Published in final edited form as:

Neurosci Lett. 2018 January 18; 664: 139–143. doi:10.1016/j.neulet.2017.11.032.

Visuospatial function predicts one-week motor skill retention in cognitively intact older adults

Jennapher Lingo VanGilder¹, Caitlin Rose Hengge², Kevin Duff^{3,4}, and Sydney Yoshie Schaefer^{1,*}

¹School of Biological and Health Systems Engineering, 501 E. Tyler Mall, ECG 334A, Arizona State University, Tempe, AZ 85287, USA

²University of Utah Hospital, 50 N. Medical Dr., Salt Lake City, UT, 84112, USA

³Center for Alzheimer's Care, Imaging and Research, University of Utah Health Sciences Center, 650 Komas Dr. 106A, Salt Lake City UT 84108-1225

⁴Department of Neurology, University of Utah, 175 N. Medical Dr. E. Salt Lake City, UT 84132, USA

Abstract

Motor learning declines with aging, such that older adults retain less motor skill after practice compared to younger adults. However, it remains unclear if these motor learning declines are related to normal cognitive changes associated with aging. The purpose of this study was to examine which cognitive domains would best predict the amount of retention on a motor task one week after training in cognitively intact older adults. Twenty-one adults ages 65 to 84 years old were assessed with Repeatable Battery for the Assessment of Neuropsychological Status, which assesses five cognitive domains (immediate and delayed memory, visuospatial/constructional, language, and attention). Participants also completed one training session of a functional upper extremity task, and were re-tested one week later. Stepwise regression indicated that the visuospatial domain was the only significant predictor of how much skill participants retained over one week, with a visual perception subtest explaining the most variance. Results from this study support previous work reporting that older adults' capacity for motor learning can be probed with visuospatial tests. These tests may capture the structural or functional health of neural networks critical for skill learning within the aging brain, and provide valuable clinical insight about an individual's unique rehabilitation potential.

Keywords

visual perception; procedural memory; upper extremity; motor skills

*Corresponding author: Dr. Sydney Y. Schaefer sydney.schaefer@asu.edu.

Conflict of Interest: The authors have no conflict of interest to report.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Introduction

Motor learning declines with aging, such that older adults tend to learn slower and retain less motor skill than younger adults [1,2]. Given the concurrence of aging and cognitive decline [3–7], poorer motor learning may, in part, be linked to normal cognitive changes associated with aging. Studies have shown that memory deficits do not account for motor learning deficits [8–11], suggesting that other cognitive impairments may instead interfere with learning a motor skill. For example, in patients ages 65 to 89 diagnosed with amnesic Mild Cognitive Impairment (MCI), their ability to retain a motor skill may be related to visuospatial impairments rather than their memory impairments [12]. Visuospatial function has been implicated in other types of motor learning, such as motor sequence learning [13,14], but has not been explored extensively in the learning and retention of more complex motor skills in older adults. To further investigate this relationship in the absence of delayed memory impairments, cognitively intact older adults were assessed with the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) [15]. They then completed a single training session of a functional upper extremity motor task, and were re-tested on the motor task one week later. The purpose of this study was to test whether older adults' motor skill retention was related to their visuospatial function, above and beyond other cognitive domains (namely immediate and delayed memory, language, and attention). We hypothesized that better visuospatial scores would be associated with more retention of a complex motor skill from baseline to follow-up one week later.

Materials and methods

Participants

All human research procedures were approved by the university's Institutional Review Board, in accordance with the Helsinki Declaration. Twenty-one cognitively intact adults ages 65 to 84 years old (six males, 15 females) provided informed consent prior to enrollment. Participants were excluded if any cognitive test score fell 1.5 or more standard deviations below normative data, which is a common demarcation point for Mild Cognitive Impairment [16,17]. Participants were also excluded if they had any significant functional limitations, as evidenced by the Katz Inventory of Activity of Daily Living [18]. Exclusion criteria also included any self-reported history of major neurological (e.g., stroke, seizure, traumatic brain injury) or psychiatric (e.g., bipolar disorder, schizophrenia) disorder. To ensure intact sensorimotor function, grip strength (Jamar hand dynamometer, [19]), functional dexterity (Grooved Pegboard, Lafayette Instruments, [20]), and tactile sensation (Semmes-Weinstein monofilaments, [21]) of both hands were collected.

