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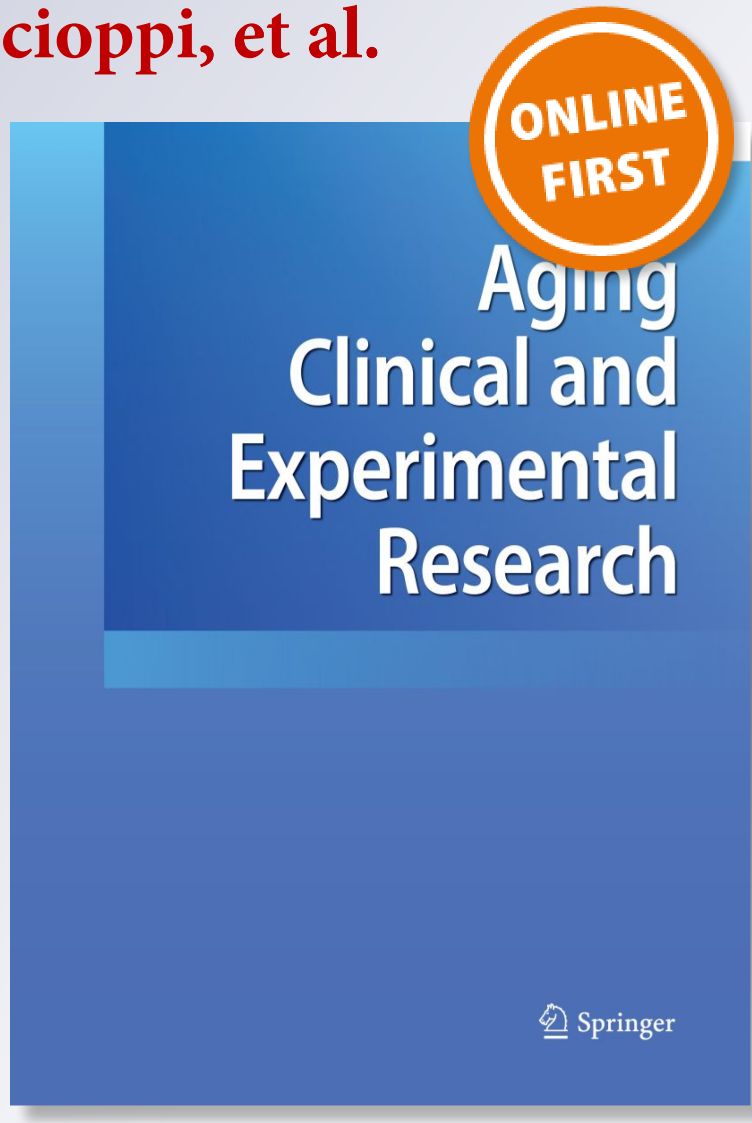

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ORIGINAL ARTICLE

Can physical and cognitive training based on episodic memory be combined in a new protocol for daily training?

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Abstract

Background Cognitive training (CT) is defined as guided practice on a set of standard tasks designed to stimulate particular cognitive functions. Recent studies have shown that physical exercise is beneficial for cognitive activity in older adults and patients with degenerative diseases.

Aims The main objective of the present study is to create a new cognitive tool able to provide training for cognitive functions that take advantage of the physical activity involved in the execution of the task. A study concerning the application of a new CT tool for episodic memory is presented and divided in two parts. The first one aims at developing a new sensorized device, called SmartTapestry, for physical and cognitive training. The second part aims at understanding its technical viability and level of sensitivity in stimulating the same cognitive domain covered by the standardized tests, despite the introduction of the physical activity variable.

Methods The SmartTapestry device was tested with a total of 53 subjects, 29 healthy subjects and 24 subjects suffering from mild cognitive impairment.

Results and discussions The results show a good correlation between the two approaches ($p < 0.005$), suggesting that SmartTapestry can stimulate the same cognitive functions of traditional cognitive tasks, with the addition of physical exercise.

Conclusions The results of this study may be useful in designing ecological and combined cognitive-physical tools, which can be used daily at home, reducing the presence of clinical staff, to train at the same time the brain and the body so as to improve the cognitive treatments efficacy.

