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The Combined Impact of Physical Activity and Sedentary Behavior on Executive Functions in Older Adults: A Cross-Sectional Study

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Background: The interplay between physical activity (PA) and sedentary behavior (SB) significantly influences cognitive health in older adults, with executive functions (EFs) being particularly vulnerable to lifestyle factors. However, previous research on older adults focused mainly on PA and is limited due to the lack of comprehensive consideration of other factors that influence EFs. Current guidelines suggest an association between sedentary behavior (SB) and EFs, yet few studies have examined the combined effects of PA and SB on EFs.

Objective: This cross-sectional study aimed to explore the relationship between PA, SB, and EFs in older adults.

Methods: A total of 116 healthy older adults aged ≥65 years were recruited and categorized into four groups based on activity lifestyles: higher PA and higher SB (PHSH); higher PA and lower SB (PHSL); lower PA and higher SB (PLSH); and lower PA and lower SB (PLSL). EFs were assessed using the Tower of London (TOL) task and the Stroop test, which measure high-order EFs (planning and problem-solving) and core EFs (inhibitory control), respectively.

Results: The PHSL group performed better on the TOL task, with lower total move scores and shorter total problem-solving times, compared to the PLSH group. The total move score of the PLSL group was better, and the total problem-solving time of the PHSH group was shorter than those of the PLSH group. However, the Stroop test scores did not differ between the four groups.

Conclusion: These findings suggest that increasing PA or reducing SB selectively enhances executive functions, particularly in planning and problem-solving, while less impacting inhibitory control in older adults. This highlights the importance of considering the nuanced effects of PA and SB on different aspects of executing functioning in older adults.

Keywords: cognition, planning, inhibition, cognitive decline, sitting

Introduction

Cognitive function (CF) decline, considered a normal part of aging, increases at a rate of 0.04 to 0.05 standard deviation units per year.[1,2] CF decline, ranging from mild cognitive impairment (MCI) to severe cognitive diseases such as dementia, has become a significant societal concern. For instance, a new case of dementia is estimated to be detected every four seconds globally.[3] In 2010, approximately 30.1 million people were diagnosed with dementia worldwide, with this number projected to rise by 30%, reaching 65.7 million by 2030 and continuing to increase to 106.2 million by 2050.[4,5] Effective treatments for CF decline have yet to be developed; therefore, it is anticipated that the global economic burden associated with healthcare would increase.[6,7]

Physical activity (PA) is a promising strategy for preventing CF declines.[8,9] Cohort studies have shown that PA reduces CF decline and helps maintain high-order CFs such as executive function (EF).[10–12] EF, also known as executive control, encompasses the CFs necessary to regulate purposeful, goal-directed behaviors, including high-order EFs, eg, planning and

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problem-solving, and core EFs, eg, inhibitory control, working memory, and switching.[13–15] High-order and core EFs are crucial for adapting to new situations, managing tasks efficiently, and achieving long-term goals, making them essential for daily functioning and behavior regulation.[16,17] Importantly, current systematic reviews found that PA positively impacts several facets of EF in adults over 50,[18,19] suggesting that PA benefits multiple EFs in the older population.

Increased PA is associated with improved core EFs but has limited effects on high-order EFs. Previous studies showed that adults who engage in PA perform better in inhibitory control,[20] working memory,[21] and switching.[22] However, the effects of PA on EFs related to planning and problem-solving remain underexplored. The current meta-analysis showed that older adults undergoing PA interventions in randomized controlled trials improved overall EFs (the effect size was 0.21) and the three core EFs (the effect size ranged from 0.14 to 0.27).[23] However, due to limited data on high-order EFs, their effect size could not be evaluated in the review. Indeed, several reviews supported the findings and further suggested that future research should focus on multiple facets of executing functioning in older adults.[24,25]

The optimal duration of PA for improving or maintaining EF in older adults is still unclear. Most studies on this topic focused on basic CF and yielded conflicting results. For instance, a cross-sectional study observed an inverse-U relationship between PA duration and CF, with moderate-intensity PA for 22 to 38 minutes per day (154 to 266 minutes per week) providing the most benefits.[26] Conversely, the current study found that longer durations of moderate to vigorous-intensity PA, exceeding current PA recommendations, were associated with decreased CF decline.[27] To clarify this inconsistency, future studies should explore the relationship between PA and EFs in the older population to determine the optimal benefits for EFs.

