Journal of Cognitive Enhancement
https://doi.org/10.1007/s41465-024-00294-1

ORIGINAL RESEARCH

Stair Climbing Improves Cognitive Switching Performance and Mood in Healthy Young Adults: A Randomized Controlled Crossover Trial

Andreas Stenling[1,2] · Jordan Quensell[3] · Navjyot Kaur[3] · Liana Machado[3,4]

Received: 4 December 2023 / Accepted: 21 March 2024

Abstract

Although stair-climbing intervals provide a simple mode of physical activity that can be easily carried out in naturalistic settings and incorporated into the daily lives of a significant proportion of the global population, addressing physical inactivity issues, very little research has focused on the psychological benefits of stair climbing. To address this, the current prospectively registered randomized controlled crossover trial tested whether brief bouts of stair climbing (6 × 1 min intervals) elicit immediate subsequent improvements in cognitive performance and mood in a sample of healthy young adults (final sample: $n = 52$, 50% female, age range 18–24 years), with consideration of sex, physical activity habits, and exercise intensity as potentially relevant variables. Compared to a no-exercise control session, following the stair climbing participants exhibited superior cognitive switching performance and reported feeling more energetic and happy. In addition, linear regression analyses linked higher stair-climbing intensity (indicated by heart-rate data) to faster response latencies. None of the effects depended on sex or physical activity habits, which implies that males and females can benefit irrespective of their current physical activity habits. Collectively, these results demonstrate that interval stair climbing can confer immediate psychological benefits, providing further evidence in support of stair climbing as a promising means to address physical inactivity issues. TRN: ACTRN12619000484145, Date of registration: 25/03/2019.

Keywords Physical activity · Interval training · Cognition · Executive functioning · Affect

Introduction

Mounting research including randomized controlled trials in healthy adults supports positive effects of short bouts of physical activity on psychological outcomes, such as cognition and mood (Basso & Suzuki, 2017; Chang et al., 2012; Hsieh et al., 2021; see also Ligeza et al., 2023). Mechanisms that potentially can explain such acute effects are for example activation of the locus coeruleus and release of norepinephrine, and increases in cerebral blood flow, catecholamines, and neurotropic factors (e.g., BDNF, IGF-1; see Pontifex et al., 2019). However, differences between modes of physical activity and their effect on psychological outcomes (e.g., cognitive performance) have been found in a meta-analysis (Lambourne & Tomporowski, 2010), suggesting a lack of generalizability of effects across different forms of physical activity. To date, most research has involved forms of aerobic exercise (e.g., on a treadmill or cycle ergometer) inaccessible to large parts of the population.

One form of aerobic physical activity with practical value related to accessibility and potential for incorporating it into daily activities is stair climbing. Although research involving stair climbing is currently quite limited, we suspect that the nature of stair climbing, requiring upward movement against gravity, may place it in a strong position for conferring benefits in a time-efficient manner (Mir et al., 2017; Webb & Cheng, 2010), which addresses one of the biggest barriers to exercise (Peng et al., 2023; Stutts, 2002). Considered in tandem with the noteworthy potential of stair climbing to be incorporated into daily lives, as has recently been recommended by the Centers for

✉ Andreas Stenling
Andreas.stenling@umu.se

[1] Department of Psychology, Umeå University, 901 87 Umeå, Sweden

[2] Department of Sport Science and Physical Education, University of Agder, Kristiansand, Norway

[3] Department of Psychology and Brain Health Research Centre, University of Otago, Dunedin, New Zealand

[4] Brain Research New Zealand, Auckland, New Zealand

Disease Control and Prevention as a means to overcome multiple barriers to physical activity (https://www.cdc.gov/physicalactivity/basics/adding-pa/barriers.html), we concur with Gay et al. (2022) that further research should be undertaken.

Stair climbing has been associated with multiple health benefits. Previous studies show that increased stair climbing is associated with improvements in adiposity, balance, blood pressure, cardiorespiratory fitness, cholesterol, blood glucose, leg strength, reduced weight, and lower risk of metabolic syndrome (Allison et al., 2017; Boreham et al., 2005; Donath et al., 2014; Honda et al., 2016; Michael et al., 2021; Mir et al., 2017; Whittaker et al., 2021; Wong et al., 2018). More frequent stair climbing has also been associated with lower risk of coronary heart disease, stroke, and all-cause mortality (Rey-Lopez et al., 2019; Sanchez-Lastra et al., 2021; Song et al., 2023). The health benefits of stair climbing are promising given the accessibility of stairs in many naturalistic settings (e.g., schools, workplaces), which suits the new physical activity global guidelines highlighting that even brief bursts of physical activity are important for improving and maintaining health and wellbeing (Bull et al., 2020). The new emphasis on the importance of accumulation of daily minutes of physical activity—which stands in contrast to the previous recommendations of at least 10-min activity bouts for positive health change—makes stair climbing an attractive option for everyday physical activity, noting also that indoor stair climbing obviates weather issues that can pose a barrier to intended outdoor physical activity (Peng et al., 2023). Brief bouts of physical activity incorporated into daily routines may also be more achievable than formal exercise sessions for many individuals and may be better placed to aid toward the new recommendation to replace sedentary time with physical activity (Bull et al., 2020).

Although previous research indicates multiple health benefits associated with increased stair climbing, most studies have focused on physical health outcomes, and surprisingly little is known about the psychological outcomes associated with stair climbing. Gay et al. (2022) conducted a systematic review and found 22 studies focused on stair use and psychological outcomes. A majority of the studies ($n = 12$) used subjective (e.g., self-report) measures of stair use, whereas a minority ($n = 10$) of the studies used objective measures. Although some evidence was found for a link between stair use (based on objective measures) and less anxiety and depression symptoms, the authors highlighted several limitations, for example, that the majority of the studies were cross-sectional, included older samples with a disease, small sample sizes, and variability in measures of stair use. The authors concluded that stair climbing may be a low-cost strategy for increasing physical activity levels especially in more urban areas where multilevel buildings are prevalent and expressed an urgent need for research on the effects of stair use on psychological outcomes (Gay et al., 2022).

Two recent studies examined psychological benefits (i.e., cognitive function and mood) of brief bouts of stair climbing in healthy young adults (Stenling et al., 2019) and older adults (Nasrollahi et al., 2022). In the older adults, six 1-min intervals of stair climbing benefitted subsequent cognitive performance; however, the older adults reported feeling more tired following the stair climbing (Nasrollahi et al., 2022). In the young adults, three 1-min intervals of stair climbing improved subsequent executive functioning (specifically, switching performance) in males but not females, whereas both males and females felt more energetic, less tense, and less tired; in addition, higher exercise intensity during the stair climbing predicted better switching performance and higher energetic ratings following the stair climbing (Stenling et al., 2019). Taken together, these two studies (Nasrollahi et al., 2022; Stenling et al., 2019) provide initial evidence of psychological benefits of brief bouts of stair climbing and suggest that stair climbing might serve as an effective intervention, not only for physical health benefits, but also for psychological health benefits. However, they also highlight that effects may differ between younger and older adults and also as a function of sex and exercise intensity.

Building on the initial evidence indicating psychological health benefits of stair climbing, the current randomized controlled crossover trial tested in healthy young adults the effects of interval stair climbing involving six 1-min bursts on cognitive performance and self-reported mood using the same computerized battery as Stenling et al. (2019) and Nasrollahi et al. (2022). We also examined whether the effects of stair climbing depend on sex, based on findings from the Stenling et al. (2019) stair climbing study and indications from studies on the acute effects of exercise involving other modes of physical activity (Hsieh et al., 2021; McDowell et al., 2016). However, it should be noted that in the Stenling et al. (2019) study, sex was not counterbalanced and more females participated (final sample 66% female). In the current study, we included equal proportions of males and females and counterbalanced sex with session order. Moreover, we doubled the number of 1-min stair-climbing intervals (from three to six) as we suspected that the lack of cognitive benefits in females in Stenling et al. (2019) may have reflected an insufficient number of intervals. We also examined effects of exercise intensity during the stair climbing on subsequent cognitive performance and mood, given previous findings that exercise intensity can influence both the duration and magnitude of the effects of physical activity on cognition (Chang et al., 2012; McMorris & Hale, 2012; Stenling et al., 2019) and mood (Legrand et al., 2018; Loy et al., 2013; Reed & Ones, 2006; Stenling et al., 2019). We hypothesized that executive functioning (as indicted by inhibitory control and switching performance) and self-reported mood would be superior following the interval stair climbing, compared to a control session without exercise, and that benefits would be seen in both sex groups, although the extent of benefits may depend on sex, physical activity habits, and the intensity of the stair climbing.