Keywords Combined cognitive-motor exercise · Elderly · Sensorized cognitive tool · SmartTapestry tool

Abbreviations

CT	Cognitive training
MCI	Mild cognitive impairment
VPA	Verbal paired associated
WMS-IV	Wechsler Memory Scale-Fourth Edition
ROM	Range of motion
TCT	Traditional cognitive tasks
SUS	System usability scale

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Background

Today, almost 98 million Europeans (19.2% of the entire population) are aged 65 and over and will reach 150 million by 2080 (29.1% of the entire future population) [1]. There will be more elderly people suffering from degenerative diseases, including dementia, impacting the ability of older adults to live safely and independently [2]. In this regard, there is a growing urgency to identify the most effective strategies to prevent cognitive decline [3]. There are currently no definitive pharmacological treatments able to improve symptoms or slow progression of dementia diseases [4]. Therefore, there is increased interest for cognitive training (CT) that is assumed to improve, or at least stabilize, performance in a given cognitive domain (i.e. near transfer effect). CT is based on the principles of neuronal plasticity and cognitive ability restoration, but also generalized effects beyond immediate training contexts are expected (i.e. far

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transfer effects) [5]. The most common approaches for CT use structured material for each function or cognitive process, usually administered through paper and pencil or, in recent years, computerized tools [6].

In recent years, to maximize the effect of such interventions, the interest to combine CT with a program of physical exercises is growing, to benefit from the synergistic impacts of the two typologies of training [7]. CT and combined cognitive-physical training are based upon the principle of brain plasticity. For this reason, to exploit the treatment potential, subjects retaining a large range of cognitive capacities are considered perfect targets [8]. Therefore, several studies regarding CT and a combination of CT and physical exercise take into consideration older adults and subjects suffering from mild cognitive impairment (MCI) [9, 10]. MCI is a clinical condition characterized by objective slight deficits in one single domain (e.g. memory) or in multiple cognitive domains, which do not yet configure as overt dementia [11]. Between 16 and 41% of patients with MCI develop dementia within 1 year [12]. Therefore, early identification and management of MCI may help prevent further deterioration.

More recent studies have examined the efficacy of combined training formats such as pairing exercise and cognitive training, either in simultaneous and sequential formats [13–15]. For example, cognitive training followed by aerobic training in the same session produced significantly greater gains on executive functions and verbal episodic memory when compared to cognitive training alone [16]. In [17], older adults simultaneously performed a verbal working memory test and a cardiovascular training session to improve cognitive and motor-cognitive dual task performance. Both combined and pure cognitive training groups showed the same degree of cognitive improvement, with the exception of a visual memory task, which improved more in the combined group.

Following such a research line, the main goal of the present study is to provide a tool for cognitive functions that take advantage of physical activity in the execution of the task. The current study comprises two parts. The first aims to design and develop a new CT tool, called SmartTapestry, to combine physical exercise and a traditional cognitive test. In particular, the SmartTapestry tool involves the episodic memory domain, particularly vulnerable to decline in aging, while the exercise training is a physical one, which involves exercises for articulation, reinforcement and stretching of upper limbs. The second part involves evaluating the equivalence between a classical assessment instrument for episodic memory [18] and a parallel form of such exercises administered through SmartTapestry in a sample of 53 subjects. Such equivalence will allow the use of SmartTapestry for rehabilitation purposes: a future study will determine whether SmartTapestry will improve the efficacy of training, taking advantage of the introduction of physical activity, to include SmartTapestry in a future rehabilitation protocol performed at home. Specifically, the characteristics of SmartTapestry will allow its utilization at home, reducing the presence of clinical staff, empowering the ecological aspect of the training and its potential frequency by reducing costs. Additionally, since SmartTapestry was designed as an ecological tool to be used daily, the perceived usability is also evaluated.

Methods

Traditional test

The type of chosen test focuses on a specific cognitive function: episodic memory. Episodic memory loss is one of the most reported in the elderly [19]. We chose as a cognitive exercise the subtest Verbal Paired Associated (VPA) Learning Task of the Wechsler Memory Scale-Fourth Edition WMS-IV (Pearson Assessment 2009, 2010UK) [18]. The use of VPA has been driven by the literature evidences about the emblematic relationship between performances at VPA test and the episodic memory. In fact, according to Hiscox et al. [20] the VPA task involves the association between two pieces of information, semantically related or unrelated. The ability to bind together information is rely heavily on the hippocampal activity [21]. Furthermore, the data presented in [20] demonstrated the relationship between hippocampal structure and episodic memory. Due to its emblematic relation to the episodic memory, speaking about cognition and referring to its neuroanatomic basis, we decided that VPA test was very adequate to our purpose. The subtest comprises:

