The Role of Eye Movements, Attention, and Hand Movements on Age-Related Differences in Pegboard Tests

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Well-documented manual dexterity impairments in older adults may critically depend on the processing of visual information. The purpose of this study was to determine age-related changes in eye and hand movements during commonly used pegboard tests and the association with manual dexterity impairments in older adults. The relationship between attentional deficits and manual dexterity was also assessed. Eye movements and hand kinematics of 20 young (20–38 yr) and 20 older (65–85 yr) adults were recorded during 9-Hole Pegboard, Grooved Pegboard, and a visuospatial dual test. Results were compared with standardized tests of attention (The Test of Everyday Attention and Trail Making Test) that assess visual selective attention, sustained attention, attentional switching, and divided attention. Hand movement variability was 34% greater in older versus young adults when placing the pegs into the pegboard and this was associated with decreased pegboard performance, providing further evidence that increased movement variability plays a role in dexterity impairments in older adults. Older adults made more corrective saccades and spent less time gazing at the pegboard than young adults, suggesting altered visual strategies in older compared with young adults. The relationship between pegboard completion time and Trail Making Test B demonstrates an association between attentional deficits and age-related pegboard impairments. Results contribute novel findings of age-associated changes in eye movements during a commonly used manual dexterity task and offer insight into potential mechanisms underlying hand motor impairments in older adults.

NEW & NOTEWORTHY This eye tracking study contributes novel findings of age-associated changes in eye movements during the commonly used pegboard tests of manual dexterity, including a greater number of corrective saccades and lesser time gazing at the pegboard holes in older compared with young adults. An association between attentional deficits and dexterity impairments in older adults is also highlighted. Results shed light on potential mechanisms underlying well-documented motor deficits in older adults.

Keywords
aging, attention, eye movements, manual dexterity, older adults

INTRODUCTION

The number of older adults (65+ yr) living in the United States is expected to double from years 2016 to 2060 (1) and hand function progressively declines with advancing age (2, 3). Impaired manual dexterity in older adults is associated with difficulties performing common hand tasks (e.g., opening a jar, handling coins, tying a knot; 4, 5) and negatively impacts functional independence (6–8). Specifically, manual ability was found to be one of the main determinants of admittance to nursing homes (7) and the best marker of dependency compared with a plethora of other factors (e.g., socioeconomic status, education level, number of medications, etc.; 6, 8).
Pegboard tests are common, standardized measures of manual dexterity included in the NIH Toolbox (9, 10). Pegboard tests ask participants to pick up small pegs from a tray and place them into holes on a pegboard one at a time and as quickly as possible. Declines in pegboard performance are well-documented with age (9, 10). Studies have examined age-related changes associated with these performance decrements, such as handgrip strength (11, 12), fingertip sensation (11), and movement variability (13). For example, greater movement variability during a finger force-matching task in older versus young adults was associated with increased pegboard completion time (13). A generalized movement slowing also occurs with advancing age (2) and could contribute to pegboard performance impairments in older adults.

Visual information plays an important role in many dexterous tasks (14). Changes in the amount of visual information have been shown to preferentially impair hand motor performance in older versus young adults (15). For example, older adults were just as good as young adults when performing a pegboard test under normal vision conditions but performance preferentially declined in older versus young adults when vision of the hand was obstructed, suggesting a greater reliance on visual information in older adults (15). Research examining the use of visual information during reaching tasks reports consistent findings, specifically, greater movement impairments in older versus young adults during the later phase of reaching when visual information is incorporated into movement control (16).

Despite a greater reliance on visual information for dexterous manipulation (15), it is not known where older adults look during the pegboard tests of manual dexterity. Eye movements are used to obtain task-relevant information and provide insight into ongoing visual and cognitive processes (17). Specifically, saccades are the rapid relocation of eye position used to align gaze with areas of interest in the visual field. Fixations are periods of relatively stable gaze used to obtain task-relevant information (14, 18). Studies have examined age-related differences in eye movements during manual reaching and object manipulation tasks (19–21), both component parts of the pegboard tests. During a manual reaching task, both young and older adults fixated on target locations when reaching to them; however, older adults made more corrective saccades than young adults (21). Another study asked participants to pick up objects and place them onto designated targets (19). Both young and older adults fixated on the object when picking it up and on the target when placing the object. However, older adults spent less time fixating on the object and more time fixating on the target than young adults and authors suggest this was used to obtain more visual information during the more complex part of the task (19). Despite these findings, no study to date has recorded eye movements during the pegboard tests in young and older adults.

Declines in attention occur with advancing age (22) and have been associated with manual dexterity impairments in older adults (23). Though the word “attention” is commonly used to refer to a singular mechanism or resource, authors suggest that attention includes multiple subsystems (24–26) including visual selective attention, sustained attention, attentional switching, and divided attention. In addition, dual-task paradigms are commonly used to examine age-related changes in the ability to allocate attentional resources across multiple tasks (27). Dual tasks preferentially impair motor performance in older adults (28–32). However, a majority of studies using dual tasks have targeted falls risk by asking participants to complete tasks of balance, posture, and locomotion (28, 30, 31). Fewer studies have examined the effect of dual tasks on upper extremity motor performance in older adults (29, 32). Determining the relationships between subsystems of attention and pegboard performance and implementation of a dual task would further the current understanding of age-related manual dexterity impairments.

