

Effects of a Brief Stair-Climbing Intervention on Cognitive Functioning and Mood States in Older Adults: A Randomized Controlled Trial

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Despite an abundance of evidence that exercise benefits cognition and mood, physical activity levels among older adults remain low, with time and inaccessibility posing major barriers. Interval stair climbing is an accessible time-efficient form of physical activity demonstrated to benefit cognition and mood in young adults, but effectiveness in older adults remains unknown. To address this, 28 older adults ($M_{\text{age}} = 69.78$ years, 16 females) undertook cognitive and mood assessments twice, 1 week apart, once preceded by interval stair climbing. A fairly large, albeit only marginally significant, effect size ($\eta_p^2 = .12$) indicated improved cognition following the moderate- to high-intensity intervention; however, rather than improving mood, older adults reported feeling more tired ($g = 0.51$). These outcomes provide initial indications that this mode of exercise that can easily translate to naturalistic settings offers promise as an intervention strategy, but more research is needed to optimize the protocol to suit aged populations (ACTRN1261900169014).

Keywords: acute exercise, interval training, cognitive performance, affect

As people age, cognitive decline is inevitable (Bierre et al., 2017; Fjell et al., 2013; Machado, 2021; Warsch & Wright, 2010), which negatively affects quality of life in older adults (Stites et al., 2018). Due to the rapid increase in population aging, the burden of age-related cognitive decline has increased significantly in recent decades (Qiu et al., 2019; Wimo et al., 2017). Consequently, increasing attention has been directed toward developing interventions for optimizing cognitive functioning in older adults. A growing body of research suggests that engaging in exercise confers acute benefits on older adults' cognitive functions (Córdova et al., 2009; Kamiyo et al., 2009; McSween et al., 2019; Petrella et al., 2019), and performance on more cognitively challenging tests tends to benefit most (Ludyga et al., 2016; Pesce & Audiffren, 2011). Acute exercise has also been shown to improve mood states in younger adults (Basso & Suzuki, 2017; Legrand et al., 2018; Reed & Ones, 2006), but the findings in older adults are mixed and limited. While several studies have reported that acute light- to moderate-intensity aerobic or resistance exercise positively affects mood states in older adults (Hogan et al., 2013; Hyodo et al., 2019; Nouchi et al., 2020; Pierce & Pate, 1994), Focht et al. (2007) observed a decrease in positive mood states and an increase in physical exhaustion following an acute bout of moderate-intensity aerobic exercise. Thus, acute exercise does not necessarily improve mood states in older adults.

Despite an abundance of evidence that exercise benefits cognitive functioning, physical activity levels among older adults remain low (Guiney & Machado, 2018; Guthold et al., 2018). Lack of time has been reported as the most common factor causing less engagement in physical activity (Gothe & Kendall, 2016). In consideration of this, interval training has been proposed as a time-efficient form of exercise (Buchheit & Laursen, 2013; Klein

et al., 2019), as it involves repeated short intervals of relatively high-intensity exercise interspersed with brief recovery periods that collectively require a fairly short time commitment (Buchheit & Laursen, 2013). The benefits of high-intensity interval training on cognitive performance have been reported to be at least as great as those of longer periods of low- and moderate-intensity continuous exercise in samples of young adults (Kao et al., 2017; Kujach et al., 2018; Tsukamoto et al., 2016). As the total duration of interval training is typically much shorter than continuous exercise, this type of physical activity can be a time-efficient alternative strategy to enhance cognitive function (Kujach et al., 2018).

