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Predicting motor skill learning in older adults using visuospatial performance

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Abstract

Between-group comparisons of older and younger adults suggest that motor learning decreases with advancing age. However, such comparisons do not necessarily account for group differences in cognitive function, despite the co-occurrence of aging and cognitive decline. As such, cognitive differences may explain the observed age effects on motor learning. Recent work has shown that the extent to which a motor task is learned is related to visuospatial function in adults over age 65. The current study tested whether this relationship is replicable across a wider age range and with a brief, widely available cognitive test. Thirty-three adults (aged 39–89 years old) completed the Montreal Cognitive Assessment (MoCA) prior to practicing a functional upper extremity motor task; performance on the motor task was assessed 24 hours later to quantify learning. Backward elimination stepwise linear regression identified which cognitive domains significantly predicted retention. Consistent with previous findings, only the Visuospatial/Executive subtest score predicted change in performance 24 hours later, even when accounting for participant age. Thus, the age-related declines in motor learning that have been reported previously may be explained in part by deficits in visuospatial function that can occur with advancing age.

Keywords

visuospatial function; aging; motor learning; MoCA

Introduction

Much of what is known about aging and motor learning has come from between-group comparisons of older (typically 65 years and older) and younger adults (typically college-aged). The current consensus is that older adults tend to retain less motor skill after practice compared to younger adults, as evidenced by several types of motor learning paradigms, including sensorimotor adaptation (McNay & Willingham, 1998; Seidler, 2006), complex motor skill acquisition (Brown, Robertson, & Press, 2009; Pratt, Chasteen, & Abrams, 1994), and motor sequence learning (Ehsani, Abdollahi, Mohseni Bandpei, Zahiri, &

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Jaberzadeh, 2015; Harrington & Haaland, 1992). While this suggests that motor learning capacity, on average, decreases with advancing age, comparing learning between older and younger adults tends to overlook 1) the notable variations in motor learning within older age groups (Bock & Girgenrath, 2006; Ehsani et al., 2015) and 2) the age-related differences in cognition (Harada, Natelson Love, & Triebel, 2013; Hedden & Gabrieli, 2004) despite the reliance of motor learning on cognitive processes, especially in the early stages (Fitts & Posner, 1967). Thus, differences in cognitive status may explain why older adults tend to have poorer motor learning outcomes than younger adults.

Motor learning is a relatively permanent change in the ability to execute movements as a result of practice or experience (Schmidt & Lee, 2005). As such, the extent of learning can be approximated by the amount of improvement following a period of delayed retention (Kantak & Winstein, 2012). Recent findings have suggested that neither chronological age nor global cognitive status is predictive of retained improvements (Schaefer, Dibble, & Duff, 2015; Schaefer & Duff, 2015), while visuospatial function may be (Schaefer & Duff, 2017; Lingo VanGilder, Hengge, Duff, & Schaefer, 2018). However, these studies only used one neuropsychological assessment (the Repeatable Battery for the Neuropsychological Status, RBANS) (Randolph, 1998) and only tested adults age 65 years and older, making it unclear whether these previous findings truly reflect a relationship between visuospatial function and motor learning, or are simply an artifact of the cognitive test used. Thus, the purpose of this study was to test the robustness of the previous findings with the more commonly used Montreal Cognitive Assessment (MoCA) (Brenkel, Shulman, Hazan, Herrmann, & Owen, 2017; Tsoi, Chan, Hirai, Wong, & Kwok, 2015), and with a wider age range. We hypothesized that the Visuospatial/Executive subtest of the MoCA would be the most predictive of how much participants learned the motor task, compared to all other MoCA subtests.

Methods

Participants

Data from thirty-three adults (aged 39–89 years old) with no self-reported physician-diagnosed neurological disorders (e.g. no history of stroke, Parkinson’s disease, or dementia) were retrospectively analyzed. Informed consent was obtained prior to study participation. The research procedures were approved by the University Institutional Review Board, in accordance with the Helsinki Declaration.

Cognitive, sensorimotor, and functional assessments

Cognitive status was measured using the Montreal Cognitive Assessment (MoCA), a brief and widely-available screening tool. It has seven subtests including Visuospatial/Executive, Naming, Attention, Language, Abstraction, Delayed Recall and Orientation (Nasreddine et al., 2005). The subtests are summed to provide a total score of 0–30 points (“normal” total score cut-off ≥ 26), with higher scores indicating better overall cognitive status. Although it is typically used as a cognitive screen, it can be used in cognitively-intact individuals for purposes such as quantifying overall function (e.g., Kenny et al., 2013), change over time (e.g., Krishnan et al., 2017) or acute cognitive performance (e.g., Kaliyaperumal, Elango, Alagesan, & Santhanakrishanan, 2017). Unlike other more expensive and more time-consuming cognitive assessments (e.g., Repeatable Battery for the Assessment of Neuropsychological Assessment or Wechsler Adult Intelligence Scale), the MoCA is not age-adjusted against normative data and therefore does not account for age-related differences in its scoring, although studies associate lower scores with older age (Malek-Ahmadi, O'Connor, Schofield, Coon, & Zamrini, 2018; Rossetti, Lacritz, Cullum, & Weiner, 2011), even in cognitively-intact adults (Krishnan et al., 2017; Oren et al., 2015).