The primary purpose of this study was to determine relations among eye movements, hand movements, attentional deficits, and pegboard performance impairments in young and older adults. Eye and hand movements were recorded during pegboard tests of manual dexterity. Participants completed measures of subsystems of attention. A visuospatial task was performed during the pegboard test to examine age-related
changes in manual dexterity when allocating attention across multiple tasks. Our hypothesis was that older adults would demonstrate age-related changes in eye movements (19, 21), hand movements (2, 13), and decreased performance on measures of attention (22), and these would be associated with pegboard performance impairments.

METHODS

Participants
A total of 40 participants, 20 young (age, 25.2 ± 4.7 yr; range, 20–38 yr; 10 females) and 20 older (age, 71.9 yr; range, 65–85 yr, 11 females) adults, were included in this study. Written informed consent was obtained from all participants as approved by the Institutional Review Board at the University of Wisconsin-Milwaukee. All participants were right-handed as assessed by the Edinburgh Handedness Inventory (33) and had normal or corrected to normal vision as assessed by the Snellen Eye Chart test for visual acuity (34). Exclusion criteria included the presence of functional deficiencies that involved the upper extremities, including difficulties performing everyday tasks (e.g., reaching for an object, opening a jar, picking up objects), neuromuscular disorders, pain currently in the upper extremities that may limit normal movement, hand pathologies (e.g., arthritis), currently taking medications that influence neuromuscular function or vision, and inability to sit comfortably for at least two hours. Participants were asked to abstain from caffeine 12 h before testing (35). The Montreal Cognitive Assessment was used to assess cognitive impairments (36).

Pegboard Tests
Participants sat facing a pegboard stand rigidly fixed to a table (Fig. 1). A head support was used to minimize extraneous head movement and control visual angle. This setup was selected among others tested during piloting based on its ability to best 1) decrease eye data artifact, 2) promote participant comfort and natural movement, 3) minimize self-reported upper extremity fatigue, and 4) encourage visibility of the hand and pegboard.

Figure 1. Experimental setup for the pegboard test and representative eye movement data. A: participants sat with their eyes positioned 40.5 cm in front of the pegboard on a custom-built stand. The bottom edge of the pegboard was 21.0 cm above the table surface with the tray located directly to the right of the pegboard. A kinematic sensor was secured to the right wrist. Participants began with their fingers on a tape marker on the
Participants completed the pegboard test under three conditions: 1) 9-Hole Pegboard, 2) Grooved Pegboard, and 3) Grooved Pegboard + Visuospatial (VS) task. The Jamar 9-Hole Pegboard test (4MD Medical Solutions, Lakewood, NJ) and Grooved Pegboard test (Lafayette Instrument Company, Lafayette, IN) are two of the more commonly used pegboard tests (9, 10). The 9-Hole Pegboard consists of 9 round pegs (0.6 cm diameter) and a pegboard with 9 round holes. The Grooved Pegboard consists of 25 grooved pegs (0.3 cm diameter) and a pegboard with 25 grooved holes oriented in different directions. Each peg must be manipulated so the groove matches the orientation of the hole, presenting greater motor coordination and visual perceptual demands compared with 9-Hole Pegboard (9, 10, 37). Instructions were to place the pegs into the holes one at a time and as quickly as possible. During pilot testing, some participants self-reported “fatigue” when completing all 25 holes of the Grooved Pegboard test, especially in older adults. To minimize this concern, participants completed the top two rows of the Grooved Pegboard resulting in a total of 10 holes in a 2 × 5 grid.

For the Groove Pegboard + VS condition, participants completed the Grooved Pegboard test while simultaneously performing a visuospatial task based on Brooks’ spatial memory task (38) and that used previously (30). Participants visualized a star moving around four boxes in a 2 × 2 grid, labeled 1 through 4. The star always started in Box 1. Participants were told a series of four randomized directions that signified the direction of the star’s movement (i.e., right, left, up, down, or diagonal). Each series began when the experimenter said, “Start” followed by four directions, and ended when the experimenter asked, “Location?” upon which the participant stated the final star location. The visuospatial task sequence was repeated until the pegboard test was completed. Before testing, participants completed five trials while viewing an image of the grid followed by a series of practice trials without the image. Three consecutive correct practice trials without the image were required before proceeding.

For all pegboard conditions, participants began with their hand resting on the table and fingers placed on a tape marker (Fig. 1A). The trial started when the experimenter said, “Go” and ended when the last peg was in the final hole. One practice trial and two test trials were performed for each condition using the right hand. At least 30 s of rest were provided between trials. Additional trials were performed if the participant 1) dropped one or more pegs, 2) picked up two pegs at once, or 3) began before the “Go” signal. Completion time was calculated as the time from the start to end of each trial, averaged across two trials for each condition.

Eye movements were recorded in the horizontal (X) and vertical (Y) directions with an infrared R6 Remote Optics Eye Tracking System (Applied Science Laboratories, Bedford, MA) at 120 Hz (23, 39) (Fig. 1B). Participants completed a full-field 9-point eye tracking calibration before testing and a 5-point calibration to establish the pegboard location within the eye tracking coordinate system. Kinematics were recorded using an electromagnetic miniBIRD tracking system (Ascension Technology, Burlington, VT) at 120 Hz, similar to sampling rates used during previous studies of kinematics during object manipulation tasks (19, 40). The miniBIRD sensor (1.80 cm × 0.81 cm × 0.81 cm) was secured to the right wrist at the radial styloid process using medical tape and prewrap. Sensor placement was selected to minimize obstruction of dexterous movement and vision of the fingers, peg, and pegboard, and is consistent with previous work assessing hand movements in older adults while picking up and placing objects (19). MiniBIRD sensor position was recorded in the direction relative to a transmitter coordinate reference frame. A 5-point calibration was completed to establish the location of the pegboard within the transmitter coordinate reference frame. Eye movement and kinematic data were collected.
on a laptop computer (Dell Optiplex GX620, Austin, TX) using Eye-Trac 6 User Interface program (Applied Science Laboratories, Bedford, MA). The sequence of trials was block randomized across pegboard conditions.

