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Rey-Osterrieth Complex Figure Recall scores and motor skill learning in older adults: A non-linear mixed effect model-based analysis

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Abstract

Age-related declines in motor learning are well documented. Visuospatial memory has been proposed as a key factor explaining age-related declines in sensorimotor adaptation, but most studies have not used standardized visuospatial memory tests nor controlled for age-related visuospatial memory declines. The present study explores the relationship between visuospatial memory and motor learning in older adults while also controlling for age and utilizing a standardized visuospatial memory test. Forty-nine nondemented older adults repetitively practiced a functional upper-extremity motor task and were re-assessed one week later. Training data were modeled with mixed-effect exponential decay functions, with parameters representing amount of performance change, rate of improvement, and final performance. Age and visuospatial memory were included as possible covariates for the parameter measuring rate of improvement (τ). After controlling for age, higher visuospatial memory scores were associated with faster rates of skill acquisition and better short-term retention one week later. These associations with visuospatial memory were dependent, however, on the level of initial skill. These findings suggest that the extent of re-learning motor skills in geriatric physical rehabilitation may depend on intact visuospatial memory.

Keywords

Rey-Osterrieth Complex Figure Test; visuospatial; motor learning; aging; motor skill

1. INTRODUCTION

Numerous studies have shown that motor learning declines with advancing age. For example, older adults have slower rates and lower amounts of improvement in motor performance (e.g., motor sequence response time, bimanual coordination accuracy) during a single session of task practice compared to younger adults (Harrington & Haaland, 1992; Swinnen, 1998). Older age has also been associated with less transfer of skill learning (Walter, Hengge, Lindauer, & Schaefer, 2019). Furthermore, during sensorimotor adaptation

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training, where participants learn to reach towards targets during visual or dynamic perturbations, older adults typically show less and slower within-session sensorimotor adaptation than younger adults as well (Buch, Young, & Contreras-Vidal, 2003; Seidler, 2006; Vandevoorde & Orban de Xivry, 2019).

Visuospatial memory has recently been proposed as a key correlate for age-related declines in sensorimotor adaptation (Anguera, Reuter-Lorenz, Willingham, & Seidler, 2011; Christou, Miall, Mcnab, & Galea, 2016; Trewartha, Garcia, Wolpert, & Flanagan, 2014; Wolpe et al., 2020), as evidenced by correlations between visuospatial memory and measures of motor adaptation (e.g., direction error at the end of training, as well as adaptation rate). However, since visuospatial memory can begin to decline even in young adulthood (Hedden & Gabrieli, 2004; Park et al., 2002), it is important to control for age *and* visuospatial memory (or any other cognitive ability) when considering motor learning in an older adult sample. To the best of our knowledge, very few studies have controlled for participant age, making it difficult to explore effects of visuospatial memory on motor learning without age as a confound. For example, Anguera et al. (2011) reported no association between visuomotor adaptation and spatial working memory in an older adult cohort but did not consider how the age range (71.4±4.2 years) might have been a factor. In contrast, Wolpe et al. (2020) assessed the effect of both age and visual short-term memory on motor adaptation, and reported that reduced adaptation was related to worse short-term memory regardless of age.

Additionally, non-standardized, unvalidated methods have been used previously to evaluate and quantify visuospatial memory (Anguera et al., 2011; Christou et al., 2016; Trewartha et al., 2014; Wolpe et al., 2020) rather than using established and validated neuropsychological tests to do so. To better dissociate the effects of age and visuospatial function on motor learning, we have used standardized, validated neuropsychological assessments. By doing so, we too have found that functional motor skill learning (measured as one-week or one-month retention) is associated with visuospatial memory and function in older adults even after controlling for age (Lingo VanGilder, Hengge, Duff, & Schaefer, 2018; Lingo VanGilder, Lohse, Duff, Wang, & Schaefer, 2021; Schaefer & Duff, 2017; VanGilder, Walter, Hengge, & Schaefer, 2019; Wang, Infurna, & Schaefer, 2020). By using validated measures of visuospatial memory (rather than unvalidated ones that *may* probe visuospatial memory), our work strongly suggests that findings from previous visuomotor adaptation studies on the role of visuospatial memory in aging and motor learning also apply to the learning of less constrained, more functional movements (like those performed in clinical motor rehabilitation) (Toglia, Fitzgerald, O'Dell, Mastrogiovanni, & Lin, 2011). To understand how generalizable previous models of adaptation are to skill learning, however, it is important to test how acquisition (i.e., within-session changes in performance) and learning (i.e., retention) of a more functional motor skill relate to visuospatial memory.