1. Immediate recall subtest: this subtest measures the immediate verbal memory of the associated word pairs. 14 or 10 word pairs are read to the subject (the WMS-IV provides an adult version and one for the elderly aged 65 and older). Later, the examiner reads the first word of each pair and asks the subject to recall the associated word. In the subtest, there are four versions of the same list of word pairs presented in a different order. The examiner will read these four versions and every time, after presenting each list, proceed to the recall (from here reported as *Imm1, Imm2, Imm3*, and *Imm4*). The raw score is the sum of the correct answers to the four versions.
2. Delayed recall subtest: this subtest is administered 20–30 min after the subtest Immediate recall condition. Deferred condition evaluates long-term memory for word pairs. The first word of each pair learned in the immediate condition is presented to the subject, who is

asked to provide the associated word. The raw score is the sum of the correct answers.

3. Recognition subtest: this subtest must be given subsequent to the delayed recall subtest. A list of word pairs is read to the subject, who are asked to identify each pair as one of those already present in the previous subtest or as a new couple. The raw score is the sum of the correct answers.

SmartTapestry system

SmartTapestry is a sensorized tapestry, designed and developed to be used in a combined training protocol involving both physical and cognitive training.

Regarding the physical training, in elderly subjects many orthopaedic pathologies (osteoarthritis and impingement subacromiale) affect the shoulder joint, which often show a reduction in range of motion (ROM) and flexibility, particularly in flexion–extension and abduction movements [22]. Exercises for upper limbs help combat these pathologies if targeted to specific muscular reinforcement [23]. Specifically, the subject placed standing in front of the system will have to raise the upper limb to perform the exercise. This task involves flexion and rotation (internal and external) movements on the frontal plane. If the subject is placed as to have the side system, they can carry out the same exercise by performing abduction and rotation (external and internal) movements on the sagittal plane. For this purpose, SmartTapestry is 60 × 90 cm size so that any subject, at the front or side position, can touch any point of the system and the use of the upper limb within a medium ROM is required.

With respect to the cognitive exercise, SmartTapestry allows administration of the cognitive tasks described above with modalities that comprise an alternative with respect to traditional approaches. The elements that make up the system are the 21 Italian alphabet letters, plus the 'yes' and 'no' answers used for the recognition subtest. The position of the letters in the tapestry is random and new for all subjects, and do not follow any provision already used commercially (i.e. QWERTY or alphabetical order). Each letter is 15 × 15 cm in size and the subject can select it with the open palm of the hand. In this way, letters can be also recognized by those who have modest presbyopia. Therefore, SmartTapestry was designed with the following elements:

A sensitive base (60 × 90 cm) containing (Fig. 1a):

- 24 sensitive elements obtained with a double sheet of conductive textile (Adhesive Conductive Fabric—ACF by Mindsets Ltd.) divided by a 1.5 cm thick foam layer (Fig. 1b). In correspondence with each unit, holes were driven into the foam for allowing contact of the two fabric layers in case of touch (the sensing units work as on–off switches);
- Electronic hardware for data acquisition (Multifunction DAQ System NI USB-6218 by National Instruments), connected to the fabric patches with conductive threads sewn into the foam, and a USB connection to a laptop;

Interchangeable layers to be placed above the sensitive base with Velcro hooks, containing the various targets of the exercises;

A laptop with a custom LabVIEW graphic user interface to select the desired exercise (tests are administered through the software) and acquire data from the tapestry (sequence of correct answers and total test score);

A mobile support structure for the tapestry, able to adjust the height according to the subject's requirements.

