Original Article

Vol. 9, No. 1, 52-59
https://doi.org/10.15280/jlm.2019.9.1.52

Journal of Lifestyle Medicine

Experimental Evaluation of the Joint Effects of Exercise and Sedentary Behavior on Cognitive Function

Jeremiah Blough and Paul D. Loprinzi*

Department of Health, Exercise Science and Recreation Management, The University of Mississippi, University, MS, USA

Background: The objective of this study was to evaluate the potential joint effects of sedentary behavior and exercise on cognitive function.

Methods: Participants (M_{age} = 20 yrs) were randomly assigned to one of three experimental groups. The No Exercise Group (n = 19) was instructed to reduce steps to less than 5000/day and were not allowed to exercise for one-week; the Reduced MVPA (moderate-to-vigorous PA) Group (n = 18) was instructed to reduce steps to less than 5000/day but exercised for 50% of their previously reported vigorous PA for one-week; and the Control Group (n = 20) maintained normal activity for one-week. Cognitive functions (via Stroop and Trail Making tasks) were assessed at baseline, post-intervention, and after one week of resumed normal activity for the intervention groups.

Results: Statistically significant main effects for time were observed for Stroop Congruent (F_{time} = 11.7, $p < 0.001$, η^2_p = 0.18), Stroop Incongruent (F_{time} = 19.4, $p < 0.001$, η^2_p = 0.26), Stroop Control (F_{time} = 54.4, $p < 0.001$, η^2_p = 0.50), Trail Making-A (F_{time} = 19.1, $p < 0.001$, η^2_p = 0.26) and Trail Making-B (F_{time} = 13.8, $p < 0.001$, η^2_p = 0.21) tasks. However, there were no statistically significant group x time interactions (all p's > 0.05) for any of the cognitive parameters.

Conclusion: These experimental findings do not suggest an interaction effect between sedentary behavior and physical activity on cognitive function.

Key Words: Exercise, Executive function, Exercise cessation, Exercise withdrawal, Intervention, Interaction, Mental health

INTRODUCTION

Emerging experimental work suggests that exercise is associated with enhanced cognitive function [1-6]. Such benefits may occur from exercise-induced changes in neurogenesis, glialgenesis, angiogenesis, cerebral circulation, and growth factor production [7-12]. Sedentary behavior is often considered as any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalents (METs), while engaging in a sitting, reclining or lying posture [13]. The effects of sedentary behavior on health is often considered to be distinct from the effects of exercise on health [14]. Relatedly, in addition to exercise behavior, emerging work also suggests that sedentary behavior, independent of exercise, is detrimentally associated with cognitive function [15-17]. However, there is some epidemiological evidence to suggest that exercise may attenuate some of the detrimental effects of sedentary behavior on cognition [18]. Whether

Received: February 25, 2018, Accepted: July 26, 2018

*Corresponding author: Paul D. Loprinzi
Exercise & Memory Laboratory, Department of Health, Exercise Science and Recreation Management, School of Applied Sciences, The University of Mississippi, 229 Turner Center, University, MS 38677, USA
Tel: 1-662-915-5521, Fax: 1-662-915-5525
E-mail: pdloprin@olemiss.edu

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted noncommercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

similar findings occur from experimental evidence is unknown. Thus, the purpose of this study (written as a brief report) was to experimentally examine whether exercise can attenuate any potential detrimental effects of sedentary behavior on cognition.

MATERIALS AND METHODS

1. Study design

As we have described elsewhere [19], a randomized controlled trial was employed, consisting of 3 interventions arms, including a No Exercise Group (Group 1), a Reduced MVPA Group (Group 2), and a Control Group (Group 3). All study procedures were approved by the authors' institutional review board and consent was obtained from all participants prior to data collection.

2. Eligibility criteria

Participants were eligible for participation if they were aged 18-35 years, sufficiently active by meeting physical activity guidelines (defined hereafter), did not report severe depression (i.e., PHQ-9 > 20), and had not been diagnosed with a psychological disorder within the past 6 months of the baseline assessment.