Measures of Attention

Test of Everyday Attention.
The Test of Everyday Attention is a common, reliable measure of the subsystems of attention designed to reflect everyday tasks (41). Three subtests from the Test of Everyday Attention were performed to assess different subsystems of attention, including 1) visual elevator, 2) telephone search, and 3) telephone search while counting. Tests were administered and scored based on methods set forth by the manual (41).

Visual elevator (attentional switching). Participants were shown a series of elevator door images with smaller arrows signifying the direction of counting. Larger arrows were dispersed between elevator images pointing in the upward and downward directions. Each elevator door image represented one floor. Participants were instructed to count each elevator door image beginning at one and counting upward. When a downward arrow appeared, the participant said “down” and counted backward. When an upward arrow appeared, the participant said “up” and counted upward. Participants were instructed to complete the subtest as quickly and accurately as possible. Two practice trials were completed before 10 test trials. Timing score was calculated as the completion time for each trial summed across all correct trials, divided by the number of switches (i.e., number of larger upward and downward arrows) summed across all correct trials. Timing score is reported in seconds.

Telephone search (visual selective attention). Participants were presented with a telephone directory page. Two symbols (i.e., star, square, circle, or cross) were placed next to each directory entry. Participants were instructed to search the directory from top to bottom and left to right to locate and circle instances when two identical symbols appeared together. Instructions were to complete the subtest as quickly and accurately as possible. Time per target score was calculated as the completion time divided by the number of correctly circled symbols and is reported in seconds.

Telephone search while counting (divided attention and sustained attention). Participants completed the Telephone Search subtest while simultaneously counting strings of tones played on an audiotape. Each string began when the audiotape said, “Ready” and ended when the audiotape asked, “How many?,” upon which the participant stated the number of tones in the string. Dual task decrement score was calculated by subtracting the time per target score from the Telephone Search from time per target score from this subtest and is reported in seconds.

Trail Making Test.
The Trail Making Test (TMT) is a common neuropsychological assessment of cognitive processes and executive function (42) and consists of two parts, Part A and Part B. Both parts measure sustained attention and visual selective attention. Part B also measures attentional switching (43).

Participants performed Part A and Part B of the TMT using standardized procedures (44). For both tests, participants used a pencil to connect 25 circles displayed on a piece of paper as quickly as possible using the right hand. For Part A, participants connected the 25 circles numbered 1 through 25 in ascending order. For Part B, participants connected a series of 25 circles numbered 1 through 13 and lettered A through L in numerical and alphabetical order, alternating between number and letter (e.g., 1-A-2-B-3-C…13-L). One practice trial and one test trial were performed for each part. Completion time was recorded in seconds. The sequence of trials was block randomized across attention tests.
Data Analysis
Eye tracking data were exported using EyeNal software (Applied Science Laboratories, Bedford, MA). Eye tracking data and kinematic data were analyzed offline using MATLAB (The MathWorks, Inc., Natick, MA). Eye data associated with blinks and artifact were removed, defined as X, Y, or pupil size of zero. Additional data associated with blinks and artifact were removed manually, including transient spikes. Transient spikes were defined as instances when eye position exceeded the field of view. Eye position data were not filtered, consistent with previous methods (21, 23, 39). Kinematic data were filtered using a low-pass, 4th-order, zero-lag Butterworth filter with a 12-Hz cutoff frequency. Cutoff frequency was within the range used previously (19, 40) and was confirmed with a residual analysis.

All participants moved their hand through four phases to fill one pegboard hole: 1) pick up one peg from the tray, 2) move hand to the pegboard, 3) place peg into the pegboard hole, and 4) move hand from the pegboard to the tray. Hand velocity was calculated as the first derivative of hand displacement. The times the hand arrived at and left the pegboard and tray were defined as the first data point after horizontal hand velocity fell below and first data point before horizontal hand velocity exceeded 3.6 cm/s, respectively, similar to methods used previously (19, 21). Horizontal hand velocity was used to determine these landmarks based on previous methods (19) and because the hand moved primarily in the horizontal direction when reaching to and from the pegboard and tray. The velocity cutoff was determined based on review of hand velocity profiles and was similar to values used previously (19, 21). Landmarks were used to segment the movement into the four phases (Fig. 2A):

1. Peg pickup: time hand arrived at the tray to time hand left the tray.
2. Tray → Pegboard transition: time hand left the tray to time hand arrived at the pegboard.
3. Peg placement: time hand at the pegboard to time hand left the pegboard.
4. Pegboard → Tray transition: time hand left the pegboard to time hand arrived at the tray.

