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RESEARCH ARTICLE

# Visually encoded working memory is closely associated with mobility in older adults

**Toshikazu Kawagoe · Kaoru Sekiyama**

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**Abstract** Previous research suggests that older adults' motor performance is associated with cognitive function. Although this has been reported especially for executive function, it is not yet clear for various types of working memory (WM). In fact, age-related decline in WM is more severe for faces than other types of visual objects. The present study focused on the relationship between diverse WM and two types of motor performance (mobility and manual dexterity), which are implicated in pathological decline. To measure diverse WM, we adopted *N*-back tasks using three distinct types of stimuli (numbers, locations, and faces). Mobility was measured with the timed up and go test and manual dexterity was measured with the Pegboard Test. Participants were community-dwelling older adults (age: mean 78.6 years). Comparisons of younger and older adults' *N*-back performances indicated that WM for faces is more sensitive to aging compared with WM for the other stimuli. Correlation analyses within the older group indicated that WM tasks mainly correlated with mobility, but less so with manual dexterity. Among the three types of WM, spatial WM and face WM had significant partial correlation coefficients with mobility after age and general cognitive decline were controlled. These results indicate that visually encoded WM is associated only with mobility, although general cognitive function is related to both motor abilities. The selective association between the visually encoded WM and mobility is discussed in terms of the interactive processes between executive processing and perceptual encoding, where dynamic visual processing for locomotion plays a role.

**Keywords** Age-related change · Spatial working memory · Face working memory · Timed up and go test · Cognitive decline

## Introduction

A growing body of research shows that physical exercise is beneficial for protecting older adults from cognitive decline. Interventional studies have shown that daily physical activity and exercise help to maintain or improve older adults' cognitive functions (for review, Kramer et al. 2006; Deary et al. 2009). Epidemiological studies indicate the protective effects of exercise against dementia of which the most common type is Alzheimer's disease (Abbott et al. 2004; Laurin et al. 2001). For the brain volume, Erickson et al. (2009) investigated non-demented older individuals and found that higher physical exercise levels were associated with a larger hippocampal volume, which is in turn associated with better memory performance. Specifically, cognitive functions relating to exercise were, for example, attention (Bakken et al. 2001), processing speed (Panton et al. 1990), executive processing (Kramer et al. 1999), and verbal memory (Williamson et al. 2009). These findings suggest that exercise and physical activity have good effects on the brain and cognition and that exercise and cognitive states are closely related to each other. This contrasts with the fact that cognitive training has only a limited effect on improving cognitive status (Redick et al. 2013). Therefore, exercise is a good indirect approach to access and improve

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T. Kawagoe (✉)
Graduate School of Social & Cultural Sciences, Kumamoto University, Kumamoto, Japan
e-mail: toshikazukawagoe@gmail.com

K. Sekiyama
Division of Cognitive Psychology, Faculty of Letters, Kumamoto University, Kumamoto, Japan
e-mail: sekiyama@kumamoto-u.ac.jp

older adults' cognitive status, rather than a direct approach, in some situations. It is meaningful to explore such a relationship in more detail.

In this study, we focused on executive processing in working memory (WM) based on a meta-analysis, indicating that exercise effects were greatest on executive processing (Colcombe and Kramer 2003). Executive processing is thought to be heavily involved in handling novel situations outside the domain of our "automatic" psychological processes with goal-directed behavior. It involves management of the cognitive process, for example, planning, problem solving, verbal reasoning, and WM. In an attempt to investigate what aspects of physical exercise have effects to improve cognitive function, we examined different types of WM as cognitive domain. Most studies on the effect of exercise on WM have utilized only one type of WM, namely verbal WM (Clarkson-Smith and Hartley 1989; Williams and Lord 1997, Hoffman et al. 2008; Oken et al. 2006). However, aging seems to affect diverse WM differently. WM for letters is subject to age-related decline less severely than faces and objects in healthy older adults (Leonards et al. 2002). This suggests that visual WM decline cannot be solely explained by the increasing vulnerability of the prefrontal cortex, which is responsible for executive processing. In association with this, Baddeley's influential model of WM has some components with a complex and diverse neural basis (Baddeley 1986), which are the visuospatial sketchpad for spatial items (Jonides et al. 1993), the phonological loop for verbal items (Jonides et al. 1997), and the episodic buffer relating to long-term memory (Baddeley 2000). Different cortical systems have been implicated for visuospatial and verbal processing. For example, the spatial system is localized more in the right hemisphere, while the verbal system is located more in the left hemisphere, although not completely (Smith and Jonides 1997). Also, the dichotomy of visual processing, that is, the dorsal pathway representing the spatial ("where") and a ventral pathway representing visual form ("what") information (Mishkin and Ungerleider 1982 for monkey anatomy; Haxby et al. 1991 for human function) may be true for WM. In fact, diversity in cortical activations was demonstrated by a WM task for different stimuli in older adults (Grady et al. 1994). Therefore, it is reasonable to make distinctions between the different types of WM when examining the relationship with motor performance. How are the different types of WM related to motor performance? To investigate WM, we used an *N*-back task for three types of stimuli: numbers, locations, and faces. The *N*-back task is assumed to place great demands on a number of key processes within WM, such as online monitoring, updating, and manipulation of remembered information (Owen et al. 2005).

