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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Can cognitive performance predict motor learning in older adults?

Johan Collart
Robbe Thielemans

Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen

PROMOTOR :
Prof. dr. Koen CUYPERS

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Mevrouw Sara Isabel DA SILVA MAGALHAES FERREIRA

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Abstract

Background: Cognitive ageing impacts memory, attention and executive functions but older adults may also experience reduced motor performances. However, no clarity has been found about implicit motor learning capacity, including those requiring bimanual coordination. The association between cognitive functions and motor learning in complex tasks such as bimanual coordination remains underexplored.

Objectives: This study has two primary objectives: (1) To evaluate the impact of age on **implicit motor learning** by comparing the motor performance gains of older and younger adults after two weeks of training the Bimanual Tracking Task (BTT), a complex bimanual coordination task; (2) To investigate whether cognitive functions such as memory, working memory, and executive functions are associated with learning performance on the BTT.

Methods: Five older adults and three younger adults underwent a neuropsychological test battery that included the Rey Auditory and Verbal Learning Test (RAVLT), the Digit Span Backwards Test (DSBT) and the Stroop Color and Word Test (SCWT), followed by an individualised BTT motor training program consisting of six training sessions of 30 minutes, with three standardised progression tests. Motor performance gains between the two groups were compared using both a two-sample T-test and a Wilcoxon Exact Test, while the association between BTT scores and cognitive scores was analysed using correlation analyses.

Results: A statistically significant age-related group difference in learning improvement was found between the beginning and middle of the motor training program [i.e., BTT (2-1)]. Moreover, when considering all subjects, it was found that the training outcome BTT (3-1) is negatively associated with the SCWT score.

Discussion: Aging does not impair implicit learning of complex tasks as previously thought. In older adults, while motor learning gains were evident during the initial sessions, performance plateaued in later sessions, consistent with previous research on motor learning trajectories. Lower training outcome values are associated with higher SCWT values.

Conclusion: Implicit motor learning remains largely intact across age groups over a two-week complex motor program. Executive functions may play a more critical role in implicit motor learning.

Keywords: implicit motor learning; bimanual coordination; cognition; ageing

Introduction

As indicated by the World Health Organization, the percentage of the population over 60 years is expected to increase from 11% to 22% in 2050. As a result, thereof, the amount of people suffering from cognitive ageing will also increase. This cognitive decline starts in adults from the age of 20 to 30 and gains rapid momentum as they get older (Salthouse, 2009). This deficit leads to impaired executive functions, in particular a reduced inhibition and task-switching since middle to late adulthood, which are important skills to regulate dominant tendencies of cognitive stimuli and motor impulses, and to shift effectively between different tasks. Memory or the storage of information, including working memory, short-term memory, retrospective and prospective memory, is compromised just like attention which is dependent on the previously mentioned control processes and determines response speed (Ren et al., 2013; Salthouse, 2009).

As we age, our cognitive abilities naturally decline, and this can impact our motor performance as more cognitive resources are required for movement. Elderly individuals experience a decrease in their ability to learn new motor tasks, particularly when it comes to explicit motor learning, which involves conscious effort and awareness. Research has shown that older adults struggle with this type of learning, especially with motor chunking, or the ability to group individual movements into larger, more efficient units (Ren et al., 2013).

Studies have also indicated that the rate at which older adults (70-80 years old) learn new motor skills is about half that of younger adults (20 years old), and they tend to rely heavily on external cues, suggesting a reduced capacity for internal, self-directed learning (Coats et al., 2013). While it is assumed that implicit motor learning, which occurs without conscious awareness, remains relatively preserved in older adults (Wu et al., 2016), research has shown that this type of learning also declines with age, starting as early as 12 years old. Older adults may require more explicit instruction and knowledge to learn new motor skills effectively (Ren et al., 2013).

The effectiveness of motor learning in older adults appears to depend on the context and complexity of the task (Wu et al., 2016). Some studies have shown that older adults improve their motor learning when they practise a movement “online”, meaning while performing the specific task (Yan et al., 2010). However, "offline" learning, or learning that occurs without physically performing the task, seems to be more challenging for older adults (Roig et al., 2014; Yan et al., 2010). Bimanual motor learning, or the ability to coordinate movements with both hands, is an archetype of complex motor functions where age-related differences have been observed (Swinnen & Wenderoth, 2004). While Swinnen (1998) has found that older adults have difficulty acquiring new bimanual coordination skills after two consecutive test days, other research suggests that with two-week long Bimanual Tracking Task (BTT) motor program composed of five training sessions, older adults can show significant improvements, even surpassing younger adults after the first two sessions (Solesio-Jofre et al., 2018).

Physical activity may have a broader impact on motor skills than previously thought. Boisgontier et al. (2017) explored the relationship between the level of physical activity and performance on a bimanual coordination task that was not previously practised. They found that higher levels of physical activity were associated with better performance on the bimanual task, which suggests that physical activity may enhance general motor skills, even for tasks that are not directly related to the type of activity typically performed.

Previous studies have suggested a potential link between cognitive functions and bimanual performance, with findings indicating a role for spatial working memory in motor adaptation and learning in young adults. Anguera et al. (2011) found that spatial working memory in young adults was linked to the rate of early motor adaptation and was not seen in older adults. Supporting these findings, Langan and Seidler (2011) noticed that brain regions for spatial working memory and visuomotor adaptation had a greater overlap in young adults compared to older adults and that spatial working memory can be seen as a predictive tool of both sensorimotor learning and motor sequence learning, including both explicit and implicit motor learning (Seidler et al., 2012). Additionally, it was found that the capacity to update the information of the working memory is related to the performance at the BTT. A similarity in degree of cognitive load between the executive task and the complex BTT-condition may explain this relationship (Seer et al., 2021). However, the relationship between cognition and bimanual tasks is not yet fully understood and there is a lack of research done about the predictive value of cognitive scores on the motor performance of those kinds of complex motor tasks.