Figure 2. Segmentation of hand and eye movements during one hole of the 9-Hole Pegboard. The pegboard tray was positioned to the right of the pegboard. Increased position corresponded to movements toward the pegboard. Decreased position corresponded to movements toward the tray. A: hand velocity cutoffs were used to determine when the hand arrived at and left the tray (arrive tray and leave tray, respectively) and pegboard
(arrive board and leave board, respectively). These landmarks were used to segment the hand movement into four phases, including 1) Peg pickup, 2) Tray → Pegboard transition, 3) Peg placement, and 4) Pegboard → Tray transition. B: participants fixated on the pegboard hole for peg placement. Eye velocity cutoffs were used to determine the end of the saccade to the pegboard (arrive board) to the start of the saccade away from the pegboard (leave board). These landmarks were used to calculate gaze time at the pegboard hole (pegboard gaze time).

Data for the first and last pegboard holes were removed before analysis due to behavioral differences at the start and end of the pegboard test, including differences in eye position before fixating on the first hole and hand position after placing the peg in the last hole. Thus, succeeding kinematic and eye tracking analysis included data from hand leaving the pegboard for Hole 1 to hand leaving the pegboard for Hole 8 (9-Hole) or Hole 9 (Grooved and Grooved + VS). Time analyzed was calculated as the total time between these cutoffs.

Eye velocity was calculated as the first derivative of horizontal eye position using the first central difference method. All participants fixated on the pegboard holes for peg placement (Fig. 1B). Therefore, eye velocity was used to calculate two landmarks including, 1) end of saccade to the pegboard hole and 2) start of saccade away from the pegboard hole, defined as the data point after eye velocity fell below and exceeded a cutoff velocity of 30.5°/s, respectively (Fig. 2B). Horizontal eye velocity was used to determine these landmarks based on methods used previously to segment eye movements into phases while picking up and placing objects (19) and because eye movements were performed primarily in the horizontal direction when gazing to and from the pegboard and tray. Cutoff velocity was determined based on examination of eye velocity profiles (21).

Some participants made corrective saccades after the primary saccade to the pegboard and before fixating on the pegboard hole. The number of holes with corrective saccades were counted manually, summed across all holes, and divided by the total number of holes for each trial. Gaze time at the pegboard holes was calculated as the percent of total trial time participants fixated on the pegboard holes during peg placement (Fig. 2B). Specifically, time from the end of the saccade to the pegboard to the start of the saccade away from the pegboard was calculated for each hole, summed across all holes, and divided by the time analyzed for each trial. If a corrective saccade was made, pegboard gaze time was calculated from the end of the corrective saccade to the start of the saccade away from the pegboard (21). Pegboard gaze time and percentage of holes with corrective saccades are reported as the average across the two trials for each condition.

Participants were instructed to place the pegs into the holes one at a time and as quickly as possible. To examine whether age-related movement slowing (2) played a role in pegboard performance impairments, peak hand velocity was calculated to examine age-related differences in hand velocity when moving to and from the pegboard and tray. Peak hand velocity was calculated during Tray → Pegboard transition and Pegboard → Tray transition for each hole, averaged across all holes for each trial. Peak hand velocity was averaged across the two trials for each condition and is reported in cm/s. Because movement variability has been associated with impaired pegboard performance in older adults (13), hand position variability during peg placement was calculated (Fig. 3). Specifically, the line of best fit between the horizontal hand position when the hand arrived at and left the pegboard was determined. The root mean square error (RMSE) between the line of best fit and participant’s horizontal hand position was calculated during peg placement to quantify the amount of hand position variability. RMSE was used to account for differences in peg placement time across pegboard tests and age groups. RMSE was calculated as the average across all pegboard holes, reported in millimeters, and is reported as the average across two trials for each condition.
Figure 3. Representative hand position data and calculation of hand position variability. Data are from one young (A) and older adult (B) during Grooved Pegboard with lower and higher root mean square error (RMSE), respectively. B, inset: The line of best fit (horizontal solid line) was calculated from the time the hand arrived at the pegboard to the time the hand left the pegboard (vertical dashed lines). RMSE was calculated between the line of best fit and participant’s hand position to quantify movement variability while placing the peg. Greater RMSE corresponds to greater hand position variability during the placement of the peg into the hole. Greater and lesser horizontal hand position is associated with pegboard location and tray location, respectively (Fig. 1A).

Statistical Analysis
Statistical analysis was performed using SPSS 25 (SPSS, Chicago, IL). Statistical significance for all tests was set at $P < 0.05$. Data are reported as means ± SD in text and means ± SE in figures unless otherwise noted. Normality was confirmed using a Shapiro–Wilk’s test and visual inspection of Q-Q plots. A two-sample, independent t test was used to examine differences in the Montreal Cognitive Assessment scores between young and older adults. Pegboard completion time did not conform to a normal distribution and was transformed using an inverse transformation (45). A mixed between-within subjects ANOVA was performed to examine differences in pegboard completion time, pegboard gaze time, percent holes with corrective saccades, and hand position variability between young and older adults and across the 9-Hole Pegboard, Grooved Pegboard, and Grooved Pegboard + VS, with a between-subjects factor of age group and within-subjects factor of pegboard condition. A mixed between-within subjects ANOVA was performed to investigate differences in peak hand velocity between age groups (young and older adults), and across transitions (Tray → Pegboard transition and Pegboard → Tray transition) and pegboard conditions (9-Hole, Grooved, and Grooved + VS), with a between-subjects factor of age group and within-subjects factors of transition and pegboard condition. Significant results were followed with post hoc tests with Bonferroni corrections. Pearson’s correlations were performed to determine the relationship between pegboard gaze time and pegboard completion time and between percent holes with corrective
saccades and pegboard completion time. A Pearson’s correlation was also used to determine the relationship between hand position variability and pegboard completion time. Attention scores did not follow a normal distribution. A normal distribution was not achieved with transformations. Therefore, a Kruskal–Wallis test was performed to examine differences in attention scores between young and older adults. Spearman’s correlations were used to examine the relationship between attention scores and pegboard completion time.