3. Participants

The sample involved 57 participants in total with 19 in Group 1, 18 in Group 2, and 20 in Group 3. The sample size was selected as it was similar to our previous experimental research (employing an *a-priori* power analysis) on this paradigm [20,21].

4. Recruitment

The participants were students recruited by a convenience-based sampling approach (e.g., classroom announcement at the authors' University). Recruitment began in February of 2017 and ended in November of 2017.

5. Study procedures

The intervention groups (Group1 and Group 2) participated in 4 visits and the control (Group 3) completed 3 visits, with all visits occurring 1 week apart and at approximately the same time of day. All visits were conducted in the Exercise Psychology Laboratory at the University of Mississippi. These temporal procedures are also detailed in the narrative that follows.

6. Baseline physical activity eligibility assessment

As described elsewhere [22], at the first visit (Baseline), physical activity was subjectively assessed via the two-item PAVS (Physical Activity Vital Sign) questionnaire (described below). Participants were eligible for participation if they were initially sufficiently active (based on self-report), defined as ≥ 150 minutes of MPA (Moderate Physical Activity) and/or ≥ 75 minutes of VPA (Vigorous Physical Activity). If eligible based on self-report, an accelerometer was given to be worn (at the midaxillary line on the right hip at the level of the iliac crest) until the next visit one week later. For the following visit (Visit 1), the accelerometer data was analyzed, and the participant continued in the study if he/she was deemed active (≥ 150 minutes of MVPA) per the accelerometry data (details on accelerometer data reduction are noted below).

7. Pre-intervention assessment

As described elsewhere [22], after the one-week of accelerometry assessment to confirm that participants were sufficiently active, they re-completed the PAVS questionnaire as well the cognitive assessments (described below). After these assessments, participants were given an accelerometer (again) and a pedometer and randomly assigned to a group via a computer-generated random sequence algorithm. Allocation of the grouping sequence was concealed and the participants were blinded to their group assignment until the end of the first visit. If assigned to the No Exercise Group (Group 1), the instructions for the following week were to not exercise whatsoever and to reduce daily steps to less than 5000, hence the pedometer. Participants were only included in the Reduced MVPA Group (Group 2) if 75 minutes or more of VPA was reported via the PAVS at Visit 1. If assigned to Group 2, the instructions for the intervention week were to only exercise at 50% of his/her reported VPA from the PAVS at Visit 1 (e.g., 90 min VPA reported, thus, 45 min prescribed vigorous exercise) and to also reduce daily steps below 5000. Participants in the Control Group (Group 3) were instructed to continue nor-

mal activity for the following week.

8. Post-intervention assessment

As described elsewhere [22], the next visit (Visit 2) consisted of a re-assessment of cognition. The Control Group finished the study at this time. However, the intervention groups (Group 1 and Group 2) were given another accelerometer and pedometer and instructed to return to their normal physical activity patterns. Thus, all exercise restrictions were lifted for this final week. At the final visit for the intervention groups (Visit 3), the same measures were conducted and the study was then complete for Group 1 and Group 2.

9. Measures

1) Physical activity

Subjective assessment of physical activity was assessed using the PAVS, indicating the number of minutes per week engaged in MVPA. This assessment has demonstrated evidence of validity [23-27]. Notably, this self-report MVPA measure correlates with accelerometer-assessed number of days ≥ 30 bout-min MVPA ($r = 0.52$, $p < 0.001$) [24].

As described elsewhere [22], physical activity was objectively measured using the ActiGraph GT9X Link accelerometer which has been shown to be reliable and valid [28,29]. Accelerometer-derived step counts were evaluated. Non-wear was defined as 60 minutes or more of zero activity counts, with a 1-2 minute tolerance interval [30]. For participant awareness of their steps during the intervention, participants wore (hip) a Digi-Walker SW-200 pedometer, which has shown evidence of reliability and validity in comparison with other pedometers [31].