Participants

The recruitment was performed at the neuropsychological clinic of Pontedera (Italy), by means of the medical records of MCI outpatients starting from September 2014 until May 2017. The diagnosis for MCI was made according to Petersen criteria [11]; all examined subjects were also evaluated by a neurologist and underwent instrumental exams (computed tomography—CT, magnetic resonance imaging—MRI). Subjects showing dementia or who were

Fig. 1 **a** SmartTapestry hardware, **b** sensing units in the soft base layer, **c** participant performing the SmartTapestry test

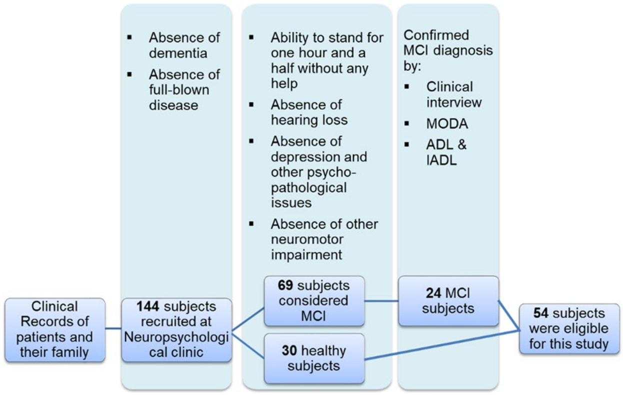

Fig. 2 Recruitment process: the total group considered eligible for this study was 54 subjects

completely deficit incumbent so that they could not perform the activity were not included. After analyzing the medical records, we contacted by telephone a total of 144 subjects, among patients and their familiars, which met the general requirement criteria mentioned above (Fig. 2).

Subsequently, further inclusion criteria of this study were verified by telephone: (1) ability to stand for 1 h and a half without any help; (2) absence of hearing loss; (3) absence of depression and other psychopathological issues; (4) absence of other neuromotor impairment. Subjects with physical impairment were held if this impairment was able to be appropriately corrected with prosthesis (e.g. glasses or hearing aid). At the end of this preliminary screening, a total of 99 subjects confirmed inclusion criteria. 30 of them were deemed cognitively normal whereas, according to the medical records and as confirmed by telephone, the 69 remaining subjects were considered MCI (Fig. 2).

Before starting the protocol, as a mental status exam to verify the inclusion criteria and document the MCI diagnosed, the battery of tests in the MODA [24] ('Milan Overall Dementia Assessment') was used. This retest was used to neutralize the risk that some MCI subjects become demented in the meantime and also to assess the visual-spatial and the selective visual attention abilities of the subject, which could affect the SmartTapestry performance. Then, to test the impairment in daily-life activities the 'Activities of Daily Living (ADL)' [25] and the 'Instrumental Activities of Daily Living (IADL)' [26] scales were used as another element to confirm the condition of MCI. Finally, to perfect the clinical judgment, neuropsychologists conducted a clinically structured interview. A total of 24 of the 69 subjects confirmed the MCI diagnosis. In addition, enrolled MCI subjects were classified as MCI type I (amnesic, single domain) and II (amnesic, multiple domain) = 13, and MCI type III (non-amnesic, single domain) and IV (non-amnesic, multiple domain) = 11, according to the diagnostic algorithm proposed by Peterson during the neuropsychology international symposium [27].

One participant from the healthy cohort was excluded from the final dataset because not enough data were acquired to compute the output measures. Table 1 summarizes the demographic characteristics of the 53 people involved in the study: 24 people diagnosed with MCI and 29 healthy subjects (Fig. 2).

Experimental protocol

All subjects performed both traditional cognitive tasks (TCT) and the parallel forms of these cognitive exercises administered through the SmartTapestry system. Half of the subjects performed before TCT and then SmartTapestry, half of the subjects vice versa. Each subject was randomly assigned to one of those designs.

During the traditional test, a neuropsychologist administered the exercise as required by the traditional protocol. Whereas, during the SmartTapestry test, as soon as the participant was ready, he/she pressed 'start' on the software module and thus the instructions were autonomously administered by SmartTapestry software. The instructions and the list of word pairs are provided by the software, while the subject has to type the remembered word by touching letters displayed on the tapestry (Fig. 1c). The data were acquired and stored by a computer.

At the end of the trial, the system usability scale (SUS) [28] was administered to participants to evaluate the perceived usability of the proposed system. The SUS is a survey instrument comprising ten items giving a global view of subjective assessments of usability.