Sensorimotor function of the tested hand was characterized using tactile sensation, grip strength and handedness. Tactile sensation was measured with Semmes Weinstein monofilaments (Touch-Test, North Coast Medical, Inc, Gilroy, CA) at the distal end of the index finger. Maximal grip strength of the tested hand was tested via hand dynamometer (Jamar, Sammons-Preston-Rolyan, Bolingbrook, IL) (Andrews, Thomas, & Bohannon, 1996) as the average of three consecutive measurements. Hand dominance was determined using a modified Edinburgh Handedness Questionnaire.

General disability was screened for with the Index of Independence in Activities of Daily Living (Katz, Downs, Cash, & Grotz, 1970), in order to assess functional ability in daily life and to rule out the presence of dementia. This index is a paper-and-pencil test in which participants report their level of assistance needed to complete each of the six ADL functions: feeding, continence, transferring, going to toilet, dressing, and bathing. Reports of "no assistance needed" were scored as 1; the maximum (worst) score was 18, which indicated "dependent in all six functions." Thus, a total score of 6 indicates no disability (best). All cognitive, sensorimotor, and functional assessments were administered only one time in this study.

Upper extremity motor task

The upper extremity motor task used in this study was a functional motor task involving reaching, grasping, and object manipulation (Fig. 1). In this task, participants were required to use their nondominant hand to spoon raw kidney beans from a "home cup", to one of three distal cups as fast as possible. Because this task is used to study changes in performance over time due to practice, the nondominant hand was used to minimize any ceiling effects (Schaefer, 2015). The cups (9.5 cm in diameter) were fixed to a thin board (60.5 cm × 40.0 cm). The home cup was oriented along the participant's midline and 15 cm in front of the seated participant. The three distal target cups were radially placed 16 cm away around the home cup at 45°, 90°, and 135°. One trial of the motor task consisted of 15 repetitions of spooning two and only two beans at once from the home cup to one of the target cups. Participants first moved beans to the ipsilateral cup, then to the middle cup, and lastly to the contralateral cup, with respect to their nondominant hand. This procedure was repeated for five times in one trial, resulting in 15 repetitions in total. Each trial began when the participants picked up the spoon (plastic, 5.21 g) and ended when participants finished 15 repetitions. If any beans were dropped during transport, participants were instructed not to re-scoop them, but to proceed on to the next repetition; this repetition was counted as an error. The error rate in this sample was <1% of total repetitions, and therefore not considered as a factor in learning. Trial time (to the nearest 100th of a second via stopwatch) was recorded.

Experimental Protocol

Participants were evaluated over two consecutive days. On Day 1, participants completed all cognitive, sensorimotor, and functional assessments, then completed two trials of the functional motor task for familiarization. Then participants completed 50 trials of the functional motor task (i.e., a total of 750 out-and-back movements). Baseline performance on the motor task was defined as the trial time of the first practice trial. On Day 2, participants completed a follow-up trial of the functional motor task 24 hours later. We note that only the motor task was re-evaluated on Day 2; the MoCA nor any of the other assessments were not.

Data and statistical analyses

The primary measure of motor learning was the change in trial time from baseline on Day 1 to follow-up on Day 2, normalized to baseline performance (Eq. 1):

$$24 - hour\ performance\ change = \frac{Trial\ Time_{baseline} - Trial\ Time_{follow-up}}{Trial\ Time_{baseline}} \times 100 \qquad \text{(Eq. 1)}$$

A positive value indicates improved task performance 24 hours later, relative to baseline, with higher values indicated more learning. This measure quantified the extent to which individuals learned the task (Schaefer et al., 2015; Lingo VanGilder et al., 2018). Additional measures of interest were within-session performance change and retention. Within-session performance change was quantified as the change in trial time between baseline and the last practice trial on Day 1, normalized to baseline (Eq. 2):

$$within{-}session\ performance\ change = \frac{Trial\ Time_{baseline} - Trial\ Time_{last\ trial}}{Trial\ Time_{baseline}} \times 100 \qquad \text{(Eq. 2)}$$

Again, a positive value indicates improved task performance at the end of practice, relative to baseline. This measure reflects more transient, immediate changes in response to repetitive practice, whereas Equation 1 reflects more persistent, longer-lasting effects that are conceptualized as learning (Kantak & Winstein, 2012). Lastly, retention was quantified as the change in trial time between the last trial of practice on Day 1 and follow-up on Day 2, normalized to baseline (Eq. 3):

$$retention = \frac{Trial\ Time_{last\ trial} - Trial\ Time_{follow-up}}{Trial\ Time_{baseline}} \times 100 \qquad \text{(Eq. 3)}$$

This measure reflects the relative permanence of the level of performance achieved in acquisition (Kantak & Winstein, 2012) and is based on established measures of relative retention (Schmidt & Lee, 2005). To account for any initial differences in motor performance, due to factors such as age-related slowing (Birren & Fisher, 1991, 1995;

Krampe, 2002; Myerson, Hale, Wagstaff, Poon, & Smith, 1990), all measures were normalized to baseline for each participant as recommended by Nuzzo, 2018.