Inaccessibility of physical activity facilities and poor physical conditions in the neighborhood (e.g., uneven paths) have been reported as other major barriers to engaging in physical activity among older adults (Booth et al., 2000; Gothe & Kendall, 2016). Given that the majority of previous studies investigating the effects of acute exercise on cognitive performance and mood states in older adults used specialized equipment such as a treadmill (Netz et al., 2009; Peiffer et al., 2015) or a cycle ergometer (Córdova et al., 2009; Hyodo et al., 2019; Kamiyo et al., 2009), which is not readily available to most older adults, more research is clearly needed to determine the effects of more accessible forms of exercise that can be easily translated to older adults' households and workplaces and that circumvent issues with deteriorating public paths. Allison et al. (2017) proposed stair climbing as a simple and feasible means of exercise that can be performed in a naturalistic setting. They investigated the effects of brief intense interval stair climbing protocols on cardiorespiratory fitness in a sample of sedentary but healthy young women, and discovered that the interval stair-climbing protocols led to improvements in cardiorespiratory fitness, as determined by increased peak oxygen uptake.

Compared with other forms of exercise, stair climbing is more physically challenging, as an individual must lift their body weight upward against gravity (Webb & Cheng, 2010). Furthermore, stair

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climbing has been linked to healthier brain aging, as indicated by brain volume (Steffener et al., 2016), which may help support better cognitive functioning. A recent study by Stenling et al. (2019) discovered that a brief, moderate-intensity interval stair-climbing protocol improved both cognitive functioning and mood in younger adults. Although the cognitive benefits in Stenling et al. (2019) were limited to males and the most challenging cognitive domain (task switching), considering that older adults tend to show greater cognitive benefits than younger adults (Ludyga et al., 2016), interval stair climbing may prove to be a more generally effective cognitive enhancer in older adults than previously shown in younger adults.

The aim of the current study was to determine the effects of an interval training protocol involving short bouts of stair climbing on cognitive performance and mood states in older adults. In the current study, we used a randomized controlled crossover design and hypothesized that cognitive functioning and mood would improve following the stair-climbing intervention compared with a control session without stair climbing. This would manifest as superior cognitive performance, particularly for more challenging tests, and increases in positive and decreases in negative mood states after the stair climbing intervention.

Method

This study was approved by the University of Otago Human Ethics Committee (18/012), and participants provided written informed

consent prior to participating. Data collection began in December 2019 and ended in February 2020.

Participants

Figure 1 provides a summary of participant recruitment. We initially recruited 73 older adults from the local community by advertising in a local newspaper, approaching clubs (e.g., Lawn Bowls, Bridge), and asking potential participants to tell their friends about the study. Those 73 older adults were screened for meeting the following criteria: aged between 65 and 74 years (in an effort to target people of retirement age while avoiding people of older ages who might have difficulties safely ascending and descending stairs at a rapid pace), normal or corrected-to-normal vision, no color blindness, no history of and not taking any medications for neurological or psychological disorders, no concussion in the past 6 months, and passed the Physical Activity Readiness Questionnaire (PAR-Q), which enquires about contraindications to physical activity engagement (including blood pressure medication), assessed via a phone call or email. These eligibility criteria led to the exclusion of 36 older adults for the reasons detailed in Figure 1. The 22 older adults excluded in relation to the PAR-Q failed for the following reasons: 19 due to blood pressure medication, one due to both osteoporosis and gout, one due to gout, and one due to a hip replacement. The remaining 37 began participation. After arriving at the laboratory for their first