Thus, the purpose of this study was to investigate whether visuospatial memory (measured as the Delayed Recall portion of the Rey-Osterrieth Complex Figure Test), which is a standardized visuospatial memory test) is associated with changes in performance on a functional motor task during a single session of practice (i.e., skill acquisition) in older adults, after controlling for age. To this end, data from the first motor practice session reported by Lingo VanGilder, Lohse, et al. (2021) was retrospectively analyzed. This dataset was chosen because it demonstrated the expected association between one-month motor retention and visuospatial memory, but this previous study did not quantify rate of acquisition within a training session nor the amount of short-term retention (learning in between weekly training sessions). The previous study also assumed that acquisition followed exponential decay patterns. To test this assumption, changes in performance during motor practice were modeled with a three-parameter exponential decay function to capture rate and amplitude of change, with age and the Rey-Osterrieth Complex Figure (ROCF) Test Delayed Recall scores added as covariates for model parameters. We hypothesized that the rate of skill acquisition and short-term retention would be negatively associated with age and positively associated with Delayed Recall score.

2. MATERIALS AND METHODS

2.1 Participants

A subset of participants included in this study has been published previously (Lingo VanGilder, Lohse, et al. 2021); however, the current study includes additional participants and evaluates different data. Fifty-one nondemented, community-dwelling older adults provided informed consent prior to study participation. This study was approved by the Arizona State University Institutional Review Board (Study 000004214). Prior to any analysis, two participants were excluded from the current study for being ambidextrous or having a questionable neurological history (tremor), resulting in a sample size of 49 older adults (mean±SD age = 69.69 ± 6.35 years; 17 males, 32 females). More information about the motor task, as well as the visuospatial assessment, is provided below.

2.2 Experimental design and protocol

Participants practiced a functional upper extremity task, which is shown in Figure 1. Concurrent validity (Schaefer & Hengge, 2016) and ecological validity (Schaefer, Hooyman, & Duff, 2020) of the task have been established previously. The task was completed with the nondominant hand to minimize ceiling effects and allow for the opportunity to improve with practice (Schaefer 2015). For each trial, participants use their nondominant hand to acquire and transport two raw beans at a time from a center ‘home’ cup to one of three target cups, arranged at a radius of 16 cm relative to the home cup. The home cup was placed at the participants’ midline, with the target cups arranged at 0° (directly in front of) and 40° to the left and right of the home cup (see Fig. 1). Participants were instructed to reach for the ipsilateral cup first, then the center cup, then the contralateral cup, then repeat this sequence four more times for a total of 15 reaches. The goal of the task was to complete each trial “as quickly yet as accurately as possible”. The amount of time taken to complete all 15 reaches was recorded as *trial time*, with lower values indicating better task performance. Trial time was recorded for all trials.

Participants overall completed 50 practice trials per session, completing three weekly sessions (see Lingo VanGilder, Lohse, et al., 2021). However, the dataset considered the first 20 trials of training because 1) early, rather than later, phases of learning have been related to visuospatial processes (Fleishman & Rich, 1963); and 2) our previous studies indicate asymptotic performance is typically achieved by then (Schaefer, Dibble, & Duff, 2015).

Visuospatial assessment was done via the Rey-Osterrieth Complex Figure (ROCF) Test (Osterrieth, 1944), which includes a Copy trial (for visual construction), and Immediate and Delayed Recall trials (for visuospatial memory). The Delayed Recall subtest from the ROCF is the visuospatial measure of interest in this analysis, based on our previous studies (Lingo VanGilder, Hooyman, Bosch, & Schaefer, 2021; Lingo VanGilder, Lohse, et al., 2021). Briefly, participants were presented with an image of a complex figure and asked to redraw it as accurately as possible; the image was then removed and a timer was set for 30 minutes, at which point participants were asked to redraw the image from memory. Age-adjusted ROCF delayed recall scores were used to account for the typical effect of age on this test (Caffarra, Vezzadini, Dieci, Zonato, & Venneri, 2002).

2.3 Nonlinear mixed-effect modeling of motor skill acquisition

Based on previous literature (Lang & Bastian, 1999; Martin, Keating, Goodkin, Bastian, & Thach, 1996; Schaefer et al., 2015), motor performance data (i.e., trial time in this study) for the first 20 practice trials were modeled with a decreasing exponential decay function for each participant (Model 1), specified by:

$$Trial\ Time_{i,j} = A_j e^{-i/\tau_j} + C_j + \varepsilon_{i,j}$$

where i was trial number and j was participant number. For each participant, skill acquisition was measured as a change in task performance, which was characterized by the decreasing exponential term. A_j is the amplitude of skill acquisition; τ_j is the time constant of the exponential decay, larger values indicating slower rate of skill acquisition; C_j is performance asymptote and $\varepsilon_{i,j}$ the error term. Each of the three model parameters (A_j, τ_j and C_j) were estimated as the sum of a fixed term (representing the group mean) and a random term (representing individual variability). A_j, τ_j and C_j were assumed to be independent, log-normal random variables, and the error model was specified as exponential.