To test whether individual subtest(s) of the MoCA significantly predicted 24-hour performance change (i.e., learning), within-session performance change (i.e., acquisition), and retention, all scores of the MoCA subtests (Visuospatial/Executive, Naming, Attention, Language, Abstraction, Delayed Recall and Orientation) were entered into three separate backward elimination stepwise linear regression models with an elimination criterion of $p > .05$. However, because the MoCA is not an age-adjusted assessment, participant age and any significant predictor(s) remaining from the stepwise regression were entered into a second regression model. Statistical analyses were done using R 3.4.1 (R Core Team, 2017). 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

Summary statistics for participants are provided in Table 1, including age, education, ADL index, cognitive and sensorimotor variables. Most participants had intact tactile sensation in the tested hand (finest Semmes-Weinstein monofilament detectable, 2.83: n = 22; next finest detectable, 3.61: n = 9). Only two of the 33 participants had ‘diminished protective sensation’ in their index finger based on monofilament results. As shown in Table 1, the mean and standard deviation for the MoCA Total Score was 24.79 ± 2.65 (range = 18 – 30). Scores for each subtest of the MoCA are also provided in Table 1. Confirmatory analyses of linear regression indicated no significant relationship between baseline motor performance and the MoCA total score ($p = .51$), verifying that lower cognitive status did not interfere with participants’ ability to understand the instructions and perform the motor task initially.

As expected, practice on the motor task improved participants’ performance. Figure 2 shows how trial time decreased (i.e., improved) over the course of the 50 practice trials on Day 1 across participants. Also shown in Figure 2 is the mean (and standard error) trial time at the 24-hour follow-up. As described above, this trial was compared to participants’ first trial on Day 1 to quantify the amount of learning (see Eq. 1). Overall, the amount of learning was significant with mean±SD = 13.38±13.68% (95% CI [8.71, 18.05]). However, the large standard deviation also indicated a wide range in this measure. As such, this study aimed to test whether variation in motor learning could be explained by cognitive factors associated with aging, described next.

Relationship between learning and MoCA subtests

Bivariate linear regression revealed that none of the dependent variables were significantly correlated with the total MoCA score (all $p > .27$), indicating that learning, acquisition, and retention were not predicted by global cognitive status. Because the MoCA is comprised of seven subtests, however, individual subtest scores were entered into a backward elimination stepwise linear regression to identify whether specific cognitive domains could predict learning. The final model revealed that the only significant predictor of 24-hour performance change (see Eq. 1) was the Visuospatial/Executive score ($R^2 = 0.21$; adjusted $R^2 = .19$, $p = .007$), indicating a moderate effect size. Table 2 provides the iterative stepwise elimination of each predictor based on $p > .05$. Stepwise regressions for within-session performance change (Eq. 2) and retention (Eq. 3) measures eliminated all MoCA subtests as predictors, indicating no significant relationships (all $p > .05$).

Because the MoCA does not account for age (Nasreddine et al., 2005), age was added to the final regression model to account for any potential age-related differences in MoCA scores. As shown in Table 3, both Visuospatial/Executive score ($p = .04$) and age ($p = .02$) were significantly related to 24-hour performance change, indicating that participants' visuospatial function predicts learning above and beyond their age.

Discussion

The purpose of this study was to test whether the Visuospatial/Executive subtest of the MoCA predicted learning of a functional motor task, as measured by a change in performance at a 24-hour follow-up. The relationship between visuospatial function and motor learning has been suggested by previous studies using a lengthier cognitive test in adults over age 65 with and without cognitive impairment (Schaefer and Duff 2017; Lingo VanGilder et al., 2018), but this study extends these findings by demonstrating the same trend with a briefer cognitive screen and in a wider age range.

Moreover, the Visuospatial/Executive score of the MoCA remained a significant predictor of learning even when accounting for participant age, suggesting that earlier studies showing age-related declines in motor learning (e.g., Harrington & Haaland, 1992) may in part be due to age-related visuospatial deficits (Techentin, Voyer, & Voyer, 2014). In other words, two older adults may have the same chronological age but one may have visuospatial deficits, while the other does not, resulting in differences in motor learning. This was the case in this study, for example, with two participants with similar ages (age 67 and 68), but one had a Visuospatial/Executive score of 2 and had a learning value of −19.4%. This is contrast to another who had a Visuospatial/Executive score of 5 and had a learning value of +28.5%. These findings, particularly in the context of previous work (Schaefer & Duff, 2017; Lingo VanGilder et al., 2018), suggest that visuospatial tests could be used in rehabilitation to predict how much an older patient can recover motor skill and/or probe the patient's capacity for skill learning.

Furthermore, this study adds to the longstanding findings of Fleishman and Rich (1963), which showed that the early stages of learning a new motor task rely on visuospatial abilities. By re-testing participants 24 hours after practice, the current study extends this classical paper to show the role of visuospatial ability not just early on (as shown by Fleishman & Rich, 1963) but also for inducing longer-lasting change. The lack of relationship between the Visuospatial/Executive subtest and the acquisition and retention measures further underscores the role that visuospatial abilities play in the process of learning, rather than in immediate and transient behavioral changes. This relationship thereby raises interesting questions about 1) the underlying mechanism and, in turn, 2) the practical application of this study. The extent to which older adults learn to compensate for visuomotor perturbations has been associated with spatial working memory processes linked to mental rotation (Anguera, Reuter-Lorenz, Willingham, & Seidler, 2009; Fernandez-Ruiz, Wong, Armstrong, & Flanagan, 2011). Moreover, Jeunet and colleagues have shown that the ability to learn motor imagery brain-computer interfaces (i.e., BCI literacy) is also related to mental rotation (Jeunet, N'Kaoua, Subramanian, Hachet, & Lotte, 2015), so much so that they advocate for additional training for people who perform poorly on mental rotation tasks initially (Jeunet, Jahanpour, & Lotte, 2016). These studies implicate a shared mechanism between visuospatial ability (specifically mental rotation) and motor learning that leads to hypotheses about learning enhancement. There is evidence that visuospatial abilities, including mental rotation, can be improved through targeted interventions (Hohenfeld et al., 2017; Oldrati, Colombo, & Antonietti, 2018; Zhou et al., 2018), which, in the context of the current study, would suggest that if older adults with low visuospatial scores (e.g., ≤2 on the MoCA subtest) underwent some sort of visuospatial training prior to motor practice, the visuospatial training may generalize to improve their motor learning. Future proof-of-concept studies are needed, however, as well as to identify what sorts of visuospatial training might generalize to improve motor learning above and beyond the known benefits of motor practice itself.