Comparison of the two tests

Considering the different numbers of associated word pairs administered to adults and elderly (14 and 10, respectively), raw scores (four immediate, one delayed and one recognition) were normalized with respect to the total number of associated word pairs. These were used for the statistical analysis that was performed offline using Matlab software

Table 1 Description of Participants

	Mean (SD) All subjects	Mean (SD) Healthy	Mean (SD) MCI
Men	27	14	13
Women	26	15	11
Age (years)	56.53 (21.34)	41.96 (16.91)	75.73 (4.91)
Education (years)	14.60 (3.83)	16.48 (2.82)	12.33 (3.70)

Table 1 reports the mean value and the standard deviation (SD) for the subjects involved in the study (53 participants)

(MathWorks Inc., Natick, MA, USA). For each subtest, the normal distribution of the normalized raw scores was verified using the Kolmogorov–Smirnov normality test. Because all raw scores were not normally distributed, the Spearman (ρ) correlation coefficient was used to evaluate the relation between the different approaches on the entire sample (53 participants). In addition, to investigate similarity in the performances of the SmartTapestry test between the two cohorts (MCI vs healthy subjects) and between the two MCI groups (types I and II vs types III and IV), a Mann–Whitney *U* test for non-parametric independent variables was carried out. The alpha level of significance was set to 0.05 for all statistical tests.

After completion, each SUS item's score contribution ranged from 0 to 4. For positively worded items (1, 3, 5, 7 and 9), the score contribution is the scale position minus 1. For negatively worded items (2, 4, 6, 8 and 10), it is 5 minus the scale position. To obtain the overall SUS score, the sum of the item score contributions was multiplied by 2.5. Thus, SUS scores range from 0 to 100 in 2.5-point increments. Finally, the Mann–Whitney and the Kruskal–Wallis tests were applied to SUS results to compare different conditions or users.

Results

Spearman coefficients between the TCT and SmartTapestry are reported together with the relevant *p* value in Table 2. Strong positive correlations were obtained for all exercises ($p < 0.005$). These results are aligned to our preliminary conclusions obtained with only 15 subjects [29].

The results of the Mann–Whitney test (Table 3) underline a significant difference ($p < 0.005$) in the performance of the SmartTapestry test between healthy and MCI subjects for all exercises.

These results are also highlighted in the scatter plot of Fig. 3 between the two tests, where the red stars represent the healthy subjects and the blue circles represent the MCI subjects. It can be clearly observed that MCI subjects have lower performance compared to healthy subjects (see also Table 3).

Analyzing the differences between the two tests in the entire sample, it can be seen that the scores obtained with the SmartTapestry tool are higher to those obtained with TCT (Table 3), despite the two sets of scores being significantly correlated. However, the analysis of the two cohorts separately shows that the scores obtained with the two tests follow different trends.

Results shown in Table 4 highlight a significant difference ($p < 0.05$) in the performance of the SmartTapestry test for the two groups of MCI subjects (types I and II, types III and IV) in *Imm2, Imm3, Imm4* and *Delayed* subtests. In addition, MCI subjects with diagnosis of types III and IV achieved higher scores in all subtests compared to MCI subjects with a diagnosis of types I and II.

In terms of usability, the examined results show that the SmartTapestry approach is well evaluated (84.34 ± 12.13) by participants. In particular it was found to be not usable for five volunteers (58.50 ± 7.83), usable for 21 of them (78.33 ± 5.44) and excellent for 27 participants (93.80 ± 3.42). In Table 5, descriptive statistics are reported and the results show that the odd-numbered items have a mean value higher than 4 and a mode value equal to 5,

Table 2 Spearman correlation coefficients (level of significance $p < 0.005$)

	Imm1	Imm2	Imm3	Imm4	Delayed	Recog.
ρ	0.4265	0.5233	0.6018	0.7484	0.7601	0.5247
p	1.5E−03	5.8E−05	1.9E−06	1.2E−10	4.1E−11	5.5E−05

Table 3 Mean value and SD of normalized correct answers and Mann–Whitney tests between MCI and healthy subjects

Mean value (SD)	Imm1	Imm2	Imm3	Imm4	Delayed	Recognition
All subjects						
SmartTapestry	0.42 (0.19)	0.64 (0.20)	0.72 (0.21)	0.76 (0.23)	0.75 (0.23)	0.93 (0.09)
TCT	0.30 (0.20)	0.58 (0.21)	0.69 (0.23)	0.74 (0.23)	0.69 (0.24)	0.93 (0.10)
Healthy						
SmartTapestry	0.50 (0.18)	0.76 (0.14)	0.86 (0.12)	0.92 (0.10)	0.90 (0.10)	0.98 (0.02)
TCT	0.32 (0.17)	0.64 (0.20)	0.78 (0.20)	0.84 (0.16)	0.82 (0.16)	0.98 (0.02)
MCI						
SmartTapestry	0.33 (0.16)	0.49 (0.17)	0.54 (0.16)	0.56 (0.19)	0.56 (0.20)	0.86 (0.10)
TCT	0.28 (0.23)	0.52 (0.21)	0.58 (0.21)	0.62 (0.24)	0.53 (0.24)	0.87 (0.13)
p*	1.9E−03	3.2E−06	3.6E−08	7.2E−09	4.7E−08	2.0E−07