The intent of this research is twofold. Firstly, we will investigate if implicit motor learning of a complex task is affected in healthy older adults compared to healthy younger adults, by comparing between groups, the motor performance gains after two weeks of training the BTT, -a commonly used bimanual coordination task to assess motor learning (Sisti et al., 2011). Secondly, we will investigate if this motor learning performance can be predicted through cognitive tests. This involves assessing participants' cognitive abilities through standardised tests assessing memory, attentional, and executive functions, and examining the relationship between cognitive test scores and motor performance gains on the BTT. We intend to have a better knowledge of the relationship between cognitive functions and implicit motor learning. We anticipate that implicit motor learning is impaired and that the level of cognitive health will be predictive of motor gains.

Methods

Participants

Thirteen adults divided into two groups of older and younger older adults underwent this experiment. Initially, the group of older adults was composed of seven healthy older adults between the ages of 65 to 80 years, with a mean age of 70 ± 3 years and a mean of 16 ± 2 years of education. The second group consisted of six younger adults between the ages of 25 and 40 years, with a mean age of 26 ± 5 years and a mean of 15 years ± 2 years of education. The ratio between men and women in the two groups was 1:3 and 1.5:1 in each group, respectively.

The recruitment process for this study involved the placement of posters in public places and on social media.

All participants had a normal to corrected-to-normal vision and didn't suffer from any neurological, psychiatric or cardiovascular diseases. Participants were not included if they were proficient in bimanual tasks, that is, if they performed a bimanual task, such as gaming or playing an instrument for more than 5 hours per week. This was done to ensure that all included participants had a similar level of bimanual proficiency. Further exclusion criteria were smoking, alcohol and drug abuse, taking medication that could potentially interfere with the test results, not being a Dutch-native speaker, and/or not filling in the criteria for Magnetic Resonance Imaging (MRI).

At the start of the experiment, the participants completed the Edinburgh Handedness Inventory (EHI) and the Montreal Cognitive Assessment (MoCA). The Edinburgh Handedness Inventory was used to objectively determine the handedness of a subject in activities of daily living, while the Montreal Cognitive Assessment (MoCA) was used as a screening tool to determine the presence of cognitive impairment and evaluate visuospatial skills, attention, language, abstract reasoning, delayed recall, executive function and orientation. Individuals with a score equal or lower than + 60 on the handedness questionnaire (Milenkovic & Dragovic, 2013), and or equal or lower than 26 on the MoCA (Nasreddine et al., 2005) were excluded from the study.

After the screening, five younger (age of 67 ± 3 years and 16 ± 2 years of education) and three older (age of 32 years ± 5 years and 17 years ± 1 years education) participants remained. One participant was found ineligible based on MRI screening, one based on their MoCA score, and one because of proficiency in bimanual tasks. One person missed the first progression test, while one missed the last one.

Prior to the beginning of the experiment, participants signed a written informed consent after having received detailed and extensive information about the study. The Ethics Committee of UZ Leuven approved the current study (S-number s66028). In accordance with the Declaration of Helsinki, all ethical principles concerning research with human subjects were adhered to.

Procedure

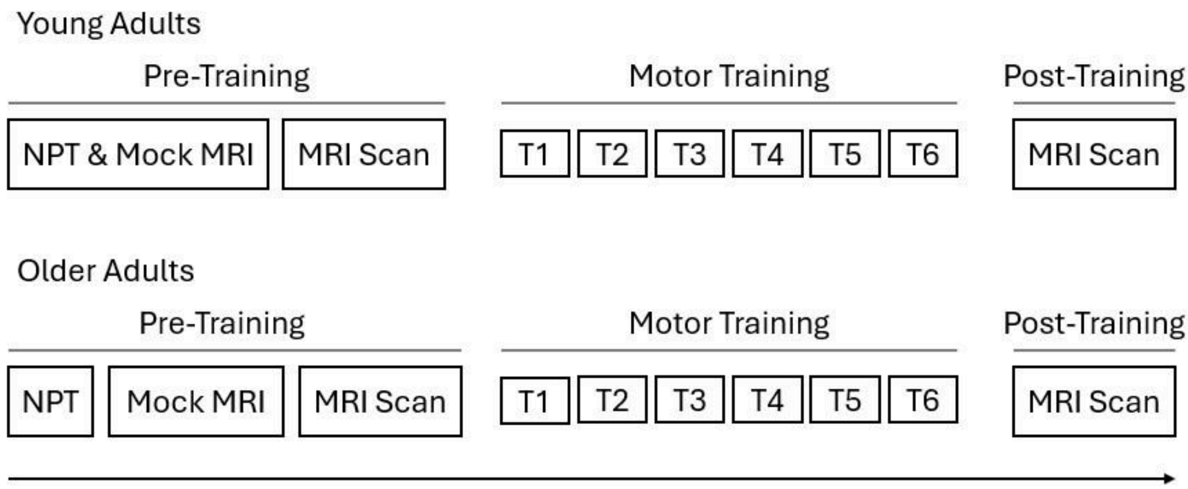
The study's protocol consisted of multiple sessions, varying slightly for young and older adults.

For young adults, three sessions were scheduled. The first sessions, lasting approximately two hours, involved administering an extensive neuropsychological test battery, followed by a mock session in a dummy MRI machine to familiarise participants with the MRI environment. The second and third sessions were dedicated to MRI scans, with the second session lasting two hours and the third session lasting an hour and a half.
Older adults participated in a total of four sessions. The first session, similar to that of the young adults, included the administration of a neuropsychological test battery. However, this session was longer for older adults as they completed additional tests specifically related to ageing. The second session was a brief mock session in a dummy MRI scanner, lasting approximately 30 minutes. The third and fourth sessions, mirroring those of the young adults, were MRI sessions lasting two hours and an hour and a half, respectively.

Between the two MRI sessions, the participants followed an home-based motor training programme, for which they were lent a BTT setup (cf. fig. 1).

Figure 1

Protocol



Note. NPT = Neuropsychological test battery; MRI = Magnetic Resonance Imaging; T = training.

<u>Neuropsychological test battery</u>

As mentioned above, during the screening session, the participants underwent an extensive neuropsychological assessment among which there was the Rey Auditory and Verbal

Learning Test (RAVLT), the Stroop Color and Word Test (SCWT) and the Digit Span Backwards Test (DSBT).