Interestingly, within-session performance change (i.e., acquisition) was not predicted by any global or specific cognitive measure, including visuospatial. Although the group overall improved over the course of practice on Day 1 (refer to Fig. 2), some individual participants actually showed negative acquisition values, indicating worse performance at the end of practice compared to the beginning. It is argued that within-session performance change is not reflective of true learning (Kantak & Winstein, 2012), particularly for older adults or neurological populations (Park & Schweighofer, 2017) due to fatiguability or attentional factors. Future studies are needed to identify which cognitive tests can predict poor acquisition in older adults such that their practice scheduling can be optimized, much like Schweighofer et al. (2011).

Finally, there are several limitations to this study. First, while the MoCA is a quick and simple test for probing global cognitive function, the individual subtests of the MoCA may not necessarily yield sufficient information to draw conclusions about specific impairments that can be detected by lengthier and more thorough neuropsychological testing (Moafmashhadi & Koski, 2013). Thus, the MoCA and its individual subtests are not typically used to diagnose any specific cognitive impairments, be they visuospatial or otherwise. Nevertheless, individual subtests have been used experimentally to explore cognitive predictors of functional outcomes in clinical settings (Schweizer, Al-Khindi, & Macdonald, 2012; Toglia, Fitzgerald, O'Dell, Mastrogiovanni, & Lin, 2011). Second, most neuropsychological assessments used clinically (e.g., Wechsler Adult Intelligence Scale, WAIS, or RBANS) report scores as age-adjusted percentiles to account for normal variations in chronological age, whereas the MoCA does not. However, once the effect of age was accounted for statistically in this study, the effect of the Visuospatial/Executive subtest on learning was still significant. Third, the visuospatial tests used in this study all involve a motor response (i.e., drawing). Although participants in this study completed the MoCA with their dominant hand and the motor practice with their nondominant hand, their scores on the Visuospatial/Executive subtest could in part reflect participants' overall motor function, which could then partially explain variations in learning of the skill among older adults (Park & Schweighofer, 2017). Thus, future research should incorporate both motoric and non-motoric visuospatial tests to better control for any potential confounds. A more comprehensive visuospatial battery will also determine which specific visuospatial function(s), such as visuospatial working memory, mental rotation, visuoconstruction, or visual perception, are most predictive of motor skill learning.

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References

Andrews A, Thomas M, & Bohannon R (1996). Normative values for isometric muscle force measurements obtained with hand-held dynamometers. Physical Therapy, 76(3), 248–59. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8602410 [PubMed: 8602410]

Anguera JA, Reuter-Lorenz PA, Willingham DT, & Seidler RD (2009). Contributions of Spatial Working Memory to Visuomotor Learning. Journal of Cognitive Neuroscience, 22(9), 1917–1930. 10.1162/jocn.2009.21351

Birren JE, & Fisher LM (1991). Aging and slowing of behavior: consequences for cognition and survival. Nebraska Symposium on Motivation. Nebraska Symposium on Motivation, 39, 1–37. [PubMed: 1843133]

Birren JE, & Fisher LM (1995). Aging and speed of behavior: possible consequences for psychological functioning. Annual Review of Psychology, 46, 329–353. 10.1146/annurev.ps.46.020195.001553

Bock O, & Girgenrath M (2006). Relationship between sensorimotor adaptation and cognitive functions in younger and older subjects. Experimental Brain Research, 169(3), 400–406. 10.1007/s00221-005-0153-4 [PubMed: 16328306]

Brenkel M, Shulman K, Hazan E, Herrmann N, & Owen AM (2017). Assessing Capacity in the Elderly: Comparing the MoCA with a Novel Computerized Battery of Executive Function. Dementia and Geriatric Cognitive Disorders Extra, 7(2), 249–256. 10.1159/000478008 [PubMed: 28868068]

Brown RM, Robertson EM, & Press DZ (2009). Sequence skill acquisition and off-line learning in normal aging. PLoS ONE, 4(8). 10.1371/journal.pone.0006683

Cohen J (1988). Statistical power analysis for the behavioral sciences. Statistical Power Analysis for the Behavioral Sciences. 10.1234/12345678

Ehsani F, Abdollahi I, Mohseni Bandpei MA, Zahiri N, & Jaberzadeh S (2015). Motor Learning and Movement Performance: Older versus Younger Adults. Basic and Clinical Neuroscience, 6(4), 231–238. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4668870/ [PubMed: 26649161]

Fernandez-Ruiz J, Wong W, Armstrong IT, & Flanagan JR (2011). Relation between reaction time and reach errors during visuomotor adaptation. Behavioural Brain Research, 219(1), 8–14. [PubMed: 21138745]

Fitts PM, & Posner MI (1967). Human performance. Human performance. Oxford, England: Brooks/Cole.