Methods

The current study was preregistered at the Australian New Zealand Clinical Trials Registry (Registration number ACTRN12619000484145). The University of Otago Human Ethics Committee (reference 18/012) approved this study and all methods employed were performed in accordance with relevant guidelines and regulations. All participants gave written informed consent prior to participating. Data collection took place from 8 April to 1 August 2019.

Participants

Inclusion criteria for participation were aged 18–24 years, normal or corrected-to-normal vision, no color blindness, no neurological or psychiatric conditions, and able to participate in the exercise intervention (all based on self-report). We recruited 63 undergraduate students from the University of Otago; all met the inclusion criteria and participated. However, data from 11 participants had to be excluded from the study to achieve full counterbalancing due to an error in the allocation process; in selecting the 11 to exclude, we first removed three with missing data and then randomly selected the other eight from the relevant counterbalancing groups (defined by session order and sex) using a random number generator in Excel (see Fig. 1 for recruitment, allocation, and exclusion details). The final sample included 52 students ($M_{\text{age}} = 19.8$ years, $SD = 2.18$, range = 18–24; 26 females; 47 right-handed).

Prior to participation, the physical activity readiness questionnaire (PAR-Q; Thomas et al., 1992) confirmed all participants as appropriate to engage in physical activity. Based on the New Zealand physical activity questionnaire-short form (NZPAQ-SF; McLean & Tobias, 2004), on average the participants engaged in 8.4 ($SD = 6.0$) hours of physical activity per week. Mean body mass index (BMI) was 23.2 kg/m^2 ($SD = 3.0$, range 17.3–30.7). According to international BMI classification guidelines (WHO, 2019), 1.9% were underweight (< 18.5 kg/m^2), 75.0% were normal weight (18.5–24.99 kg/m^2), and 23.1% were overweight ($\geq$ 25 kg/m^2).

Procedure

We used a randomized controlled crossover design with counterbalancing of the order of the two sessions (i.e., stair climbing or control) by sex group. Randomization was achieved using the random number generator in Microsoft Excel, for each sex group. Participants were not aware of the sequence allocation before entering the laboratory. Participants reported to the laboratory for each session at the same time of day, exactly 1 week apart. A heart rate (HR) monitor was placed on the participant's left wrist to measure and record HR throughout the sessions. Initially, the participant was asked to remain seated for 5 min to obtain a measure of resting HR, after which the participant completed the stair-climbing or control protocol as described in the following subsections.

Stair-Climbing Protocol Participants received verbal instructions regarding the ratings of perceived exertion (RPE) scale (Borg, 1998) and the stair-climbing protocol, and were then shown a demonstration video of the stair-climbing phase. Participants then left the testing room with the experimenter to complete the protocol, during which further instructions were provided. The stair-climbing protocol tested here was previously tested in an older adult sample by Nasrollahi et al. (2022); it is an adapted version of the stair-climbing protocols from Allison et al. (3 × 60-s 1F; 2017) and Stenling et al. (2019), which both entailed three 1-min stair-climbing intervals tested in young adults. The protocol used here entailed six stair-climbing intervals and involved the following (in this order): 2-min warm up, 45-s instructional interval, 1-min stair climbing, 1-min recovery, 1-min stair climbing, 1-min recovery, 1-min stair climbing, 1-min recovery, 1-min stair climbing, 1-min recovery, 1-min stair climbing, 1-min recovery, 1-min stair climbing, and 3-min cool down. For the warm up, the participant walked at a moderate pace on a flat surface from the laboratory to the stairwell and then up two flights of 12 stairs (each 17 cm in height). The participant then walked at a brisk pace back and forth along the corridor for the remainder of the 2 min. During the 45-s instructional interval, the experimenter provided final instructions for the stair-climbing and recovery phases. The six stair-climbing intervals were completed on one flight of 12 stairs, measuring 17 cm in height. Participants receive the following instruction adapted from Allison et al. (2017): "For the stair climbing please move vigorously. This means relatively intense but not all out, so please move up the stairs as fast as you can while taking one step at a time. Maintain control and safety at all times." Each recovery phase involved the participant descending to the landing from their place on the stairs and then walking back and forth, all at a self-selected pace. RPE ratings were given immediately before (pre RPE) and after (post-RPE) each stair-climbing

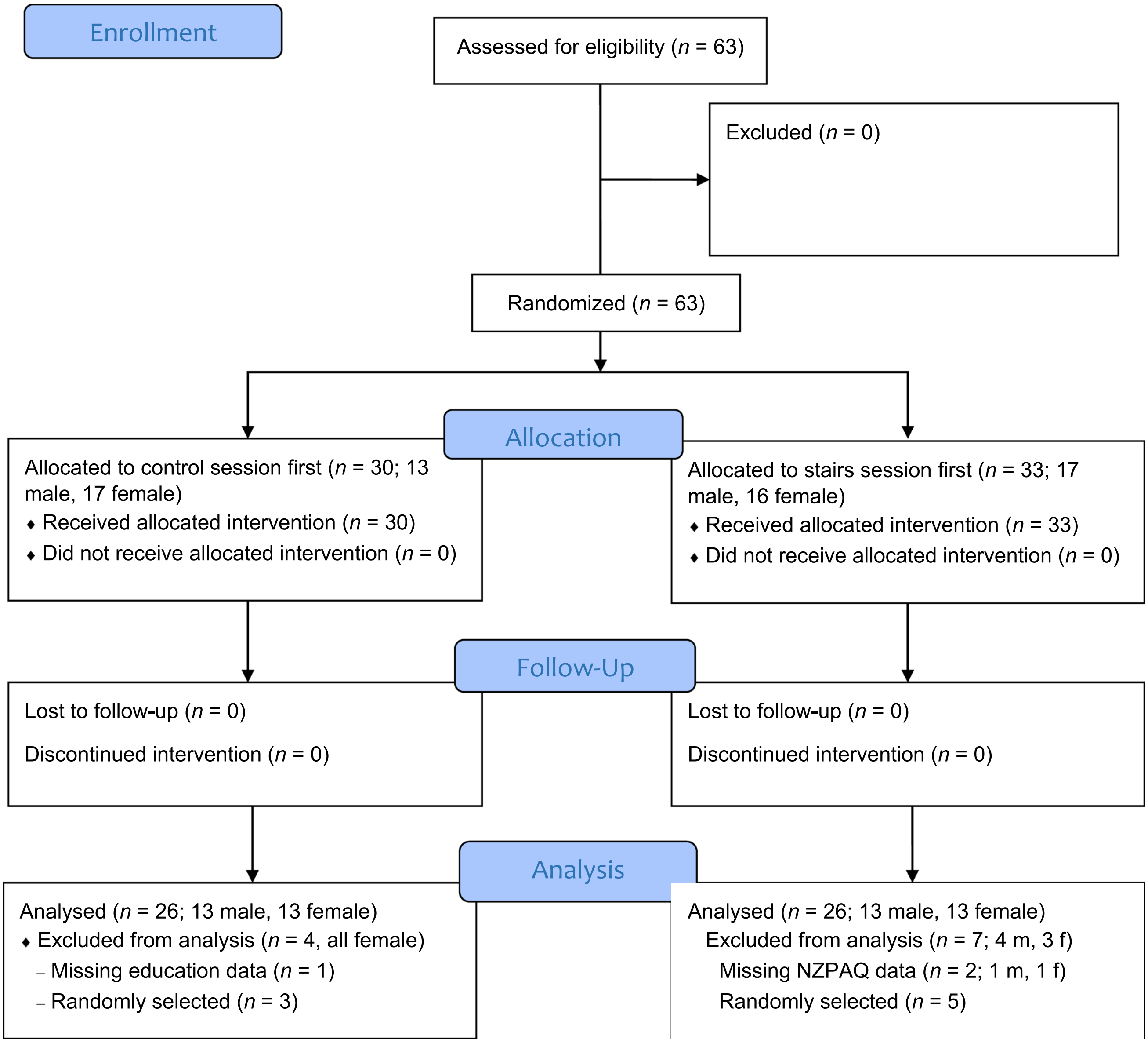

Fig. 1 CONSORT flow diagram summarizing all participants, reasons for exclusion, and the final sample

interval. The cool down phase involved walking down two flights of stairs and then back and forth on a flat surface for a total of 3 min, all at a self-selected pace. Following cool down, the participant returned to the testing room and sat for 5 min, after which they completed a computerized battery (which included cognitive tests followed by visual analogue mood scales) that took approximately 7 min.

Control Protocol All aspects of the control protocol were identical to the stair-climbing protocol, except that following the initial 5-min resting HR period, the participant remained seated in the testing room for 5 min, after which they began the cognitive tests.