The Rey Auditory and Verbal Learning Test (RAVLT) was administered to assess the participants' memory. The participant had to remember as much as possible a list of 15 words, list A, in five consecutive trials. The words were read to the participant before each trial. A new list of 15 words, list B, was then introduced and participants were asked to recall it immediately. Once this was done, participants were asked to recall list A again, as well as thirty minutes after recalling list B. The sum of the first five consecutive trials of list A was calculated, resulting in a total recall outcome used to evaluate their short-term memory. Additionally, a score for long term memory was calculated by dividing the number of recalled words from list A after the 30 minutes divided by the number of words recalled from list A on the fifth trial (Moradi et al., 2017).

To assess executive functions, the Stroop Color and Word Test (SCWT) was used to assess the capacity of an individual to inhibit conflicting information while reading names of colours as fast as possible (Stroop, 1935). They are first presented with a series of colour names written in black ink that they had to read out loud, followed by a series of colours that participants had to name. These were the congruent conditions of the task. The third and last condition of the task was the incongruent condition, wherein the participant had to indicate out loud the colour of the ink in which unmatched names of colours were written. Inhibition of automated reading of the word was required. An interference score was calculated by subtracting from the time required for the interference condition, the time spent naming the colours in the second condition.

In the DSBT, digit span is assessed by measuring a participant’s ability to recall a sequence of digits (from two up to eight digits), both by the order they were presented, and in reverse. To perform the task, participants needed to transform information, which provided insight into their working memory capabilities (Reynolds, 1997). Participants are initially presented with two-digit sequences, and two trials are given at each progressively longer sequence length. Testing stops if the participant fails both trials at a given length or when the maximum length is reached (eight digits backwards).

Physical activity

Because it was shown that someone's performance on an unpractised bimanual task benefits from by a higher level of physical activity (Boisgontier et al., 2017), subjects were assessed with the International Physical Activity Questionnaire (IPAQ) long form to determine their level of activity. This questionnaire is a validated measure of health-related physical activity across a wide population (Wanner et al., 2016). The questionnaire contains 27 questions in four different domains (containing leisure time physical activity, domestic and gardening (yard) activities, work-related physical activity and transport-related physical activity) with detailed assessment of the time spent in different intensities of the activity with Metabolic Equivalent of Task intensity in each domain a subject does as part of their daily lives and ask about the time spent being physically active during the past seven days (Sjostrom et al., 2005).

BTT task

Bimanual coordination was individually trained and measured using a bimanual visuomotor tracking task (BTT). This was done by rotating two dials, each with the index finger. The left dial controls the cursor along the Y-axis, while the right one controls the X-axis (fig. 3). When the left hand is rotated counterclockwise, this action results in the cursor moving upwards along the Y-axis. And the opposite for clockwise finger movements. A counterclockwise rotation of the right hand directs the cursor to move left along the X-axis. Each trial lasted for 15 seconds and started by a planning phase displaying the intended target trajectory (blue line) and a target (white dot) for two seconds. Once the planning phase ended, the target dot began moving along its predetermined path at a consistent speed for 10 seconds. Throughout this period, participants were directed to attentively follow the target dot by rotating both hand dials simultaneously (tracking phase). During the tracking phase, the participants received real-time visual feedback on their performance through a red line that indicated their trajectory (fig. 2). Once the trial was finished, the screen went blank for three seconds (inter-trial interval), signalling the beginning of the next trial. Various tracking patterns with different levels of difficulty were used. In the easier task conditions, as the straight lines 1:1; 1:3; 3:1 the direction of rotation was kept unchanged throughout the time, and the only variation among these task conditions was the rotation rate for each hand: in the line 1:1, both hands rotated at the same speed, whereas in line 1:3 and 3:1, one of the hands had to rotate the dials at a faster speed, in a ratio of 1:3 (fig. 4). Conversely, in the more complex patterns, such as the zig-zag (fig. 5A), the wave (fig. 5B) and the flamingo (fig. 5C), a correct task performance required adjusting both the speed and direction at which each hand rotated.

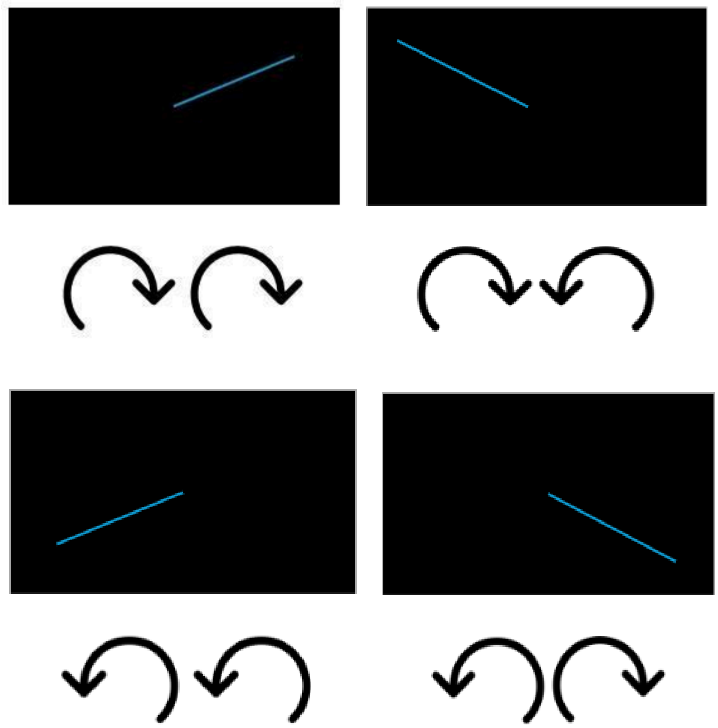
The accuracy score was calculated by analysing the subject's trajectory in samples (S0-30) with an interval of 10 ms in between, and for each, the minimal Euclidean distance from the participant's position and the target points in the target pattern was determined. The closest target point was then checked, considering that each target point could only be "checked" once. Hence, the final score corresponded to the percentage of covered points, that is the number of covered points, divided by the full number of checkpoints (fig. 6; Adab et al., 2020).