Since it possible that some participants may not exhibit exponential learning during skill acquisition (Newell, Liu, & Mayer-Kress, 2001), we included an initial quality control step to examine whether this model was sufficient for our sample. Because τ values that are too small are not meaningful in describing “exponential” performance change within 20 practice trials, we tested multiple τ values (0.2 – 2) as the threshold with which to exclude participants. For example, τ values <1 indicated considerable performance change from the first to second trial, but with little improvement after the second trial, a pattern not amenable to being modeled with an exponential function. To determine a data-driven exclusion criteria (rather than an arbitrary or potentially biased one) based on this observation, we created a family of 20 threshold values for τ between 0.1 and 2, at increments of 0.1. For each threshold value, participants with τ values below the threshold were removed, and we fit the exponential decay model again to the remaining participants’ data. We then compared the root mean squared errors (RMSEs) of the 20 model fits and selected the threshold value of $\tau = 1$, which has the least RMSE. Sixteen participants with $\tau < 1$ were therefore removed from further modeling analyses. The formal analyses were conducted with the remaining participants with $\tau > 1$ (n=33). Figure 2 shows exemplar data from three participants from each group, and illustrates how task performance for participants with $\tau < 1$ (shown in red) plateaued immediately after the first trial and that their practice data should not be modeled with an exponential decay fit.

2.4 Modeling the effect of age and visuospatial memory on skill acquisition

To test the effects of age and ROCF Delayed Recall score on skill acquisition, age and ROCF Delayed Recall score were entered as covariates into the exponential model (Model 2). To do so, the random effects of the model parameters from Model 1 were plotted against ROCF age and Delayed Recall scores, and we evaluated if the random effects of each parameter varied across age and ROCF. Specifically, age, as well as ROCF Delayed Recall score, was mean-centered and included as covariates for model parameters that demonstrated co-variation with age and ROCF score during visual inspection (for resulting details of Model 2, see Results). Variance inflation factor (VIF) was calculated to quantify the collinearity between age and age-adjusted ROCF Delayed Recall. Models were fitted using the MATLAB (Mathworks) *nlmefit* and *nolmefitsa* function. Model comparisons were tested with the log-likelihood Ratio Test (Comets, Lavenu, & Lavielle, 2017).

2.5 Statistical analyses on short-term retention

Here we also quantified learning as *short-term retention* by comparing the average trial time from the first five trials of the first practice session (i.e., baseline performance) against the average trial time of the first five trials of the second practice session (i.e., one-week follow-up). Short-term retention was calculated as the percent change from baseline to one-week follow-up testing, normalized by baseline performance. Longer-term (i.e., one-month) retention data have been published previously (Lingo VanGilder, Lohse, et al., 2021).

Independent two-sample t-tests were used to test whether the $\tau > 1$ and $\tau < 1$ groups (described in section 2.3) were different in terms of age, visuospatial memory scores, within-session motor performance changes and short-term retention. Satterthwaite approximation was used to account for any unequal group variances. Upon identifying the $\tau < 1$ group whose performance plateaued after the 1st trial, we investigated whether the previously identified relationship between ROCF scores and retention can be replicated with this sample (Lingo VanGilder, Lohse, et al., 2021). Thus, for each group, multivariate linear regression was used to for each group to test the relationship between age, ROCF scores and short-term retention. Robust linear regression was used when appropriate (noted in section 3.3) to reduce the effects of outliers, through the iteratively reweighted least squares algorithm implemented in MATLAB *lmfit* function. Independent variables (age and visuospatial memory scores) were normally distributed, as determined by Shapiro-Wilk tests. Furthermore, VIF test indicated minimal collinearity between age and visuospatial memory scores (VIF = 1.01). This method is more robust than the standard least-squares regression, as it can identify and remove outliers and still estimates the model coefficients using ordinary least squares.