Previous research has focused on the physical aspect of exercise as an influencing factor on cognition (Barnes et al. 2003; Erickson et al. 2011; Smiley-Oyen et al. 2008). However, exercise may be seen as a multifaceted concept, including not only physical strength (i.e., cardiovascular function and muscular strength), but also motor abilities indexed by components such as flexibility, speed, dynamic balance, and fine coordination. Voelcker-Rehage et al. (2010) found that both exercise and motor performance are related significantly to cognitive executive functioning, while only motor performance is related to perceptual speed in older adults without motor or cognitive restriction. According to their study, motor performance, rather than physical strength, may tap a wider range of cognitive functions.

To assess older adults' motor performance, mobility and dexterity are useful because they are not only easy to measure, but also implicated in relation to cognitive function in both demented and non-demented populations. In the clinical context, they are both known to have some association with dementia and its precursor state, that is, mild cognitive impairment (MCI). For mobility, walking is related to cognitive function in older adults. For example, gait dysfunction has been found in MCI syndrome and dementia (Montero-Odasso et al. 2009; Verghese et al. 2008; Waite et al. 2005). As a measure of mobility, the "timed up and go" test (TUG) is a widely-used performance-based clinical measure (Podsiadlo and Richardson 1991). The performance of TUG is associated with executive processing in non-demented older adults (Donoghue et al. 2012; Herman et al. 2011). Dexterity is also related to cognitive status. Previous research has shown a relationship between manual dexterity performance assessed by a pegboard test (PEG) and general cognitive function assessed by a Mini-Mental State Examination and Clinical Dementia Rating. These studies found that older adults with MCI or dementia often experience dexterity dysfunction relative to normal controls (Kluger et al. 1997; Sakamoto et al. 2007). Also, Yoon et al. (2010) demonstrated that cognitive decline coincides with the impairment of manual dexterity assessed by PEG in non-demented independently living older adults. Another study found that motor speed observed in PEG decreases with normal aging (Scuteri et al. 2005). Based on these facts, we focused on mobility and dexterity as indices of motor performance in this study.

The purpose of this study was to clarify the behavioral relationships between the three types of WM and the two types of motor performance, which presumably have an association with cognitive decline (mobility: Montero-Odasso et al. 2009, dexterity: Kluger et al. 1997). The relationship between executive function and the physical aspect of exercise is already known, yet little is known regarding the association between motor control and executive processing.

In addition to these measurements, we used the Montreal Cognitive Assessment test (MoCA) to quantify each participant's level of general cognitive function. MoCA is a specifically developed test for screening MCI and early Alzheimer's disease (Nasreddine et al. 2005; Fujiwara et al. 2010; Luis et al. 2008) and detects MCI or mild Alzheimer's disease better than the Mini-Mental State Examination (Aggarwal and Kean 2010). We defined the MoCA score as the degree of cognitive decline in older adults and examined whether the level of cognitive decline and WM performance were similarly associated with motor functions. Before analyzing the relationship between WM performances and motor performances, we examined age-related changes in diverse WM by comparing the WM performance between older and younger adults. After this verification, we analyzed the relationship between cognitive function and motor performance in older adults.