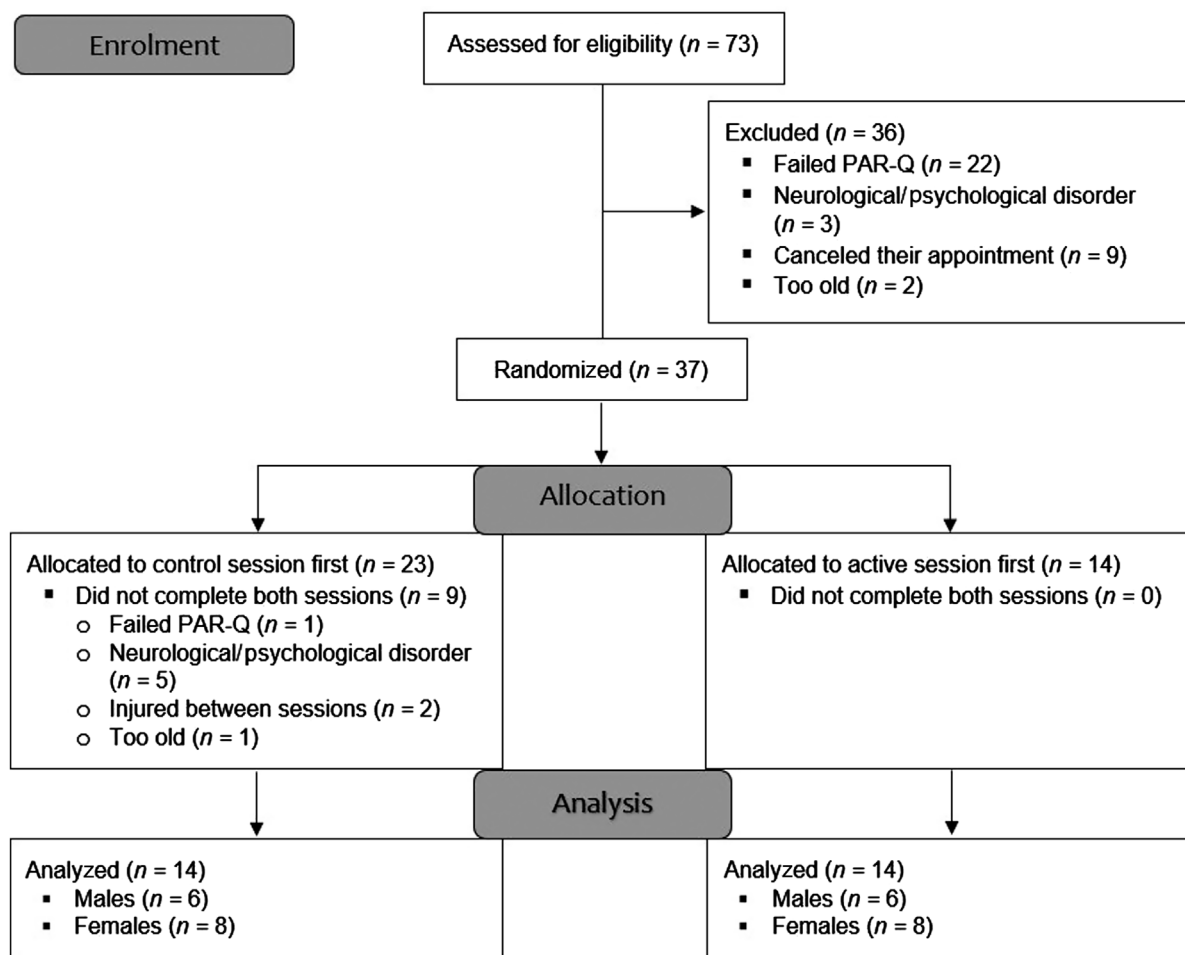


Figure 1 — Summary of participant recruitment. PAR-Q = Physical Activity Readiness Questionnaire.

session, the participants were once again assessed for readiness to engage in physical activity using the PAR-Q to ensure that it was safe for them to participate in the study. The participants were also screened for possible dementia using the Mini-Mental State Examination (Folstein et al., 1975); all scored at least 26, indicating no dementia. Nine participants had to be excluded after the first session for the following reasons: One participant exceeded the age limit (in contrast to what the participant had originally reported), five participants reported having a neurological or psychological condition (in contrast to what the participants had originally reported), one participant failed the PAR-Q (diagnosed with an undisclosed condition that made her ineligible to participate), and two participants injured themselves between sessions (in incidents unrelated to the current study). Thus, the final sample included in the analysis was composed of 28 self-reported healthy older adults (16 females; 26 right handed; see Table 1 for a summary of participant characteristics). All participants were reimbursed with NZ\$20 per visit.