3. RESULTS

3.1 Model-based groups with distinct skill acquisition characteristics

As described in 2.3, we used a data-driven approach to determine whether an exponential decay model sufficiently quantified skill acquisition for all participants. This yielded a subset of participants (n = 16) whose task performance plateaued immediately after the first trial, indicating that their practice data should not be modeled with an exponential decay fit. This subset of participants also demonstrated a high level of skill on the motor task initially, compared to the remaining participants (n = 33). Results showed that this subset of participants with τ <1 had significantly better task performance initially (prior to practice) than the remaining participants with τ >1 (t-tests with Satterthwaite approximation for unequal variances: $M = 48.53$, $SD = 5.77$ vs. $M = 55.63$, $SD = 7.36$, $t(37.2) = -3.68$, $p < 0.001$). This subset also had less within-session performance improvement (t-tests with Satterthwaite approximation: $M = -1.19$ sec, $SD = 5.56$ vs. $M = 5.14$, $SD = 4.83$, $t(26.4) = -3.90$, $p < .001$). The two subsets of participants did not differ, however, in their ROCF Delayed Recall scores (p = .263) or age (p = .112). Based on this, participants in this study were separated into two groups based on the τ parameter: a “high skill” group with $\tau < 1$ and a “low skill” group with $\tau > 1$. Group characteristics are summarized in Table 1. Since the “high skill” group did not follow an exponential decay pattern in terms of repeated performance or show performance improvement in the first 20 trials (p = .582), these participants were excluded from further analyses.

3.2 Effect of age and visuospatial memory on rate of skill acquisition

We next tested the effects of ROCF Delayed Recall score and age on skill acquisition parameters only on remaining ‘low skill’ participants. To do so, the random effects of the model parameters were plotted against ROCF Delayed Recall score and age, and we evaluated the variances across the plots through random effects. This revealed that only parameter τ demonstrated visible covariation with ROCF Delayed Recall score and age, whereas parameters A and C did not, suggesting that ROCF Delayed Recall score and age were the most promising covariates for parameter τ.

We then included ROCF Delayed Recall score and age as covariates and tested for model significance. We evaluated models with different combinations of age and ROCF as model covariates: 1) model with age as the only covariate, 2) model with ROCF as the only covariate, and 3) model with both age and ROCF as covariates. Using log-likelihood ratio test for model comparison, the model with age as the only covariate for τ out-performed Model 1 ($p < .020$), whereas the model with only ROCF Delayed Recall score as the covariate for τ did not outperform Model 1 (p = .070). The model with both ROCF Delayed Recall score and age as covariates for τ outperformed Model 1 ($p < .004$), and therefore was selected (Model 2). The comparison between Model 1 and Model 2 were presented in Table 2.

Specifically for Model 2, both ROCF Delayed Recall score and age were included as covariates (mean-centered) for τ, such that:

$$\ln(\tau_j) = \beta_\tau + \beta_{age,\tau} \times age_j + \beta_{visuospatial,\tau} \times VisuospatialScore_j + b_{\tau,j} + \varepsilon_\tau$$

where β_τ is the fixed effect parameter; $\beta_{age,\tau}$ and $\beta_{visuospatial,\tau}$ are the fixed effect coefficients for age and visuospatial memory scores, respectively, and $b_{\tau,j}$ is the random effect parameter. Model parameters were fit via a log transformation to ensure non-negativity. Collinearity between age and age-adjusted ROCF Delayed Recall was not a concern (VIF = 1.01). Older age was associated with larger time constants (95% CI of $\beta_{age,\tau}$ = [0.051, 0.180]), and thus a slower rate of skill acquisition. In contrast, the association between higher (better) delayed recall scores and smaller time constants (i.e., faster skill acquisition) trended towards significance (95% CI of $\beta_{Rey,\tau}$ = [−0.126, 0.001]), suggesting that the rate of skill acquisition is negatively associated with age and positively associated with ROCF delayed recall score.

3.3 Effect of visuospatial memory, but not age, on motor retention

We then tested for the relationship between age, ROCF Delayed Recall scores and short-term retention (described in section 2.5). As shown in Table 3, robust multiple linear regression revealed ROCF Delayed Recall score predicted short-term retention ($\beta = 0.52$, $t = 2.67$, $p < 0.012$; Fig. 3), whereas age did not ($t = -1.06$, $p = 0.298$)[1]. These results were consistent with previous studies showing that visuospatial function, rather than age, predict retention following motor training (Lingo VanGilder et al., 2018; Schaefer & Duff, 2017; Wang et al., 2020).

Although visuospatial memory alone did not seem to affect skill acquisition, after accounting for age, visuospatial memory (as measured by ROCF Delayed Recall) was associated with faster skill acquisition and more short-term retention.

3.4 Specificity of findings to the low skill group

In the excluded high skill group, neither ROCF Delayed Recall score nor age predicted short-term retention ($t = -0.36$, $p = 0.725$ and $t = -1.95$, $p = 0.073$, respectively). This finding further clarified that ROCF Delayed Recall score only predicted in the low skill group, but not the high skill group (Fig. 3), despite the two groups being comparable in age and Delayed Recall scores (see Table 1). Thus, collectively these data suggest that age negatively impacted the rate of skill acquisition but was not associated with the amount of short-term retention in older adults.