Fleishman EA, & Rich S (1963). Role of kinesthetic and spatial-visual abilities in perceptual-motor learning. Journal of Experimental Psychology, 66(1), 6–11. 10.1037/h0046677 [PubMed: 13945480]

Harada CN, Natelson Love MC, & Triebel K (2013). Normal Cognitive Aging. Clinics in Geriatric Medicine, 29(4), 737–752. 10.1016/j.cger.2013.07.002 [PubMed: 24094294]

Harrington DL, & Haaland KY (1992). Skill learning in the elderly: Diminished implicit and explicit memory for a motor sequence. Psychology and Aging. US: American Psychological Association. 10.1037/0882-7974.7.3.425

Hedden T, & Gabrieli JDE (2004). Insights into the ageing mind: a view from cognitive neuroscience. Nature Reviews Neuroscience, 5(2), 87–96. 10.1038/nrn1323 [PubMed: 14735112]

Hohenfeld C, Nellessen N, Dogan I, Kuhn H, Muller C, Papa F, … Reetz K (2017). Cognitive Improvement and Brain Changes after Real-Time Functional MRI Neurofeedback Training in

Healthy Elderly and Prodromal Alzheimer's Disease. Frontiers in Neurology, 8, 384. 10.3389/fneur.2017.00384 [PubMed: 28848488]

Jeunet C, Jahanpour E, & Lotte F (2016). Why standard brain-computer interface (BCI) training protocols should be changed: an experimental study. Journal of Neural Engineering, 13(3), 36024. 10.1088/1741-2560/13/3/036024

Jeunet C, N'Kaoua B, Subramanian S, Hachet M, & Lotte F (2015). Predicting Mental Imagery-Based BCI Performance from Personality, Cognitive Profile and Neurophysiological Patterns. PloS One, 10(12), e0143962. 10.1371/journal.pone.0143962 [PubMed: 26625261]

Kaliyaperumal D, Elango Y, Alagesan M, & Santhanakrishanan I (2017). Effects of Sleep Deprivation on the Cognitive Performance of Nurses Working in Shift. Journal of Clinical and Diagnostic Research : JCDR, 11(8), CC01–CC03. 10.7860/JCDR/2017/26029.10324

Kantak SS, & Winstein CJ (2012). Learning–performance distinction and memory processes for motor skills: A focused review and perspective. Behavioural Brain Research, 228(1), 219–231. [PubMed: 22142953]

Katz S, Downs TD, Cash HR, & Grotz RC (1970). Progress in Development of the Index of ADL1. The Gerontologist, 10(1_Part_1), 20–30. Retrieved from 10.1093/geront/10.1_Part_1.20 [PubMed: 5420677]

Kenny RA, Coen RF, Frewen J, Donoghue OA, Cronin H, & Savva GM (2013). Normative values of cognitive and physical function in older adults: findings from the Irish Longitudinal Study on Ageing. Journal of the American Geriatrics Society, 61 Suppl 2(supplement s2), S279. 10.1111/jgs.12195 [PubMed: 23662720]

Krampe RT (2002). Aging, expertise and fine motor movement. Neuroscience and Biobehavioral Reviews, 26(7), 769–776. [PubMed: 12470688]

Krishnan K, Rossetti H, Hynan LS, Carter K, Falkowski J, Lacritz L, … Weiner M (2017). Changes in Montreal Cognitive Assessment Scores Over Time. Assessment, 24(6), 772–777. 10.1177/1073191116654217 [PubMed: 27318033]

Malek-Ahmadi M, O'Connor K, Schofield S, Coon DW, & Zamrini E (2018). Trajectory and variability characterization of the Montreal cognitive assessment in older adults. Aging Clinical and Experimental Research, 30(8), 993–998. 10.1007/s40520-017-0865-x [PubMed: 29188578]

McNay EC, & Willingham DB (1998). Deficit in learning of a motor skill requiring strategy, but not of perceptuomotor recalibration, with aging. Learning & Memory, 4(5), 411–420. 10.1101/lm.4.5.411 [PubMed: 10701880]

Moafmashhadi P, & Koski L (2013). Limitations for Interpreting Failure on Individual Subtests of the Montreal Cognitive Assessment. Journal of Geriatric Psychiatry and Neurology, 26(1), 19–28. 10.1177/0891988712473802 [PubMed: 23385364]

Myerson J, Hale S, Wagstaff D, Poon LW, & Smith GA (1990). The information-loss model: a mathematical theory of age-related cognitive slowing. Psychological Review, 97(4), 475–487. [PubMed: 2247538]

Nasreddine Z, Phillips N, Bédirian V, Charbonneau S, Whitehead V, Colllin I, … Chertkow H (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. Journal of the American Geriatrics Society, 53(4), 695–699. 10.1111/j.1532-5415.2005.53221.x [PubMed: 15817019]

Nuzzo R (2018). Percent Differences: Another Look. PM & R : The Journal of Injury, Function, and Rehabilitation. United States. 10.1016/j.pmrj.2018.05.003

Oldrati V, Colombo B, & Antonietti A (2018). Combination of a short cognitive training and tDCS to enhance visuospatial skills: A comparison between online and offline neuromodulation. Brain Research, 1678, 32–39. 10.1016/j.brainres.2017.10.002 [PubMed: 29017911]

Oren N, Yogev-Seligmann G, Ash E, Hendler T, Giladi N, & Lerner Y (2015). The Montreal Cognitive Assessment in cognitively-intact elderly: a case for age-adjusted cutoffs. Journal of Alzheimer's Disease : JAD, 43(1), 19–22. 10.3233/JAD-140774

Park H, & Schweighofer N (2017). Nonlinear mixed-effects model reveals a distinction between learning and performance in intensive reach training post-stroke. Journal of NeuroEngineering and Rehabilitation, 14(1), 21. 10.1186/s12984-017-0233-2 [PubMed: 28302158]

Pratt J, Chasteen AL, & Abrams RA (1994). Rapid aimed limb movements: Age differences and practice effects in component submovements. Psychology and Aging. US: American Psychological Association. 10.1037/0882-7974.9.2.325

R Core Team. (2017). R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL Http://Www.R-Project.Org/.