Procedure

We used a controlled crossover design with session order (stair climbing or control) counterbalanced across the participants. Session order was randomly generated in a prepopulated log sheet using Microsoft Excel, and the participants were assigned to the randomized conditions in order. The participants visited the laboratory on two occasions at the same time of the day, exactly 1 week apart. The participants' height and weight were measured during the first session after completing the PAR-Q, Mini-Mental State Examination and a general information questionnaire asking about age, years of education, sex, dominant hand, medication intake for any neurological or psychological disorder, normal or corrected-to-normal vision, and color blindness. The participants' weight was also measured at the start of the second session for entering into a heart rate (HR) monitor. During both sessions, the HR monitor was placed on the participants' left wrist to obtain an objective measure of exercise intensity. The participants were then asked to sit and relax and were left alone in the room for 5 min to measure their resting baseline HR, after which they completed either the stair-climbing or control session (Figure 2 for a step-by-step outline of the procedure). Due to the nature of the intervention, the experimenter and participants were not blinded to the session order, and the participants were informed which session they would be completing the day before to ensure they wore appropriate clothing for the stair-climbing session.

Stair-Climbing Session

The participants were given instructions about the indoor stair-climbing protocol and were shown a demonstration video of the main stair-climbing phase. In the current study, in an effort to

ensure that the participants reach a fairly high exercise intensity, we altered the 3 × 1-min stair-climbing protocol from Allison et al. (2017) and Stenling et al. (2019) by doubling the number of stair-climbing intervals, yielding 6 × 1 min of stair climbing, which involved six 1-min intervals of climbing up and down a single flight of stairs. The protocol included the following phases: 2-min warm-up, 45-s instruction interval, six 1-min stair-climbing intervals separated by 1-min recovery periods, and then a 3-min cooldown. The warm-up involved walking 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, followed by a brisk walk back and forth on a flat landing. During the 45-s instruction phase, the experimenter repeated the instructions for the stair-climbing and recovery phases. The participants were told the following: "You will complete six lots of 1 min stair climbs with a 1 min rest between each stair climb. 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." The experimenter then counted down from five to zero, and the participant started the stair climb when a beep occurred at zero. We used an interval-training application (interval timer high-intensity interval training workouts; Deltaworks Limited, London, UK) on a smartphone (Motorola, M2C63, and iPhone 8) to time the stair-climbing and recovery intervals. The stair-climbing phases were completed on one flight of 12 stairs, each 17 cm in height. The experimenter recorded the number of steps climbed for each stair-climbing interval, and HR was recorded throughout the entire protocol. For each recovery phase, which was signaled with a beep, the participants were asked to descend to the landing from their place on the stairs and walk back and forth across the landing at a self-selected pace. Once the participants had completed all six stair-climb phases, they completed a cooldown phase, which involved walking down two flights of stairs and back and forth across a flat surface at a self-selected pace. The participants were asked to rate their perceived exertion twice during the warm-up (once at 1 min 15 s and once at 1 min 45 s; data not reported) as well as 15 s before and immediately after each stair-climbing interval. After the cooldown phase, the participants returned to the testing room and completed another seated rest for 5 min, after which they underwent neuropsychological testing. At the end of the session, they were given ethnicity (if it was the first session) and physical activity questionnaires to complete. The stair-climbing session took approximately 1 hr to complete.

Control Session

All aspects of the control session were identical to the stair-climbing session, except that the stair-climbing protocol was omitted, such that after having their resting baseline HR recorded, the participants were asked to sit quietly for an additional 5 min and then underwent neuropsychological testing. The control session took approximately 25 min to complete.