Figure 2

Setup for home-based motor training

Figure 3

Directions of rotation in the Bimanual Tracking Task (BTT)



Note. Arrows indicate the direction of rotational finger movement. The left arrow shows the left hand while the right arrow shows the right one. Left hand: Rotates cursor along Y-axis—upwards with counterclockwise rotation, downwards with clockwise rotation. Right hand: Rotates cursor along X-axis—left with counterclockwise rotation, right with clockwise rotation.

Figure 4

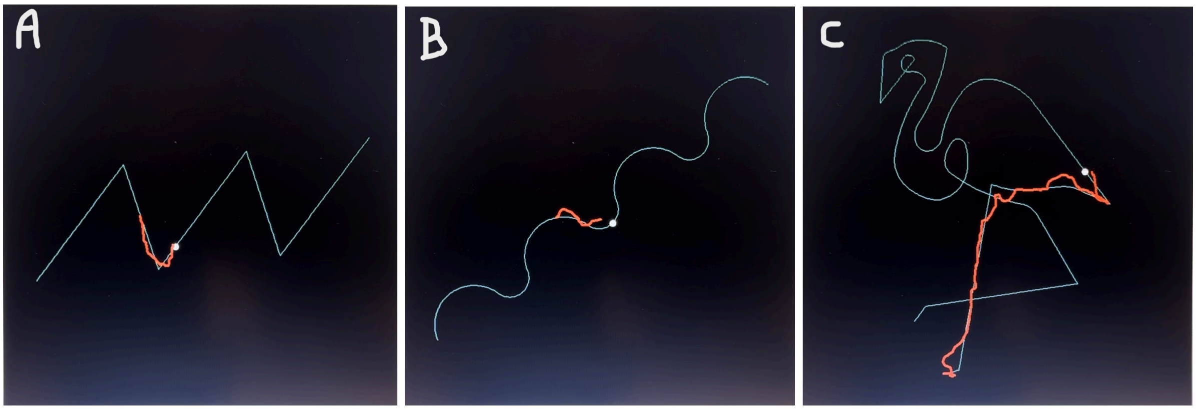
Different BTT task conditions and respective rotation frequencies (i.e., 1:1; 1:3; 3:1)

1:3 3:1 1:1

Note. The rotation speed ratio between the left and right hands is indicated as (left hand rotation speed : right hand rotation speed). In the (1:1) condition, both hands rotate at the same speed. In the (1:3) condition, one hand rotates at three times the speed of the other, resulting in a ratio of 1:3. Conversely, in the (3:1) condition.

Figure 5

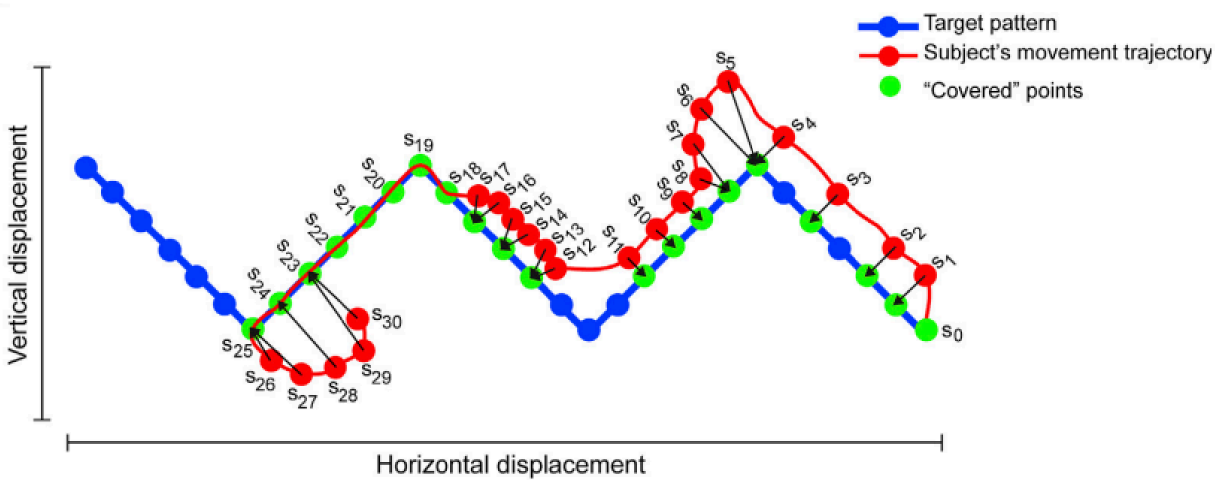
Complex conditions from the Bimanual Tracking Task (BTT)



Note. (A) Zig-zag. (B) Wave. (C) Flamingo.

Figure 6

Calculation of accuracy score for the Bimanual Tracking task (BTT)



Note. Excerpted from ''Fiber-specific variations in anterior transcallosal white matter structure contribute to age-related differences in motor performance,'' by Adab et al., 2020, NeuroImage, 209, p. 3 (https://doi.org/10.1016/j.neuroimage.2020.116530)

Motor training

The participants underwent an individualised BTT motor training program of six training sessions of 30 minutes, each consisting of six five-minute blocks of 20 trials, over the course of two weeks. There were 91 difficulty levels and the level of difficulty at each block was determined based on the participants' accuracy score on the previous block. Specifically, participants would progress two levels at once upon reaching an accuracy above 65% on the last training block and a regress one level when accuracy was less than 40%.

In total, three progression tests were done by the participants: one at the beginning (i.e., before the first training session), one in the middle (i.e., before the beginning of the fourth training session), and one at the end of the training program. These tests were used to assess their motor learning skills and consisted of a predetermined set of BTT conditions with variable difficulty levels. Namely, six trials of line 1:1, four trials of the line 1:3, four trials of the line 3:1, two trials of the 3:1 zigzag, two of the wave, two of flamingo.
These different task conditions were included in their training program. To calculate the participants' level of progression in their motor capacity, a score was determined by calculating the difference between the overall accuracy score (i.e., the accuracy level for all task conditions) in the third and the 1st progress tests, hereafter known as BTT (3-1).

Statistical Analysis

SAS JMP Pro 17 (SAS Institute Inc., 2023) was used for statistical analysis. To compare motor performance gains after training the BTT between the group of older and younger adults, we first started by performing the Shapiro-Wilk and the Brown-Forsythe tests to check respectively normality and variance of the BTT outcomes. Both groups consist of a small sample size (less than 20 subjects).