Materials and Apparatus

Heart Rate Monitor HR was measured and recorded every second using a Polar M430 wristwatch (Polar Electro Oy, Kempele, Finland). This device uses light emitting diodes to shine green light on the skin, with a photodiode measuring the intensity of light reflected to obtain a HR measurement (https://www.polar.com/us-en/continuous_heart_rate_tracking). Date of birth, gender, weight, and height details for each participant were entered into the device to improve measurement accuracy. Mean HR was calculated over the initial 5-min resting period and over the period of cognitive/mood testing in both the stair-climbing and control sessions. We calculated percentage of HRmax (%HRmax = HR/HRmax*100, where HRmax = 220 – age) and percentage of HR reserve (%HRR = HR – HRmin)/HRR*100, where HRmin = mean resting HR and HRR = HRmax – HRmin) as indicators of exercise intensity during the stair-climbing intervals. The %HRR represents the amount HR increased from resting HR and is often used to determine exercise intensity (ACSM, 2018; Pesce & Audiffren, 2011; Swain, 2000).

Perceived Exertion Ratings on the Borg RPE scale (Borg, 1998) were used as a subjective measure of intensity during the stair-climbing protocol. The Borg RPE scale has ratings from 6 (*No exertion at all*) to 20 (*Maximal exertion*), and every uneven number is anchored (e.g., 13 = *Somewhat hard*). The Borg RPE scale has been validated as a measure of exercise intensity, with multiple studies demonstrating high correlations (r = 0.80–0.90) between RPE and HR (Borg, 1998).

Cognitive Tests and Mood Scales The computer-based battery, which was identical to that used in the previous stair climbing trials (Nasrollahi et al., 2022; Stenling et al., 2019) and included the same cognitive tests as used in several other exercise-cognition studies (Cameron et al., 2015; Guiney et al., 2015, 2019; Shoemaker et al., 2019, 2020), was run with a 64-bit Ubuntu 16.04 operating system. Stimuli were presented on a 600 × 340 mm screen using MATLAB R2016b (The MathWorks, Natrick, MA) and The Psychophysics Toolbox-3 (Brainard, 1997; Pelli, 1997). Participants sat with their head held in position using a chin rest, such that the center of the monitor was at eye level, 57 cm from the participant's eyes. The battery included three cognitive tasks (termed Pro, Anti and Pro/Anti, and always presented in this order) previously shown to exhibit adequate test–retest reliability (White et al., 2018) that were designed to assess basic visuomotor processing (Pro), inhibitory control (Anti), and switching abilities (Pro/Anti; Flannery et al., 2018; Forsyth et al., 2016; White et al., 2020). These tasks involved a key press response and were originally adapted from eye movement tasks (Brett & Machado, 2017). For all tasks, participants received both verbal and written instructions. Responses to the cognitive tasks were made using a centrally positioned button box, which had two buttons of 2-cm diameter positioned 2 cm apart (DirectIN Rotary Controller with Buttons, Empirisoft Corporation, NYC) on which participants placed their left and right index fingers. Each trial began with the presentation of a white fixation dot, subtending 0.3° of visual angle on a black background in the center of the monitor. After a variable interval (400, 600, 800, 1000, or 1200 ms), a 2° green or red square (depending on the task: always green for Pro, always red for Anti, and randomly intermixed for Pro/Anti) appeared 8° to the left or right of the fixation dot (measured to the center of the square). Participants were instructed to press the button corresponding to the same side as green squares (thus making the prepotent response) and the opposite side of red squares (thus requiring inhibition of the prepotent response). Participants were asked to respond as quickly as possible while maintaining accuracy. A 900-Hz error tone sounded for 300 ms if the participant made an incorrect response, made no response within 1500 ms, or responded in less than 100 ms (anticipation error). An interval of 500 ms occurred between trials. Variable intervals and stimulus positions were presented randomly with the constraint that each combination occurred equally often. Participants completed four practice trials in the Pro and Anti tasks and six practice trials in the Pro/Anti task, followed by 40 test trials (in all cases). Reaction time (RT) and accuracy were recorded for each trial.

After completing the cognitive tests, participants completed six visual analogue mood scales (sad, energetic, tense, happy, tired, and calm), always presented in this order (Forsyth et al., 2016; Machado et al., 2019). For each mood scale, the following instruction was displayed: "Click the position on the line that best represents how you feel right now." Below was a black 100-mm horizontal line comprising (but not displaying) 101 distinct positions representing ratings from 0 to 100. The mood descriptor was prefixed by "Not at all" (e.g., Not at all happy) at the left end of the line, and "Extremely" (e.g., Extremely happy) at the right end. Participants responded by clicking on the horizontal line using the mouse, which caused a small black vertical line (that could be repositioned) to appear, displaying their response until they clicked on a rectangle labeled "DONE."

Physical Activity We assessed physical activity habits using the NZPAQ-SF, a brief self-report questionnaire designed to assess three dimensions of physical activity behavior; frequency, duration, and intensity (McLean & Tobias, 2004). Participants were asked to provide information about physical activity in the 7 days prior to each session. Answers on the NZPAQ-SF provide estimates of duration (time/week) of brisk walking, moderate physical activity, and vigorous physical activity. Hours of physical activity (sum of vigorous, moderate, and walking hours), averaged across the two sessions, was used in the analyses. A moderate correlation (r = 0.41) between physical activity self-reported on the NZPAQ-SF and physical activity captured by objective HR monitoring has been reported in 18–39 year olds (Moy et al., 2008).

Statistical Analysis

Regarding the HR variables, repeated measures ANOVAs tested for a main effect of stair-climbing interval on mean and peak HR, mean %HRR, mean %HRmax, pre and post RPE, and stairs climbed. When data did not meet the assumption of sphericity, the Greenhouse–Geisser correction was used. Planned follow-up comparisons between each interval were

Table 1 Exercise intensity measures

Variable	Stair climb 1		Stair climb 2		Stair climb 3		Stair climb 4		Stair climb 5		Stair climb 6	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Heart rate (bpm)												
Mean	114.0	16.5	132.5	20.4	145.5	23.6	153.4	23.9	157.9	23.0	160.6	22.8
Peak	126.7	22.2	143.7	22.5	158.7	25.0	166.6	24.6	170.8	23.2	172.2	23.7
Mean %HRmax	57.0	8.3	66.2	10.4	72.7	12.0	76.6	12.1	78.9	11.7	80.2	11.5
Mean %HRR	29.3	12.3	44.8	15.9	56.0	17.9	62.4	18.5	66.0	17.8	68.2	17.5
RPE												
Pre	6.5	1.0	10.0	2.0	10.7	2.0	11.2	2.1	12.0	2.2	12.6	2.5
Post	11.3	2.3	12.4	2.1	13.2	1.7	14.0	1.8	14.6	1.9	15.2	2.0
Stairs climbed	86.8	9.4	83.9	9.8	84.4	10.5	84.1	12.0	84.2	11.4	84.1	14.7

Note: Values reflect the average during each stair-climbing bout; recovery phases were not included. *bpm*, beats per minute; *HRmax*, heart rate maximum; *HRR*, heart rate reserve; *RPE*, ratings of perceived exertion

performed using paired-samples *t* tests and *p* values corrected for multiple comparisons using the Holm method.

For the cognitive tasks (Pro, Anti, and Pro/Anti), median RTs for correct responses were the main dependent variable of interest as ceiling effects on accuracy were expected (White et al., 2018, 2022). Median RTs were used to minimize the potential effects of outliers, in line with the previous stair climbing trials (Nasrollahi et al., 2022; Stenling et al., 2019) and other studies using the same cognitive tests (Cameron et al., 2015; Guiney et al., 2015, 2019; White et al., 2018). To help isolate inhibitory control performance, inhibition cost scores were calculated for each participant in each session by subtracting median Pro RTs from Anti RTs (Bierre et al., 2017; Brett & Machado, 2017; Cameron et al., 2015; Guiney et al., 2015). To help isolate switching performance, switching cost scores were calculated for each participant in each session by subtracting median Anti RTs from Pro/Anti RTs (Bierre et al., 2017; Brett & Machado, 2017; Cameron et al., 2015; Guiney et al., 2015).

To investigate the primary purpose of the study (i.e., the effect of stair climbing on subsequent cognitive performance and mood), repeated measures ANOVAs tested differences between the stair-climbing and control sessions in Pro, Anti, and Pro/Anti RTs, inhibition and switching costs, and the six mood scale ratings.