Materials

Perceived Exertion Scale

We used the Borg (1998) ratings of perceived exertion (RPE) scale as a subjective measure of exercise intensity. The scale has ratings from 6 (*no exertion at all*) to 20 (*maximal exertion*). Each number on the scale corresponds to an HR; for example, 6 translates to an HR of 60 beats/min. The participants were given a two-sided information sheet that explained the RPE ratings immediately after

Table 1 Participant Characteristics (*n* = 28)

Variable	<i>M</i>	<i>SD</i>	Range
Age (years)	69.78	2.60	65–74
Education (years)	15.82	4.10	10–24
Mini-Mental State Examination	28.64	1.12	26–30
Weight (kg)	70.66	10.35	51.88–97.50
Height (cm)	167.42	9.29	152–186
Body mass index (kg/m ²)	25.22	3.32	20.06–33.90

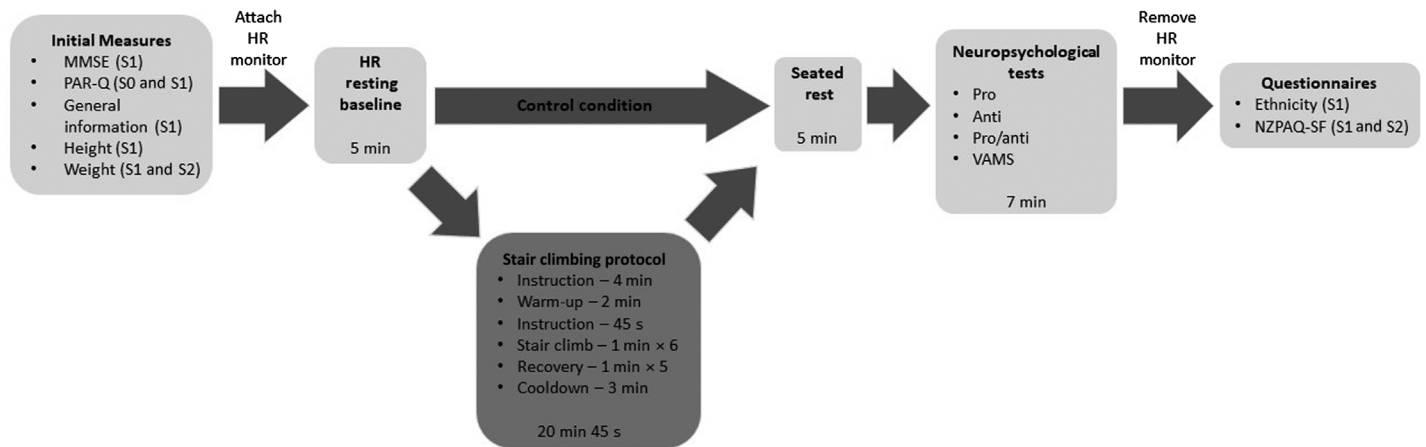


Figure 2 — A step-by-step outline of the procedure. The stair-climbing protocol did not occur during the control session. S0 = phone/email screening prior to first session; S1 = first session; S2 = second session; HR = heart rate; NZPAQ-SF = New Zealand Physical Activity Questionnaire Short Form; VAMS = visual analog mood scales; PAR-Q = Physical Activity Readiness Questionnaire; MMSE = Mini-Mental State Examination.

having their resting baseline HR recorded. Previous studies have shown high correlations ($r = .80-.90$) between RPE and HR while engaged in physical activity (Borg, 1998).

Heart Rate

We used a Polar M430 wristwatch (Polar Electro OY, Kempele, Finland) to measure and record HR during both sessions. Date of birth, sex, weight, and height details for each participant were entered into the device to improve measurement accuracy. Mean and maximum HR (HR_{Max}) were calculated separately during resting baseline, stair-climbing, and neuropsychological testing.