## Methods

### Participants

We recruited 53 older adults via a local club for the aged and the personal connections of supporters. They were living independent lives and presumably non-demented. Of those participants, 14 were excluded for the following reasons: many of them insisted on quitting when given difficult WM tasks (2-back tasks), and five had orthopedic problems. As we wanted to include frail individuals, some of the recruited participants were users of a day-care service, but were without a diagnosis of dementia or MCI. In fact, all these users were excluded based on the above criteria. Thirty-nine older adults (13 males) who could complete all of the tasks were included in the analyses (ages: 68–88 years, mean 78.62 years, SD 5.19 years, education: 6–18 years, mean: 11.9 years, SD: 2.69 years). They were without diagnosis of any type of dementia, depression, stroke, parkinsonism, visual impairment, or current treatment with neuroleptics and orthopedics. As we aimed to sample older adults across a widespread range of cognitive statuses, we did not exclude participants who were presumably MCI on the basis of the MoCA score. As a control group for *N*-back tasks, 19 younger adults (20 or 21 years, education: 14.7 years) participated only for *N*-back tasks. All participants were right-handed and had normal or corrected-to-normal visual acuity. All of the participants gave their informed written consent in accordance with the Declaration of Helsinki. The experiments were approved by the Ethics Committee of Kumamoto University.

### Tasks and stimuli

#### ***N*-back task**

The *N*-back task paradigm was utilized to assess participants' WM. We used a computer (Windows XP) to run in-house software for *N*-back tasks, a 15-inch monitor to present stimuli for participants, and a numerical keypad for participants' responses. Participants watched the screen from approximately 60-cm visual distance. The participant was requested to monitor a series of stimuli and to respond by pressing the "Enter" key of a numerical keypad whenever a stimulus was the same as the one presented in "N" trials previously, where "N" is a pre-specified integer(1 or 2) in this study; therefore, each task was called a 1-back or 2-back task. Both younger and older participants performed 1-back and 2-back tasks. The stimuli were numbers, locations, and faces (Fig. 1). Ten images were used for each type of stimuli. Numbers were single digits from 0 to 9. Locations were made up of 10 images of a single dot, each of which was presented in a randomly designated location. Faces consisted of colored images of 10 Japanese faces from the ATR Facial Expression Image Database (5 males and 5 females). The visual angles of the stimuli were 4.7° × 3.8° for numbers, 1.4° × 1.4° for dots, and 16° × 10° for faces. Stimulus duration and the inter-stimulus interval were both 2000 ms (Fig. 1). For each stimulus type, 20 items were sequentially displayed. Each item was randomly chosen from the ten stimuli and 30 % of them were targets. The participants' responses were recorded and the rates of correct answers were calculated. Each of the six conditions (1- and 2-back tasks for 3 stimulus types) was conducted in separate blocks. An experimental block consisted of 20 sequential presentations, and two blocks

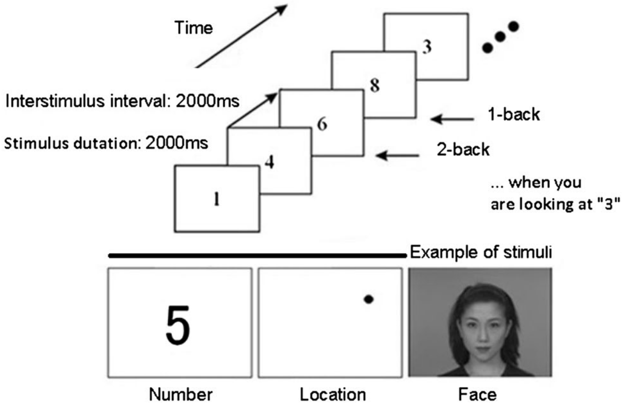

**Fig. 1** Example of *N*-back task and the stimuli. Participants were asked to monitor a series of stimuli and to respond whenever a stimulus was the same as the one presented in "*N*" trials previously. Three types of stimuli (numbers, locations, and faces) were used in this study

**Table 1** Mean performances (SD) of older adults on all of the tasks

| Task | *N*-back | | | | | |
|---|---|---|---|---|---|---|
| | Number | Location | Face | MoCA | PEG | TUG |
| Mean (SD) | 76.04 % (14.64) | 71.36 % (16.03) | 62.46 % (18.15) | 23.21 pt (4.14) | 32.52 s (6.99) | 8.03 s (3.00) |

were repeated for each condition. In total, 240 items were presented. The order of the 12 blocks was counterbalanced across participants.