*Mann–Whitney *U* independent sample tests (MCI vs healthy—SmartTapestry)

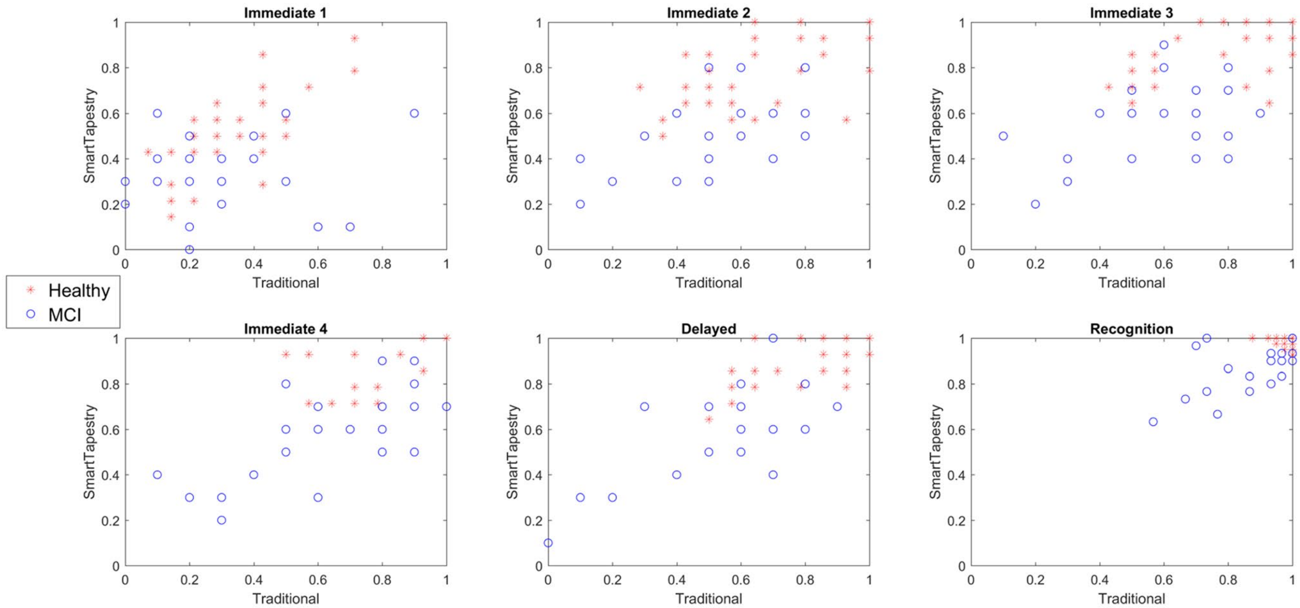

Fig. 3 Scatter plot of normalized correct answers between traditional administration and SmartTapestry in immediate, delayed and recognition subtests. Red stars are healthy subjects the blue circles are MCI subjects

Table 4 Mean value and SD of normalized correct answers and Mann–Whitney tests between two groups of MCI subjects

SmartTapestry Mean value (SD)	Imm1	Imm2	Imm3	Imm4	Delayed	Recognition
MCI Type I and II	0.30 (0.17)	0.42 (0.14)	0.46 (0.13)	0.46 (0.14)	0.46 (0.19)	0.83 (0.12)
MCI Type III and IV	0.37 (0.15)	0.58 (0.16)	0.63 (0.16)	0.68 (0.17)	0.68 (0.15)	0.90 (0.05)
p*	0.2991	0.0355	0.0198	0.0063	0.0138	0.2535

*Mann–Whitney U independent sample tests (MCI types I and II vs MCI types III and IV)