Physical Activity Questionnaire

We used the New Zealand Physical Activity Questionnaire Short Form to assess participants' recent physical activity in order to determine whether their physical activity habits differed in the week preceding each of the two sessions, as this could influence outcomes for the neuropsychological measures (Guiney et al., 2019; Orland et al., 2020). The New Zealand Physical Activity Questionnaire Short Form is a brief self-report questionnaire that measures three dimensions of physical activity: frequency, duration, and intensity (McLean et al., 2004). The participants were asked to report the number of days in the 7 days preceding the day of testing that they had engaged in the following: (a) brisk walking, (b) moderate activity, (c) vigorous activity, and (d) a combination of all three. The participants were also asked about the duration (in hours and minutes per day) of each activity. Finally, they indicated the frequency (number of days in the last 7 days) that they had engaged in at least 30 min of moderate or 15 min of vigorous physical activity. The total physical activity for those 7 days was calculated in minutes by adding time spent walking + moderate physical activity + vigorous physical activity. The New Zealand Physical Activity Questionnaire Short Form has been validated using objective HR monitoring in a sample aged between 19 and 86 years (Moy et al., 2008).

Neuropsychological Testing

After 5 min of seated rest, the participants completed neuropsychological testing using a computerized battery that took approximately 7 min to complete and has been reported in previous

randomized controlled trials (Forsyth et al., 2016; Shoemaker et al., 2019; Stenling et al., 2019; White et al., 2020) and assessed for retest effects (Machado et al., 2019; White et al., 2019). The battery consisted of three cognitive tests that progressively increased in their cognitive demands and were, respectively, designed to assess basic visuomotor performance (Pro), inhibitory control (Anti), and switching (Pro/Anti), all of which have relevance to daily functioning. Note that although in Stenling et al. (2019) the benefits following stair climbing occurred for the most challenging cognitive task only (Pro/Anti), in the current trial, which involved older instead of young adults and twice as many stair-climbing intervals, we predicted that cognitive benefits would not be restricted to the most challenging task. After the cognitive tests, the battery assessed current affective state via visual analog mood scales (VAMS; Machado et al., 2019). The battery was run using MATLAB (R2016b; The MathWorks, Natick, MA) and The Psychophysics Toolbox-3 (Brainard, 1997; Pelli, 1997). During neuropsychological testing, the participants sat 57 cm away from a computer screen (600 × 340-mm monitor, Ubuntu 16.04 operating system, Canonical Limited, London, UK), held constant using a chin rest, in a dimly lit room. During the cognitive tests, the participants were asked to use their index finger of each hand to press the left or right button on a button box (DirectIN Rotary Controller; Empirisoft Corporation, New York, NY). Each button was a 2 × 2-cm square, and the two buttons were positioned 2 cm apart. 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 screen. The participants were asked to maintain focus on the fixation dot, and after a variable interval (400, 600, 800, 1,000, or 1,200 ms), a green or red square (subtending 2° of visual angle) appeared 8° to the left or right of the fixation dot (measured center-to-center). The variable conditions (fixation interval and side of the square) were counterbalanced and randomized such that the trial order varied each time the cognitive tests ran. During Pro, the square was always green and the participants were asked to respond by pressing the button on the same side as the square. During Anti, the square was always red and the participants were instructed to press the button on the opposite side of the square, thus providing a measure of inhibitory control. During Pro/Anti, which consisted of an equal number of Pro and Anti trials randomly intermixed, the participants were instructed to press the button on the same side as

the green square and on the opposite side of the red square, thus providing a measure of switching ability. In all cases, the participants were asked to respond as fast and as accurately as they could. A 900-Hz error tone sounded for 300 ms, followed by a black screen for 500 ms before the next trial if the participant made an incorrect response, made no response within 1,500 ms, or responded in less than 100 ms (anticipation error). Reaction time (RT; in milliseconds) and accuracy were measured for each trial. The participants completed four practice trials followed by 40 test trials each for Pro and Anti, and six practice trials followed by 40 test trials for Pro/Anti.