Neuropsychological Battery

All participants completed the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), which is a widely-used cognitive measure that uses 12 standardized tests to assess the following five cognitive domains as Indexes: Immediate Memory, Visuospatial/Constructional, Language, Attention, and Delayed Memory. A Total Scale score indicating global cognition is also determined by combining all five Index scores. Index and Total scores are age-corrected standard scores (Mean=100, SD=15) based

on normative information from the assessment manual; higher values indicate better function. Generally speaking, age-corrected scores represent the participant's cognitive status relative to normative values from age-matched peers, such that the age-corrected score may be interpreted as the participant's cognitive status regardless of age.

Motor skill retention

Motor skill retention was measured using a functional upper extremity motor task. This task was selected for several reasons. First, it is feasible and efficacious for motor skill learning in older adults [22,23] and is retainable [24,25]. Second, it has concurrent and ecological validity with more traditional point-to-point reaching paradigms [26] that have been used previously to quantify retention in more cognitively impaired patients [10] yet is more functional [27].

One trial of the motor task was comprised of five repetitions to three different targets placed radially around a constant start location at a distance of 16 cm; thus, each trial equaled 15 repetitions total. The start location and all three targets were cups that were 9.5 cm in diameter and 5.8 cm in height. Additional details regarding the motor task apparatus, including a schematic, have been published elsewhere (Schaefer and Hengge 2016; Schaefer and Duff 2017). For each repetition, participants used their nondominant hand to acquire and transport two raw kidney beans from the start location to one of the three target locations with a conventional plastic spoon. At the start of each trial, participants' first repetition was out to the ipsilateral target cup, next to the center target cup, and then to the contralateral cup, relative to the hand used. As noted above, participants repeated this sequence five times to complete the trial. Each trial began when the participants picked up the spoon and ended when the last two beans were dropped into the final cup, yielding a 'trial time' as the measure of performance. Time continued to elapse in the event of any unsuccessful attempts (e.g., only one bean was placed into a target cup per repetition); thus, any errors that would have occurred during a trial would be accounted for in the performance measure. Performing this task with the nondominant hand is by design to ensure that the task is under-practiced and not over-learned, particularly in older adults [28], such that participants have the potential to show practice effects without confounds of floor or ceiling effects [29]. A modified Edinburgh Handedness Inventory was used to identify participants' nondominant hand [30].

As stated above, the measure of performance was the time taken to complete the 15 repetitions (i.e. "trial time"), with lower times indicating better performance, as participants were instructed to "move as quickly yet as accurately as possible." All trials were timed to the nearest 100th of a second via stopwatch. Participants were allowed to adopt any movement pattern during training (i.e., they were not required to move or hold the spoon in any specified manner with their nondominant hand), thereby facilitating exploratory attempts for discovering successful movement strategies for completing the task (see [31]).

After one familiarization trial to ensure participants understood the task, they completed 10 trials. The first trial served as their baseline performance. This small dose of training has also been shown to be sufficient for determining longer-term acquisition and retention

[24,32]. Participants were then re-tested a week later on a follow-up trial to identify any measureable skill retention across one week.

Motor skill retention was selected as the primary dependent variable because motor learning is defined as a relatively permanent change in motor performance due to practice or experience [33]. The amount of motor skill retention at one week relative to baseline performance was calculated using Equation 1.

$$\text{retention (\%)} = [(\text{baseline} - \text{follow-up}) / \text{baseline}] \times 100 \quad (\text{Eq.1})$$

Positive values indicated more retention. Normalizing the amount of retention accounts for variations in movement speed or performance on the motor task between participants at baseline [34].

Statistical analysis

The SAS® statistical software program JMP Pro 12 (SAS Institute Inc., Cary, NC) was used for all statistical analysis ($\alpha = 0.05$). The five individual RBANS Index scores were entered into a backwards elimination stepwise regression analysis as predictors of skill retention. This procedure was the same as in the previous study [12] in order to test the replicability of these findings, in spite of many known limitations of retrospective stepwise regression in general (e.g. [35]). Only Index scores that significantly contributed to the variance in the retention variable were included in the final model based on the criterion-to-remove of $p > 0.05$. Multiple linear regression was then used to determine which subtests within any significant Indexes were most related to retention. Subtests were entered in a single step into this regression model. Any correlation coefficients (r) greater than 0.59 were considered to be strong, between 0.30 and 0.59 were moderate, and below 0.30 were weak effect sizes (Cohen, 1988).