Group differences in motor training gains

After assuring the necessary assumptions were met, a two-sample t-Test and Wilcoxon Exact Test were performed to assess group differences in regard to the BTT training gains for the full term of the BTT motor program measured using the outcome score BTT (3-1). The non-parametric Wilcoxon Exact Test gave a more robust comparison addressing a small data set with the concern of possible outliers. Furthermore, it was also examined if group differences were more pronounced in a specific part of the motor program. For that, they compared the group differences in the improvement of bimanual performance between the beginning and the middle [BTT (2-1)], as well as between the middle to the end of the motor training program [BTT (3-2)]. Cohen's d was used for the effect size and the significance level was set to $\alpha = 0.05$.

Relationship between motor training gains and cognitive performance

To determine the relationship between the motor training gains and the abovementioned cognitive tests, a correlation analysis was performed between the BTT (3-1) score and the cognitive scores. Particularly, A Spearman's rho non-parametric test was done with a significance level of $\alpha = 0.05$, given the small sample size of each group (i.e., five younger and three older adults). In particular, for the variables referring to cognitive performance we used the total interference time from the SCWT, the total recall and retention from the RAVLT and the total number of successful trials on the DSBT. Additionally, the predictive value of the IPAQ score for the BTT outcome was examined. Regarding the other outcome measures of motor improvement, namely, BTT (3-2) and BTT (2-1), the correlation analysis was only conducted if it was previously found a statistically significant group difference in the training gains regarding those scores.

In addition, for the correlations in which it was found a statistically significant correlation taking together all subjects, a new correlation was computed at group level (i.e., for both the younger and older participants separately). Particularly, A Spearman's rho non-parametric test was done with a significance level of $\alpha = 0.05$, given the small sample size of each group (i.e., five younger and three older adults).

Subsequently, a correction for multiple comparisons using the Bonferroni method was done. Specifically, we divided the desired overall significance level ($\alpha = 0.05$) by the number of comparisons made in the correlation analyses between BTT outcomes and both cognitive scores and/or IPAQ to determine the adjusted significance level.

Results

Group differences in implicit motor learning

For the BTT (3-1), based on the Shapiro-Wilk Test, normality can be accepted for the older adults (W = 0.98, *p* = 0.750) and younger adults (W = 0.93, *p* = 0.571). Brown Forsythe Test shows that variances are equal (F(1, 6) = 0.36, *p* = 0.568) (see table 1 and figure 8). Hence, it can be assumed that the key assumptions to run the t-Test are fulfilled. For the t-Test no statistically significant difference was found [t(6) = 14.63, *p* = 0.120] between the BTT scores of healthy older adults and healthy younger adults. The Wilcoxon Exact Test shows no significant difference as well [W(5,3) = 7, *p* = 0.071], suggesting that healthy younger adults have no higher values on average for the BTT (3-1) condition as shown in table 2 and figure 8.

For conditions BTT (2-1) older (W = 1.00, *p* = 0.962) and younger adults (W = 0.97, *p* = 0.850) and condition BTT (3-2) older (W = 0.99, *p* = 0.855) and younger adults (W = 0.97, *p* = 0.858) assumptions of normality are fulfilled. Also, variances are equal with the Brown-Forsythe Test for BTT (2-1) (F(1, 6) = 2.59, *p* = 0.159) and BTT (3-2) (F(1, 6) = 0.27, *p* = 0.623) as shown in table 1. There is only a statistically significant difference in learning improvement in condition BTT (2-1) in both the t-Test [t(6) = 14.27, *p* = 0.028] and the Wilcoxon Exact Test [W(5,3) = 6, *p* = 0.036] between both groups (see table 2 and figure 8). In the BTT (3-2) condition, no statistically significant results were found with the t-Test [t(6) = 0.362, *p* = 0.956] and Wilcoxon Exact Test [W(5,3) = 13, *p* = 1.000].

Table 1

P-values of the assumption tests for the t-Test and Wilcoxon Exact Test

Condition	Shapiro-Wilk Test	Brown-Forsythe Test
BTT (3-1)	OA: 0.750 YA: 0.571	0.568
BTT (2-1)	OA: 0.962 YA: 0.850	0.159
BTT (3-2)	OA: 0.855 YA: 0.858	0.623

Note. OA = older adults; YA = younger adults; BTT (3-1) = Bimanual Tracking Task improvement between progression test 3 and 1; BTT (2-1) = Bimanual Tracking Task *improvement between progression test 2 and 1; BTT (3-2) = Bimanual Tracking Task improvement between test 3 and 2.*

Table 2

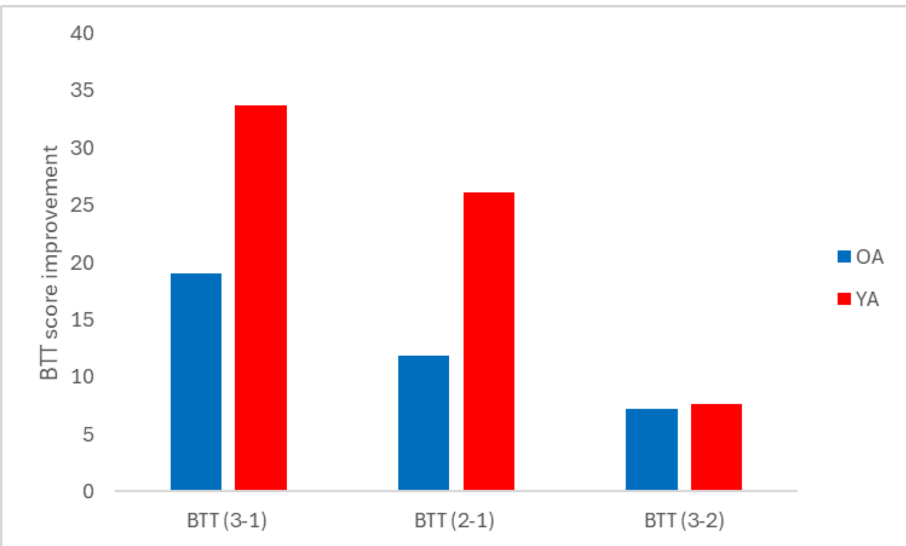
Statistical tests comparing the performance of older and younger adults across each Bimanual Tracking Task (BTT) condition, and corresponding p-values