10. Cognition

1) Stroop color word test

As described elsewhere [3], participants were given a 30 second practice period before the Stroop Color Word Test [32-35] was administered. The Stroop Color Word Test is a well-documented prefrontal activation task indicative of components of executive function [36]. Neuropsychological testing of the Stroop effect was performed using computerized software. Specifically, we used the color word Stroop testing with keyboard responding. Participants were given color words written in color and asked to indicate the color of the word (not its meaning) by key presses. They were instructed to accomplish this as quickly and accurately as possible. There were 84 total trials, consisting of 4 colors (red, green, blue, black) × 3 color congruency (congruent, incongruent, control) × 7 repetitions. The stimuli remained on the screen until the key response, with latencies measured from the onset of the stimuli. The congruent trials involved the color word and the color it presented being the same; incongruent trials involved the color word being different than the color it was presented in (e.g., it read GREEN, but this word was not in the green color); and the control trials involved colored rectangles. The outcome measure was the average latency (in milliseconds [ms]) of the correctly identified congruent, incongruent and control trials. Lower scores indicate better cognitive functioning. We intentionally reported the congruent, incongruent and control results separately, as when considering combined scenarios (e.g., stroop interference; difference between incongruent and control), results were similar.

As described elsewhere [3], previous research demonstrates adequate psychometric properties of this task. The 10-12 day test-retest reliability for this measure among young adults is 0.78 and 0.92, respectively, for congruent and incongruent trials [37]. In a separate sample of young- to middle-age adults, the one-week test-retest reliability of this measure is 0.91 [38]. This is similar to a two-week test-retest reliability assessment among older adults (ICC = 0.80) [39]. Additionally, this Color Word Stroop task did not demonstrate evidence of a practice effect over a two-week period ($F = 0.22$; $p > 0.05$) [39]. Evidence of validity for this task has been demonstrated by performance scores on this task associating with other versions of this task ($r = 0.79$, $r = 0.73$, respectively, for congruent and incongruent) [37].

2) Trail Making A and B

Both Trail Making A and B [40-44] included brief practice sessions of an abbreviated version of this test. Identical tests were utilized for cognitive testing at visits one and two. As described elsewhere [3], Trail Making A has the participant draw lines between connecting circles from one to 25 in sequential order without lifting the pencil as rapidly as

possible. Trail Making B involves alternating these tracings between numbers and letters in ascending order (e.g. 1-A-2-B-3-C-4-D) as rapidly as possible, requiring participants to rapidly shift mental set. Scores on these tests were the times taken to complete them, with faster times (lower numbers) indicating better functioning. Test is a measure of various cognitive processes, including psychomotor speed, fluid cognitive ability, attention, visual search and scanning, sequencing and shifting, working memory, cognitive flexibility, and ability to execute and modify a plan of action [45,46]. A functional neuroimaging analysis of the Trail Making B test indicated that the calcarine cortex and intraparietal sulcus are primary brain regions activated during this test [47].

As described elsewhere [3], and although a potential learning effect is possible, it is likely this is minimized with the one-week period between our visits. In support of this, previous research among healthy young- to middle-age adults reports a 1-week test-retest reliability (ICC) of 0.61 and 0.45, respectively, for Trail Making A and Trail Making B [38]. Similarly, there was no significant difference in Trail Making A ($p = 0.21$) or Trail Making B ($p = 0.22$) across the 1-week washout period [38], suggesting a 1-week washout period may be sufficient to remove a potential learning effect. Regarding the validity of the trail making tasks, previous research suggests evidence of construct validity with other tasks that measure perceptual processing and visual search (Digit Symbol) and working memory (DBack). Trail Making A performance has been shown to inversely associate with the Digit Symbol task ($\beta = -0.50$; $p = 0.002$) [46]. Similarly, Trail Making B performance is inversely associated with the DBack task ($\beta = -6.0$; $p = 0.01$) [46].