Evidence suggests that higher levels of sedentary behavior (SB), which is defined as remaining in a sitting or reclining posture with a low energy expenditure (<1.5 metabolic equivalents [METs]), increase morbidity and mortality risk.[28] Furthermore, SB also increases the risk of dementia and is associated with deficiencies in EFs across the lifespan.[29–31] Specifically, longer SB times negatively influence EF, even if recommended PA levels, are achieved.[32] However, current evidence suggests no association between SB time and EF in older adults,[33] which suggests that the relationship between specific SB time and EF remains to be further investigated.

Although PA and SB times are critical factors influencing EFs, their consequences show opposing trends. Specifically, PA positively influences EF through increased energy expenditure and muscle contraction,[34,35] whereas SB is associated with poor EF due to prolonged sitting and limited movement.[36,37] Individuals who engage in sufficient PA but prolonged SB can be described as being both physically active and sedentary. Therefore, PA and SB patterns are independent, with four activity lifestyles, including higher PA and higher SB time (PHSH); higher PA and lower SB time (PHSL); lower PA and higher SB time (PLSH); and lower PA and lower SB time (PLSL). Only two studies have examined the combined effects of PA and SB on EF. Specifically, one study found EF deficits in children with high PA and SB time compared to those with low PA and SB time.[38] Another study of Brazilian adults[39] (median age = 30 years) reported that higher levels of moderate to vigorous intensity PA were associated with better EF performance. At the same time, less than 9 hours of SB daily enhanced EF. In summary, more PA and less SB appear beneficial for EFs. While a few studies have considered both PA and SB in relation to EFs in children and adults, none have focused on older adults or examined both high-level and core EFs in a single study.

This study aimed to investigate the combined effects of PA and SB on multiple EFs in a community sample of older adults. It examined four activity lifestyles—PHSL, PHSH, PLSL, and PLSH—to understand their impacts on core and high-level EFs. Given the evidence linking PA to EFs, we hypothesized that the EF performance of older adults with a lifestyle of higher PA, ie, PHSL and PHSH, would be better than that of older adults with unfit lifestyles of lower PA and higher SB, ie, PLSH. In addition, we hypothesized that the EF performance of individuals with shorter SB time, ie, PHSL and PLSL, would be better than that of individuals with unfit lifestyles of lower PA and higher SB, ie, PLSH.

Methods

Participants

Volunteers aged ≥65 years were recruited using recruitment flyers distributed in local gyms and senior universities in Taichung, Taiwan. All participants were contacted by telephone and asked to complete a Health Screening Questionnaire. Their responses were compared with predetermined inclusion criteria to assess their suitability for fitness testing.

Participant inclusion criteria were an age of 65 years or more, no history of neurological or psychiatric disorders, living independently in the community, normal or corrected-to-normal vision (20/40), a score of 27 or more on the Mini-Mental State Examination (MMSE), and no sensory and language deficits.

The International Physical Activity Questionnaire (IPAQ) and the Sedentary Behavior Questionnaire (SBQ) were used to assess participants' PA and SB. The IPAQ, a validated tool for quantifying PA, measures the frequency (days per week) and duration (minutes per day) of activities at varying intensities, including vigorous, moderate, and light activities, with results expressed in Metabolic Equivalent Task minutes per week (MET-min/week) for classification into activity levels.[40] The SBQ, a complementary self-report tool, captures time spent in sedentary activities, such as watching television, using a computer, reading, and driving. These questionnaires comprehensively overview participants' PA and SB patterns.

Eligible participants were allocated into four groups, PHSL, PHSH, PLSL, and PLSH, based on PA expenditure and SB time: (1) higher PA (>1200 METs/week); (2) lower PA (≤1200 METs/week); (3) higher SB time (>8 hours/day or >3360 minutes/week); and (4) lower SB time (≤8 hours/day or ≤3360 minutes/week) over the previous three months.[41] All participants had to visit the laboratory twice, and each evaluation was performed individually (lasting about 1 hour). During the first visit, they completed a self-questionnaire (providing demographic information, IPAQ, and SBQ) and performed the two-minute step test (2MST) to verify their physical fitness. All participants completed two EF tasks, the Tower of London (TOL) task and the Stroop test, during the second visit. Before participation, written informed consent was obtained according to the study protocol approved by the Institutional Review Board of China Medical University (No. CMUH111-REC3-097).