The VAMS assessed participants' current mood state for the following six moods (in this order): sad, energetic, tense, happy, tired, and calm. For each mood scale, the instructions "click the position on the line that best represents how you feel right now" appeared above a horizontal line of 100 mm with a descriptor at each end of the line: "Not at all" and "Extremely." The participants clicked on the line to indicate their current mood. The responses for each mood scale ranged from 0 (*if the participant clicked on the far left side of the line*) to 100 (*if the participant clicked on the far right side of the line*). For further details about the VAMS, refer to Machado et al. (2019).

Statistical Analyses

We calculated the mean frequency (in days per week) and mean total amount of physical activity (in hours per week) for the 7 days preceding the participants' stair-climbing and control sessions, and then paired sample *t* tests were used to determine whether there was any difference between the two sessions. To examine differences in resting baseline HR and neuropsychological testing HR between the stair-climbing and control sessions, a series of paired sample *t* tests were performed. We also calculated mean HR, HR_{Max}, percentage of HR maximum (%HR_{Max}), percentage of HR reserve (%HR_{Reserve}), and the number of steps climbed during each stair-climbing interval, plus RPE rating (pre and post each stair-climbing interval). Formulas: %HR_{Max} = HR_{Mean}/HR_{Max} × 100, where HR_{Max} = 208 - 0.7 × age, adapted from Tanaka et al. (2001), and %HR_{Reserve} = (HR_{Mean} - HR_{Min})/HR_{Reserve} × 100, where HR_{Min} = mean resting HR and HR_{Reserve} = HR_{Max} - HR_{Min}. %HR_{Reserve} represents the amount HR increased from the resting HR (Swain, 2000). To investigate the main effect of stair climbing on %HR_{Max} and %HR_{Reserve}, we conducted two repeated-measures analyses of variances (ANOVAs) with the interval as a within-subject factor. Planned follow-up contrasts were conducted using the Holm-Bonferroni correction to examine differences between each successive stair-climbing interval.

For each cognitive task, we calculated the median RT in milliseconds for correct responses only and accuracy (percentage of correct responses). Median RTs were used as the analyzed variable, as ceiling accuracy performance was anticipated based on past studies utilizing these cognitive tasks (Bierre et al., 2017; Brett & Machado, 2017; White et al., 2019). To determine whether cognitive performance differed between the stair-climbing and control sessions, a repeated-measures ANOVA was conducted, with the session (stair climbing and control) and cognitive test (Pro, Anti, and Pro/Anti) as within-subject factors. When the data violated the assumption of sphericity, the Greenhouse-Geisser correction was reported. A series of paired sample *t* tests was also conducted to compare the scores for each mood state (sad, energetic, tense, happy, tired, and calm) between the stair-climbing and control sessions.

Regarding the effect of the stair-climbing intervention on cognitive functioning, an a priori power analysis using G*Power (version 3.1; Faul et al., 2007, Heinrich Heine Universität Düsseldorf, Düsseldorf, Germany) indicated that a sample size of 21 participants would provide at least 80% power to detect a medium- to large-sized main effect of the stair-climbing intervention ($f \geq 0.25$ corresponding to Hedges' $g \geq 0.67$), which could be expected based on a recent meta-analysis on acute effects of aerobic exercise on cognitive performance (Ludyga et al., 2016). To ensure a fully counterbalanced design regarding session order, a minimum sample size of 22 was thus required. Given that the result of a previous study in younger adults (Stenling et al., 2019) indicated sex differences in cognitive effects elicited by a stair-climbing intervention, we had initially planned for a sample size of 44 (22 in each sex group). However, due to the exclusion of a high number of potential participants from the study, we did not have sufficient power to analyze sex. Regarding the effect of the stair climbing on mood states, an a priori power analysis in G*Power (version 3.1; Faul et al., 2007) indicated that, given 80% power, a minimum sample size of 15 participants would detect a large-sized effect (Hedges' $g \sim 0.80$ corresponding to $\eta_p^2 \sim .14$), which could be expected based on a previous study investigating the effects of an acute bout of exercise on mood states in middle-aged and older adults (Nouchi et al., 2020).