11. Statistical analysis

Statistical Analyses were computed using SPSS (version 22.0) software. Repeated measures analysis of variance (RM-ANOVA) were conducted for all measures. Based on the comparisons, either a 3 (time) × 2 (group) RM-ANOVA or a 2 (time) × 3 (group) RM-ANOVA was computed Effect size was calculated using Partial Eta Square (η^2_p). Statistical significance was set at a two-tailed nominal α of 0.05.

RESULTS

Table 1 displays the demographic characteristics for each of the 3 groups. There were no statistically significant differences between the groups at baseline.

The intervention groups (Group 1 and Group 2) de-

Table 1. Characteristics of the analyzed sample (proportion/mean ± SD)

Variable	Group 1 (No Exercise)	Group 2 (Reduced MVPA Intervention)	Group 3 (Control)
N	19	18	20
Age, mean years	21.0 ± 1.5	20.6 ± 1.0	20.4 ± 1.6
Gender, % male	31.6	22.2	35.0
Race-ethnicity, %			
Non-hispanic white (n = 47)	84.2	83.3	80.0
Non-hispanic black (n = 5)	10.5	5.6	10.0
Other hispanic (n = 1)	5.3	0	0
Other/multi-race (n = 4)	0	11.1	10.0
Highest level of education, %			
Some college (n = 50)	84.2	94.4	85.0
Bachelor's degree (n = 6)	15.8	5.6	10.0
Master's degree or higher (n = 1)	0	0	5.0
Height, mean cm	169.0 ± 10.1	165.8 ± 6.1	171.3 ± 9.8
Weight, mean kg	71.5 ± 14.5	67.4 ± 10.9	72.6 ± 15.3
BMI, mean (kg/m^2)	24.9 ± 3.5	24.4 ± 3.3	24.6 ± 3.8

BMI: body mass index, MVPA: moderate to vigorous activity, SD: standard deviation.

creased their mean daily steps from Visit 1 to Visit 2 then increased back to near baseline at Visit 3. The mean daily steps for the Control Group (Group 3) were similar at both time points. Specifically, for the No Exercise Group, the mean (SD) daily step count estimates across the 3 respective time points were: 8808.2 (2157.0), 5994.8 (2148.6), and 8323.0 (2287.7). For the Reduced MVPA Intervention Group, the mean (SD) daily step count estimates across the 3 respective time points were: 10129.7 (2383.8), 6904.5 (2246.6), and 9160.8 (2938.5). For the Control Group, the mean (SD) daily step count estimates across the 2 respective time points were: 9286.7 (3105.0) and 9854.1 (2855.9).

The main results of this experiment are displayed in Table 2. For the Stroop Congruent (F_{time} = 10.0, p < 0.001, η^2_p =

Table 2. Cognitive function scores (mean ± SD)