Results

Group means (and standard deviations) and medians of age, education, grip strength, functional dexterity, and all RBANS Index scores are provided in Table 1. All participants had intact tactile sensation in the tested hand (finest Semmes-Weinstein monofilament detectable, $n=20$; next finest detectable, $n=1$). RBANS Total and Index scores had mean and median values ~ 100 , including that of the Delayed Memory Index, which supports that this sample was largely cognitively intact.

Performance on the motor task across all trials is shown in Figure 1. Overall, participants improved rapidly from a mean $\pm$ SD baseline performance of 62.83 ± 12.32 s to 56.71 ± 7.34 s on trial 10, consistent with previous findings [22]. To test the extent to which participants retained these improvements one week later, performance at the one-week follow-up was compared to that at baseline (Eq. 1). On average, retention was $3.22 \pm 20.10\%$ (95% CI [-5.93, 12.36]). While statistically this suggests that the group, on average, showed little retention, the large standard deviation indicated a wide range of retention scores. That is,

some participants retained little to no skill, while others did. Bivariate analysis indicated that the amount of retention was unrelated to Total Scale Index scores ($p=0.11$), consistent with previous findings [12]. However, backwards elimination indicated that the Visuospatial/Constructional Index (standardized $\beta=0.56$; $r=0.56$; adjusted $r=0.52$; $p=0.009$) was the only significant cognitive predictor of skill retention, such that higher (better) scores were associated with more retention (Fig. 2A). The strength of this effect was considered moderate. All other Index scores for Immediate Memory, Language, Attention, and Delayed Memory were eliminated in the stepwise regression due to lack of significance (all $p>0.05$).

Because the motor task itself is visuospatial in nature, requiring visually guided reaching to different spatial locations, it is plausible that participants' baseline performance could also be related to their visuospatial ability. However, baseline performance was not significantly related to Visuospatial/Constructional Index score ($p=0.22$) (Fig. 2B). This indicates that participants' change in motor skill due to practice/experience, rather than their ability to navigate the task at baseline, is dependent on visuospatial abilities.

Further analysis determined which of the two visuospatial tests that comprise the Visuospatial/Constructional Index explained the most variance in one-week skill retention: Figure Copy and Line Orientation. This was done to explore which aspects of the visuospatial domain may be most predictive of retention among older adults. Multiple linear regression showed that only the Line Orientation subtest was related to skill retention (standardized $\beta=0.52$; $p=0.02$); Figure Copy was not significant ($p=0.15$). (Assumptions of no multicollinearity were verified; VIF=1.07). For example, a participant with raw score of 20 (age-adjusted z -score=1.29) on Line Orientation improved by over 30% on the motor task from baseline to follow-up, whereas a participant with a raw score of 10 (z -score=-2.28) was ~42% worse at follow-up compared to baseline, even though both participants had similar Figure Copy scores (17 (z -score=-0.44) and 18 (z -score=-0.059), respectively).

Discussion

This study addressed whether declines in motor skill learning with aging may, in part, be linked to age-related cognitive decline. Consistent with previous findings [12], motor skill retention was related to visuospatial function in cognitively intact older adults. Furthermore, underlying motor learning processes may be more dependent on visual perception (measured with Line Orientation) than visuoconstruction (measured with Figure Copy) [36], although other visuospatial functions not tested by the RBANS may also be important [13,14,37].