4. DISCUSSION

This study found that visuospatial memory (measured with the Rey-Osterrieth Complex Figure Test) was associated with faster rates of within-session skill acquisition and short-term retention, after controlling for age. The modeling approaches taken in this study revealed, however, that some participants started motor training at a high level of skill on the task, demonstrating a ceiling effect. The primary analyses were then conducted only

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[1] Interaction was inspected and the resulting effect was not significant. Likelihood Ratio Test indicated no difference in model fit with the addition of the interaction term.

on participants who demonstrated a lower level of initial skill on the motor task. Age was negatively associated with rate of skill acquisition, but not with retention. Thus, visuospatial memory may be more important for motor learning than chronological age.

4.1 Effect of visuospatial memory on motor skill learning

Results demonstrated that better visuospatial memory, as measured by higher ROCF Delayed Recall scores, is associated with faster rates of skill acquisition, whereas older age is associated with slower rates of skill acquisition. Observational studies consistently show variable visuospatial memory scores among older individuals of similar age (Bendayan et al., 2017; Caselli et al., 2020), which clearly point to the importance of quantifying visuospatial abilities in studies of motor learning and aging. Although this relationship has been shown previously in motor adaptation studies of point-to-point reaching (Anguera et al., 2011; Christou et al., 2016; Trewartha et al., 2014; Wolpe et al., 2020), few studies have considered (and controlled for) the co-variation between age and visuospatial (as well as other cognitive) functions, or testing whether this is the case for more functional, real-world actions. This study now extends the role of visuospatial memory to motor skill acquisition, and dissociates the effect of visuospatial memory on the rate of learning from that of age. This is important, as recent evidence suggests that age-related declines in motor adaptation were largely driven by declines in explicit learning (Vandevoorde & Orban de Xivry, 2019; Wolpe et al., 2020), which could be explained by declines in visuospatial memory (Christou et al., 2016; Wolpe et al., 2020). Moreover, studies have found no correlation between visuospatial memory and implicit learning (Christou et al., 2016). As such, Wolpe et al. (2020) proposed that declines in explicit motor learning may be related to temporal brain regions, such as the hippocampus, which has been consistently shown as responsible for visuospatial memory (Longoni et al., 2015; Shavitt, Johnson, & Batistuzzo, 2020) and explicit memory. Based on these recent studies, our results suggest that the early acquisition of skill on our motor task involved explicit learning strategies, particularly since the analyses focused on the first 20 trials of a 50-trial practice session, where explicit knowledge is more relied upon at the start of learning (Fitts and Posner, 1967).

We also observed that the effect of visuospatial memory on short-term motor retention (i.e., learning) differed depending on skill level, such that visuospatial memory was positively correlated with motor improvement for the “low skill” group but not the “high skill’ group. This finding clarified the previous findings of Lingo VanGilder, Lohse, et al. (2021) by revealing that the observed correlation relationship between visuospatial memory and motor improvement could be, in part, driven by older adults who were at a lower skill level. One explanation for such group differences could be that the low skill group learned more by explicit strategies that relied on visuospatial memory, whereas the high skill group learned more by implicit strategies. According to the stages of learning theory by Fitts and Posner (1967), as skill level advances, learning gradually transitions from depending more on cognitive, explicit knowledge to more on procedural, implicit knowledge. When skill level is low (which can and often be the case in older adults, compared to younger adults), participants need to rely on visuospatial ability to explore the spatial relationship between the hand, the tool (spoon) and the objects (beans) in order to construct explicit task strategies to improve performance. The high skill group, on the other hand, may have relied less on explicit knowledge (because they could) and more on automatic, procedural learning. This interpretation is in line with data from a similar tool-use skill learning study (Bosch et al., 2018), in which improved performance was associated with fewer confirmatory fixations (i.e., eye fixations on the interactions between the hand, tool, and objects) and shorter fixation duration, indicating that performance is less dependent on forming explicit strategies. Although our study included short-term retention, it is again consistent with (but also expands) Christou et al. (2016) who found that visuospatial working memory capacity was correlated with visuomotor adaptation only when the task relies on explicit learning strategies, and not for implicit learning. Thus, future studies are needed to investigate if and which cognitive factors contribute to implicit learning.

4.2 Effect of age on motor skill learning

Unlike previous studies of skill acquisition, we found a dissociation in the effect of age on motor skill learning such that age was associated with slower rate of within-session acquisition but not with short-term retention. This finding is not entirely surprising. Motor memory encoding during skill acquisition, memory consolidation at task intervals, and memory retrieval at follow-up testing are separate processes (Kantak & Winstein, 2012), so it is plausible that aging impacts the processes differently. For example, some studies have shown that compared to younger adults, older adults have slower acquisition but comparable learning capacity (Carnahan 1996; Voelcker-Rehage 2006; Boyke 2008). It is possible that the lack of an age effect on short-term retention may be due to more implicit learning mechanisms. As noted above, motor adaptation studies suggest that implicit learning may be spared by aging (Vandervoorde et al., 2019; Wolpe et al., 2020), such that the more implicit learning components of motor skill acquisition are not affected by advancing age), as evidenced by our findings in our high skill group. It is also possible that the low skill group in this study also demonstrated extensive implicit learning, since age-related differences in learning between younger and older adults diminished when learning was primarily non-declarative and implicit, even during early stages of learning (Chauvel et al., 2012). More research is needed, however, to explore the interactions between skill level and cognition and their effects on implicit and explicit learning in older adults.