The Two-Minute Step Test

The 2MST is part of the senior fitness test.[42] Participants were asked to march in place, lifting their knees above a set height, and the number of steps taken within two minutes was recorded. This test is advantageous because it takes only a limited amount of space and a short time and no expensive equipment is required.[43] Previous studies have shown that the 2MST is correlated with the six-minute walking test[44] and is a reliable measure of PA levels in healthy individuals.[45]

Executive Function Assessments

The Tower of London-Drexel University (TOL_{DX}) task was used to assess high-order EFs, especially the planning and problem-solving aspect.[46] The task involves two identical wooden boards (30 × 7 × 10 cm) and two sets of three colored beads (blue, green, and red). Each board has three vertical pegs: the tallest peg holds three beads, the middle peg holds two, and the shortest peg holds one. Participants were presented with ten problems (ranging from 3 to 7 moves) and asked to use the fewest moves to achieve the goal position from the start position (Figure 1). Five indices were

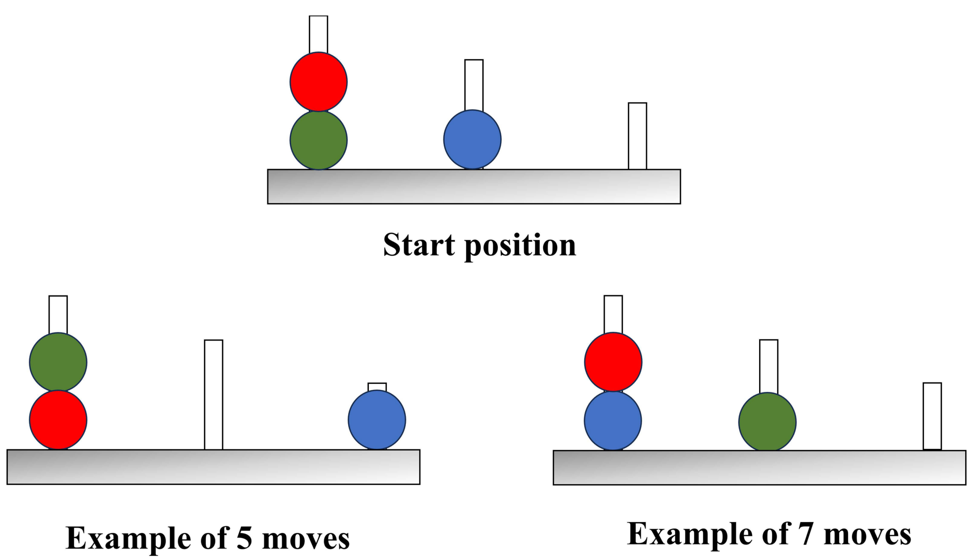

Figure 1 The example of the start and goal position of the Tower of London Task.

computed:[47] (1) total move score (TMS), ie, the number of actual moves minus the minimum number of moves; (2) total correct score (TCS), ie, the number of problems solved in which only the minimum number of moves was used; (3) total initial time (TIT), ie, the time when the participant initially moved the first bead; (4) total executive time (TET), ie, the time from initiation of the first move to the solving of the problem; and (5) total planning-solving time (TPST), ie, the sum of initial time and executive time. The TOL task required 20–25 minutes.

The Stroop test in this study mainly assessed the core EF, ie, inhibitory control, and information processing speed.[48] Participants were instructed to verbally state the color of the stimulus as quickly as possible. The modified Stroop test included five conditions: word, congruent, color, neutral, and incongruent,[49] and each condition included 50 stimuli (Figure 2). Specifically, the incongruent condition was regarded as examining inhibitory control. In contrast, other conditions are assessed to determine the information processing speed. The word condition involved color names presented in black ink, eg, "RED" in black. The congruent condition involved color names in ink of the matching color, eg, "RED" in red. The color condition consisted of colored rectangles. The neutral condition had unrelated words in colored ink, eg, "PAPER" in red. The incongruent condition had color names in different-colored ink, eg, "RED" in blue. Stimuli were displayed on a sheet, and participants named the colored stimuli from top to bottom and left to right. Each participant practiced with five stimuli before starting each condition. Reaction time was recorded using a handheld stopwatch. The Stroop test took about 10–15 minutes.