Although the motor task in this study requires participants to use vision to guide their movements to different spatial locations, it is important to note that the RBANS Visuospatial/Constructional Index was unrelated to participants' baseline performance on this motor task, consistent with previous studies [12,38]. Because the Visuospatial/Constructional Index correlated with changes in performance (Fig. 2A) rather than to baseline performance (Fig. 2B), it suggests that visuospatial tests may probe the neural processes that are more crucial to *learning* a movement over time than to the execution of a given movement at a given time. In other studies, visuospatial assessments have been shown to predict rates and amounts of motor skill learning [13,39–41] even in older adults

[14,42,43]. For example, surgeons with higher visuospatial ability typically learn complex surgical procedures better and faster than those with lower visuospatial abilities [44–46]. As in our study, visuospatial abilities also tend to not predict baseline surgical performance prior to any training [38], but rather predict the amount of skill learning [47]. One explanation is that visuospatial tests may probe the structural or functional health of critical neural structures or networks for skill learning. Structural neuroimaging has shown that various types of motor learning (e.g., sequencing, force production) is correlated with the integrity of white matter tracts connecting premotor and visual cortex and the cerebellum [48–50] as well as with the functional activation of premotor, prefrontal, and parietal regions [48]. Moreover, these frontal-parietal networks may be lateralized for processing information and/or learning different aspects of a complex motor skill (i.e., reaching, grasping, and object manipulation) [51,52]. Future work is needed to determine how older adults' scores on specific visuospatial tests are related to specific white or gray matter regions of interests that have been implicated in motor learning [53].

The Visuospatial/Constructional Index of the RBANS is comprised of only two visuospatial tests: Line Orientation (for visual perception) and Complex Figure Copy (for visuoconstruction). In reality, however, the visuospatial domain is much broader. Future research is therefore needed to determine which tests of visuospatial function, such as visual perception, visual attention, visuospatial working memory, and/or visuoconstruction, are most predictive of older adults' capacity for learning and retaining a motor skill. Determining older adults' capacity for motor learning has significant rehabilitative implications, given that motor learning (also referred to as *procedural* or *errorless* learning [54,55]), has great rehabilitative potential for older adults with dementia [56–59]. This and previous studies suggest, however, that the effectiveness of such approaches may depend on the extent of any concomitant visuospatial impairment in these patients [60], and that visuospatial testing may be a viable way for clinicians to screen for ‘non-responders’ who may not benefit as much from more procedurally-based therapies.

The purpose of this study was to test whether older adults' motor skill retention was related to their visuospatial function, above and beyond other cognitive domains (namely immediate and delayed memory, language, and attention). Stepwise regression indicated that visuospatial function was the only significant predictor of how much skill participants retained over one week, with a visual perception subtest explaining the most variance. These findings suggest these visuospatial tests may capture the structural or functional health of neural networks critical for skill learning within the aging brain, and provide valuable clinical insight about cognitive therapeutic responsiveness.

Acknowledgments

This work was supported by the National Institutes of Health (K01AG047926 to S.Y.S.).

References

1. Raz N, Williamson A, Gunning-Dixon F, Head D, Acker JD. Neuroanatomical and cognitive correlates of adult age differences in acquisition of a perceptual-motor skill. *Microsc Res Tech*.