One advantage of this study is that it utilized a naturalistic motor task with ecological validity among older adults (Schaefer et al., 2020) that, compared to more constrained motor tasks (e.g., planar reaching), can allows for more informative variability in motor behavior to emerge. Individual differences in skill level (i.e., task performance) are, unsurprisingly, more pronounced in older cohorts with increased sample heterogeneity due to sensorimotor declines with age (Sosnoff & Newell, 2011). The present study highlights the need for caution when identifying relationships between cognitive functions and motor learning, especially in the research context of aging. Specifically, we advocate for developing and employing methods to better quantify participants' baseline skill levels and acquisition to potentially identify and group participants accordingly (Brooks, Hilperath, Brooks, Ross, & Freund, 1995; Uehara, Mawase, Therrien, Cherry-Allen, & Celnik, 2019).

4.3 Limitations and future work

Although we reasoned that the two groups of participants learned by differentially recruiting explicit and implicit learning components, no clear methods exist for dissociating explicit and implicit learning processes in functional, real-world movements. Such methods are needed to better isolate and therefore guide learning at different stages of acquisition, particularly when implicit learning is relied upon for cognitive rehabilitation in older adults (Kessels & Haan, 2003). Furthermore, this study did not identify any age or cognition effects on longer-term improvement in the high skill group, leaving this question largely unanswered. It is plausible, as described above, that these individuals relied primarily on more implicit/procedural learning, which may be robust to any declines in visuospatial memory. This highlights the importance of identifying factors that can promote/maintain implicit learning that can compensate for explicit learning deficits due to advancing age or pathology (Harrison, Son, Kim, & Whall, 2007; Machado et al., 2009; van Halteren-van Tilborg, Scherder, & Hulstijn, 2007).

We also acknowledge that this study may also not have accounted for other age-related factors that may impact acquisition or retention. For example, we did not measure reaction time here, which is known to decline with age (Tun & Lachman, 2008). Educational attainment appears to attenuate age-related declines in reaction time, however, and the current sample is quite educated (see Table 1), suggesting that any effect associated with reaction time is likely much smaller than that of visuospatial memory. Similarly, grip strength (which is a general measure of frailty) also declines with age (Sternäng et al., 2015), but it also varies by sex and overall body size. In our previous studies, we have observed no significant effect of sex on the learning of the motor task used here (Schaefer, Malek-Ahmadi, Hooyman, King, & Duff, 2022), and have shown that grip strength does not change from baseline to one-month follow-up (Schaefer et al., 2015), suggesting that age-related declines in grip strength are likely not a major factor in determining the extent of learning in older adults. Nevertheless, we acknowledge the limitation that other central and peripheral factors associated with aging may also influence the rate and extent of learning, and should be considered/controlled for in the future.

5. CONCLUSIONS

This study is consistent with our previous work demonstrating the association between visuospatial function and motor skill learning in older adults. This study is novel in its modeling exponential decay parameters of the early phase of learning during functional skill training (rather than visuomotor adaptation), and using this approach to test assumptions about non-linear patterns of performance improvement. This body of work suggests that visuospatial memory tests (like the ROCF) may have prognostic value for physical therapists and other rehabilitation clinicians in predicting how responsive older patients might be to motor training.

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Fig. 1.

Motor task apparatus. Each trial consists of 15 sequential out-and-back reaches with the goal of transporting beans via a spoon to center-out targets (cups) as fast as possible. Note that the task was completed with the non-dominant hand to prevent ceiling effects. This figure was adapted from “Dexterity and Reaching Motor Tasks” by MRL Laboratory licensed under CC BY 2.0. A video demonstration of the task can be found at https://osf.io/phs57/.