Table 2 Cognitive performance and mood scale ratings in the control and stair-climbing sessions

	Males (*n* = 26)				Females (*n* = 26)			
	Control		Stair climbing		Control		Stair climbing	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Cognitive performance								
Pro RTs (ms)	312	38	304	48	291	30	290	30
Pro accuracy (%)	99.81	0.68	100.00	0.00	99.52	1.00	99.50	1.23
Anti RTs (ms)	363	47	353	53	345	48	338	47
Anti accuracy (%)	98.46	2.01	98.85	2.26	98.17	2.40	98.65	2.03
Pro/anti RTs (ms)	487	74	469	79	515	77	481	73
Pro/anti accuracy (%)	97.31	3.39	97.12	2.42	95.48	3.61	96.83	3.36
Inhibition cost	50	30	49	30	54	32	48	30
Switching cost	124	49	116	59	170	51	142	46
Mood states								
Sad	12.92	14.15	9.62	10.01	17.54	15.94	12.50	13.46
Energetic	49.15	23.01	62.35	19.92	40.69	21.68	50.42	19.21
Tense	29.27	22.37	29.15	20.33	31.31	22.49	33.39	21.74
Happy	61.00	16.24	65.77	17.36	56.58	14.15	62.96	10.85
Tired	38.00	24.30	41.39	22.47	54.69	21.48	49.69	22.82
Calm	70.01	19.11	65.50	15.49	59.73	19.64	62.00	22.09

Note: *RT*, reaction time; *ms*, milliseconds

Table 3 Repeated measures ANOVAs (RM-ANOVA) and repeated measures ANCOVAs (RM-ANCOVA) on the cognitive variables

	Pro RT			Anti RT			Pro/Anti RT			Inhibition cost			Switching cost		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
RM-ANOVA[a]															
Session	1.54	.220	0.03	2.93	.093	0.05	11.56	.001	0.19	0.92	.343	0.02	5.02	.030	0.09
RM-ANCOVA[b]															
Session	1.52	.223	0.03	2.83	.099	0.06	11.50	.001	0.20	0.90	.347	0.02	5.08	.029	0.09
Session*sex	1.28	.263	0.03	0.08	.778	0.00	0.65	.423	0.01	0.53	.469	0.01	0.92	.344	0.02
Session*physical activity	0.25	.618	0.01	0.16	.689	0.00	0.72	.401	0.01	0.99	.325	0.02	1.14	.291	0.02

Note: [a]$df = 1{,}51$, [b]$df = 1{,}49$. *RT*, reaction time

Subsequently, we included sex as a between-subject factor and physical activity as a control variable in repeated measures ANCOVAs. The continuous physical activity variable was grand-mean centered prior to the being entered into the repeated measures ANCOVAs (Schneider et al., 2015). Effect sizes are reported as partial eta squared (η_p^2) in the repeated measures ANOVAs/ANCOVAs and Cohen's *d* for pairwise comparisons, with interpretation benchmarks of 0.01, 0.06, and 0.14 for η_p^2 and 0.20, 0.50, and 0.80 for Cohen's *d* used to indicate small, medium, and large effect sizes (Cohen, 1988).

To investigate the secondary purpose of the study (i.e., the effect of exercise intensity on subsequent cognitive performance and mood), we performed linear regression analyses using the difference (Δ) between the stair-climbing and control sessions as the dependent variable, %HRR as the main predictor variable, and physical activity and sex as control variables. The significance level (α) was set to 0.05 and all of the analyses were performed using JASP version 0.18 (JASP-Team, 2023).

Sample Size and Power Calculations

The original a priori and pre-registered power analysis computed using GLIMMPSE software (Kreidler et al., 2013) indicated that with a desired power of 80%, an alpha level of 0.05, session as a within-subject factor, sex as a between-subject factor, and self-reported physical activity as a control variable, 60 participants (30 males, 30 females) were needed to detect a session by sex interaction effect with a similar magnitude as the interaction effect found in Stenling et al. (2019). A re-calculation based on having only 52 participants in the final sample indicated only 74% power to detect a similar magnitude session by sex interaction effect; however, note that the current trial involved twice as many stair-climbing intervals; thus, larger effect sizes could reasonably be anticipated. Nonetheless, we conducted sensitivity analyses that included 60 participants (50% male, 50% control session first), foregoing counterbalancing of sex with session order, and found nearly identical results; thus, reduced power does not appear to have had any substantive impact on the results.

Given the final sample size of 52 participants, a power calculation using G*Power version 3.1.9.2 (Faul et al., 2007) indicated that with a one-tailed alpha level of 0.05 and a desired power of 80%, we were able to detect a fairly small repeated measures main effect (Cohen's $d = 0.35$) of the stair-climbing intervention (thus, ample power based on the larger effect sizes for cognitive and mood benefits in Stenling et al., 2019). In addition, with three predictors (exercise intensity, self-reported physical activity, and sex), a desired power of 80%, and a one-tailed alpha level of 0.05, we could detect a medium effect size ($f^2 = 0.15$, which corresponds to Cohen's $d = 0.50$; Cohen, 1992).

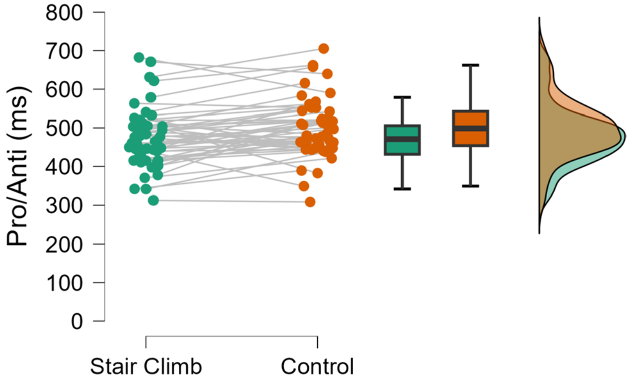

Fig. 2 Raincloud plot showing differences in Pro/Anti between the stair-climbing and control sessions

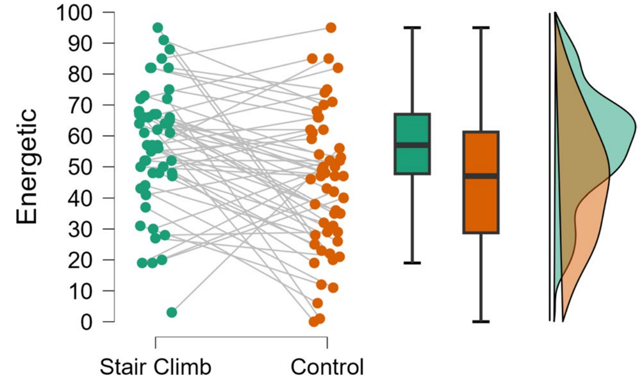

Fig. 4 Raincloud plot showing differences in energetic mood scale ratings between the stair climb and control session

Results

Stair-Climbing Intensity

Descriptive statistics for the HR measures, RPE, and stairs climbed in each interval are displayed in Table 1. Repeated measures ANOVA showed a statistically significant effect of interval on mean HR, $F(2.01,\ 102.65)=130.49$, $p<0.001$, $\eta_p^2=0.72$, peak HR, $F(2.14,\ 109.27)=101.22$, $p<0.001$, $\eta_p^2=0.67$, %HRmax, $F(2.03,\ 103.28)=130.54$, $p<0.001$, $\eta_p^2=0.72$, %HRR, $F(1.88,\ 95.79)=117.05$, $p<0.001$, $\eta_p^2=0.70$, pre RPE, $F(2.50,\ 127.45)=155.78$, $p<0.001$, $\eta_p^2=0.75$, post RPE, $F(2.02,\ 103.19)=100.14$, $p<0.001$, $\eta_p^2=0.66$, and stairs climbed, $F(2.44,\ 124.67)=2.64$, $p=0.064$, $\eta_p^2=0.49$. Planned follow-up comparisons indicated a statistically significant increase in mean HR, peak HR, %HRmax, and %HRR with each successive interval until the fourth interval, whereas the increase between the fourth, fifth, and sixth intervals was not statistically significant. Planned follow-up comparisons indicated statistically significant increases in pre and post RPE ratings with each successive interval. Differences in the number of stairs climbed were not statistically significant across the six intervals. Mean HR during the 5-min resting period ($M_{\text{stair climb}}=78.24$ vs. $M_{\text{control}}=80.48$) did not differ between the stair climbing and control sessions, $t(51)=-1.48$, $p=0.146$, Cohen's $d=-0.21$. However, mean HR during the cognitive and mood testing in the stair climbing session ($M_{\text{stair climb}}=101.46$) was higher than in the control session ($M_{\text{control}}=79.70$), $t(51)=12.67$, $p<0.001$, Cohen's $d=1.76$, and in the 5-min resting period that preceded the stair climbing ($M=78.24$), $t(51)=12.79$, $p<0.001$, Cohen's $d=1.77$.