- 2000; 51:85–93. DOI: 10.1002/1097-0029(20001001)51:1<85::AIDJEMT9>3.0.CO;2-0 [PubMed: 11002356]
2. Swinnen SP. Age-related deficits in motor learning and differences in feedback processing during the production of bimanual coordination pattern. *Cogn Neuropsychol*. 1998; 15:439–466. DOI: 10.1080/026432998381104 [PubMed: 28657466]
 3. Harada CN, Natelson Love MC, Triebel K. Normal Cognitive Aging. *Clin Geriatr Med*. 2013; 29:737–752. DOI: 10.1016/j.cger.2013.07.002 [PubMed: 24094294]
 4. Ren J, Wu YD, Chan JSY, Yan JH. Cognitive aging affects motor performance and learning. *Geriatr. Gerontol Int*. 2013; 13:19–27. DOI: 10.1111/j.1447-0594.2012.00914.x
 5. Li SC, Hämmerer D, Müller V, Hommel B, Lindenberger U. Lifespan development of stimulus-response conflict cost: Similarities and differences between maturation and senescence. *Psychol Res*. 2009; 73:777–785. DOI: 10.1007/s00426-008-0190-2 [PubMed: 19023594]
 6. Jenkins L, Myerson J, Hale S, Fry AF. Individual and developmental differences in working memory across the life span. *Psychon Bull Rev*. 1999; 6:28–40. [PubMed: 12199312]
 7. Zelinski EM, Burnight KP. Sixteen-Year Longitudinal and Time Lag Changes in Memory and Cognition in Older Adults. *Psychol Aging*. 1997; 12:503–513. DOI: 10.1037/0882-7974.12.3.503 [PubMed: 9308097]
 8. Eslinger PJ, Damasio R. Preserved motor learning in Alzheimer's disease: Implications for anatomy and behavior. *J Neurosci*. 1986; 6:3006–3009. [PubMed: 3760945]
 9. Yan JH, Zhou CL. Effects of motor practice on cognitive disorders in older adults. *Eur Rev Aging Phys Act*. 2009; 6:67–74. DOI: 10.1007/s11556-009-0049-6
 10. Yan JH, Dick MB. Practice Effects on Motor Control in Healthy Seniors and Patients with Mild Cognitive Impairment and Alzheimer's Disease. *Neuropsychol Cogn*. 2006; 13:385–410. DOI: 10.1080/138255890969609
 11. Gobel EW, Blomeke K, Zadikoff C, Simuni T, Weintraub S, Reber PJ. Implicit Perceptual-Motor Skill Learning in Mild Cognitive Impairment and Parkinson's Disease. *Neuropsychology*. 2013; 27:314–321. DOI: 10.1037/a0032305 [PubMed: 23688213]
 12. Schaefer SY, Duff K. Within-session and one-week practice effects on a motor task in amnesic mild cognitive impairment. *J Clin Exp Neuropsychol*. 2017; 39:473–484. DOI: 10.1080/13803395.2016.1236905 [PubMed: 27690745]
 13. Bo J, Seidler RD. Visuospatial working memory capacity predicts the organization of acquired explicit motor sequences. *J Neurophysiol*. 2009; 101:3116. doi: 10.1152/jn.00006.2009 [PubMed: 19357338]
 14. Bo J, Borza V, Seidler RD. Age-related declines in visuospatial working memory correlate with deficits in explicit motor sequence learning. *J Neurophysiol*. 2009; 102:2744–2754. DOI: 10.1152/jn.00393.2009 [PubMed: 19726728]
 15. Randolph C, Tierney MC, Mohr E, Chase TN. The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS): Preliminary Clinical Validity. *J Clin Exp Neuropsychol*. 1998; 20:310–319. DOI: 10.1076/jcen.20.3.310.823 [PubMed: 9845158]
 16. Albert MS, DeKosky ST, Dickson D, Dubois B, Feldman HH, Fox NC, Gamst A, Holtzman DM, Jagust WJ, Petersen RC, Snyder PJ, Carrillo MC, Thies B, Phelps CH. The diagnosis of mild cognitive impairment due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimers Dement*. 2011; 7:270–279. DOI: 10.1016/j.jalz.2011.03.008 [PubMed: 21514249]
 17. Petersen RC, Aisen P, Boeve BF, Geda YE, Ivnik RJ, Knopman DS, Mielke M, Pankratz VS, Roberts R, Rocca WA, Weigand S, Weiner M, Wiste H, Jack CRJ. Mild cognitive impairment due to Alzheimer disease in the community. *Ann Neurol*. 2013; 74:199–208. DOI: 10.1002/ana.23931 [PubMed: 23686697]
 18. Katz S, Downs TD, Cash HR, Grotz RC. Progress in Development of the Index of ADL1. *Gerontologist*. 1970; 10:20–30. http://dx.doi.org/10.1093/geront/10.1_Part_1.20. [PubMed: 5420677]
 19. Mathiowetz V, Kashman N, Volland G, Weber K, Dowe M, Rogers S. Grip and pinch strength: Normative data for adults. *Arch Phys Med Rehabil*. 1985; 66:69–74. [PubMed: 3970660]