RESULTS

Participants
There was no significant difference in Montreal Cognitive Assessment scores \(t(38) = 1.082, P = 0.143\) between young \(28.5 ± 1.2\) and older \(28.0 ± 1.2\) adults. No participants scored below the cutoff for cognitive impairment (i.e., <26) (36).

Pegboard Performance
Pegboard completion time was significantly greater \(F(1) = 46.077, P < 0.001, \eta_p^2 = 0.979\) for older versus young adults (Fig. 4). There was a main effect of pegboard condition on completion time \(F(2) = 753.44, P < 0.001, \eta_p^2 = 0.952\). Participants completed 10 out of 25 holes for the Grooved Pegboard. Completion time was greater for Grooved versus 9-Hole \(P < 0.001\), Grooved + VS versus 9-Hole \(P < 0.001\), and Grooved + VS versus Grooved \(P < 0.001\). There was no significant interaction effect on completion time \(P = 0.845\).

Eye Movements
All participants fixated on the pegboard hole during peg placement. All older adults and most young adults also fixated on the pegboard tray for peg pickup (Fig. 1B). A select number of young adults \(n = 4\) did not fixate on the pegboard tray during the pegboard tests and instead, made saccades directly from one hole to the next. Statistical comparisons were difficult given the small sample size (46); however, completion time was relatively similar between young adults who did and did not fixate on the pegboard tray during the pegboard test for 9-Hole \(\text{Mdn} = 15.21\) s, interquartile range \(\text{IQR} = 14.24–15.46\) and \(\text{Mdn} = 16.33\) s, \(\text{IQR} = 15.40–17.15\).
respectively), Grooved (Mdn = 26.51 s, IQR = 24.79–28.66 and Mdn = 26.80 s, IQR = 24.13–34.26, respectively), and Grooved + VS (Mdn = 28.35 s, IQR = 24.89–29.54 and Mdn = 30.04 s, IQR = 28.17–34.49, respectively).

Corrective saccades were significantly greater \( [F(1) = 17.285, P < 0.001, \eta_p^2 = 0.313] \) for older versus young adults (Fig. 5A). There was a main effect of pegboard condition on corrective saccades \( [F(2) = 11.242, P < 0.001, \eta_p^2 = 0.228] \). Participants made more corrective saccades during 9-Hole versus Grooved \( (P = 0.002) \) and 9-Hole versus Grooved + VS \( (P = 0.001) \). There was no difference in corrective saccades for Grooved versus Grooved + VS \( (P = 0.940) \). The age by condition interaction was not significant \( (P = 0.311) \).

**Figure 5.** Corrective saccades and pegboard gaze time in young and older adults. A: percent holes with corrective saccades were significantly greater \( (‡P < 0.001) \) in older vs. young adults for all conditions. There was a main effect of pegboard condition on corrective saccades \( (P < 0.001) \). Corrective saccades were greater for 9-Hole vs. Grooved \( (*P = 0.002) \) and 9-Hole vs. Grooved + VS \( (**P = 0.001) \). B: young adults spent a significantly \( (‡P = 0.001) \) greater percentage of total time gazing at the pegboard holes than older adults. There was a main effect of pegboard condition on gaze time \( (P < 0.001) \). Gaze time at the pegboard holes was lesser for 9-Hole vs. Grooved \( (*P < 0.001) \) and Grooved + VS \( (**P < 0.001) \). Lines within the boxes indicate the median. Boxes are bound by the first and third quartiles. Whiskers indicate highest and lowest values, excluding outliers. Dots indicate outliers. VS, visuospatial.

Young adults spent a significantly greater percentage of time gazing at the pegboard holes \( [F(1) = 12.120, P = 0.001, \eta_p^2 = 0.242] \) compared with older adults (Fig. 5B). There was a significant main effect of condition on pegboard hole gaze time \( [F(2) = 53.429, P < 0.001, \eta_p^2 = 0.584] \). Participants spent a greater percentage of
pegboard test completion time gazing at the pegboard holes for Grooved versus 9-Hole ($P < 0.001$) and Grooved + VS versus 9-Hole ($P < 0.001$), with no difference in pegboard gaze time between Grooved and Grooved + VS ($P = 0.631$). The age by condition interaction was not significant ($P = 0.122$).

Because corrective saccades and pegboard gaze time were different between age groups, their relationships with pegboard completion time were examined. There was a significant, inverse relationship between pegboard gaze time and completion time for Grooved Pegboard in older adults ($r = -0.466, P = 0.038$). Specifically, increased pegboard gaze time was associated with decreased pegboard completion time. There were no other significant correlations ($P > 0.087$).