Variable	Visit 1	Visit 2	Visit 3	2 (group) × 3 (visits) RM-ANOVA	3 (group) × 2 (visits) RM-ANOVA
				F-value, p-value, η^2_p	
Stroop, Congruent (ms)				F_{Time} = 10.0, p < 0.001, η^2_p = 0.22, $F_{Interaction}$ = 0.37, p = 0.68, η^2_p = 0.01	F_{Time} = 11.7, p < 0.001, η^2_p = 0.18, $F_{Interaction}$ = 0.52, p = 0.59, η^2_p = 0.01
Group 1 (No Exercise)	806.6 ± 232.4	733.0 ± 114.7	704.6 ± 100.1		
Group 2 (Reduced Activity)	828.3 ± 312.1	755.9 ± 136.7	685.4 ± 116.8		
Group 3 (Control)	941.7 ± 375.9	810.5 ± 217.3	N/A		
Stroop, Incongruent (ms)				F_{Time} = 15.5, p < 0.001, η^2_p = 0.30, $F_{Interaction}$ = 1.07, p = 0.34, η^2_p = 0.03	F_{Time} = 19.4, p < 0.001, η^2_p = 0.26, $F_{Interaction}$ = 1.24, p = 0.29, η^2_p = 0.04
Group 1 (No Exercise)	969.2 ± 221.5	906.9 ± 190.1	841.3 ± 171.1		
Group 2 (Reduced Activity)	1047.7 ± 380.5	914.5 ± 239.8	837.3 ± 219.3		
Group 3 (Control)	1115.0 ± 387.9	949.7 ± 277.8	N/A		
Stroop, Control (ms)				F_{Time} = 28.8, p < 0.001, η^2_p = 0.45, $F_{Interaction}$ = 0.18, p = 0.82, η^2_p = 0.005	F_{Time} = 54.4, p < 0.001, η^2_p = 0.50, $F_{Interaction}$ = 0.74, p = 0.47, η^2_p = 0.02
Group 1 (No Exercise)	825.1 ± 155.4	717.5 ± 98.2	708.6 ± 120.3		
Group 2 (Reduced Activity)	848.9 ± 213.8	741.2 ± 149.2	713.3 ± 114.6		
Group 3 (Control)	945.9 ± 322.6	797.7 ± 213.5	N/A		
Trail Making-A (sec)				F_{Time} = 24.6, p < 0.001, η^2_p = 0.41, $F_{Interaction}$ = 0.60, p = 0.54, η^2_p = 0.02	F_{Time} = 19.1, p < 0.001, η^2_p = 0.26, $F_{Interaction}$ = 0.86, p = 0.42, η^2_p = 0.03
Group 1 (No Exercise)	18.7 ± 5.7	16.1 ± 3.6	13.7 ± 2.7		
Group 2 (Reduced Activity)	19.0 ± 5.1	15.4 ± 4.7	14.5 ± 3.3		
Group 3 (Control)	18.3 ± 4.4	16.6 ± 3.4	N/A		
Trail Making-B (sec)				F_{Time} = 12.8, p < 0.001, η^2_p = 0.28, $F_{Interaction}$ = 1.87, p = 0.16, η^2_p = 0.05	F_{Time} = 13.8, p < 0.001, η^2_p = 0.21, $F_{Interaction}$ = 1.87, p = 0.16, η^2_p = 0.06
Group 1 (No Exercise)	39.2 ± 16.7	36.6 ± 14.8	28.5 ± 8.0		
Group 2 (Reduced Activity)	45.3 ± 25.7	33.1 ± 11.6	30.7 ± 9.3		
Group 3 (Control)	44.2 ± 13.1	36.9 ± 9.6	N/A		

0.22), Stroop Incongruent (F_{time} = 15.5, p <0.001, η^2_p = 0.30), Stroop Control (F_{time} = 28.8, p < 0.001, η^2_p = 0.45), Trail Making-A (F_{time} = 24.6, p < 0.001, η^2_p = 0.41) and Trail Making-B (F_{time} = 12.8, p < 0.001, η^2_p = 0.28) tasks, there were statistically significant main effects for time for the 2 (groups) × 3 (visits) RM-ANOVA. Similarly, for the 3 (groups) × 2 (visits) RM-ANOVA, there were statistically significant main effects for time for Stroop Congruent (F_{time} = 11.7, p < 0.001, η^2_p = 0.18), Stroop Incongruent (F_{time} = 19.4, p < 0.001, η^2_p = 0.26), Stroop Control (F_{time} = 54.4, p < 0.001, η^2_p = 0.50), Trail Making-A (F_{time} = 19.1, p < 0.001, η^2_p = 0.26) and Trail Making-B (F_{time} = 13.8, p < 0.001, η^2_p = 0.21) tasks. However, for both the 2 (groups) × 3 (visits) RM-ANOVAs and 3 (groups) × 2 (visits) RM-ANOVAs, there were no statistically significant group × time interactions (all p's > 0.05) for any of the cognitive parameters.