Condition	Pooled t-Test	Wilcoxon Exact Test
BTT (3-1)	0.120	0.071
BTT (2-1)	0.028*	0.036*
BTT (3-2)	0.956	1.000

*Note. BTT (3-1) = Bimanual Tracking Task improvement between progression test 3 and 1; BTT (2-1) = Bimanual Tracking Task improvement between progression test 2 and 1; BTT (3-2) = Bimanual Tracking Task improvement between test 3 and 2; * $p < 0.05$.*

Figure 7

BTT score improvement



Note. OA = older adults; YA = younger adults; BTT (3-1) = Bimanual Tracking Task improvement between progression test 3 and 1; BTT (3-2) = Bimanual Tracking Task improvement between progression test 3 and 2

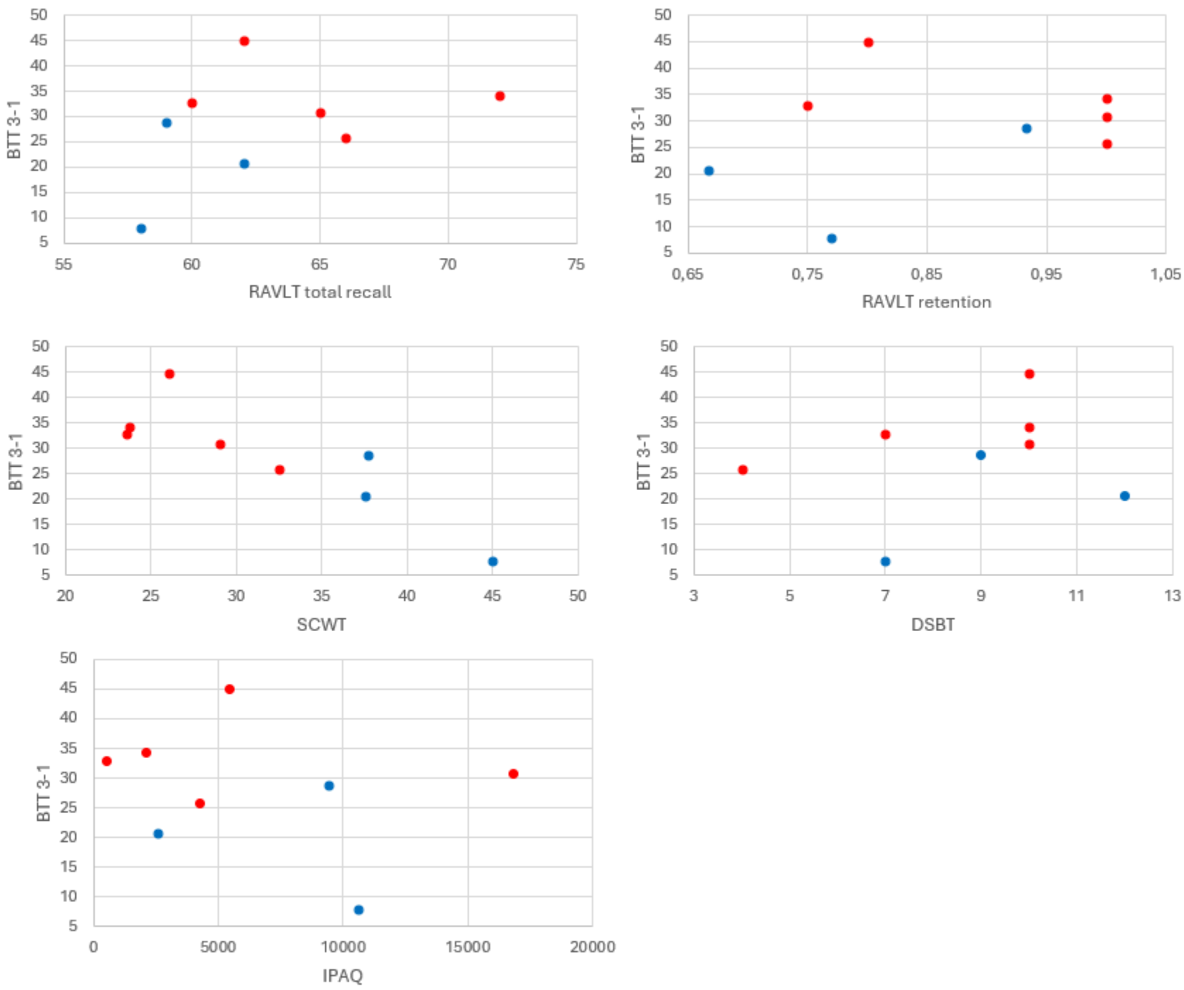
Correlations between BTT outcomes and cognitive scores