Statistical Analysis

Statistical analyses were performed using SPSS 22.0, with a significance set at p <0.05. The participants' background data and intelligent indices, ie, age, height, body mass index, MMSE, digit forward span, digit backward span, IPAQ, sitting time, and 2MST, were analyzed using one-way analysis of variance (ANOVA) to compare differences between the four groups (PHSL, PHSH, PLSL, and PLSH). One-way ANOVA was also used to determine differences in TOL performance (TMS, TCS, TIT, TET, and TPST) between the groups. Furthermore, a two-way (group × task condition) ANOVA was used to compare differences in reaction time between Stroop test task conditions (word, congruent, color, neutral, and incongruent) and between the four groups. The Greenhouse–Geisser correction was applied when sphericity was violated, and post-hoc analyses were performed using Bonferroni-adjusted multiple comparisons.

Results

Participants

The sample comprised 116 participants distributed across the four groups (Figure 3): PHSL (n = 35), PHSH (n = 23), PLSL (n = 33), and PLSH (n = 25). A power analysis was conducted, considering the effect sizes observed in related studies.[50,51] The analysis determined that a sample size of 100–120 participants would provide sufficient power (80%) to detect meaningful differences between groups, ensuring the study is adequately powered to identify significant effects. One-way ANOVA revealed no significant differences between the groups in participants' backgrounds, ie, age, height, and BMI, and intelligence indices, ie, MMSE, digit forward span, and digit backward span (p > 0.05). However,

RED	GREEN	GREEN	GREEN	GREEN
GREEN	GREEN	GREEN	RED	GREEN
RED	GREEN	RED	GREEN	RED
GREEN	RED	BLUE	BLUE	BLUE
RED	GREEN	GREEN	GREEN	GREEN
GREEN	BLUE	BLUE	GREEN	BLUE
RED	BLUE	RED	GREEN	RED
BLUE	GREEN	RED	RED	GREEN
BLUE	GREEN	GREEN	GREEN	GREEN
BLUE	GREEN	RED	BLUE	GREEN

Figure 2 The example of the incongruent condition of the Stroop test.

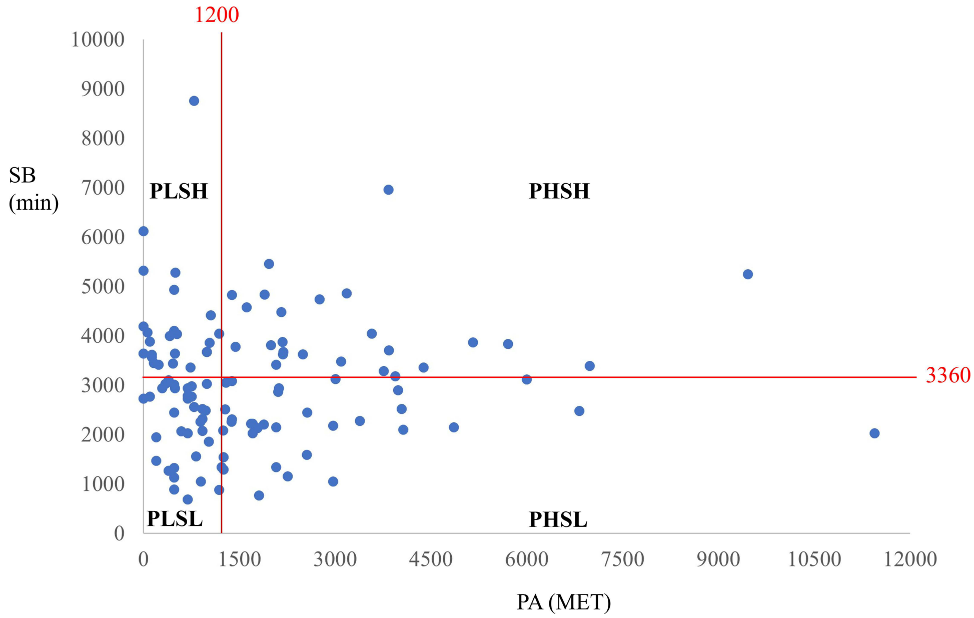

Figure 3 The distribution of recruited participants based on their physical activity expenditure and sedentary behavior time.
Abbreviations: PHSL, higher physical activity and lower sitting time; PHSH, higher physical activity and higher sitting time; PLSL, lower physical activity and lower sitting time; PLSH, lower physical activity and higher sitting time.