DISCUSSION

Previous epidemiological evidence suggests that exercise is favorably associated with cognitive function [48]. Research also suggests that higher levels of sedentary behavior are associated with worse cognitive function, even independent of exercise [15-17]. However, emerging epidemiological evidence suggests that exercise engagement may help attenuate some of the negative effects of prolonged sedentary behavior on cognition [18]. We extend this epidemiological work with an experimental evaluation of the potential joint effects of sedentary behavior and exercise on cognitive function. Our findings do not provide evidence of such an exercise-induced attenuation effect, and in fact, our experiment did not demonstrate any evidence of a sedentary-induced detrimental effect on cognitive function, which aligns with our other experimental work [49].

There is biological plausibility through which prolonged sedentary behavior may negatively influence cognition. As detailed elsewhere [16], prolonged sedentary behavior may alter glycemic control and cerebral blood flow, and in theory, some exercise engagement may offset these negative effects. Our null findings may have been a result of several factors. Our employed sample were young adults, which were intentionally recruited as, per our evaluated paradigm, it was of interest to recruit physically active participants. It is possible that our observations would have been different if we employed an older adult sample, with greater variability in cognitive functioning. Additionally, our experiment was not a bed-rest study, which was intentional in an effort to be as ecologically valid as possible. However, it is possible that the daily ambulatory activity (6,000-7,000 steps/day) were sufficient to stave off any potential detrimental effects of reduced activity on cognition. Relatedly, it is possible that the degree of reduced activity (an approximate 3,000 step/day reduction) was not sufficient enough to induce changes in cognition. Further, a limitation of our study was the use of only two cognitive function tests, and thus, it is uncertain if results would have been different if other cognitive parameters were evaluated. It is also unknown if a longer period of inactivity (e.g., 2-week reduced activity vs. 1-week) would have induced different findings. Importantly, though, it is also possible that sedentary behavior is not causally related to changes in cognition.

In conclusion, our experimental results did not demonstrate any negative effects of sedentary behavior on cognition, nor any attenuation effects with exercise engagement. Future lifestyle-based experimental work is needed to further evaluate this important line of inquiry.

CONFLICT OF INTERESTS

None to declare.

REFERENCES

1. Loprinzi PD, Frith E, Edwards MK, Sng E, Ashpole N. The effects of exercise on memory function among young- to middle-age adults: Systematic review and recommendations for future research. *Am J Health Promot* 2018;32:691-704.
2. Loprinzi PD, Kane CJ. Exercise and cognitive function: A randomized controlled trial examining acute exercise and free-living physical activity and sedentary effects. *Mayo Clin Proc* 2015;90:450-60.
3. Crush EA, Loprinzi PD. Dose-response effects of exercise duration and recovery on cognitive functioning. *Percept Mot Skills* 2017;124:1164-93.
4. Frith E, Sng E, Loprinzi PD. Randomized controlled trial evaluating the temporal effects of high-intensity exercise on learning, short-term and long-term memo-