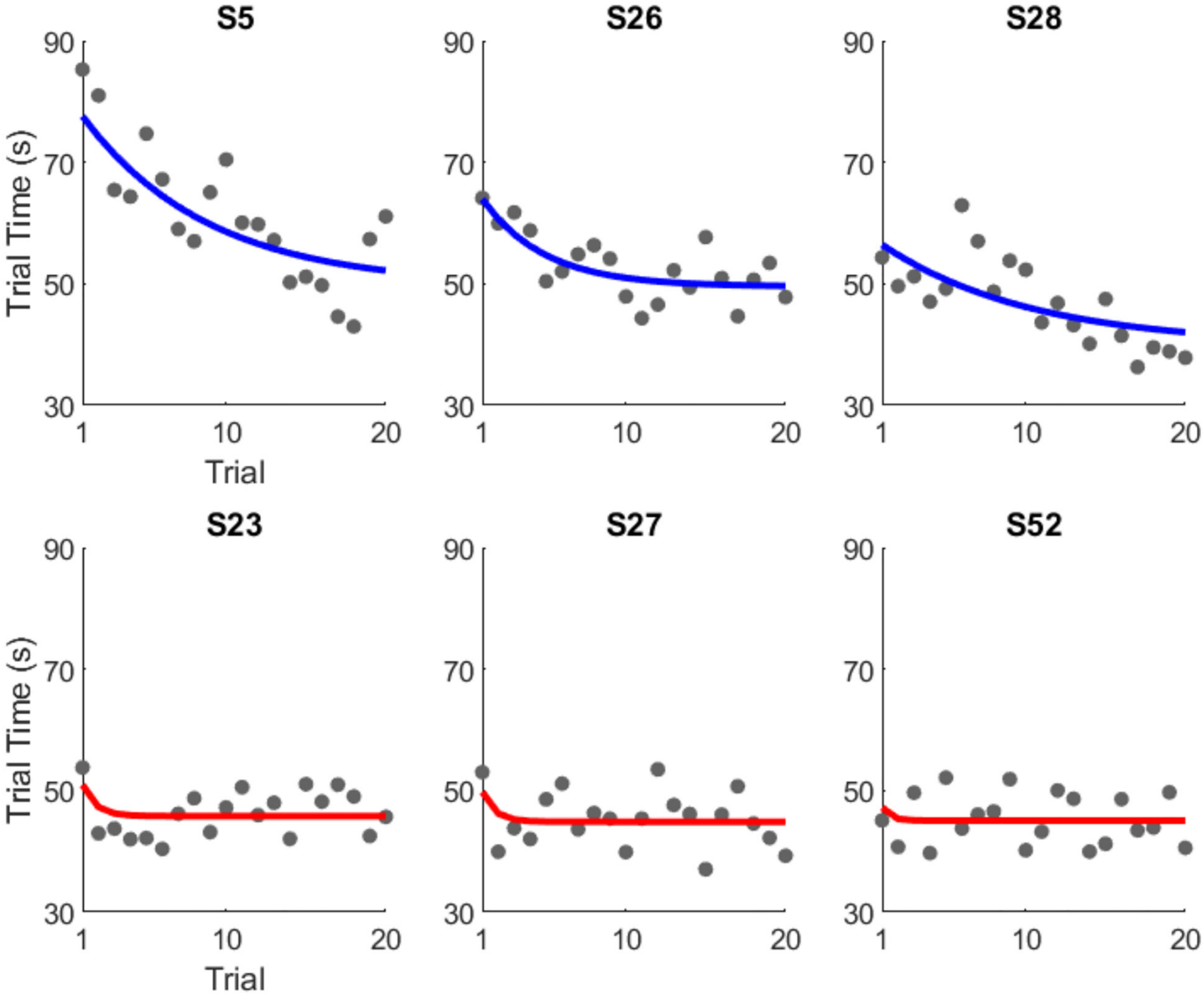

Fig. 2.

Examples of participants with t > 1 and < 1. Blue color indicates performance curves with $\tau > 1$; red color indicates $\tau < 1$. Participants with $\tau < 1$ (shown in red) demonstrated performance plateaus on the task immediately after the first trial, and were therefore removed from the primary analyses of this study.