20. Merker, B., Podell, K. Grooved Pegboard Test. Kreutzer, JS.DeLuca, J., Caplan, B., editors. 2011. p. 1176-1178.
21. Bell-Krotoski JA, Fess EE, Figarola JH, Hiltz D. Threshold detection and Semmes-Weinstein monofilaments. *J Hand Ther.* 1995; 8:155–162. [PubMed: 7550627]
22. Schaefer SY, Dibble LE, Duff K. Efficacy and Feasibility of Functional Upper Extremity Task-Specific Training for Older Adults With and Without Cognitive Impairment. *Neurorehabil Neural Repair.* 2015; 29:636–644. DOI: 10.1177/1545968314558604 [PubMed: 25416739]
23. Schaefer SY, Patterson CB, Lang CE. Transfer of Training Between Distinct Motor Tasks After Stroke, *Neurorehabil. Neural Repair.* 2013; 27:602–612. DOI: 10.1177/1545968313481279
24. Schaefer SY, Duff K. Rapid Responsiveness to Practice Predicts Longer-Term Retention of Upper Extremity Motor Skill in Non-Demented Older Adults. *Front Aging Neurosci.* 2015; 7:214.doi: 10.3389/fnagi.2015.00214 [PubMed: 26635601]
25. Glenberg A, Goldberg A, Zhu X. Improving early reading comprehension using embodied CAI. *An Int J Learn Sci.* 2011; 39:27–39. DOI: 10.1007/s11251-009-9096-7
26. Schaefer SY, Hengge C. Testing the concurrent validity of a naturalistic upper extremity reaching task. *Exp Brain Res.* 2016; 234:229–240. DOI: 10.1007/s00221-015-4454-y [PubMed: 26438508]
27. Jebsen RH, Taylor N, Trieschmann RB, Trotter MJ, Howard LA. An objective and standardized test of hand function. *Arch Phys Med Rehabil.* 1969; 50:311–319. [PubMed: 5788487]
28. Schaefer SY. Preserved motor asymmetry in late adulthood: Is measuring chronological age enough? *Neuroscience.* 2015; 294:51–59. DOI: 10.1016/j.neuroscience.2015.03.013 [PubMed: 25772792]
29. Suchy Y, Kraybill ML, Franchow E. Practice effect and beyond: Reaction to novelty as an independent predictor of cognitive decline among older adults. *J Int Neuropsychol Soc.* 2011; 17:101–111. DOI: 10.1017/S135561771000130X [PubMed: 21073771]
30. Oldfield RC. The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia.* 1971; 9:97–113. DOI: 10.1016/0028-3932(71)90067-4 [PubMed: 5146491]
31. Taubert M, Draganski B, Anwender A, Muller K, Horstmann A, Villringer A, Ragert P. Dynamic Properties of Human Brain Structure: Learning-Related Changes in Cortical Areas and Associated Fiber Connections. *J Neurosci.* 2010; 30:11670–11677. DOI: 10.1523/JNEUROSCI.2567-10.2010 [PubMed: 20810887]
32. Park H, Schweighofer N. Nonlinear mixed-effects model reveals a distinction between learning and performance in intensive reach training post-stroke. *J Neuroeng Rehabil.* 2017; 14:21.doi: 10.1186/s12984-017-0233-2 [PubMed: 28302158]
33. Schmidt R, Lee T. Motor Control And Learning: A Behavioral Emphasis. *Human Kinetics* (Fourth). 2005 citeulike-article-id:5722542.
34. Temprado JJ, Sleimen-Malkoun R, Lemaire P, Rey-Robert B, Retornaz F, Berton E. Aging of sensorimotor processes: A systematic study in Fitts' task. *Exp Brain Res.* 2013; 228:105–116. DOI: 10.1007/s00221-013-3542-0 [PubMed: 23649969]
35. Copas JB. The Editor: Technometrics. *Technometrics.* 1983; 25:303–304. DOI: 10.1080/00401706.1983.10487885
36. Spencer RJ, Wendell CR, Giggey PP, Seliger SL, Katzel LI, Waldstein SR. Judgment of Line Orientation: An Examination of Eight Short Forms. *J Clin Exp Neuropsychol.* 2013; 35:160–166. DOI: 10.1080/13803395.2012.760535 [PubMed: 23350928]
37. Schweighofer N, Lee JY, Goh HT, Choi Y, Kim SS, Stewart JC, Lewthwaite R, Winstein CJ. Mechanisms of the contextual interference effect in individuals poststroke. *J Neurophysiol.* 2011; 106:2632.doi: 10.1152/jn.00399.2011 [PubMed: 21832031]
38. Langlois J, Wells GA, Lecourtois M, Bergeron G, Yetisir E, Martin M. Spatial abilities of medical graduates and choice of residency programs. *Anat Sci Educ.* 2015; 8:111–119. DOI: 10.1002/ase.1453 [PubMed: 24953052]
39. Jeunet C, Kaoua B, Subramanian S, Hachet M, Lotte F. Predicting Mental Imagery-Based BCI Performance from Personality, Cognitive Profile and Neurophysiological Patterns: e0143962. *PLoS One.* 2015; 10doi: 10.1371/journal.pone.0143962