ry, and prospective memory. *Eur J Neurosci* 2017;46: 2557-64.
5. Sng E, Frith E, Loprinzi PD. Temporal effects of acute walking exercise on learning and memory function. *Am J Health Promot* 2018;32:1518-25.
6. Loprinzi PD, Edwards MK, Frith E. Potential avenues for exercise to activate episodic memory-related pathways: A narrative review. *Eur J Neurosci* 2017;46:2067-77.
7. Gligoroska JP, Manchevska S. The effect of physical activity on cognition - physiological mechanisms. *Mater Sociomed* 2012;24:198-202.
8. Gomez-Pinilla F, Hillman C. The influence of exercise on cognitive abilities. *Compr Physiol* 2013;3:403-28.
9. Kirk-Sanchez NJ, McGough EL. Physical exercise and cognitive performance in the elderly: Current perspectives. *Clin Interv Aging* 2014;9:51-62.
10. Laitman BM, John GR. Understanding how exercise promotes cognitive integrity in the aging brain. *PLoS Biol* 2015;13:e1002300.
11. Barnes JN. Exercise, cognitive function, and aging. *Adv Physiol Educ* 2015;39:55-62.
12. Halperin JM. Joggin'for your noggin: The role of physical activity in attention-deficit/hyperactivity disorder. *J Am Acad Child Adolesc Psychiatry* 2015;54:537-8.
13. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, Chastin SFM, Altenburg TM, Chinapaw MJM, Participants STCP. Sedentary Behavior Research Network (SBRN) - Terminology Consensus Project process and outcome. *Int J Behav Nutr Phys Act* 2017;14:75.
14. Owen N, Sparling PB, Healy GN, Dunstan DW, Matthews CE. Sedentary behavior: Emerging evidence for a new health risk. *Mayo Clin Proc* 2010;85:1138-41.
15. Falck RS, Davis JC, Liu-Ambrose T. What is the association between sedentary behaviour and cognitive function? A systematic review. *Br J Sports Med* 2017;51: 800-11.
16. Wheeler MJ, Dempsey PC, Grace MS, Ellis KA, Gardiner PA, Green DJ, Dunstan DW. Sedentary behavior as a risk factor for cognitive decline? A focus on the influence of glycemic control in brain health. *Alzheimers Dement (N Y)* 2017;3:291-300.
17. Edwards MK, Loprinzi PD. Combined associations of sedentary behavior and cardiorespiratory fitness on cognitive function among older adults. *Int J Cardiol* 2017;229:71-4.
18. Edwards MK, Loprinzi PD. The association between sedentary behavior and cognitive function among older adults may be attenuated with adequate physical activity. *J Phys Act Health* 2017;14:52-8.
19. Blough J, Loprinzi PD. Experimentally investigating the joint effects of physical activity and sedentary behavior on depression and anxiety: A randomized controlled trial. *J Affect Disord* 2018;239:258-68.
20. Edwards MK, Loprinzi PD. Experimentally increasing sedentary behavior results in increased anxiety in an active young adult population. *J Affect Disord* 2016;204: 166-73.
21. Edwards MK, Loprinzi PD. Effects of a sedentary behavior–inducing randomized controlled intervention on depression and mood profile in active young adults. *Mayo Clin Proc* 2016;91:984-98.
22. Blough J, Loprinzi PD. Randomized controlled trial investigating the experimental effects of reduced habitual physical activity on cardiometabolic profile. *Physiol Behav* 2018;194:48-55.
23. Greenwood JL, Joy EA, Stanford JB. The physical activity vital sign: A primary care tool to guide counseling for obesity. *J Phys Act Health* 2010;7:571-6.
24. Ball TJ, Joy EA, Goh TL, Hannon JC, Gren LH, Shaw JM. Validity of two brief primary care physical activity questionnaires with accelerometry in clinic staff. *Prim Health Care Res Dev* 2015;16:100-8.
25. Ball TJ, Joy EA, Gren LH, Cunningham R, Shaw JM. Predictive validity of an adult physical activity "Vital Sign" recorded in electronic health records. *J Phys Act Health* 2016;13:403-8.
26. Ball TJ, Joy EA, Gren LH, Shaw JM. Concurrent validity of a self-reported physical activity "vital sign" questionnaire with adult primary care patients. *Prev Chronic Dis* 2016;13:150228.
27. Fowles JR, O'Brien MW, Wojcik WR, d'Entremont L, Shields CA. A pilot study: Validity and reliability of the CSEP—PATH PASB-Q and a new leisure time physical activity questionnaire to assess physical activity and sedentary behaviours. *Applied Physiology, Nutrition, and Metabolism* 2017;42:677-80.
28. Kelly LA, McMillan DG, Anderson A, Fippinger M, Fillerup G, Rider J. Validity of actigraphs uniaxial and triaxial accelerometers for assessment of physical activity in adults in laboratory conditions. *BMC Med Phys* 2013;13:5.
29. Mcclain JJ, Sisson SB, Tudor-Locke C. Actigraph accelerometer interinstrument reliability during free-living in adults. *Med Sci Sports Exerc* 2007;39:1509-14.
30. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc* 2008;40:181-8.
31. Schneider PL, Crouter SE, Lukajic O, Bassett DR. Accuracy and reliability of 10 pedometers for measuring steps over a 400-m walk. *Med Sci Sports Exerc* 2003;35:1779-84.
32. Wapner S, Krus DM. Effects of lysergic acid diethylamide, and differences between normals and schizophrenics on the Stroop Color-Word Test. *J Neuropsychiatr*