Effect of Stair Climbing on Cognitive Performance

Descriptive statistics for Pro, Anti, Pro/Anti median RTs and accuracy, and inhibition and switching costs are shown in Table 2. As expected, accuracy was generally high, ranging from 95.48% to 100%, and the lowest accuracy was displayed in Pro/Anti, which is the most cognitively demanding of the tests. Results from the repeated measures ANOVAs on the cognitive variables are displayed in Table 3. No statistically significant main or interaction effects of stair-climbing

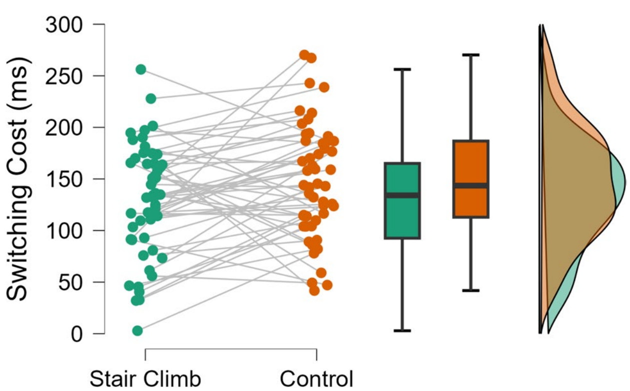

Fig. 3 Raincloud plot showing differences in switching cost between the stair-climbing and control sessions

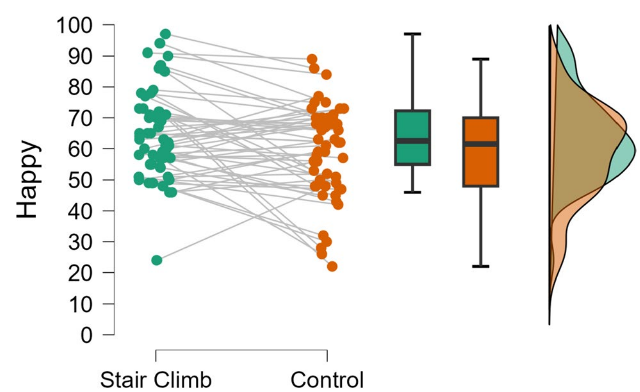

Fig. 5 Raincloud plot showing differences in happy mood scale ratings between the stair-climbing and control sessions

Table 4 Repeated measures ANOVAs (RM-ANOVA) and repeated measures ANCOVAs (RM-ANCOVA) on mood scale ratings

	Sad			Energetic			Tense			Happy			Tired			Calm		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
RM-ANOVA[a]																		
Session	3.23	.078	0.06	10.45	.002	0.17	0.11	.742	0.00	7.01	.010	0.12	0.05	.830	0.00	0.18	.671	0.00
RM-ANCOVA[b]																		
Session	3.30	.075	0.06	10.48	.002	0.18	0.11	.746	0.00	6.82	.012	0.12	0.05	.831	0.00	0.18	.672	0.00
Session*sex	0.00	.990	0.00	0.62	.437	0.01	0.17	.684	0.00	0.11	.747	0.00	1.49	.228	0.03	1.38	.245	0.03
Session*physical activity	2.97	.091	0.06	1.94	.170	0.04	0.06	.808	0.00	0.04	.842	0.00	0.36	.552	0.01	0.06	.804	0.00

Note: [a]$df=1{,}51$, [b]$df=1{,}49$

intervals were observed for Pro, Anti, or Inhibition Cost. However, the results indicate a main effect of session for Pro/Anti RTs, $F(1, 51)=11.56$, $p=0.001$, $\eta_p^2=0.19$, and Switching Cost, $F(1, 51)=5.015$, $p=0.030$, $\eta_p^2=0.09$. As displayed in Figs. 2 and 3, participants performed better following the stair-climbing intervals when compared to the control session (Pro/Anti RTs, $M_{\text{stair climb}}=475$ ms vs. $M_{\text{control}}=501$ ms; Switching Cost, $M_{\text{stair climb}}=129$ ms vs. $M_{\text{control}}=147$ ms). Repeated measures ANOVAs with sex as a between-subject factor indicated that effects of stair climbing on cognitive performance did not depend on sex. In interpreting individual patterns illustrated in Figs. 2 and 3, it is important to keep in mind that practice effects counteract stair climbing benefits for participants who completed the control session second and add on to stair climbing benefits for participants who completed the stair climbing session second, which is why fully counterbalancing session order was essential.

Effect of Stair Climbing on Mood

Descriptive statistics for the mood scales are displayed in Table 2 and the results from the repeated measures ANOVAs are displayed in Table 4. A main effect of session was observed for the mood scales energetic, $F(1, 51)=10.45$, $p=0.002$, $\eta_p^2=0.17$, and happy, $F(1, 51)=7.07$, $p=0.010$, $\eta_p^2=0.12$; participants reported feeling more energetic ($M_{\text{stair climb}}=56.39$ vs. $M_{\text{control}}=44.92$) and happier ($M_{\text{stair climb}}=64.37$ vs. $M_{\text{control}}=58.79$) following the stair climbing (see Figs. 4 and 5). None of the other mood scale ratings differed between the stair climbing and control sessions. Furthermore, repeated measures ANOVAs with sex as a between-subject factor indicated that effects of stair climbing on mood did not depend on sex.

Effect of Exercise Intensity on Cognitive Performance and Mood

After controlling for sex and average physical activity, exercise intensity, as indicated by %HRR, had a statistically significant effect on ΔPro ($b=-0.66$, $SE=0.25$, $p=0.013$). The model explained 14.6% of the variance in ΔPro. Note that the dependent variable is a difference score (Δ) calculated by subtracting control session RTs from stair-climbing session RTs. Thus, the negative regression coefficients indicate that as exercise intensity increased, the difference in RTs between the stair-climbing and control sessions increased (i.e., faster RTs in the stair-climbing session). Exercise intensity did not have a statistically significant effect on any of the other cognitive or mood variables (see Table 5 and 6). Sensitivity analyses using a different measure of exercise intensity (%HRmax

Table 5 Linear regression analysis examining the effect of stair-climbing intensity on cognitive performance

	ΔPro RT			ΔAnti RT			ΔPro/Anti RT			ΔInhibition cost			ΔSwitching cost		
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
%HRR	−0.66	0.25	.013	−0.68	0.34	.053	−0.28	0.56	.623	−0.03	0.28	.928	0.40	0.58	.489
Sex	−7.73	7.21	.289	−1.93	9.78	.845	13.19	16.01	.414	5.81	8.01	.472	15.12	16.48	.364
Physical activity	0.10	0.46	.831	−0.40	0.62	.518	0.79	1.01	.442	−0.50	0.51	.328	1.19	1.04	.260
R^2	14.6%			8.2%			4.0%			2.5%			6.1%		

Note: Sex was coded as 0 = female, 1 = male. *RT*, reaction time; *Δ*, difference between stair-climbing and control session

Table 6 Linear regression analysis examining the effect of stair-climbing intensity on mood scale ratings

	ΔSad			ΔEnergetic			ΔTense			ΔHappy			ΔTired			ΔCalm		
	b	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
%HRR	0.02	0.17	.927	0.30	0.25	.239	0.18	0.22	.426	0.07	0.16	.669	−0.02	0.27	.952	−0.28	0.19	.148
Sex	−0.08	4.76	.986	5.28	7.24	.469	−2.76	6.21	.658	−1.51	4.42	.734	9.43	7.80	.232	−6.16	5.50	.269
Physical activity	0.51	0.30	.095	−0.57	0.46	.220	0.13	0.39	.736	−0.04	0.28	.885	−0.30	0.49	.554	−0.15	0.35	.671
R^2	6.0%			7.0%			1.7%			0.8%			3.2%			7.4%		

Note: Sex was coded as 0 = female, 1 = male. *Δ*, difference between stair-climbing and control session

instead of %HRR) showed the same results (see Tables S1 and S2 in the supplemental material).

Exploratory Follow-up Analyses

We also conducted exploratory follow-up analyses to examine whether HR (i.e., an indicator of physiological arousal) during cognitive and mood testing was related to cognitive performance. Bivariate correlations indicated that a higher average HR during testing was related to better cognitive performance (faster RTs) for Anti ($r = -0.305$) and Pro/Anti ($r = -0.317$) in the stair climbing session (but not in the control session; see Table S3 and S4 in the supplemental material). Although not statistically significant, the correlations with Pro, Inhibition Cost, and Switching Cost showed a similar pattern, with higher average HR during cognitive testing related to faster RTs. To further examine the role of physiological arousal, we also conducted mediation analyses with %HRR during stair climbing as the predictor, average HR during cognitive and mood testing as the mediator, and cognitive performance as the outcome variable. The mediation analyses showed a statistically significant indirect effect of %HRR on Anti RTs ($ab = -0.40$, 95% bootstrap CI [−1.27, −0.05]) and Pro/Anti RTs ($ab = -0.79$, 95% bootstrap CI [−2.34, −0.06]). Although not statistically significant, a similar pattern of indirect effects was found for Pro, Inhibition Cost, and Switching Cost. Thus, higher exercise intensity during the stair climbing predicted higher average HR during testing that, in turn, predicted better cognitive performance.