significant differences were found in fitness indices, including IPAQ, sitting time, and two-minute step (all $p = 0.000$), confirming the appropriate assignment of participants to the lifestyle groups. Post-hoc analysis showed the following. The IPAQ scores of the participants in the PHSH and PHSL groups were higher than those in the PLSH and PLSL groups ($p < 0.05$), but no significant difference was observed between PHSH and PHSL ($p > 0.05$). Participants in the PHSL and PLSL groups had less SB time than PHSH and PLSH participants, with no significant difference between PHSH and PHSL or between PHSL and PLSL ($p > 0.05$). The step count of participants in the PHSH group was higher than that of the other three groups ($p < 0.05$), with no significant difference observed between these three groups ($p > 0.05$). The means and SDs of participants' demographic data are summarized for the four groups in Table 1.

Table 1 Participants' Demographic Data Among Four Groups

Variable	Group			
	PHSL	PHSH	PLSL	PLSH
Sample (%female)	35 (77%)	23 (78%)	33 (78%)	25 (68%)
Background				
Age (year)	72.57 ± 5.16	70.96 ± 5.61	71.18 ± 5.65	71.80 ± 4.13
Height (cm)	157.25 ± 6.77	156.50 ± 7.23	157.25 ± 6.59	159.84 ± 6.93
BMI (kg/m^2)	22.45 ± 2.96	23.61 ± 3.38	24.09 ± 5.67	25.04 ± 3.24
Fitness index				
IPAQ (Met-min/week)	2838.27 ± 2041.97	3286.39 ± 1972.31	629.00 ± 291.41	463.19 ± 380.59
Sitting time (min/week)	2227.67 ± 660.78	4240.04 ± 862.95	2200.82 ± 751.19	4504.60 ± 1642.33
Two-min step test (step)	92.06 ± 25.93	111.43 ± 28.27	90.03 ± 21.12	90.39 ± 22.57
Intelligent index				
MMSE (score)	28.94 ± 1.26	29.04 ± 1.07	29.18 ± 1.26	28.44 ± 1.69
Digit forward span (score)	14.17 ± 2.13	13.35 ± 1.87	14.79 ± 1.98	13.96 ± 2.13
Digit backward span (score)	8.14 ± 3.03	8.22 ± 2.98	8.70 ± 3.93	8.08 ± 2.74

Abbreviations: PHSL, higher physical activity and lower sitting time; PHSH, higher physical activity and higher sitting time; PLSL, lower physical activity and lower sitting time; PLSH, lower physical activity and higher sitting time; BMI, body mass index; IPAQ, the International Physical Activity Questionnaires; MMSE, the Mini-Mental State Examination.

Table 2 Performance of the Tower of London Task Among Four Groups

Index	Group			
	PHSL	PHSH	PLSL	PLSH
TCS	3.37 ± 1.40	3.13 ± 1.89	3.79 ± 1.75	3.04 ± 1.72
TMS	37.17 ± 10.79	42.17 ± 11.86	36.12 ± 14.57	46.64 ± 17.87
TIT	71.63 ± 26.38	68.64 ± 43.78	78.40 ± 37.47	83.90 ± 30.50
TET	278.25 ± 83.31	294.94 ± 88.42	301.84 ± 109.90	347.68 ± 118.60
TPST	349.73 ± 85.45	363.59 ± 108.95	380.25 ± 129.16	431.58 ± 123.59

Abbreviations: PHSL, higher physical activity and lower sitting time; PHSH, higher physical activity and higher sitting time; PLSL, lower physical activity and lower sitting time; PLSH, lower physical activity and higher sitting time; TCS, Total Correct Score; TMS, Total Move Score; TIT, Total Initiation Time; TET, Total Executive Time; TPST, Total Problem-Solving Time.