Table 5 SUS results

Item	Question	Mean	SD	Mode
Item1	I think that I would like to use SmartTapestry frequently	3.64	1.23	3
Item2	I found SmartTapestry unnecessarily complex	1.68	1.11	1
Item3	I thought the SmartTapestry tool was easy to use	4.19	1.13	5
Item4	I think that I would need the support of a technical person to be able to use SmartTapestry	1.92	1.25	1
Item5	I found that the various functions in this system were well integrated	4.58	0.72	5
Item6	I thought that there was too much inconsistency in SmartTapestry tool	1.32	0.64	1
Item7	I would image that most people would learn to use SmartTapestry very quickly	4.47	0.85	5
Item8	I found SmartTapestry very cumbersome to use	1.36	0.81	1
Item9	I felt very confident using SmartTapestry	4.49	0.85	5
Item10	I needed to learn a lot of things before I could get going with SmartTapestry	1.36	0.83	1

except for *Item1*. On the other hand, the even-numbered items have a mean value lower than 2 and a mode value equal to 1.

Concerning the effect of gender, women (87.50 ± 11.83) gave the SmartTapestry system an overall SUS score higher than men did (81.30 ± 11.84) (p = 0.023). However, male participants suffering from MCI (92.17 ± 4.90) evaluated the proposed system as being more usable than healthy male ones did (82.86 ± 10.96) (p = 0.021). Regarding the impact of age, subjects aged 65–75 years (74.15 ± 15.47) gave the SmartTapestry system an overall SUS score lower than those aged 31–55 (93.18 ± 4.48) (p = 0.019).

Discussions

The main objective of the present study was to demonstrate the effectiveness of SmartTapestry in stimulating the episodic memory domain by comparing scores obtained with SmartTapestry with those obtained by a standard paper-and-pencil test in a sample of 53 subjects (29 healthy and 24 MCI). According to the results, the correlations were statistically significant for all subtests, which means that both instruments are substantially equivalent in the stimulation of episodic memory (Table 2).

Another important goal of this work was to investigate whether the two cohorts had different performance. The results underline that MCI and healthy subjects present significant differences in all subtests of SmartTapestry, which confirms that the test is able to detect the differences in the cognitive abilities of the subjects (Table 3). Indeed, as shown in Fig. 3, MCI subjects have lower performance compared to healthy subjects. We could hypothesize that this result might be due to the MCI condition itself or because MCI subjects are generally older than other experimental subjects. These findings are aligned with the most recent results in this area; indeed, both age and MCI condition lead to physiological decline of all executive functions [30].

Additionally, healthy subjects achieved higher scores with SmartTapestry compared to TCT in all subtests (Table 3). These results can suggest facilitation in the memory performance may be due to the multiple nature of the mnemonic trace: the SmartTapestry task involves auditory (the auditory track repeating the list of words), visual–spatial (the position of the letters in the tapestry) and kinaesthetic information (the movements of the arms needed to press the letters in the tapestry). In fact, the subject has both to remember the associated word and press it on the tapestry, and this may help in cognitive consolidation for the added visual search strategy [31]. In addition, this trend could be explained by the presence of a potential motivating factor. The technological nature of the device may lead the subject to enhance their attention during the training with SmartTapestry, with satisfactory results.

In contrast, MCI subjects obtained higher score in *Imm2, Imm3* and *Imm4* subtests administered with TCT compared to SmartTapestry (Table 3). This might be explained by a greater request, in terms of cognitive resources, during the execution of the task using SmartTapestry. In fact, SmartTapestry demands the subject to process information in two ways, both verbal and visual. Moreover, for the task accomplishment, the subject has to organize a motor plan and put in place a visual search. This result is aligned with the literature [32], which underlines that the addition of a motor task during the execution of a cognitive task causes a worse performance in elderly subjects. Regarding the delayed subtest, the score obtained with SmartTapestry is higher compared to TCT (0.56 and 0.53, respectively). This improvement can be explained by the mechanisms of implicit memory, recruited by the motor part of the task. The output channel for the response, using SmartTapestry system, in fact, impose that the subject pushes some part of the tapestry, where letters are printed, so to form the right word. The repetition of this task could recruit neural networks involved in implicit memory. The combined effects of explicit and implicit memory could allow MCI subjects to recall in the delayed condition during the SmartTapestry test, which is better than during TCT [33].