Discussion

The current prospectively registered randomized controlled crossover trial tested whether brief bouts of stair-climbing (6 × 1 min intervals) elicit immediate subsequent improvements in cognitive performance and mood in a sample of healthy young adults, with consideration of sex as a potential moderator, physical activity habits (hours/week, as measured by the NZPAQ-SF) as a control variable, and exercise intensity (as measured by %HRR) as a predictor of differences between sessions. The results indicated that, following the stair climbing, participants showed better cognitive switching performance and reported feeling more energetic and happier, compared to a no-exercise control session. In addition, linear regression analyses linked faster response latencies in the stair climbing (compared to control) session to higher stair-climbing intensity (indicated by %HRR), particularly for the basic visuomotor task (Pro), for which the model including %HRR, sex, and self-reported physical activity explained over 14% of the variance. Effects of the stair climbing on the cognitive and mood variables did not depend on sex or physical activity habits, indicating that males and females can benefit irrespective of current physical activity habits. These results demonstrate that interval stair climbing can induce immediate subsequent psychological benefits, providing further evidence in support of stair climbing as a means to address physical inactivity and related issues, which is promising given the practicality of daily stair climbing for much of the global population. The following paragraphs discuss each of the findings in turn, alongside considerations of the limitations of the trial and recommendations for future research.

Regarding the cognitive benefits, although participants showed numerically better performance following the stair climbing relative to the control session for all of the cognitive variables analyzed, only the switching task (Pro/Anti) showed statistically significant effects, reflected in both faster correct RTs and smaller switching costs. These findings align with what was reported only in male (not female) participants following a similar stair climbing protocol that involved only half as many stair-climbing intervals (Stenling et al., 2019). Taken together, these outcomes could indicate that males do not require as many stair-climbing intervals to gain the cognitive benefits (i.e., three intervals may be enough); however, a purpose-designed trial would be needed to confirm this given that the Stenling et al. (2019) trial only included 11 males. In the current study, there was no evidence of males benefitting more (Pro/Anti RTs reduced 18 ms in males and 34 ms in females; switching costs reduced 8 ms in males and 28 ms in females; note that although these averages may appear to suggest greater improvements in females, the statistical models indicated that the effects did not depend on sex). Given that Pro/Anti was the most challenging of the tasks, the selective benefits may pertain to cognitive difficulty (i.e., higher demand on executive functioning) rather than switching abilities specifically. Future research can address this by including other challenging cognitive tests that tap different cognitive domains. Inclusion of other switching paradigms may be useful as well toward understanding whether cognitive switching abilities in general benefit.

Regarding the benefits to self-reported mood, the higher ratings for the energetic and happy scales only partially align with the significant benefits in energetic, tired, and tense ratings reported in Stenling et al. (2019) following the three-interval stair climbing protocol. In that study, happy ratings were numerically higher following the stair climbing, but the difference was not statistically significant. This suggests that undertaking more intervals of stair climbing may have been more beneficial with regard to happy feelings, although again a purpose-designed trial would be needed to confirm. Given that participants reported feeling more energetic following the stair climbing in the current study, it is unclear why they did not also feel less tired (in contrast to Stenling et al., 2019). Given that older adults felt more tired following the six-interval stair climbing protocol utilized here (Nasrollahi et al., 2022), it may be that six intervals is a bit much for some young adults too when it comes to tired feelings, which fits with the increase in energetic ratings being numerically lower in the current study (increase = 11.47) compared to the three-interval study (increase = 22.56; Stenling et al., 2019). It could be the case that prolonging the rest interval intervening the stair climbing and psychological testing would lead to more robust benefits in the case of six intervals of stair climbing, having allowed more time for post-exercise recovery.

Exercise intensity (as measured by %HRR) showed a significant relationship only with performance changes for the easiest of the three cognitive tests (ΔPro), which was designed to assess basic visuomotor functioning without requiring executive control (although a similar pattern emerged for ΔAnti RT; see Table 5). This contrasts with findings from the three-interval stair climbing protocol (Stenling et al., 2019), for which %HRR showed significant relationships with performance improvements in the switching measures (ΔPro/Anti RT and ΔSwitching Cost) and increases in energetic ratings. These differences could potentially relate to the higher intensity of the current exercise protocol; however, previous research involving other modes of exercise does not backup this conjecture with respect to cognitive improvements; although more straining physical activity adversely affected cognitive performance during the exercise, post-exercise cognitive assessments indicated greater improvements following more intense exercise (Wohlwend et al., 2017). Setting the nuances aside, in the current study, the exercise intensity analyses indicate that higher stair-climbing intensity does not appear to have been a major factor in gaining psychological benefits. However, the findings from the exploratory follow-up analyses (i.e., bivariate correlations and mediation analyses) suggest that physiological arousal (i.e., indicated by elevated HR) during testing may explain some of the cognitive benefits observed in the current study. Further research is needed to gain a better understanding of the underlying mechanisms that can explain cognition and mood benefits following short bouts of physical activity (cf. Pontifex et al., 2019).

Limitations

Despite using a controlled crossover design with session order counterbalanced within each sex group and a 1-week washout intervening the two sessions, thereby obviating a number of issues that can arise in the context of weaker designs, the current trial had several limitations worthy of discussion. Of note, we had planned for a sample size of 60; however, after exclusions only 52 remained. Although the power analyses indicated that the final sample size was sufficient for detecting medium-to-small effects sizes, a larger sample size would nonetheless have strengthened the current trial and may have allowed us to detect additional benefits of stair climbing. Regarding participant characteristics, based on the NZ-PAQ data, the current sample of young adults was atypically physically active, with the average amount of weekly physical activity (8.4 h) well exceeding recommended amounts of at least 2.5 h; this may reflect more active (but not less active) young adults being interested in participating, given the nature of the study. This signals that the current sample is not representative of the young adult population, although given that none of the effects reported here depended on physical activity habits, we have no reason to think that the results would not generalize to the wider population. Regarding the design of the control session, the omission of stair climbing leaves open the possibility that expectancy effects could underpin some of the effects (although research does not necessarily support this; Oberste et al., 2017). A stronger design would include an active comparison session, for example, involving an active control (such as walking back and forth at a self-selected pace on a flat surface for the duration of the stair climbing protocol—similar to the recovery and cool down phases) or a different dose of stair climbing (varied by altering the number of stair-climbing intervals or the stair-climbing pace).

Another limitation relates to the lack of pre-test assessments in the current study, which makes it difficult to rule out potential confounding by day-to-day variability in behavioral responses (Pontifex et al., 2019); although such factors should be random given the design, the sample size may not be sufficient to protect against such randomness. Furthermore, the pace of the stair climbing was not controlled, which has the advantage of allowing participants to work toward a person-specific level of exertion, but also adds variability. In addition, we measured heart rate using a wrist-worn device, which is known to be less accurate than a chest strap (Polar, 2019), and we assessed cognitive performance using only three cognitive tests focused on only two domains of executive functioning (inhibition and switching abilities), thus leaving unknown potential benefits pertaining to other cognitive tests/domains.

Future Research

In addition to the suggestions we already put forward, including the need to determine the number of stair-climbing intervals necessary for cognitive benefits in males (based on Stenling et al., 2019, three may be enough, and this was sufficient for mood benefits in males and females), an important next step toward tackling physical inactivity and related issues is to try interleaving stair climbing into daily routines to confirm feasibility and investigate adherence and other factors relevant to it being incorporated successfully. Given the immediate psychological benefits demonstrated in the current trial, employers and educators may be interested in determining whether stair climbing can improve performance and productivity in workplace and education contexts. In light of recent research indicating improvements in creative thinking following stair climbing (Matsumoto et al., 2021), it may be that intervals of stair climbing interleaved into one's day can boost a range of work- and education-relevant psychological factors, noting also that over time longer-term health benefits associated with chronic exercise engagement (e.g., vascular and immunological) will likely lead to better general health and fewer sick days, resulting in further psychological benefits (via chronic pathways). Thus, introducing regular stair climbing into the daily activities of employees and pupils in multistory buildings may prove to be beneficial.

Conclusions

The current randomized controlled crossover trial counterbalanced for sex and session order (stair climbing or no-stair-climbing control) and involving just six 1-min intervals of stair climbing provides proof of concept that stair climbing can be used to improve cognitive performance and mood in both male and female young adults. The psychological benefits are encouraging given the ease with which stairs can be accessed in many daytime environments (workplaces, schools, and dwellings), making it feasible for a significant proportion of the global population to incorporate stair climbing into their daily lives. An important next step will be to translate the controlled and monitored stair climbing undertaken in the current trial to self-initiated stair climbing undertaken in natural environments as a regular part of one's day. Given that conserving energy is a well-ingrained survival mechanism, it will likely take a concerted effort to assist people toward incorporating non-essential stair climbing into their day, at least initially while the new more-active behaviors become habit. Encouragingly, although more effective ideas are still needed, progress on this front has been made (Dolan et al., 2006, 2008; Webb & Cheng, 2010), taking us closer to realizing stair climbing as a simple mode of physical activity that can be incorporated into daily lives and help address physical inactivity and related issues.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41465-024-00294-1.