1960;2:76-81.
33. Dalrymple-Alford EC, Budayer B. Examination of some aspects of the Stroop Color-Word Test. *Percept Mot Skills* 1966;23:1211-4.
34. Stroop JR. Studies of interference in serial verbal reactions. *J Exp Psychol* 1935;18:643-62.
35. Jensen AR, Rohwer WD, Jr. The Stroop color-word test: A review. *Acta Psychol (Amst)* 1966;25:36-93.
36. Audenaert K, Lahorte P, Brans B, van Laere K, Goethals I, van Heeringen K, Dierckx RA. The classical stroop interference task as a prefrontal activation probe: A validation study using 99Tcm-ECD brain SPECT. *Nucl Med Commun* 2001;22:135-43.
37. Vora JP, Varghese R, Weisenbach SL, Bhatt T. Test-retest reliability and validity of a custom-designed computerized neuropsychological cognitive test battery in young healthy adults. *J Psychol Cogn* 2016;1:11-9.
38. Beglinger LJ, Gaydos B, Tangphao-Daniels O, Duff K, Kareken DA, Crawford J, Fastenau PS, Siemers ER. Practice effects and the use of alternate forms in serial neuropsychological testing. *Arch Clin Neuropsychol* 2005;20:517-29.
39. Lemay S, Bedard MA, Rouleau I, Tremblay PL. Practice effect and test-retest reliability of attentional and executive tests in middle-aged to elderly subjects. *Clin Neuropsychol* 2004;18:284-302.
40. Reitan RM. The relation of the trail making test to organic brain damage. *J Consult Psychol* 1955;19:393-4.
41. Reitan RM. Validity of the Trail Making test as an indicator of organic brain damage. *Percept Mot Skills* 1958;8:271-6.
42. Army Individual Test Battery. Manual of directions and scoring. War Department, Adjutant General's Office; Washington, DC. 1944.
43. Smith TE. Relation of the trail making test to mental retardation. *Percept Mot Skills* 1963;17:719-22.
44. Parsons OA, Maslow HI, Morris F, Denny JP. Trail Making Test performance in relation to certain experimenter, test and subject variables. *Percept Mot Skills* 1964;19:199-206.
45. Salthouse TA. When does age-related cognitive decline begin? *Neurobiol Aging* 2009;30:507-14.
46. Sanchez-Cubillo I, Perianez JA, Adrover-Roig D, Rodriguez-Sanchez JM, Rios-Lago M, Tirapu J, Barcelo F. Construct validity of the Trail Making Test: role of task-switching, working memory, inhibition/interference control, and visuomotor abilities. *J Int Neuropsychol Soc* 2009;15:438-50.
47. Allen MD, Owens TE, Fong AK, Richards DR. A functional neuroimaging analysis of the Trail Making Test-B: Implications for clinical application. *Behav Neurol* 2011;24:159-71.
48. Loprinzi PD, Edwards MK, Crush E, Ikuta T, Del Arco A. Dose–response association between physical activity and cognitive function in a national sample of older adults. *Am J Health Promot* 2018;32:554-60.
49. Edwards MK, Loprinzi PD. Effects of a sedentary intervention on cognitive function. *Am J Health Promot* 2018;32:595-605.