kavcic V, Duffy CJ: Spatial disorientation in Alzheimer's disease: the remembrance of things passed. Neurology 2003;61:1491–1497.
25. Passini R, Rainville C, Marchand N, Joanette Y: Wayfinding in dementia of the Alzheimer type: planning abilities. J Clin Exp Neuropsychol 1995;17:820–832.
26. Meilinger T, Berthoz A, Wiener JM: The integration of spatial information across different viewpoints. Mem Cognit 2011;39:1042–1054.
27. Folstein MF, Folstein SE, McHugh PR: 'Mini-mental state'. A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–198.
28. Dubois B, Slachevsky A, Litvan I, Pillon B: The FAB: a Frontal Assessment Battery at bedside. Neurology 2000;55:1621–1626.
29. Reitan RM, Tarshes EL: Differential effects of lateralized brain lesions on the trail making test. J Nerv Ment Dis 1959;129:257–262.
30. Stroop JR: Studies of interference in serial verbal reactions. J Exp Psychol 1935;18:643–662.
31. Wechsler D: Wechsler Adult Intelligence Scale – Third Edition. San Antonio, The Psychological Corporation, 1997.

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32    Dubois B, Touchon J, Portet F, Ousset PJ, Vellas B, Michel B: 'The 5 words': a simple and sensitive test for the diagnosis of Alzheimer's disease (in French). Presse Med 2002;31:1696–1699.

33    Yesavage JA, Brink TL, Rose TL, Lum O, Huang V, Adey M, Leirer VO: Development and validation of a geriatric depression screening scale: a preliminary report. J Psychiatr Res 1982;17:37–49.

34    Milner B: Interhemispheric differences in the localization of psychological processes in man. Br Med Bull 1971;27:272–277.

35    Smyth MM, Scholey KA: Interference in immediate spatial memory. Mem Cognit 1994;22:1–13.

36    Stoffers D, Berendse HW, Deijen JB, Wolters E: Deficits on Corsi's block-tapping task in early stage Parkinson's disease. Parkinsonism Relat Disord 2003;10:107–111.

37    Nelson RE, Dickson AL, Banos JH: An automated administration of Corsi's block-tapping test. Percept Mot Skills 2000;91:578–580.

38    Berch DB, Krikorian R, Huha EM: The Corsi block-tapping task: methodological and theoretical considerations. Brain Cogn 1998;38:317–338.

39    Richard JF, Poitrenaud S, Tijus C: Problem-solving restructuration: elimination of implicit constraints. Cogn Sci 1993;17:497–529.

40    Raz N, Gunning-Dixon F, Head D, Rodrigue KM, Williamson A, Acker JD: Aging, sexual dimorphism, and hemispheric asymmetry of the cerebral cortex: replicability of regional differences in volume. Neurobiol Aging 2004;25:377–396.

41    Grossi D, Fasanaro AM, Cecere R, Salzano S, Trojano L: Progressive topographical disorientation: a case of focal Alzheimer's disease. Neurol Sci 2007;28:107–110.

42    Laczo J, Vlcek K, Vyhnalek M, Vajnerova O, Ort M, Holmerova I, Tolar M, Andel R, Bojar M, Hort J: Spatial navigation testing discriminates two types of amnestic mild cognitive impairment. Behav Brain Res 2009;202: 252–259.

43    Lithfous S, Dufour A, Despres O: Spatial navigation in normal aging and the prodromal stage of Alzheimer's disease: insights from imaging and behavioral studies. Ageing Res Rev 2013;12:201–213.

44    Weniger G, Ruhleder M, Lange C, Wolf S, Irle E: Egocentric and allocentric memory as assessed by virtual reality in individuals with amnestic mild cognitive impairment. Neuropsychologia 2011;49:518–527.

45    McDowd JM, Shaw RJ: Attention and aging: a functional perspective; in Craik FIM, Salthouse TA (eds): The Handbook of Aging and Cognition. Mahwah, Lawrence Erlbaum, 2000, pp 221–292.

46    Perrochon A, Kemoun G, Watelain E, Berthoz A: Walking Stroop carpet: an innovative dual-task concept for detecting cognitive impairment. Clin Interv Aging 2013;8:317–328.

47    Bramell-Risberg E, Jarnlo GB, Elmståhl S: Separate physical tests of lower extremities and postural control are associated with cognitive impairment. Results from the general population study Good Aging in Skåne (GÅS-SNAC). Clin Interv Aging 2012;7:195–205.

48    Millet X, Raoux N, Le Carret N, Bouisson J, Dartigues JF, Amieva H: Gender-related differences in visuospatial memory persist in Alzheimer's disease. Arch Clin Neuropsychol 2009;24:783–789.