Author Contribution Conceptualization: LM, AS; methodology: LM, AS; software: LM, JQ, NK; validation: LM, AS; formal analysis: AS; investigation: JQ, NK; resources: LM; data curation: AS; writing—original draft: LM, AS; writing—review and editing: AS, JQ, NK, LM; visualization: AS; supervision: LM; project administration: LM; funding acquisition: LM, AS.

Funding Open access funding provided by Umea University. Andreas Stenling was supported by an international postdoc grant from the Swedish Research Council (dnr: 2017–00273). This research project was also supported by funding from the University of Otago.

Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

References

ACSM. (2018). *ACSM's guidelines for exercise testing and prescription* (10th ed.). Wolters Kluwer.

Allison, M. K., Baglole, J. H., Martin, B. J., Macinnis, M. J., Gurd, B. J., & Gibala, M. J. (2017). Brief intense stair climbing improves cardiorespiratory fitness. *Medicine and Science in Sports and Exercise, 49*(2), 298–307. https://doi.org/10.1249/MSS.0000000000001188

Basso, J. C., & Suzuki, W. A. (2017). The effects of acute exercise on mood, cognition, neurophysiology, and neurochemical pathways: A review. *Brain Plasticity, 2*(2), 127–152. https://doi.org/10.3233/BPL-160040

Bierre, K. L., Lucas, S. J., Guiney, H., Cotter, J. D., & Machado, L. (2017). Cognitive difficulty intensifies age-related changes in anterior frontal hemodynamics: Novel evidence from near-infrared spectroscopy. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 72*(2), 181–188.

Boreham, C. A., Kennedy, R. A., Murphy, M. H., Tully, M., Wallace, W. F., & Young, I. (2005). Training effects of short bouts of stair climbing on cardiorespiratory fitness, blood lipids, and homocysteine in sedentary young women. *British Journal of Sports Medicine, 39*(9), 590–593. https://doi.org/10.1136/bjsm.2002.001131

Borg, G. (1998). *Borg's perceived exertion and pain scales*. Human kinetics.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision, 10*(4), 433–436.

Brett, C. H. R., & Machado, L. (2017). Manual versus saccadic assessment of cognitive inhibition and switching in young and older adults. *Psychological Assessment, 29*(11), 1420–1425. https://doi.org/10.1037/pas0000453

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., . . . Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, *54*(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Cameron, T. A., Lucas, S. J., & Machado, L. (2015). Near-infrared spectroscopy reveals link between chronic physical activity and anterior frontal oxygenated hemoglobin in healthy young women. *Psychophysiology, 52*(5), 609–617. https://doi.org/10.1111/psyp.12394

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research, 1453*, 87–101. https://doi.org/10.1016/j.brainres.2012.02.068

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Earlbaum Associates.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155–159. https://doi.org/10.1037//0033-2909.112.1.155

Dolan, M. S., Weiss, L. A., Lewis, R. A., Pietrobelli, A., Heo, M., & Faith, M. S. (2006). 'Take the stairs instead of the escalator': Effect of environmental prompts on community stair use and implications for a national 'Small Steps' campaign. *Obesity Reviews, 7*(1), 25–32. https://doi.org/10.1111/j.1467-789x.2006.00219.x

Dolan, M. S., Weiss, L. A., Pietrobelli, A., Heo, M., & Faith, M. S. (2008). Stair climbing and obesity prevention. *Obesity Reviews, 9*(1), 85–86. https://doi.org/10.1111/j.1467-789x.2007.00373.x

Donath, L., Faude, O., Roth, R., & Zahner, L. (2014). Effects of stair-climbing on balance, gait, strength, resting heart rate, and submaximal endurance in healthy seniors. *Scandinavian Journal of Medicine & Science in Sports, 24*(2), e93–e101. https://doi.org/10.1111/sms.12113

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statisical power analysis program for the social, behavioural, and biomedical scies. *Behaviour Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Flannery, S. L., Jowett, T., Garvey, A., Cutfield, N. J., & Machado, L. (2018). Computerized testing in Parkinson's disease: Performance deficits in relation to standard clinical measures. *Journal of Clinical and Experimental Neuropsychology, 40*(10), 1062–1073. https://doi.org/10.1080/13803395.2018.1485880

Forsyth, B., Machado, L., Jowett, T., Jakobi, H., Garbe, K., Winter, H., & Glue, P. (2016). Effects of low dose ibogaine on subjective mood state and psychological performance. *Journal of Ethnopharmacology, 189*, 10–13. https://doi.org/10.1016/j.jep.2016.05.022

Gay, J. L., Cherof, S. A., LaFlamme, C. C., & O'Connor, P. J. (2022). Psychological aspects of stair use: A systematic review. *American Journal of Lifestyle Medicine, 16*(1), 109–121. https://doi.org/10.1177/1559827619870104

Guiney, H., Lucas, S. J., Cotter, J. D., & Machado, L. (2015). Evidence cerebral blood-flow regulation mediates exercise-cognition links in healthy young adults. *Neuropsychology, 29*(1), 1–9. https://doi.org/10.1037/neu0000124

Guiney, H., Lucas, S. J. E., Cotter, J. D., & Machado, L. (2019). Investigating links between habitual physical activity, cerebrovascular function, and cognitive control in healthy older adults. *Neuropsychologia, 125*, 62–69. https://doi.org/10.1016/j.neuropsychologia.2019.01.011

Honda, H., Igaki, M., Hatanaka, Y., Komatsu, M., Tanaka, S.-I., Miki, T., Suzuki, T., Takaishi, T., & Hayashi, T. (2016). Stair climbing/descending exercise for a short time decreases blood glucose levels after a meal in participants with type 2 diabetes. *BMJ Open Diabetes Research & Care, 4*(1), e000232. https://doi.org/10.1136/bmjdrc-2016-000232

Hsieh, S. S., Chueh, T. Y., Huang, C. J., Kao, S. C., Hillman, C. H., Chang, Y. K., & Hung, T. M. (2021). Systematic review of the acute and chronic effects of high-intensity interval training on executive function across the lifespan. *Journal of Sports Sciences, 39*(1), 10–22. https://doi.org/10.1080/02640414.2020.1803630

Kreidler, S. M., Muller, K. E., Grunwald, G. K., Ringham, B. M., Coker-Dukowitz, Z. T., Sakhadeo, U. R., Baron, A. E., & Glueck, D. H. (2013). GLIMMPSE: Online power computation for linear models with and without a baseline covariate. *Journal of Statistical Software*, *54*(10). https://doi.org/10.18637/jss.v054.i10

Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research, 1341*, 12–24. https://doi.org/10.1016/j.brainres.2010.03.091

Legrand, F. D., Race, M., & Herring, M. P. (2018). Acute effects of outdoor and indoor exercise on feelings of energy and fatigue in people with depressive symptoms. *Journal of Environmental Psychology*, *56*, 91–96. https://doi.org/10.1016/j.jenvp.2018.03.005

Ligeza, T. S., Maciejczyk, M., Wyczesany, M., & Junghofer, M. (2023). The effects of a single aerobic exercise session on mood and neural emotional reactivity in depressed and healthy young adults: A late positive potential study. *Psychophysiology*, *60*(1). https://doi.org/10.1111/psyp.14137

Loy, B. D., O'Connor, P. J., & Dishman, R. K. (2013). The effect of a single bout of exercise on energy and fatigue states: A systematic review and meta-analysis. *Fatigue: Biomedicine, Health & Behavior*, *1*(4), 223–242. https://doi.org/10.1080/21641846.2013.843266

Machado, L., Thompson, L. M., & Brett, C. H. R. (2019). Visual analogue mood scale scores in healthy young versus older adults. *International Psychogeriatrics, 31*(3), 417–424. https://doi.org/10.1017/S1041610218000996

Matsumoto, K., Chen, C., Hagiwara, K., Shimizu, N., Hirotsu, M., Oda, Y., Lei, H., Takao, A., Fujii, Y., Higuchi, F., & Nakagawa, S. (2021). The effect of brief stair-climbing on divergent and convergent thinking. *Frontiers in Behavioral Neuroscience, 15*, 834097. https://doi.org/10.3389/fnbeh.2021.834097

McDowell, C. P., Campbell, M. J., & Herring, M. P. (2016). Sex-related differences in mood responses to acute aerobic exercise. *Medicine and Science in Sports and Exercise, 48*(9), 1798–1802. https://doi.org/10.1249/MSS.0000000000000969

McLean, G., & Tobias, M. (2004). *The New Zealand physical activity questionnaires: Report on the validation and use of the NZPAQ-LF and NZPAQ-SF self-report physical activity survey instruments*. Sport and Recreation New Zealand.