40. Jeunet C, Jahanpour E, Lotte F. Why standard brain-computer interface (bci) training protocols should be changed: an experimental study. *J Neural Eng.* 2016; 13:36024.doi: 10.1088/1741-2560/13/3/036024
41. Hammer R, Sloutsky V, Grill-Spector K. Feature saliency and feedback information interactively impact visual category learning. *Front Psychol.* 2015; 6doi: 10.3389/fpsyg.2015.00074
42. Schaffert J, Lee CM, Neill R, Bo J. Visuomotor adaptability in older adults with mild cognitive decline. *Acta Psychol (Amst).* 2017; 173:106–115. DOI: 10.1016/j.actpsy.2016.12.009 [PubMed: 28039795]
43. Baweja H, Kwon M, Onushko T, Wright D, Corcos D, Christou E. Processing of visual information compromises the ability of older adults to control novel fine motor tasks. *Exp Brain Res.* 2015; 233:3475–3488. DOI: 10.1007/s00221-015-4408-4 [PubMed: 26298044]
44. Brandt MG, Davies ET. Visual-spatial ability, learning modality and surgical knot tying. *Can. J Surg.* 2006; 49:412.
45. Roach VA, Mistry MR, Wilson TD. Spatial visualization ability and laparoscopic skills in novice learners: Evaluating stereoscopic versus monoscopic visualizations. *Anat Sci Educ.* 2014; 7:295–301. DOI: 10.1002/ase.1412 [PubMed: 24136843]
46. Duce NA, Gillett L, Descallar J, Tran MT, Siu SCM, Chuan A. Visuospatial ability and novice brachial plexus sonography performance. *Acta Anaesthesiol Scand.* 2016; 60:1161–1169. DOI: 10.1111/aas.12757 [PubMed: 27324187]
47. Maan ZN, Maan IN, Darzi AW, Aggarwal R. Systematic review of predictors of surgical performance. *Br J Surg.* 2012; 99:1610–1621. DOI: 10.1002/bjs.8893 [PubMed: 23034658]
48. Tomassini V, Jbabdi S, Kincses ZT, Bosnell R, Douaud G, Pozzilli C, Matthews PM, Johansen-Berg H. Structural and functional bases for individual differences in motor learning. *Hum Brain Mapp.* 2011; 32:494–508. DOI: 10.1002/hbm.21037 [PubMed: 20533562]
49. Steele CJ, Scholz J, Douaud G, Johansen-Berg H, Penhune VB. Structural correlates of skilled performance on a motor sequence task. *Front Hum Neurosci.* 2012; 6:1–9. DOI: 10.3389/fnhum.2012.00289 [PubMed: 22279433]
50. Zhang, F., Savadjiev, P., Cai, W., Song, Y., Verma, R., Westin, CF., O'Donnell, LJ. Fiber clustering based white matter connectivity analysis for prediction of Autism Spectrum Disorder using diffusion tensor imaging. 2016 IEEE 13th Int. Symp. Biomed. Imaging; 2016; p. 564-567.
51. Budisavljevic S, Dell'Acqua F, Zanatto D, Begliomini C, Miotto D, Motta R, Castiello U. Asymmetry and Structure of the Fronto-Parietal Networks Underlie Visuomotor Processing in Humans. *Cereb. Cortex.* 2017; 27:1532–1544. DOI: 10.1093/cercor/bhv348
52. Mutha PK, Haaland KY, Sainburg RL. Rethinking motor lateralization: specialized but complementary mechanisms for motor control of each arm. *PLoS One.* 8(n.d):e58582.
53. Biesbroek JM, van Zandvoort MJE, Kuijf HJ, Weaver NA, Kappelle LJ, Vos PC, Velthuis BK, Biessels GJ, Postma A. The anatomy of visuospatial construction revealed by lesion-symptom mapping. *Neuropsychologia.* 2014; 62:68–76. DOI: 10.1016/j.neuropsychologia.2014.07.013 [PubMed: 25062545]
54. White L, Ford MP, Brown CJ, Peel C, Triebel KL. Facilitating the use of implicit memory and learning in the physical therapy management of individuals with Alzheimer disease: A case series. *J Geriatr Phys Ther.* 2014; 37:35–44. DOI: 10.1519/JPT.0b013e3182862d2c [PubMed: 23459238]
55. Lekeu F, Wojtasik V, Van der Linden M, Salmon E. Training early Alzheimer patients to use a mobile phone. *Acta Neurol Belg.* 2002; 102:114–121. [PubMed: 12400249]
56. Van Halteren-Van Tilborg IADA, Scherder EJA, Hulstijn W. Motor-Skill learning in Alzheimer's disease: A review with an eye to the clinical practice. *Neuropsychol Rev.* 2007; 17:203–212. DOI: 10.1007/s11065-007-9030-1 [PubMed: 17680369]
57. De Vreese LP, Neri M, Fioravanti M, Belloi L, Zanetti O. Memory rehabilitation in Alzheimer's disease: A review of progress. 2001; :794–809. DOI: 10.1002/gps.428
58. Zanetti O, Zanieri G, Di Giovanni G, De Vreese LP, Pezzini A, Metitieri T, Trabucchi M. Effectiveness of procedural memory stimulation in mild Alzheimer's disease patients: A controlled study. *Neuropsychol Rehabil.* 2001; 11:263–272. DOI: 10.1080/09602010042000088
59. Voigt-Radloff S, de Werd M, Leonhart R, Boelen D, Rikkert M, Fliessbach K, Kloppel S, Heimbach B, Fellgiebel A, Dodel R, Eschweiler G, Hausner L, Kessels R, Hull M. Structured