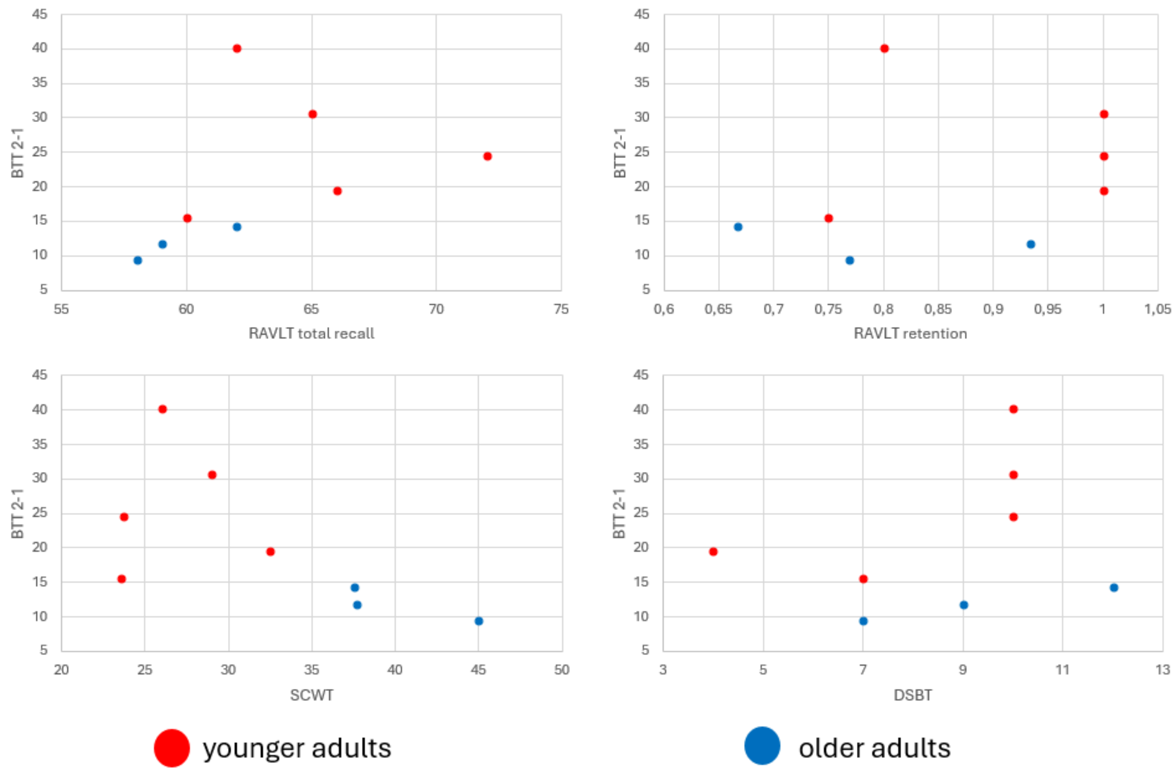
In the correlation analysis a good to excellent negative correlation [r(8)= -0.83, p = 0.010] between training outcome BTT (3-1) and SCWT was found when taking all subjects together. Concerning the correlation between the training outcomes and the RAVLT, there seems to be a moderate to good positive correlation for the total recall [r(8) = 0.41, p = 0.317] and for retention [r(8) = 0.29, p = 0.482]. For BTT (3-1) and DSBT, results indicated a fair relationship [r(8) = 0.26, p = 0.538] between both variables. However, when looking at statistical significance, only the correlation between training outcome BTT (3-1) values and SCWT has shown statistical significance. For BTT (2-1), a moderate to good negative correlation was found with the SCWT [r(8) = -0.69, p = 0.058], as well as a moderate to good positive correlation with the RAVLT total recall [r(8) = 0.71, p = 0.0501], a fair relationship with the RAVLT retention [r(8) = 0.49, p = 0.220] and with the DSBT score [r(8) = 0.33, p = 0.423]. However, none of these correlations reached statistical significance, apart from BTT (2-1) and RAVLT total recall, which was marginally significant.

Regarding the within-group correlation analysis between BTT (3-1) OA and the cognitive scores [r(3) = 0.50, p = 0.667] and between BTT (3-1) YA and RAVLT total recall [r(5) = -0.20, p = 0.747] and retention [r(5) = -0.45, p = 0.450], SCWT [r(5) = 0.87, p = 0.054] and DSBT [r(5) = -0.60, p = 0.285], none was statistically significant. Nevertheless, an insignificant weak correlation between BTT (3-1) and the IPAQ [r(8) = -0.31, p = 0.456] was found. All the correlations and corresponding p-values are shown in figure 8 and table 3.

Figure 8

Scatter plots of the tested pairs with BTT (3-1) and BTT (2-1)





Note. *BTT (3-1) = Bimanual Tracking Task improvement between progression test 3 and 1; RAVLT = The Rey Auditory and Verbal Learning Test; SCWT = Stroop Color and Word Test; DSBT = Digit Span Backwards Test; IPAQ: International Physical Activity Questionnaires*

Table 3

Correlations values for the relationship between BTT improvement scores and the cognitive scores, and corresponding p-values

BTT improvement score	Cognitive score	Spearman's rho	*p*
All subjects together			
BTT (3-1)	RAVLT total recall	0.41	0.317
BTT (3-1)	RAVLT retention	0.29	0.482
BTT (3-1)	SCWT	-0.83	0.010*
BTT (3-1)	DSBT	0.26	0.538
BTT (3-1)	IPAQ	-0,31	0.456
BTT (2-1)	RAVLT total recall	0.71	0.0501

BTT improvement score	Cognitive score	Spearman's rho	*p*
BTT (2-1)	RAVLT retention	0.49	0.220
BTT (2-1)	SCWT	-0.69	0.058
BTT (2-1)	DSBT	0.33	0.423
Within group			
BTT (3-1) OA	RAVLT total recall OA	0.50	0.667
BTT (3-1) OA	RAVLT retention OA	0.50	0.667
BTT (3-1) OA	SCWT OA	-0.50	0.667
BTT (3-1) OA	DSBT OA	0.50	0.667
BTT (3-1) YA	RAVLT total recall YA	-0.20	0.747
BTT (3-1) YA	RAVLT retention YA	-0.45	0.450
BTT (3-1) YA	DSBT YA	0.87	0.054
BTT (3-1) YA	SCWT YA	-0.60	0.285

*Note. OA = older adults; YA = younger adults; BTT (3-1) = Bimanual Tracking Task improvement between progression test 3 and 1; BTT (3-2) = Bimanual Tracking Task improvement between progression test 3 and 2; RAVLT = The Rey Auditory and Verbal Learning Test; SCWT = Stroop Color and Word Test; DSBT = Digit Span Backwards Test; IPAQ: International Physical Activity Questionnaires; * p < 0.05*

After correcting for multiple comparisons using the Bonferroni method, the negative correlation between BTT (3-1) and SCWT [r(8)= -0.83, *p* = 0.010] remained statistically significant, based on an adjusted alpha = 0.010. See table 3 for an overview of the Bonferroni Correction for the multiple comparisons.

Discussion

By employing the Bimanual Tracking Task (BTT) across a two-week training period after an extensive cognitive test battery, we sought to understand if 1) implicit motor learning of a complex bimanual task differs between healthy older and younger adults, and, 2) if one's cognitive performance relates to their capacity to learn a bimanual motor task.