Randolph C (1998). Repeatable Battery for the Assessment of Neuropsychological Status. San Antonio, TX: The Psychological Corporation.

Rossetti HC, Lacritz LH, Cullum CM, & Weiner MF (2011). Normative data for the Montreal Cognitive Assessment (MoCA) in a population-based sample. Neurology, 77(13), 1272–1275. 10.1212/WNL.0b013e318230208a [PubMed: 21917776]

Schaefer SY (2015). Preserved motor asymmetry in late adulthood: Is measuring chronological age enough? Neuroscience, 294, 51–59. 10.1016/j.neuroscience.2015.03.013 [PubMed: 25772792]

Schaefer SY, Dibble LE, & Duff K (2015). Efficacy and feasibility of functional upper extremity task-specific training for older adults with and without cognitive impairment. Neurorehabilitation and Neural Repair, 29(7), 636–644 9p. 10.1177/1545968314558604 [PubMed: 25416739]

Schaefer SY, & Duff K (2015). Rapid Responsiveness to Practice Predicts Longer-Term Retention of Upper Extremity Motor Skill in Non-Demented Older Adults. Frontiers in Aging Neuroscience, 7, 214. 10.3389/fnagi.2015.00214 [PubMed: 26635601]

Schaefer SY, & Duff K (2017). Within-session and one-week practice effects on a motor task in amnestic mild cognitive impairment. Journal of Clinical and Experimental Neuropsychology, 39(5), 473–484. 10.1080/13803395.2016.1236905 [PubMed: 27690745]

Schmidt RA & Lee TD (2005). Motor control and learning : a behavioral emphasis. (Lee TD, Ed.) (4th ed.). Champaign, IL: Champaign, IL : Human Kinetics.

Schweighofer N, Lee J-Y, Goh H-T, Choi Y, Kim SS, Stewart JC, … Winstein CJ (2011). Mechanisms of the contextual interference effect in individuals poststroke. Journal of Neurophysiology, 106(5), 2632–2641. 10.1152/jn.00399.2011 [PubMed: 21832031]

Schweizer TA, Al-Khindi T, & Macdonald RL (2012). Mini-Mental State Examination versus Montreal Cognitive Assessment: rapid assessment tools for cognitive and functional outcome after aneurysmal subarachnoid hemorrhage. Journal of the Neurological Sciences, 316(1–2), 137–140. 10.1016/j.jns.2012.01.003 [PubMed: 22280947]

Seidler RD (2006). Differential effects of age on sequence learning and sensorimotor adaptation. Brain Research Bulletin, 70(4), 337–346. [PubMed: 17027769]

Techentin C, Voyer D, & Voyer SD (2014). Spatial abilities and aging: a meta-analysis. Experimental Aging Research, 40(4), 395–425. 10.1080/0361073X.2014.926773 [PubMed: 25054640]

Toglia J, Fitzgerald KA, O'Dell MW, Mastrogiovanni AR, & Lin CD (2011). The Mini-Mental State Examination and Montreal Cognitive Assessment in persons with mild subacute stroke: relationship to functional outcome. Archives of Physical Medicine and Rehabilitation, 92(5), 792–798. 10.1016/j.apmr.2010.12.034 [PubMed: 21530727]

Tsoi KKF, Chan JYC, Hirai HW, Wong SYS, & Kwok TCY (2015). Cognitive Tests to Detect Dementia: A Systematic Review and Meta-analysis. JAMA Internal Medicine, 175(9), 1450–1458. 10.1001/jamainternmed.2015.2152 [PubMed: 26052687]

Lingo VanGilder J, Hengge CR, Duff K, & Schaefer SY (2018). Visuospatial function predicts one-week motor skill retention in cognitively intact older adults. Neuroscience Letters, 664, 139–143. 10.1016/j.neulet.2017.11.032 [PubMed: 29154858]

Zhou RJ, Hondori HM, Khademi M, Cassidy JM, Wu KM, Yang DZ, … Cramer SC (2018). Predicting Gains With Visuospatial Training After Stroke Using an EEG Measure of Frontoparietal Circuit Function. Frontiers in Neurology, 9, 597. 10.3389/fneur.2018.00597 [PubMed: 30087653]

Fig. 1.

Overhead view of motor task apparatus. The start and center locations were placed at participants' midlines.