#### *Montreal cognitive assessment (MoCA, Japanese edition)*

The MoCA is a neuropsychological test for screening cognitive impairment with high sensitivity and specificity for detecting MCI in those who are diagnosed as normal on the Mini-Mental State Examination (Nasreddine et al. 2005). It assesses different cognitive domains: attention and concentration, executive functions, memory, language, visuoconstructional skills, conceptual thinking, calculations, and orientation. MoCA can assess these cognitive skills within approximately 15 min. The total possible score is 30 points; a score of 26 or above is considered normal. However, we used the MoCA score as a continuous measure of the degree of cognitive decline rather than for screening.

#### *Timed up and go test (TUG)*

We followed the original version (Podsiadlo and Richardson 1991) of the TUG procedure. Participants were asked to stand up from a standard chair with a seat height of 40 cm, walk a distance of 3 m to a marker as fast as possible, turn, walk back to the chair, and sit-down. The time recorded in the two trials was averaged to obtain the TUG score. Each participant was tested twice and the faster time was taken for analysis.

#### *Peg board test (PEG)*

We used a set of pegs and a board for occupational training (Sakai Medical Corporation SOT-2102). It consisted of 20 wooden pegs (1.4 cm in diameter and 5.0 cm long) and a board (28 cm by 23 cm) with 20 holes. The 20 pegs were inserted in all 20 holes in the board at the beginning. The participant was asked to turn all the 20 pegs up-side-down as fast as possible and the performance time was measured. They used their dominant hand (right hand) to complete this task. As in TUG, each participant was tested twice and the faster time was taken for analysis.

### Procedures

All tests were conducted in two sessions (days). Session one included three types of *N*-back task and lifestyle questions to ascertain their medical history and health status. Session two included MoCA, PEG, and TUG. The order of the tasks within a day was counterbalanced across the participants. Except for the *N*-back task, there was no opportunity to practice tasks. For the *N*-back task, participants could practice until they understood the demands of the task, with at least two practice blocks.

### Data analysis and statistical tests

Because the data could be analyzed only for those participants who completed the entire test battery, there were no missing data for these participants. Performances of *N*-back tasks were calculated in the following manner. Trials were sorted into one of four categories; hit: response to target, miss: no response to target, false alarm: response to non-target, and correct rejection: no response to non-target. We used "100 * hit/(hit + miss + false alarm)" to calculate the correct response percentages of each *N*-back performance. We removed "correct rejection" for this calculation because "no response to non-target" does not necessarily indicate only correct rejection and could also indicate inattention or hesitation. First, the performances of the *N*-back tasks were compared between young and older adults by three-way ANOVA. For post hoc analysis, we used Ryan's method. Next, we conducted a correlation analyses for performances by older adults (Table 1). First, we calculated their distribution via the Kolmogorov–Smirnov test. The distribution for normality was not confirmed for some data sets, so we used a nonparametric statistics method for the correlation analyses. Specifically, we analyzed the data by using Spearman's rank-order correlation (Table 2). Then, we conducted a partial correlation analyses by controlling age and general cognitive function to examine the relationships between WM and two measurements of motor functions (Table 3).

## Results

All of the older participants' data are shown in Table 1. The accuracy for *N*-back tasks indicates means across 1-back and 2-back tasks. These means suggest that the facial *N*-back task was more difficult than the other types of *N*-back task. This will be examined in the next section. The mean score for MoCA was approximately 23, which was

**Table 2** Correlation coefficients indicated by Spearman's rho among all factors

| Task | *N*-back | | | Cognitive and motor assessment | | | |
|---|---|---|---|---|---|---|---|
| | Number | Location | Face | Age | MoCA | PEG | TUG |
| AGE | −0.11 | −0.36* | −0.19 | 1 | | | |
| MoCA | 0.40* | 0.53** | 0.39* | −0.44** | 1 | | |
| PEG | −0.16 | −0.38* | −0.30 | 0.21 | −0.46** | 1 | |
| TUG | −0.38* | −0.68** | −0.59** | 0.56** | −0.66** | 0.49** | 1 |

* *p* < 0.05, ** *p* < 0.01

**Table 3** Partial correlation coefficients for the index of motor tests controlling age and MoCA score

| Task | Number | Location | Face |
|---|---|---|---|
| TUG | −0.21 | −0.50** | −0.52** |
| PEG | 0.03 | −0.20 | −0.15 |

* *p* < 0.05, ** *p* < 0.01

slightly below the criterion of MCI (25). This may be partly because many of our participants were old-old. The mean time needed for PEG was 32.5 s (for 20 pegs), indicating that each peg was turned in less than 2 s. The mean time needed for TUG was about 8 s (to walk about 6 m with a stand-up, a turn, and sit-down). No one fell on the floor during the TUG test, and no one erroneously dropped pegs during the PEG test.