The Tower of London Task

The results of the TOL task are presented in Table 2. One-way ANOVA revealed a significant difference in the TMS between groups ($F_{3,112}$ = 3.449, p = 0.019). Post-hoc analysis showed that the TMS of the PHSL group was significantly lower than that of the PLSH group (p = 0.010). The TMS of the PLSL group was significantly lower than that of the PLSH group (p = 0.005). One-way ANOVA revealed a significant difference in the TPST ($F_{3,112}$ = 2.771, p = 0.045). Post-hoc analysis showed that the TPST was shorter in the PHSL group than that in the PLSH group (p = 0.006); it was also shorter in the PHSH group than in the PLSH group (p = 0.038). However, TCS (p = 0.325), TIT (p = 0.385), and TET (p = 0.071) did not differ significantly between the four groups (Figure 4).

Stroop Test

The results for the Stroop test are presented in Table 3. Two-way ANOVA revealed a significant main effect of task condition ($F_{4,112}$ = 363.081, p < 0.001). Post-hoc analysis showed that the reaction time was longest (83.36 ± 2.87 ms) for the

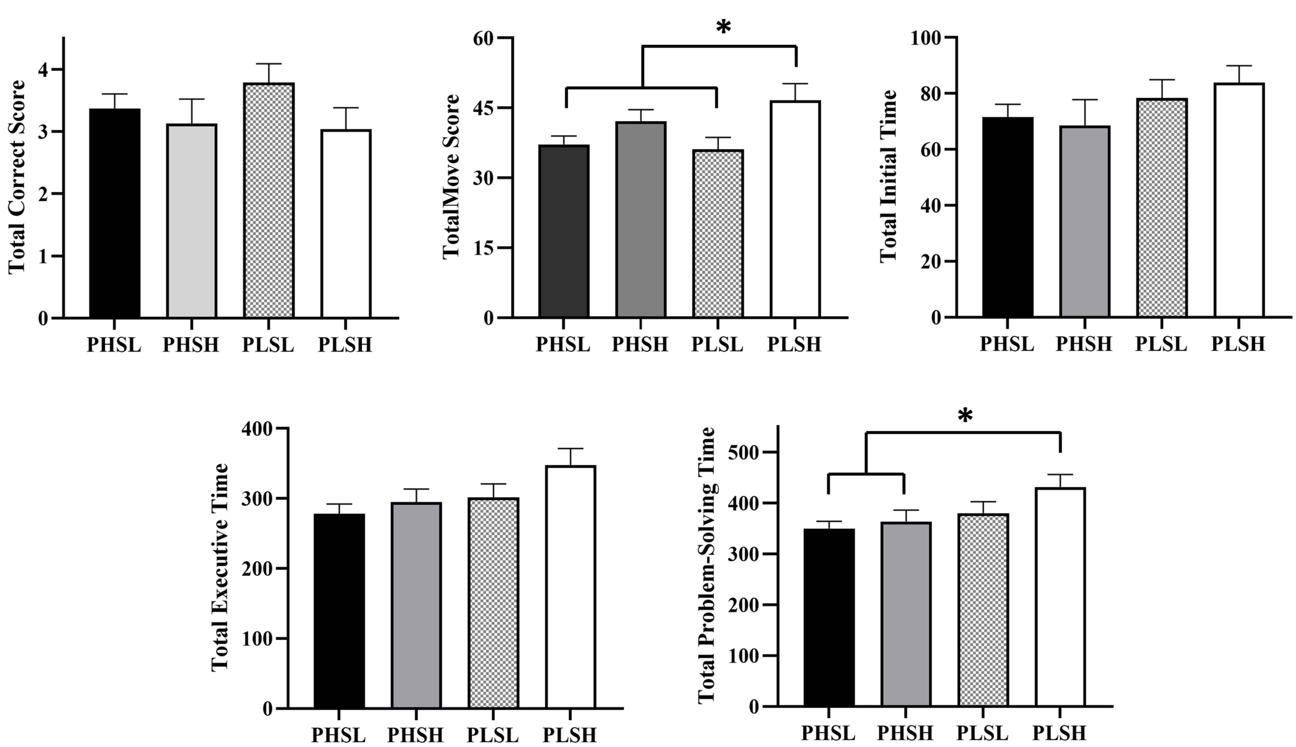

Figure 4 The performance of the Tower of London task among four groups.
Note: * represents a significant difference (p < 0.05).