**Hand Movements**

There was a significant pegboard condition by transition (i.e., Tray $\rightarrow$ Pegboard transition and Pegboard $\rightarrow$ Tray transition) interaction effect on peak velocity [$F(2) = 119.800, P < 0.001$, $\eta^2_p = 0.759$]. Peak velocity was greater when moving from the pegboard to tray versus tray to pegboard for all pegboard conditions, including 9-Hole ($P < 0.001$; $38.68 \pm 6.35$ cm/s and $32.30 \pm 4.76$ cm/s, respectively), Grooved ($P < 0.001$; $41.49 \pm 8.01$ cm/s and $24.42 \pm 5.58$ cm/s, respectively), and Grooved + VS ($P < 0.001$; $39.93 \pm 7.86$ cm/s and $22.89 \pm 4.38$ cm/s, respectively). Peak velocity when moving from the tray to pegboard was greater for 9-Hole versus Grooved ($P < 0.001$), 9-Hole versus Grooved + VS ($P < 0.001$), and for Grooved versus Grooved + VS ($P = 0.007$). Peak velocity when moving from the pegboard to tray was greater for Grooved versus 9-Hole ($P = 0.003$) and Grooved versus Grooved + VS ($P = 0.034$), however there was no difference for 9-Hole versus Grooved + VS ($P = 0.397$). There was a significant main effect of transition on peak velocity [$F(1) = 195.760, P < 0.001$, $\eta^2_p = 0.837$] and a significant main effect of pegboard condition on peak velocity [$F(2) = 23.343, P < 0.001$, $\eta^2_p = 0.381$]. There was no significant effect of age on peak velocity ($P > 0.258$).

There was a significant age by condition interaction effect on hand position variability during peg placement [$F(2) = 7.631, P < 0.001$, $\eta^2_p = 0.167$] (Fig. 6). Hand position variability was greater in older versus young adults for all pegboard conditions, including 9-Hole ($P = 0.001$), Grooved ($P = 0.001$), and Grooved + VS ($P = 0.001$). In young adults, hand position variability was greater for Grooved versus 9-Hole ($P < 0.001$) and Grooved + VS versus 9-Hole ($P < 0.001$). In older adults, hand position variability was greater for Grooved versus 9-Hole ($P < 0.001$) and Grooved + VS versus 9-Hole ($P < 0.001$). There was no difference in hand position variability between Grooved and Grooved + VS in young ($P = 0.215$) and older ($P = 0.388$) adults. There was a significant main effect of pegboard condition [$F(2) = 148.800, P < 0.001$, $\eta^2_p = 0.797$] and a significant main effect of age [$F(1) = 14.414, P < 0.001$, $\eta^2_p = 0.275$] on hand position variability.

![Figure 6. Hand position variability during peg placement between age groups and across conditions. Hand position variability, calculated by root mean square error (RMSE), was greater for older vs. young adults for all](image-url)
conditions ($\ddagger P < 0.001$). Hand position variability was greater for Grooved vs. 9-Hole in young ($* P < 0.001$) and older ($# P < 0.001$) adults and for Grooved + VS. 9-Hole in young ($** P < 0.001$) and older ($¥ P < 0.001$) adults. VS, visuospatial.

Because hand position variability differed between age groups, the relationships between hand position variability and pegboard completion time were examined (Fig. 7). In older adults, there was a significant, positive correlation between hand position variability and completion time for 9-Hole ($P < 0.001$), Grooved ($P < 0.001$), and Grooved + VS ($P < 0.001$). In young adults, there was a significant, positive correlation between hand position variability and completion time for Grooved ($P = 0.020$) and Grooved + VS ($P = 0.048$), but not for 9-Hole ($P = 0.060$).

**Figure 7.** Relationship between hand position variability and pegboard completion time. There was a significant, positive relationship in older ($P < 0.001$) but not young ($P = 0.060$) adults for 9-Hole pegboard (A), a significant, positive relationship in older ($P < 0.001$) and young ($P = 0.020$) adults for Grooved pegboard (B), and a significant, positive relationship in older ($P < 0.001$) and young ($P = 0.048$) adults for Grooved + VS (C). Data are presented as back-transformed values. VS, visuospatial.

**Attention**
There was a significant difference in performance on all measures of attention for older versus young adults (Table 1). In older adults, there was a significant, positive relationship between TMT B completion time and pegboard completion time for all conditions, including 9-Hole ($r_s = 0.627; P = 0.003$), Grooved ($r_s = 0.645, P = $
0.002), and Grooved + VS ($r_s = 0.731, P < 0.001$) (Fig. 8). In young adults, there was a significant, positive relationship between TMT B completion time and pegboard completion time for Grooved ($r_s = 0.488, P = 0.048$) and Grooved + VS ($r_s = 0.506, P = 0.023$) but not for 9-Hole ($r_s = 0.241; P = 0.306$). There was a significant, positive relationship between Dual Task Decrement and pegboard completion time for 9-Hole ($r_s = 0.558, P = 0.011$), Grooved ($r_s = 0.645, P = 0.002$), and Grooved + VS ($r_s = 0.694, P = 0.001$) in young adults. There were no other significant relationships between attention test scores and pegboard completion time in young and older adults ($P > 0.096$).

**Figure 8.** Relationship between Trail Making Test (TMT) B completion time and pegboard completion time. Spearman’s correlations revealed significant, positive relationships between TMT B completion time and pegboard completion time for all conditions in older adults including 9-Hole (A), Grooved (B), and Grooved + VS (C). In young adults, there was a significant, positive relationship TMT B and pegboard completion time for Grooved and Grooved + VS but not for 9-Hole. VS, visuospatial.