McMorris, T., & Hale, B. J. (2012). Differential effects of differing intensities of acute exercise on speed and accuracy of cognition: A meta-analytical investigation. *Brain and Cognition, 80*(3), 338–351. https://doi.org/10.1016/j.bandc.2012.09.001

Michael, E., White, M. J., & Eves, F. F. (2021). Home-based stair climbing as an intervention for disease risk in adult females; a controlled study. *International Journal of Environmental Research and Public Health, 18*(2), 603. https://doi.org/10.3390/ijerph18020603

Mir, I. A., Yu, V. L. K., Jia, F. S., & Bhat, A. H. (2017). Comparison between stair climbing and 1 mile walking in relation to cardiorespiratory fitness among sedentary adults. In F. Ibrahim, J. P. G. Cheong, J. Usman, M. Y. Ahmad, R. Razman, & V. S. Selvanayagam (Eds.), *3rd International Conference on Movement, Health and Exercise. MoHE 2016* (pp. 14–18). Springer. https://doi.org/10.1007/978-981-10-3737-5_4

Moy, K. L., Scragg, R. K., McLean, G., & Carr, H. (2008). The New Zealand Physical Activity Questionniares: Validation by heart-rate monitoring in a multiethnic population. *Journal of Physical Activity and Health, 5*, S45–S61.

Nasrollahi, N., Quensell, J., & Machado, L. (2022). Effects of a brief stair-climbing intervention on cognitive functioning and mood states in older adults: A randomized controlled trial. *Journal of Aging and Physical Activity, 30*(3), 455–465. https://doi.org/10.1123/japa.2021-0125

Oberste, M., Hartig, P., Bloch, W., Elsner, B., Predel, H. G., Ernst, B., & Zimmer, P. (2017). Control group paradigms in studies investigating acute effects of exercise on cognitive performance-An experiment on expectation-driven placebo effects. *Frontiers in Human Neuroscience, 11*, 600. https://doi.org/10.3389/fnhum.2017.00600

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*(4), 437–442.

Peng, B., Ng, J. Y. Y., & Ha, A. S. (2023). Barriers and facilitators to physical activity for young adult women: A systematic review and thematic synthesis of qualitative literature. *International Journal of Behavioral Nutrition and Physical Activity, 20*(1), 23. https://doi.org/10.1186/s12966-023-01411-7

Pesce, C., & Audiffren, M. (2011). Does acute exercise switch off switch costs? A study with younger and older athletes. *Journal of Sport and Exercise Psychology, 33*(5), 609–626. https://doi.org/10.1123/jsep.33.5.609

Polar. (2019). *Polar Precision Prime OHR [White paper]. Polar Research and Technology*. Retrieved 2024-03-04 from www.polar.com/en/img/static/whitepapers/pdf/polar-precision-prime-white-paper.pdf

Pontifex, M. B., McGowan, A. L., Chandler, M. C., Gwizdala, K. L., Parks, A. C., Fenn, K., & Kamijo, K. (2019). A primer on investigating the after effects of acute bouts of physical activity on cognition. *Psychology of Sport and Exercise, 40*, 1–22. https://doi.org/10.1016/j.psychsport.2018.08.015

Reed, J., & Ones, D. S. (2006). The effect of acute aerobic exercise on positive activated affect: A meta-analysis. *Psychology of Sport and Exercise, 7*(5), 477–514. https://doi.org/10.1016/j.psychsport.2005.11.003

Rey-Lopez, J. P., Stamatakis, E., Mackey, M., Sesso, H. D., & Lee, I. M. (2019). Associations of self-reported stair climbing with all-cause and cardiovascular mortality: The Harvard Alumni Health Study. *Preventive Medicine Reports, 15*, 100938. https://doi.org/10.1016/j.pmedr.2019.100938

Sanchez-Lastra, M. A., Ding, D., Dalene, K. E., Del Pozo Cruz, B., Ekelund, U., & Tarp, J. (2021). Stair climbing and mortality: A prospective cohort study from the UK Biobank. *Journal of Cachexia, Sarcopenia and Muscle, 12*(2), 298–307. https://doi.org/10.1002/jcsm.12679

Schneider, B. A., Avivi-Reich, M., & Mozuraitis, M. (2015). A cautionary note on the use of the analysis of covariance (ANCOVA) in classification designs with and without within-subject factors. *Frontiers in Psychology, 6*, 474. https://doi.org/10.3389/fpsyg.2015.00474

Shoemaker, L. N., Wilson, L. C., Lucas, S. J. E., Machado, L., & Cotter, J. D. (2020). Acute exercise-related cognitive effects are not attributable to changes in end-tidal CO2 or cerebral blood velocity. *European Journal of Applied Physiology, 120*(7), 1637–1649. https://doi.org/10.1007/s00421-020-04393-7

Shoemaker, L. N., Wilson, L. C., Lucas, S. J. E., Machado, L., Thomas, K. N., & Cotter, J. D. (2019). Swimming-related effects on cerebrovascular and cognitive function. *Physiological Reports, 7*(20), e14247. https://doi.org/10.14814/phy2.14247

Song, Z., Wan, L., Wang, W., Li, Y., Zhao, Y., Zhuang, Z., Dong, X., Xiao, W., Huang, N., Xu, M., Clarke, R., Qi, L., & Huang, T. (2023). Daily stair climbing, disease susceptibility, and risk of atherosclerotic cardiovascular disease: A prospective cohort study. *Atherosclerosis*, 117300. https://doi.org/10.1016/j.atherosclerosis.2023.117300

Stenling, A., Moylan, A., Fulton, E., & Machado, L. (2019). Effects of a brief stair-climbing intervention on cognitive performance and mood states in healthy young adults. *Frontiers in Psychology*, *10*(2300). https://doi.org/10.3389/fpsyg.2019.02300

Stutts, W. C. (2002). Physical activity determinants in adults. Perceived benefits, barriers, and self efficacy. *AAOHN Journal*, *50*(11), 499–507. https://doi.org/10.1177/216507990205001106

Swain, D. P. (2000). Energy cost calculations for exercise prescription: An update. *Sports Medicine, 30*(1), 17–22. https://doi.org/10.2165/00007256-200030010-00002

Thomas, S., Reading, J., & Shephard, R. J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Canadian Journal of Sport Sciences, 17*(4), 338–345.

Webb, O. J., & Cheng, T. F. (2010). An informational stair climbing intervention with greater effects in overweight pedestrians. *Health Education Research, 25*(6), 936–944. https://doi.org/10.1093/her/cyq043

White, N., Forsyth, B., Lee, A., & Machado, L. (2018). Repeated computerized cognitive testing: Performance shifts and test-retest reliability in healthy young adults. *Psychological Assessment, 30*(4), 539–549. https://doi.org/10.1037/pas0000503

White, N., Kouwenhoven, M., & Machado, L. (2022). Short-term retest performance in young versus older adults: Consideration of integrated speed-accuracy measures. *Experimental Aging Research, 48*(1), 68–85. https://doi.org/10.1080/0361073X.2021.1919475

White, N., Naldoza-Drake, P., Black, K., Scullion, L., & Machado, L. (2020). Can improving the nutritional content of bread enhance cognition? Cognitive outcomes from a randomized controlled trial. *Journal of Cognitive Enhancement, 4*(2), 167–178. https://doi.org/10.1007/s41465-019-00149-0

Whittaker, A. C., Eves, F. F., Carroll, D., Roseboom, T. J., Ginty, A. T., Painter, R. C., & de Rooij, S. R. (2021). Daily stair climbing is associated with decreased risk for the metabolic syndrome. *BMC Public Health, 21*(1), 923. https://doi.org/10.1186/s12889-021-10965-9

WHO. (2019). *Body mass index - BMI*. Retrieved 2019-01-14 from http://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi

Wohlwend, M., Olsen, A., Haberg, A. K., & Palmer, H. S. (2017). Exercise intensity-dependent effects on cognitive control function during and after acute treadmill running in young healthy adults. *Frontiers in Psychology, 8*, 406. https://doi.org/10.3389/fpsyg.2017.00406

Wong, A., Figueroa, A., Son, W. M., Chernykh, O., & Park, S. Y. (2018). The effects of stair climbing on arterial stiffness, blood pressure, and leg strength in postmenopausal women with stage 2 hypertension. *Menopause, 25*(7), 731–737. https://doi.org/10.1097/GME.0000000000001072