No difference was found in implicit motor learning of BTT between healthy older and younger adults after the analysis of BTT (3-1) with both the Pooled t-Test and the Wilcoxon Exact Test. For BTT (2-1), both the Pooled t-Test and the Wilcoxon Exact Test showed a statistically significant group difference. These results show that the biggest difference in gains between the groups was made between the first two progression tests and that the gains in implicit motor learning between the second and third progression tests was much more equal between the groups. These findings align with some aspects of the Compensation-Related Utilisation of Neural Circuits Hypothesis (CRUNCH) as written in Van Ruitenbeek et al. (2022). This hypothesis proposes that older adults engage additional brain regions or exhibit greater neural activity compared to younger adults when performing the same cognitive task. Therefore we can assume that the greater gains made by younger adults between the first two progression tests are due to the CRUNCH hypothesis, as younger adults can engage additional brain regions to a greater extent compared to older adults. Thus, showing a greater improvement in the beginning of the motor training programme. The improvement for both groups between the second and third progression tests is almost similar. This could be explained by a plateauing effect that occurs after the initial learning period where the both groups can no longer engage additional brain regions and therefore further improvement in motor learning is similar between younger and older adults. Also, older adults demonstrated increased activation in motor/visuospatial and higher cognitive brain areas at lower task complexity levels. However, contrary to the CRUNCH hypothesis, no evidence was found that older adults reach activation limits sooner than younger adults, even at the highest task complexity levels. Solesio-Joffre et al. (2018) supported these findings, where there was an obvious improvement in the first two motor training days, whereafter a plateauing effect of motor learning occurred from the third session onwards.

Concerning executive functions, working memory, as well as short-term memory and long-term memory, as tested by SCWT, DSBT and RAVLT respectively, only BTT (3-1) and SCWT showed a statistically significant negative correlation. The negative correlation between BTT (3-1) and SCWT indicates that lower training outcome values are associated with higher SCWT values. Fair but statistically insignificant correlation between the BTT (3-1) and the components of the RAVLT (total recall and retention) and the DSBT are found for the sample with younger and older adults together. Consequently, executive functions may play a more crucial role in the implicit motor learning of complex motor tasks compared to working memory, short-term memory and long-term memory. Since the cognitive load required for executive functions like working memory updating is similar to the demands imposed by the Bimanual Tracking Task (BTT) (Seer et al., 2021), this parallel in cognitive demands may explain the correlation between both parameters. Higher SCWT scores, which indicate poorer inhibitory control, are associated with reduced ability to perform simultaneous bimanual actions during the Bimanual Tracking Task (BTT). The reduced cognitive flexibility may be the primary control process impaired in cognitive decline associated with ageing, in addition to the contributions from declines in attention and memory (Ren et al., 2013). However, cognitive scores do not appear to serve as reliable predictors for BTT performance improvements across the entire two-week program when analysed separately for each group. It could be influenced by factors such as the overall variability in the data or limitations in the statistical analysis methods used. For the sample with younger and older adults together, insignificant correlations between the BTT (2-1) condition and cognitive scores are found suggesting that performances in the first three to four sessions can't be predicted any better than gains across the full motor program. Despite the odds, a negative insignificant correlation is found between BTT (3-1) and the IPAQ. However, in general, the lack of correlation can be a consequence of the small sample sizes and this should be taken into account when interpreting these results.

When scatter plots are used to visualise the data, several age-related observations can be made in addition to the trends between BTT (3-1) and BTT (2-1) outcomes and SCWT. In the RAVLT retention plots, older adults generally exhibit lower BTT (3-1) and BTT (2-1) scores compared to younger adults at equivalent levels of RAVLT retention. For RAVLT total recall, a between-group trend is observed, as indicated by a marginally statistically significant result in the Spearman's rho analysis of BTT (2-1). This suggests that BTT scores may be associated with short-term memory performance, particularly in older adults, where lower RAVLT total recall scores appear to correspond with lower BTT (2-1) scores. Regarding the DSBT variables, age-related patterns are less pronounced, with both age groups displaying a range of BTT (3-1) and BTT (2-1) scores across different DSBT values. However, there is a noticeable trend between BTT (2-1) and DSBT scores in older adults, supported by marginally statistically significant results. This suggests an association between implicit motor learning of complex motor tasks and working memory capacity (see Figure 7). Caution is warranted due to the small sample size.

A positive aspect of our research is the longitudinal follow-up of seven training days spread over two weeks in comparison to other studies which do not have a training period or only a pre- and post-training evaluation of the BTT and can confirm that age-related implicit motor learning was not affected when a longer training period is observed, due to the fact young and older participants end up reaching a plateau. Limitations of our research is that p-values should be treated with caution as the groups have small sample sizes of only eighth participant overall. This may not provide the necessary statistical power to generalise its results. The differences in implicit learning are small, which means that possibly greater sample sizes and effect sizes may be able to show other results or differences. Additionally, consideration should be given to the lower statistical power typically associated with a non-parametric test like Spearman's rho, which was chosen because of that small sample size. There were also some difficulties with data collection and measurement wherein one participant missed the first progression test possibly through troubles with the used BTT applications, leading to the participant's exclusion from this study. Inclusion of this participant in the analysis could have yielded different results.

Implications for further research are studies with greater sample sizes to have more statistical power to analyse differences in implicit motor learning in both groups. A greater sample size is interesting for the prediction of implicit motor learning by cognitive scores in older and younger adults separately. Making sure all participants know how the training programme should be executed could help in avoiding the need to exclude participants due to mistakes made during the training programme. This could be achieved by doing a practice training session under the supervision of the researchers. For future research, the scope could be expanded to include age groups covering the entire lifespan, as well as, the potential to develop cognitive training tools aimed at improving motor coordination in older adults (Seer et al., 2021). Additional research is required about the impact of performance across various Bimanual Tracking Task (BTT) conditions. In our study, we used an overall score of improvement, which may have obscured statistical relationships between cognitive functions and BTT performance. This lack of a significant correlation between cognitive and overall BTT performance could be due to this wide measurement approach. Maybe working memory is more relevant in the most complex task conditions (Seidler et al., 2012). Also, the question arises if training executive functions has an influence on the capacity of implicit motor learning of complex tasks.

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