In the following sections, we first compared *N*-back task performances between young and older adults to see the WM transition in aging. Then, we conducted simple and partial correlation analyses between various measurements within the old groups. Because performances of TUG did not conform to normal distribution, we used Spearman's rank-order correlation coefficients for analyses. Each WM score was the average of 1-back and 2-back task.

## Comparison of *N*-back task performances between young and older adults

A comparison of performances of *N*-back tasks between young and older adults is shown in Fig. 2. A 2 (age group) × 2 (WM load: 1-back or 2-back) × 3 (stimuli) ANOVA with repeated measures found significant main effects of group [*F* (1, 56) = 43.53, *p* < 0.001], representing the better performances of young participants compared with older participants, WM load [*F* (1, 56) = 190.66, *p* < 0.001], representing the poorer performances for the 2-back task compared with 1-back task, and stimuli [*F* (2, 112) = 12.63, *p* < 0.001]. There were significant interactions of group × stimuli [*F* (2, 112) = 6.435, *p* < 0.005] and group × WM load [*F* (1, 56) = 38.99, *p* < 0.001]. Post hoc analysis revealed that older adults showed significant difficulty in performing the *N*-back task for faces as compared to the other stimulus types (*p* < 0.05). No stimulus differences were found for the young adults group. Older adults' WM ability had deteriorated, but it was not uniform, that is, age-related deterioration of WM was more severe for faces than for numbers and locations.

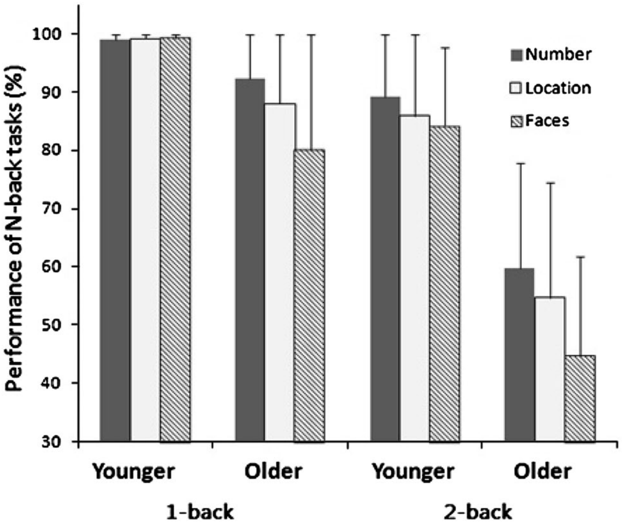

**Fig. 2** Performance of *N*-back tasks by young and older adults. Young adults accomplished each type of *N*-back task with high performance. Older adults showed lower performance than the young adults, and they showed lower performance on face stimuli than the other types of stimuli

## Rank-order correlation analyses of performances among all tasks

Spearman's rank-order correlation coefficients (Spearman's rho, $\rho$) using the present study data are provided in Table 2. Each condition of the *N*-back tasks correlated significantly with the mobility measured by TUG, but not with manual dexterity measured by PEG except performance for locations. These measures are plotted in Fig 3.

As anticipated by prior studies, both TUG and PEG significantly correlated with MoCA. However, there are many confounding factors in their correlations. For example, MoCA and TUG were correlated significantly with all of the other factors. To clarify how each WM specifically related to two motor performance indices, we conducted