Analyzing the two groups of MCI subjects with diagnosis of types I and II and MCI subjects with diagnosis of types III and IV (Table 4), it is possible to observe significant differences between amnesic and non-amnesic MCI in all the conditions with the exception of the first immediate recall task and the recognition task. These findings are in line with our expectations, in fact they reflect the amnesic MCI's (MCI I and II) consolidation process deficits as compared to non-amnesic MCI (MCI III and IV) [34].

Concerning the recognition subtest, healthy and MCI subjects showed comparable performance in the two types of administration. Such results can be explained by the nature of the task, based on similar cognitive mechanisms and on a 'yes–no' paradigm.

SmartTapestry was designed to be an ecological sensorized tool able to combine a traditional test for episodic memory with physical activity. In this framework, our CT tool has the capability to perform cognitive and physical training for the user at home, in particular for MCI subjects that are at risk of conversion to dementia. In fact as demonstrated by Nouchi et al. [35], exercise training is able to improve some cognitive functions, among which: executive functions, processing speed and episodic memory.

In addition, it is important to demonstrate not only the efficacy of the tool from a clinical point of view, but also the influence of the use of our technology in real life in terms of efficacy, efficiency and usability [36].

According to Bangor et al. [37], a SUS score higher than 70 indicates a usable product, and higher than 90 a very usable one. Examining the results, 20 participants found the SmartTapestry usable (SUS $\geq$ 70) and 26 ones considered it very usable (SUS $\geq$ 90).

Regarding users' perceived satisfaction using the SmartTapestry system, the results are positive because 56.60% of the sample would like to use the SmartTapestry system frequently (*Item1*). In particular, the percentage increases to 66.67%, considering MCI participants who could gain the most benefit from the proposed system in the future.

The proposed system was also perceived as being easy to use because 43 participants gave a score of 4–5 to *Item3*. However, participants suffering from MCI (3.83 ± 1.20) thought the SmartTapestry system was less easy to use then healthy ones did (4.48 ± 0.99) (Item3 $p = 0.030$). To confirm this, MCI subjects (2.38 ± 1.44) considered that they would need the support of a technical person to be able to use this system more than healthy ones did (1.55 ± 0.95) (Item4 $p = 0.024$). This difference between MCI and healthy participants could be explained by the difference in age between the two cohorts and by the fact that MCI subjects have greater learning difficulties.

The SmartTapestry approach was perceived as efficient because 48 persons found the various functions in this system to be well integrated (*Item5*) and no participants thought there was excessive inconsistency in this system (*Item6*).

Gender was found to significantly impact overall SUS scores and this might be related to the hypothesis that women in general are more health conscious [38]. However, considering only the male sample, MCI men (92.17 ± 4.90) gave the SmartTapestry system an overall SUS score higher than healthy ones did (82.86 ± 10.96) ($p = 0.021$) because ill users tend to be more health conscious.

Finally, age influenced the overall SUS score because elderly users typically have a less positive attitude towards technology [39].

Considering all of the above, it is reasonable to state that SmartTapestry has a high degree of usability, underlining participants' willingness to use the SmartTapestry tools in their daily routine.

Conclusions

The aim of this feasibility study is twofold. First, it aims to develop a new cognitive 'ecological' tool, called SmartTapestry, which allows the administration of standardized psychometric tests with modalities that are alternative with respect to traditional. The second goal of the study aims to compare the traditional subtest with our SmartTapestry system that includes physical activity. The results of our comparison underline that the SmartTapestry approaches could be used to stimulate episodic memory. Furthermore, the multimodal approach (auditive-visual-kinaesthetic) may improve subjects' performance. This could be crucial for a new rehabilitation strategy and both MCI and healthy subjects could benefit from such a program. Moreover, thanks to this design, the new cognitive tool can be customized according to elderly needs and can be easily integrated at home. In this study, SmartTapestry was tested for a particular cognitive domain (episodic memory), but for the design of the device, other cognitive domains could also be easily investigated.

On the basis of this preliminary study and with the purpose to investigate the potential use of SmartTapestry as a rehabilitation tool, we believe it necessary to improve this study by analyzing the CT with different cognitive domain and exercise training, with the aim of creating a complete and efficient home rehabilitation tool.

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Compliance with ethical standards

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

Research involving human participants and/or animals The study design and protocol, including subject privacy and sensitive data treatment, were approved by the Ethics Committee of the Scuola Superiore Sant'Anna, Pisa. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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