- relearning of activities of daily living in dementia: The randomized controlled REDALI-DEM trial on errorless learning. *Alzheimers Res Ther.* 2017; 9doi: 10.1186/s13195-017-0247-9
60. Mayr U. Spatial attention and implicit sequence learning: Evidence for independent learning of spatial and nonspatial sequences. *J Exp Psychol Learn Mem Cogn.* 1996; 22:350–364. [PubMed: 8901340]

Highlights

- Visuospatial function predicts one-week motor skill retention in older adults.
- Extent of delayed memory impairment does not affect retention of motor skill.
- Visuospatial tests could determine responsiveness to procedural-based therapies.

Fig. 1.

Mean $\pm$ standard error task performance for baseline, the nine remaining trials, and one-week follow-up trial. Task performance on the y-axis was measured as the time taken to complete each trial, yielding 'trial time' in which lower trial times indicate better task performance.

Fig. 2.

Motor task results were plotted for all participants as a function of the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) Visuospatial/Constructional Index score. Greater values along the x-axis indicate better Index scores. R^2 and p values are reported for reference. A: Motor skill retention at one week is expressed as a percentage of baseline performance (Eq. 1), with more positive values indicating better retention. B: Baseline performance during the initial testing session is expressed in seconds, with lower times indicating better performance.

Table 1

Participant characteristics.

	Mean $\pm$ SD	Median	Range
Age (years)	72.9 $\pm$ 6.4	74	65-84
Education (years)	15.9 $\pm$ 3.2	16	12-24
Grip strength (kg)	22.7 $\pm$ 5.5	23.3	12.3-31.6
Grooved Pegboard (s)	101.4 $\pm$ 28.5	92.6	71.3-192.7
RBANS ^a Total Scale Index	105.1 $\pm$ 10.8	102	92-136
Immediate Memory Index	103.1 $\pm$ 12.0	103	85-129
Visuospatial/Constructional Index	104.4 $\pm$ 12.1	105	84-126
Language Index	100.9 $\pm$ 11.1	101	82-125
Attention Index	110.5 $\pm$ 11.7	115	85-128
Delayed Memory Index	100.1 $\pm$ 12.4	101	81-129

N = 21; 6 males and 15 females.

^aRBANS = Repeatable Battery for the Assessment of Neuropsychological Status. Scores are age-corrected, with a normal score of 100 and with a standard deviation of 15.