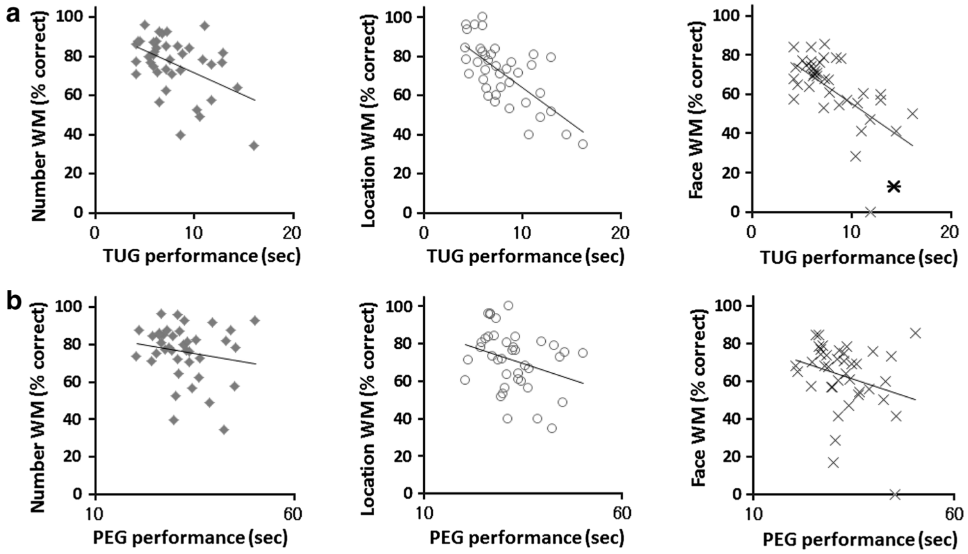

**Fig. 3** Plots of WM performance to TUG (**a**) and PEG (**b**). Correlation coefficients are described in Table 2. WM performance was highly correlated with TUG, but not with PEG

partial correlation analysis to control the confounding factors.

### Partial correlation analysis

We analyzed the partial correlation coefficients between WM performance and two measures of motor performance, TUG and PEG, to specify the correlations without confounding them with other factors. We controlled age and MoCA because of their significant correlations with motor performance measures. The results are shown in Table 2. TUG related significantly to WM for locations (partial $\rho = -0.50$, $p < 0.01$) and faces (partial $\rho = -0.52$, $p < 0.05$), but not for numbers. PEG was not significantly correlated with any type of WM when age and MoCA were controlled.

Additionally, we examined the relationship between motor performance and general cognitive decline by calculating a partial correlation. For this analysis, we controlled the age factor. The resulting partial correlation coefficients revealed that both PEG and TUG were significantly correlated with MoCA (PEG: partial $\rho = -0.32$, $p < 0.05$; TUG: partial $\rho = -0.41$, $p < 0.01$).

## Discussion

This study aimed to examine what kinds of WM (numbers, locations, and faces using the *N*-back task) are associated with two fundamentally different types of motor performance (mobility measured using TUG and manual dexterity measured by PEG). Additionally, MoCA was used to measure the level of general cognitive impairment.

A notable result in this study was the strength of the association between "visually encoded" WM and mobility. In the present study, we set up three different types of WM and found different degrees of relationship with mobility and manual dexterity. *N*-back tasks for numbers, which are thought to be phonologically encoded, related to mobility only in the simple correlation analysis, in which age or cognitive status (MoCA) was confounded. Prior studies have examined the effects of physical exercise on verbal WM and the results are equivocal (effective: Clarkson-Smith and Hartley 1989; Williams and Lord 1997, non-effective: Hoffman et al. 2008; Oken et al. 2006). The relatively weak correlation between number WM and motor performance in the present study may be a clue to support understanding of why the previous research has shown mixed results. Our results indicate that WM for locations and faces is closely associated with mobility. It suggests that not only higher-order components such as executive functioning (Colcombe and Kramer 2003; Kramer et al. 1999; Smiley-Oyen et al. 2008), but also perceptual encoding should be considered in examining the relationship between WM and motor performance. It seems that we should focus on the interaction between executive processing and perceptual encoding, as described in the influential model of WM (Baddeley 1986). All the stimuli were visually presented, but numbers are likely to be processed by a phonological loop after being transformed into phonological codes. On the other hand, location and face stimuli are less suitable for phonological encoding and phonological rehearsal and rather are thought to be visually encoded. In other words, the use of a visuospatial sketchpad (Baddeley 1986) may have the primary role in the association between WM and mobility. As far as we know, this has never been explicitly reported.