<table>
<thead>
<tr>
<th>Measure of Attention</th>
<th>Young Mdn (IQR)</th>
<th>Older MDn (IQR)</th>
<th>$H$</th>
<th>$P$</th>
<th>$e^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMT A</td>
<td>17.56 s (14.51-22.45)</td>
<td>29.13 s (23.87-46.94)</td>
<td>21.396</td>
<td>&lt;0.001</td>
<td>0.549</td>
</tr>
<tr>
<td>TMT B</td>
<td>35.70 s (32.06-42.08)</td>
<td>56.80 s (46.94-83.60)</td>
<td>18.036</td>
<td>&lt;0.001</td>
<td>0.462</td>
</tr>
<tr>
<td>Time per target</td>
<td>2.49 s (2.15-2.72)</td>
<td>3.88 s (3.44-4.32)</td>
<td>26.421</td>
<td>&lt;0.001</td>
<td>0.677</td>
</tr>
<tr>
<td>Dual task decrement</td>
<td>0.09 (-0.14-0.48)</td>
<td>0.74 (0.26-2.43)</td>
<td>8.067</td>
<td>0.005</td>
<td>0.207</td>
</tr>
</tbody>
</table>
DISCUSSION

The main findings of the current study were 1) age-related differences in eye movements during the pegboard tests, 2) an association between increased hand movement variability and decreased pegboard performance in older adults, and 3) a relationship between attentional processes and pegboard performance in older adults. This novel implementation of eye tracking allowed us to examine eye movement behavior during a commonly used, standardized measure of manual dexterity (9, 10). Results revealed that older adults made more corrective saccades and spent less time gazing at the pegboard than young adults. Simultaneous assessment of hand movements provides further evidence that increased movement variability plays a role in dexterity impairments in older adults (13). A relationship between pegboard completion time and TMT B demonstrates that a decline in cognitive processes and executive function is associated with pegboard performance impairments in older adults (42).

Eye Movements

Most participants made saccades to and then fixated on the tray and pegboard during peg pickup and placement, respectively (Fig. 1B). Consistent with previous work (21), older adults made more corrective saccades after the primary saccade to the pegboard than young adults (Fig. 5A). Corrective saccades were likely used to more closely align gaze location with the pegboard hole and are thought to be due to landing errors of the primary saccade (47). Thus, results support the idea that aging leads to greater landing errors of primary saccades when gazing to target locations (21). Previous work has also reported a greater number of corrective saccades when making saccades to smaller versus larger targets (21, 47). In the current study, percentage of holes with corrective saccades was greater for the 9-Hole compared with Grooved Pegboard test with larger and smaller pegboard holes, respectively (Fig. 5A). Increased gaze time at the pegboard holes would allow for greater amounts of visual information when placing the peg, which may be more important for successful peg placement during the Grooved versus 9-Hole Pegboard test due to the added manipulation component during peg placement for the Grooved Pegboard test. We suggest that participants were more precise in their eye movements and decreased corrective saccades to increase gaze time at the pegboard holes for the Grooved compared with 9-Hole Pegboard test, leading to a greater percentage of holes with corrective saccades for the Grooved versus 9-Hole Pegboard test.

Young adults spent a greater percentage of time gazing at the pegboard holes compared with older adults (Fig. 5B). This is contradictory to a previous study of eye movements during an object manipulation task where participants picked up and placed objects onto targets (19). Specifically, older adults used a visual strategy to obtain greater amounts of visual information during the more complex part of the task (i.e., placing the ball onto the target) compared with young adults (19). In the current study, older adults spent less time gazing at the pegboard holes during peg placement (i.e., presumably the more complex part of the task, especially for the grooved pegboard) than young adults. First, a greater number of corrective saccades in older versus young adults could have led to decreased gaze time at the pegboard holes. Second, a lesser percentage of time gazing at the pegboard holes in older compared with young adults could reflect a strategy used by older adults to allow for more visual information when picking up the pegs compared with young adults. If so, peg pickup was likely more challenging for older adults than for young adults. Comparatively, a greater percentage of time gazing at the pegboard holes in young adults could reflect an optimal visual strategy given the visual-perceptual demands of peg placement (9, 10). In addition, young and older adults spent more time gazing at the pegboard holes during the Grooved compared with 9-Hole Pegboard (Fig. 5B). The Grooved Pegboard test has an added manipulation component to align the groove of the peg with the orientation of the hole that the 9-Hole
Pegboard test does not (9, 10). Increased gaze time at the pegboard holes, and therefore greater amounts of visual information when placing the peg, may be important for successful peg placement during the Grooved Pegboard test.

**Hand Movements**

Peak hand velocity was greater when reaching from the pegboard to tray versus from the tray to pegboard. The pegboard hole presents as a smaller reaching target than the tray. Therefore, results are consistent with the well-established speed-accuracy tradeoff where movement speed decreases when reaching toward smaller targets (48). Participants were instructed to complete the pegboard tests as quickly as possible and age-related movement slowing has been documented previously (2). However, peak hand velocity when reaching to and from the pegboard and tray was no different between young and older adults. Although some studies report age-related differences in hand velocity during reaching tasks (49), the current findings concur with numerous studies reporting no difference in hand velocity between young and older adults (50, 51). Conflicting results are likely due to inherent differences across reaching tasks (e.g., muscles used, target size, task requirements, etc.; 52). Results indicate that decreased hand velocity when reaching to and from the pegboard and tray is likely not the main source of pegboard performance impairments in older adults.