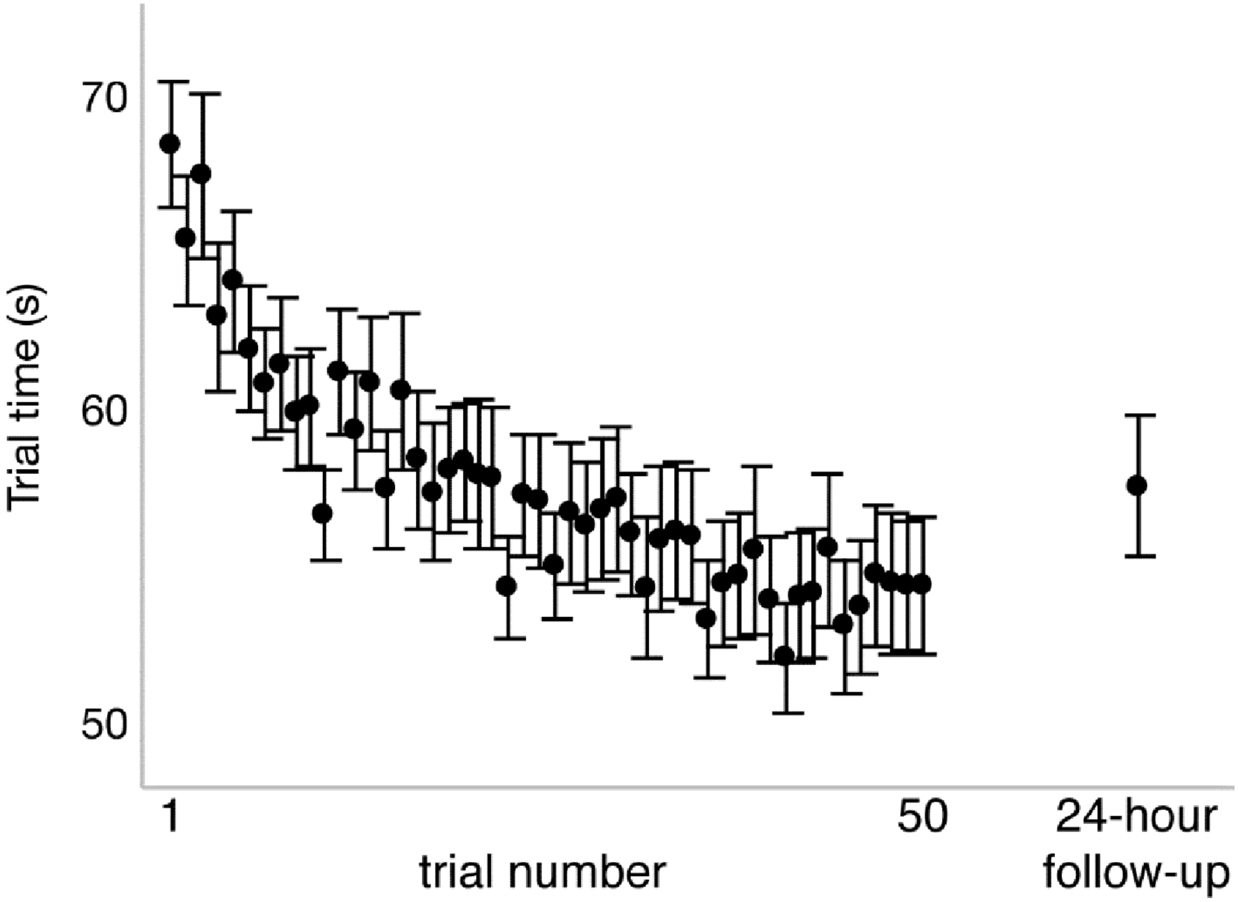

Fig. 2.

Mean trial time for trials 1 through 50 on Day 1, and for the follow-up trial 24 hours later on Day 2. Error bars indicate standard error.