The comparison of the older adults' WM performances against young adults' performances demonstrated that WM for faces is more greatly deteriorated than other WM in older adults. This result is consistent with a prior study showing that WM for faces is more vulnerable to age-related decline than WM for letters (Leonards et al. 2002). At the neural level, WM is delineated by the activity of both the prefrontal area and the perceptual areas (Courtney et al. 1997). The selective deterioration in facial WM suggests that the perceptual areas affect age-related decline of WM. Face perception is mediated by a dynamic neural system in humans that is comprised of multiple, bilateral regions such as the inferior occipital gyri, superior temporal sulcus, and lateral fusiform gyrus (Haxby et al. 2000). Some of these areas relating to face perception may be vulnerable to aging, resulting in WM for faces being more difficult than the other types of WM for older adults. We reconfirmed the differential age-related decline of WM for different types of stimuli.

For the difference between dexterity and mobility, each type of WM was related to basic mobility. The correlation between mobility and WM is consistent with a previous study showing that gait velocity was associated with executive function (Holtzer et al. 2006). On the other hand, our results indicated that dexterity was only slightly related to WM. A possible cause of the difference between the two motor tasks is that performance on the TUG incorporates leg strength and some degree of cardiovascular fitness, neither of which are required for PEG. Such a cause, if any, seems to be consistent with the reported relationship between physical exercise and executive processing (Colcombe and Kramer 2003). As a second possible cause, the difference may correspond to two distinctive motor skills, that is, gross motor skill and fine motor skill, each of which requires large muscles or small muscles (Magill 2011). A third possible cause is concerned with the different loads in processing dynamic visual information. TUG accompanies variation in the retinal image for the whole visual field as one walks, requiring recalculation of retinal coordinates relative to the somatomotor coordinates before making each step, whereas finger movements for PEG can be done in a relatively static visual field. The heavier load for dynamic visual processing in TUG may have caused an association with visually encoded WM. Concerning the processing load, a previous study found that walking intervention with variable visual goals had a greater effect on improving executive function than simple walking intervention in older adults (Yamada et al. 2010). This also suggests the relevance of the visual-encoding process working jointly with executive processing. Another possibility is that PEG was less sensitive because they were not acclimated to the PEG test. Whereas TUG was composed of movements common in everyday activities such as rising, walking, and sitting down, PEG required unaccustomed finger movements. Such differences in experience may have affected the results. All these possible causes are confounded and it is difficult to determine which one contributes more to the difference between mobility and dexterity in relation to WM. Nevertheless, the fact that only the visually encoded WM was associated with mobility suggests that a substantial role was played by the heavier load of dynamic visual processing in locomotion.

Was the PEG irrelevant to this experiment? We found a significant correlation between manual dexterity and degree of general cognitive decline. Previous studies reported that dexterity was sensitive to cognitive status in the earliest stage of Alzheimer's disease (Kluger et al. 1997), or even at the non-demented level (Yoon et al. 2010). The present study is consistent with the results of these prior studies in terms of the relationship between general cognitive function and hand dexterity. This relationship is intriguing because manual dexterity was not well correlated with WM capacity but correlated significantly with cognitive decline, even when controlling other factors. We could consider at least two distinct motor systems (mobility and dexterity) which differently relate to different aspect of cognitive functions. The present study revealed that both mobility and manual dexterity predict general cognitive decline including MCI to some extent. Of the two motor systems, mobility may predict the decline in executive control, though causal relationships are unknown.

In this study, we could not include approximately 20 % of the participants in the analyses due to their incompletion of the tasks. Many of them had difficulty in the 2-back task, and some of them had orthopedic problems for the motor tests. Therefore, the present results presuppose these abilities. Another point to be noted is an inconsistency with a previous finding that PEG performance decreases with age in the normal elderly (Scuteri et al. 2005); we did not find a significant correlation between PEG and age. Thus, this inconsistency may be due to different procedures and sample size.

To conclude, by investigating distinct types of WM, two types of WM were dissociated in terms of their relationship with motor performance. Visually encoded WM, for which phonological encoding is difficult, has a strong correlation with mobility. The correlation between visually encoded WM and mobility seems to represent the interactive processes between executive processing and visuospatial processing where dynamic visual processing for locomotion also takes place. The present results suggest that a cognitive aspect of motor function, that is dynamic visual processing, is important for affecting cognitive function in older adults. This suggestion may throw light on our understanding of what kind of intervention affects cognitive function effectively.

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

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