Hand position variability was greater during peg placement for the Grooved versus 9-Hole Pegboard (Fig. 6). This seems reasonable given the added peg manipulation component during the Grooved compared with 9-Hole Pegboard test. Hand position variability during peg placement was ~34% higher for older compared with young adults (Fig. 6) and increased movement variability was related to decreased pegboard performance in older adults (Fig. 7). This is consistent with previous studies demonstrating an association between increased motor variability and age-related declines in pegboard performance in older adults (11–13, 23, 53). Older adults depend more on visual information than young adults for dexterous tasks (15) and decreased time gazing at the pegboard holes was associated with decreased Grooved Pegboard performance in older adults. Decreased time gazing at the pegboard holes in older versus young adults could exacerbate age-related differences in movement variability and impair pegboard performance in older adults. Furthermore, results indicate that pegboard tests may be more sensitive to age-related changes in fine manual dexterity beyond those attributable to slowing of gross reaching movements. This result is similar to other studies that involved having young and older subjects press against unstable surfaces and found that age-related changes in fine motor dexterity were not related to reduced maximal forces in older adults (54). Importantly, age-related impairments in force control were greatest during the conditions when vision was present, consistent with the relationships found previously between eye movements, force control, and pegboard performance (23).

**Attention**

*TMT B* completion time was related to decreased pegboard performance in older adults for 9-Hole ($r_s = 0.627$), Grooved ($r_s = 0.645$), and Grooved + VS ($r_s = 0.731$; Fig. 8). No other measures of attention were related to pegboard performance in older adults. There are two potential reasons. First, *TMT B* may be more sensitive to age-related declines in attentional processes than the other measures of attention. For example, *TMT B* has been shown to be more sensitive to age-related changes in attentional processes than *TMT A* (42). Second, *TMT B* is a more generalized measure of cognitive processes and executive function (42). Performance on the pegboard tests may be related to a more generalized decline in cognitive processes and executive function in older adults compared with the other subsystems of attention, which is consistent with a relationship between Grooved Pegboard completion time and cognitive function reported previously (37). Findings support the use of *TMT B* as sensitive assessment of attentional processes in the aging population and highlight the role of age-related declines in attentional processes in manual dexterity impairments in older adults.
Curiously, decreased performance on the Telephone Search While Counting subtest was related to increased pegboard completion time in young but not older adults. Telephone Search While Counting is a measure of divided attention, which is the ability to attend to multiple stimuli at once (41). Young adults spent more time fixating on the pegboard holes than older adults. Therefore, young adults may have visually attended to the pegboard hole while simultaneously attending to hand movements required to pick up the peg, which would have required divided attention. We suspect that older adults attended to one part of the task (i.e., peg placement and pickup) before moving on to the next, which could explain why divided attention was not related to pegboard performance in this age group.

Decreased performance on the Grooved Pegboard test with the addition of a visuospatial task in both young and older adults (Fig. 4) provides evidence for pegboard impairments when allocating attentional resources across multiple tasks (27). However, contrary to our expected findings, older adults were not preferentially impaired by the addition of the visuospatial task compared with young adults. The effect of dual tasks on motor performance depends on the type of motor task being performed (30); therefore, it seems reasonable that a dual task would influence performance on the Grooved Pegboard test differently than it would influence performance on the force-matching tasks used in previous work (29, 32). In addition, dual tasks employed in other studies of upper extremity motor tasks (e.g., backward counting by 7 or 13 from 3- or 4-digit numbers) may have been more difficult than the visuospatial task used here, which could have led to greater motor impairments in older adults. Nonetheless, the current findings highlight the role of attentional processes in Grooved Pegboard performance and support the idea that decreased attentional resources may play a role in manual dexterity impairments.

Limitations
The following limitations should be considered. The pegboard tests were included in this study because they are common, standardized measures of manual dexterity recommended by the NIH (9, 10). However, other commonly used measures of manual dexterity exist, such as the Box and Block test (2) or tapping tasks (55). Future studies could extend these findings to other measures of manual dexterity to further understand how age-related changes in eye and hand movements contribute to impaired hand function. The current study was limited to one type of dual task during the Grooved Pegboard test. It may be useful to implement a more difficult dual task, such as the backward counting task (29) and compare the effect on pegboard performance with those found here. A unique pegboard setup was necessary to facilitate eye movement recordings. All attempts were made to replicate the standardized setup as closely as possible though there were inherent differences between the standardized setup and unique configuration. Future work could examine eye movements during the traditional setup and the unique setup to determine if differences exist. Lastly, the goal of this study was to examine age-related changes associated with impaired manual dexterity in healthy older adults. Only relatively higher functioning young and older adults were included in this study. Future studies could determine how well these results generalize to other populations where changes in eye and hand movements could influence performance, such those with Parkinson’s disease (56) or stroke survivors (57).

Conclusion
This study revealed age-related changes in eye and hand movements during the commonly used pegboard tests of manual dexterity. Older adults made more corrective saccades and spent less time gazing at the pegboard during peg placement compared with young adults. Greater hand movement variability when placing the pegs in older adults was associated with impaired pegboard performance; however, there were no differences in hand velocity when reaching to and from the pegboard and tray. We propose that pegboard tests are more sensitive to age-related changes in fine manual dexterity than a slowing of gross reaching movements. Findings also highlight the role of attentional processes in manual dexterity impairments in older adults and support the use of TMT B as a sensitive measure of age-related changes in attentional processes. Taken together, this study provides insight into age-related changes in eye and hand movements during manual dexterity tasks and the
association with motor impairments in older adults. Future work could explore these relationships in older adults and patient populations where increased movement variability is suggested to influence motor performance [e.g., those with Parkinson’s disease (56) and stroke survivors (57)].

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DISCLOSURES
No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

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REFERENCES