Table 3 Performance of the Stroop Test Among Four Groups

Condition	Group			
	PHSL	PHSH	PLSL	PLSH
Word	29.03 ± 8.62	25.95 ± 5.46	27.07 ± 7.27	28.40 ± 11.16
Congruent	27.44 ± 8.62	25.93 ± 6.25	25.11 ± 6.28	26.51 ± 9.60
Square	37.47 ± 10.73	38.75 ± 14.76	38.35 ± 14.86	37.76 ± 9.13
Neutral	50.26 ± 13.09	46.45 ± 11.79	50.07 ± 13.64	51.97 ± 11.95
Incongruent	77.19 ± 20.57	80.27 ± 30.22	84.71 ± 34.38	91.27 ± 36.22

Abbreviations: PHSL, higher physical activity and lower sitting time; PHSH, higher physical activity and higher sitting time; PLSL, lower physical activity and lower sitting time; PLSH, lower physical activity and higher sitting time.

incongruent condition, followed by the neutral condition (49.69 ± 1.21 ms), square condition (38.09 ± 1.19 ms), word condition (27.61 ± 0.79 ms), and congruent condition (26.25 ± 0.74 ms). However, group ($F_{3,112} = 0.454$, $p = 0.715$) and the group × task condition interaction ($F_{12,112} = 1.408$, $p = 0.158$) did not have a significant effect on reaction time.

Discussion

The present study examined the combined effects of PA and SB on high-order and core EFs in older adults. In the case of high-order EFs, specifically planning and problem-solving, the TOL task found that the TMS of participants in the PHSL and PLSL groups was significantly lower than that of the PLSH group. Furthermore, participants in the PHSL and PHSH groups exhibited a shorter TPST than those in the PLSH group. However, in the case of the core EF, inhibitory control, the differences in reaction time between the task conditions in the Stroop test did not depend on the lifestyle group, ie, the interaction between the group and the task condition was not significant. These results suggest that EF differences are selectively sensitive, with high-order EFs, rather than the core EF, being primarily affected, underscoring the importance of considering the nuanced effects of PA and SB on different aspects of executive functioning in older adults.

Based on the novelty of the TOL task in assessing the effects of PA and SB time on high-order EFs, our study cross-sectionally investigated EF benefits related to planning and problem-solving across different activity lifestyles. We found that older adults with high-fitness lifestyles, ie, the PHSL group, had a lower TMS and shorter TPST than those with a low-fitness lifestyle, ie, the PLSH group. According to previous studies,[47,52] the TMS primarily measures the quality of planning and problem-solving efficiency, and TPST represents the overall speed of planning and planning efficiency. Therefore, older individuals achieving a higher TMS and TPST during the TOL task transformed current mental representations into goal states by considering multiple suitable strategies.[46,52] Interestingly, we also observed that the PLSL group had a lower TMS, and the PHSH group had a shorter TPST than the PLSH group. Therefore, we concluded that participants with lower SB time, regardless of PA expenditure, ie, the PHSL and PLSL groups, showed better move-related performance in planning quality in the TOL task. In contrast, participants with higher PA, regardless of SB time, ie, the PHSL and PHSH groups, showed better speed-related performance in planning efficiency.

While current guidelines recommend a balance between PA and SB for promoting health, SB time consistently exceeds the time spent on PA during waking hours.[53] It is worth noting that in our study the TMS of older adults who engaged less in SB, even with lower PA, ie, the PLSL group, was lower than that of the individuals with lower PA and higher SB, ie, the PLSH group, implying that reducing SB time had a positive impact on EFs in older adults. This finding is supported by a previous study,[26] which showed a significant relationship between SB and global CF. Similarly, systematic reviews have suggested that lower SB time is associated with greater CF in late-middle-aged adults[54] and older adults.[55] Our findings further broaden the association between SB and EFs and suggest that older adults with lower SB time are more proficient than those with a low-fitness lifestyle in performing the TOL task, which requires the ability to recognize initial and goal states, anticipate future events, and store representations of intermediate states that guide movements from the initial to the goal state (Culbertson et al, 2004; Culbertson & Zillmer, 1998).