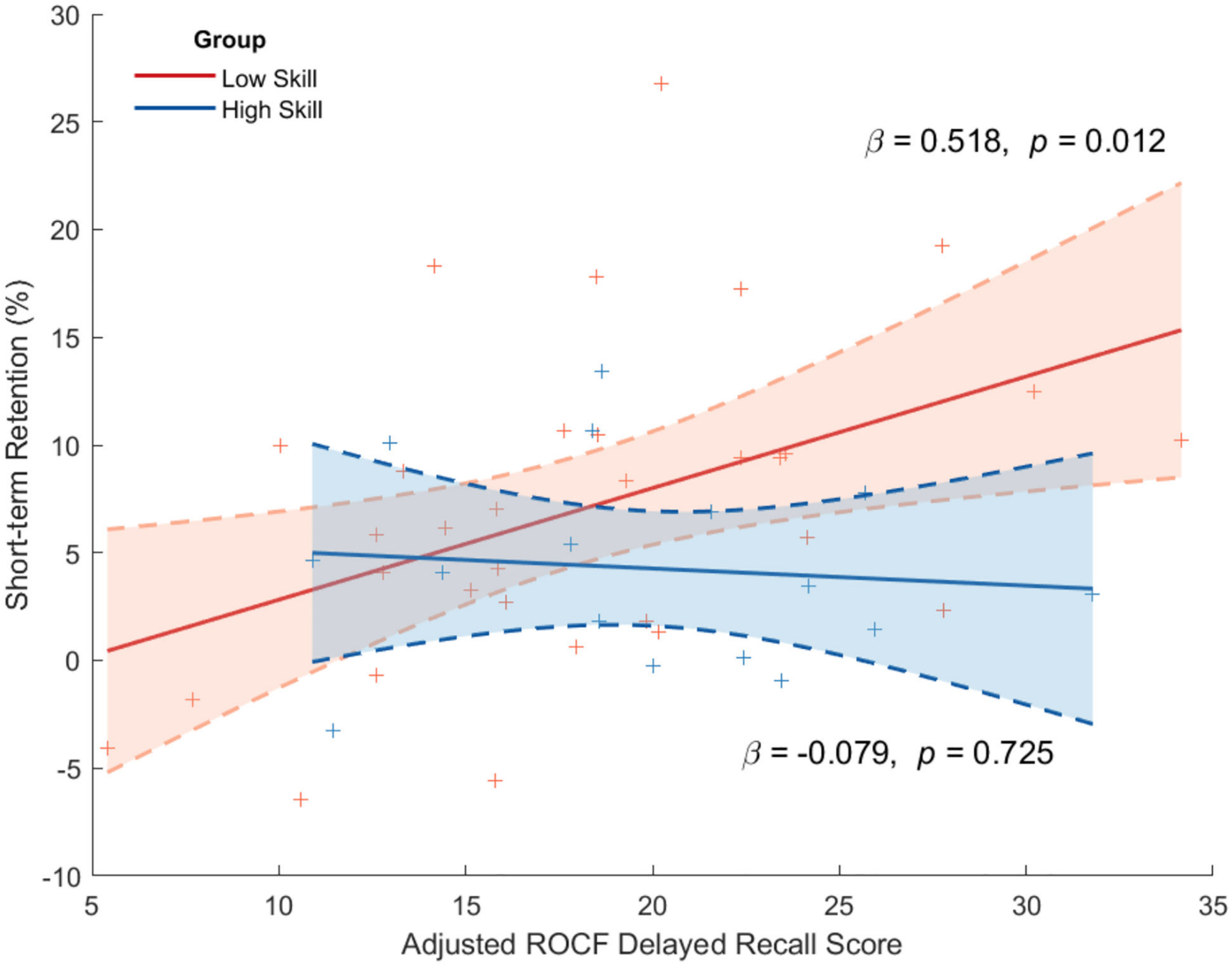

Fig. 3.

Age-adjusted visuospatial memory score was only positively correlated with short-term retention in the low skill, but not the high skill group. Shaded region = 95% CI.

Table 1.

Comparison of Low and High Skill Groups

	Low Skill $\tau > 1$ ($n = 33$)		**High Skill $\tau < 1$ ($n = 16$)**				
	M	***SD***	***M***	***SD***	***t***	***df***	***p***
Age, years	70.61	6.79	67.81	5.00	1.62	39.2	.112
ROCF Delayed Recall	17.76	6.74	19.89	5.82	−1.14	34.0	.263
Initial Performance (sec)	55.63	7.36	48.53	5.77	3.68	37.2	.001
Within-session improvement (%)	5.41	4.83	−1.19	5.56	3.90	26.4	.001
Short-term retention (%)	7.03	7.61	4.28	5.20	1.47	41.4	.148

Notes. *M*: mean, *SD*: standard deviation. Short-term retention was calculated as the percent change from baseline to one-week follow-up testing, normalized by baseline performance

Table 2.

Model comparisons for nonlinear mixed-effect models on skill acquisition.

Model	Log-likelihood	Fixed Effects 95% C.I.		
		A	τ	**C**
Model 1	−2060.830	[14.052, 19.524]	[5.131, 16.924]	[42.766, 46.039]
Model 2	−2056.727	[14.252, 19.901]	[3.846, 11.432]	[44.049, 47.301]

Note. Group-level fixed effects coefficients are shown here. Model 1 contained no covariates on model parameters. In Model 2, age and age-adjusted ROCF delayed recall scores were covariates for τ.

Table 3.

Robust linear regression results for short-term retention effects.

	β	**SE**	***t***	***p***
Intercept	6.861	1.236	5.551	.000
Age	−0.194	0.183	−1.061	.298
ROCF Delayed Recall	0.518	0.194	2.672	.012