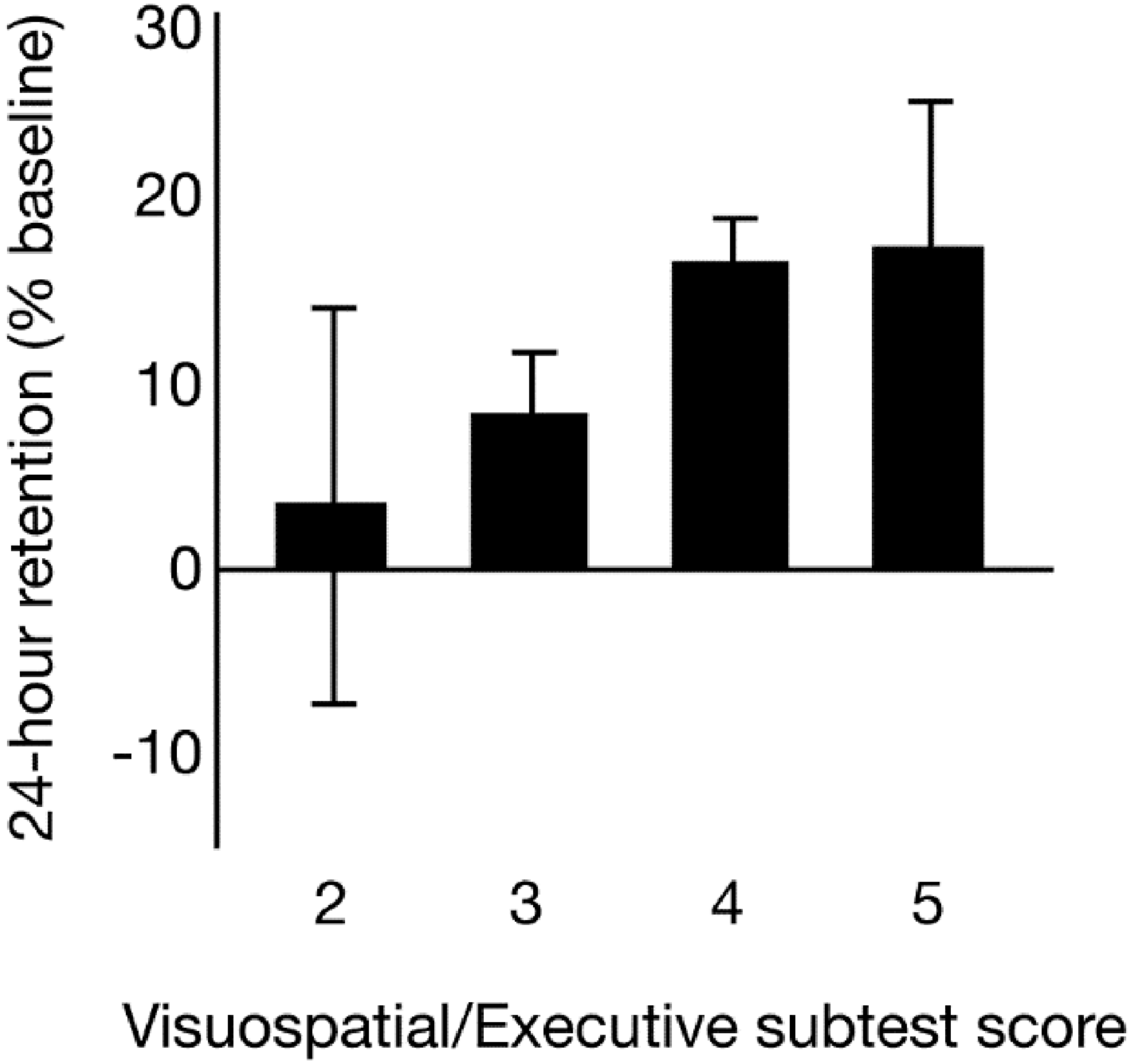

Fig. 3.

Mean 24-hour performance change for each value of Visuospatial/Executive subtest score. (No participant had scores of 0 or 1). Error bars indicate standard error.

Table 1.

Participant characteristics.

	Mean (*SD*)	**Range**
Age (years)	69.91 (11.41)	39 – 89
Education (years)	14.97 (2.51)	12 – 21
Grip strength (kg)	24.32 (8.38)	6.67 – 44.00
MoCA Total score	24.79 (2.65)	18 – 30
Visuospatial/Executive	3.56 (0.90)	2 – 5
Attention	5.27 (1.04)	2 – 6
Naming	2.91 (0.29)	2 – 3
Language	2.24 (0.87)	0 – 3
Abstraction	1.58 (0.71)	0 – 3
Delayed Recall	3.16 (1.51)	0 – 5
Orientation	5.97 (0.17)	5 – 6
Katz ADL Total score[a]	6.13(0.71)	6 – 10

n = 33; 8 males and 25 Females. 2 Left-handed, 31 Right-handed.

[a] All Katz ADL Total scores > 6 were due to continence issues, not upper extremity issues.

Table 2.

Results from backwards elimination stepwise regression.

Model		Intercept	Visuospatial/Executive	Naming	Language	Attention	Orientation	Delayed Recall	Abstraction	R^2	Adjusted R^2
1	*B*	21.36	11.96 *	13.38	−2.52	−2.30	−12.36	0.61	−0.39	0.48	0.33
	SE B	80.93	2.84	7.14	3.14	2.04	13.91	1.43	3.27		
	β		0.75	0.29	−0.16	−0.18	−0.16	0.07	−0.02		
2	*B*	23.39	11.91 *	13.44	−2.63	−2.30	−12.82	0.63		0.48	0.36
	SE B	77.57	2.76	6.98	2.95	2.00	13.11	1.39			
	β		0.76	0.29	−0.16	−0.18	−0.17	0.07			
3	*B*	−2.17	10.46 *	13.28	−3.99	−1.62	−7.20			0.37	0.26
	SE B	82.10	2.82	7.27	3.09	2.10	13.87				
	β		0.69	0.28	−0.25	−0.12	−0.09				
4	*B*	−42.55 *	10.40 *	13.33	−4.61	−1.84				0.37	0.28
	SE B	26.07	2.78	7.18	2.82	2.03					
	β		0.69	0.28	−0.29	−0.14					
5	*B*	−52.68 *	9.96 *	13.94	−4.50					0.35	0.28
	SE B	23.47	2.73	7.12	2.81						
	β		0.66	0.30	−0.29						
6	*B*	−52.51 *	7.61 *	13.29						0.29	0.24
	SE B	24.08	2.36	7.29							
	β		0.50	0.28							
7	*B*	−11.52	6.96 *							0.21	0.19
	SE B	8.91	2.42								
	β		0.46								

Note. Dependent variable was 24-hour performance change. Independent variables were scores from subtests of the MoCA. The final model shows that only Visuospatial/Executive score of the MoCA predicted 24-hour performance change.

* $p < .05$.

Table 3.

Standardized and unstandardized coefficients predicting 24-hour performance change.

	B	***SE B***	**β**	**R^2**	**Adjusted R^2**
Intercept	27.17	17.61			
Age	−0.46 *	0.19	−0.39	0.35	0.30
Visuospatial/Executive	5.19 *	2.35	0.34		

[*] $p < .05$.