The combined benefits of increasing PA or decreasing SB time in high-order EFs, ie, the TOL task, in our study, may be explained by the release of molecules important for neuronal health, for example, during increased cerebral blood flow and cerebrovascular reactivity in the frontal lobe, which is strongly associated with executive functioning.[56,57] Furthermore, a recent review demonstrated that higher PA positively impacts brain structure and function in the older population.[58] Similarly, lower SB time can mitigate the associated risks of cognitive function[59] and positively influence brain health in older adults.[60] Considering these potential mechanisms related to EFs, our findings suggest that a high-fitness lifestyle, ie, higher PA or lower SB time, might facilitate cognitive health in the older population. However, future research should comprehensively examine executive functioning and its mechanisms further to understand exercise–cognition relationships in the older population.

Despite the effects on TMS and TPST of older adults with specific lifestyles, no significant differences were observed in some indices of the TOL task—TCS, TIT, and TET— between the four activity lifestyles. TCS, the index of move-related performance in the TOL task, indicates the ability to solve more complex problems and is strongly associated with working memory.[61] Therefore, our findings implied no difference in working memory between different lifestyles. The TIT and TET indices are speed-related TOL task scores, but they represent different abilities. TIT is regarded as the ability to govern and control executive planning, whereas TET represents the efficiency of executive planning.[62] Our findings are partially consistent with the previous study,[63] which did not find an association between weekly PA and TET of the TOL task for drivers aged 61–81 years, supporting our finding of a lack of significant differences in speed-related performance in TOL between the four activity lifestyles.

In addition to the TOL task, we used the Stroop test to investigate the combined effect of PA and SB on the core EF, inhibitory control. The Stroop test consisted of assessing inhibitory control and information processing speed. Our findings revealed no significant differences in any conditions of the Stroop test between the four activity lifestyles. This result is similar to the findings from Maasakkers et al (2020), who also reported no relationship between SB time and global CF. However, a recent study observed that the inhibitory control performance of participants involved in high levels of moderate-vigorous PA or low SB time is better.[39] These discrepancies may arise due to differences in the sample populations and methodologies used in these studies. We mainly targeted a community sample of older adults, whereas they focused on young and middle-aged adults.[39] Furthermore, our work specifically used a modified Stroop task with five task conditions to investigate the relationship between PA, SB, and EFs, unlike Linhares and colleagues' work,[39] which used traditional Stroop with only congruent and incongruent conditions. Future research should focus on a sample of healthy community-dwelling older adults and use other tasks related to inhibitory control to provide updated knowledge on the benefits of PA for the executive functioning of older adults with different activity lifestyles.

While this study is the first to explore the combined effects of PA and SB on core and higher-order EFs, several limitations should be acknowledged. The cross-sectional design limits our ability to infer causality; future longitudinal or intervention-based studies are needed to establish directionality between PA, SB, and EFs. Although we accounted for confounding variables such as age, height, BMI, and intelligence indices, the sample size, while respectable, may limit generalizability. Larger, more diverse cohorts are necessary to enhance external validity. Additionally, reliance on self-reported PA and SB measures introduces potential bias, and future studies should use objective tools like accelerometers. Advanced statistical methods, such as mixed-effects models, should also be considered to account for individual differences and correlations between variables. Lastly, to further elucidate the underlying mechanisms linking PA, SB, and EFs, advanced neuroelectric and neuroimaging techniques, such as electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), along with biomarkers like brain-derived neurotrophic factor (BDNF), could be employed. Incorporating these neuroimaging and biological measures in future studies will offer deeper insights into how PA and SB influence cognitive function in older adults, providing a more comprehensive understanding of these relationships.

Conclusion

The findings of this study highlighted that older adults who engage in higher PA and lower SB performed better in the TOL task (as quantified by the TMS and TPST) than individuals with lower PA and higher SB. This emphasizes that a fit lifestyle enhances the quality and efficiency of executive planning in older individuals. This study also observed that the TMS performance of older adults with lower SB time, regardless of PA expenditure, was better than that of individuals with lower PA and higher SB, suggesting that reduced SB time, even with low PA, can positively influence the quality of executive planning in the older population. Our findings confirm that older adults' high-order EFs (the TOL task), rather than core EFs (the Stroop test), respond sensitively to higher PA or lower SB time—moving more or sitting less. However, further interventional and longitudinal studies are needed to establish a causal relationship between PA, SB, and core and high-order EFs.

Research Ethics and Consent Statements

We confirm that this study complies with the Declaration of Helsinki.

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Disclosure

The authors report no conflicts of interest in this work.

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