The interpretation of effect sizes in this study was based on recommendations in Cohen (1988): a small effect (Hedges' $g \sim 0.20$, $r \sim .10$, and $\eta_p^2 \sim .01$), a medium effect (Hedges' $g \sim 0.50$, $r \sim .30$, and $\eta_p^2 \sim .06$), and a large effect (Hedges' $g \sim 0.80$, $r \sim .50$, and $\eta_p^2 \sim .14$). Given the American Statistical Association's statement on statistical significance and *p* values (Wasserstein & Lazar, 2016), as well as recommendations to consider meaningful effect sizes in the interpretation of findings rather than solely relying on *p* values (Andrade, 2019; Wasserstein & Lazar, 2016; Wasserstein et al., 2019), we chose to consider medium effect sizes (Hedges' $g = 0.50$, $r = .30$, and $\eta_p^2 = .06$) as the threshold for interpreting our results, which could be expected based on previous studies measuring acute effects of exercise on cognitive performance and mood states in older adults (Ludyga et al., 2016; Nouchi et al., 2020).

Results

Participant Characteristics

According to the WHO (2020) classification system for body mass index, 16 participants were classified as normal weight (18.5–24.9 kg/m²), nine were classified as overweight (25–29.9 kg/m²), and three were classified as obese (≥ 30 kg/m²). The participants reported belonging to the following ethnic groups: New Zealand European ($n = 23$), New Zealand European/Māori ($n = 1$), Māori ($n = 1$), European/American ($n = 1$), Lebanese/New Zealand European ($n = 1$), and British ($n = 1$).

Physical Activity

Table 2 displays the descriptive statistics for the participants' self-reported physical activity habits. As the assumption of normality was violated (assessed by Shapiro-Wilk test, $p < .05$), we conducted Wilcoxon signed-rank nonparametric tests, which confirmed no differences between the stair-climbing and control sessions in the frequency (in days per week) and the total amount (in hours per week) of physical activity during the 7 days before each session ($p \geq .509$, $r \leq .12$ in both cases; Table 2).

Stair-Climbing Intensity

The descriptive statistics for HR measures (mean and maximum) during resting baseline and neuropsychological testing for the stair-climbing and control sessions are summarized in Table 2. The series of paired sample *t* tests for resting baseline and neuropsychological testing mean and HR_{Max} compared between the stair-climbing and control sessions confirmed, as we expected based on previous research (Stenling et al., 2019), that both mean and HR_{Max} were higher during neuropsychological testing for the stair climbing compared with the control session, and the magnitude of effect was large ($p < .001$, $g \geq 0.85$ in both cases). In contrast, there were no differences in HR measures during the resting baseline between the two sessions ($p \geq .392$, $g \leq 0.20$ in both cases). Moreover, within-session comparisons confirmed that both the mean and HR_{Max} increased from the resting baseline to neuropsychological testing during the stair-climbing session ($p < .001$, $g \geq 0.91$ in both cases), whereas neither changed during the control session ($p \geq .214$, $g \leq 0.21$ in both cases). Collectively, these outcomes confirm that the stair-climbing intervention resulted in higher HR during subsequent neuropsychological testing.

Table 3 shows the descriptive statistics for HR during each stair-climbing interval, the number of stairs climbed during each interval, and RPE pre and post each stair-climbing interval. A repeated-measures ANOVA revealed a large effect of interval on both %HR_{Max}, $F(2.63, 70.93) = 66.19$; $p < .001$; $\eta_p^2 = .71$, and

%HR_{Reserve}, $F(2.32, 62.77) = 56.41$; $p < .001$; $\eta_p^2 = .67$. As shown in Table 4, follow-up planned comparisons revealed a large increase in both %HR_{Max} and %HR_{Reserve} with each successive stair-climbing interval ($p \leq .023$, $\eta_p^2 \geq .18$ in all cases).

There was also a main effect of interval on the number of stairs climbed, $F(2.92, 78.99) = 2.90$; $p = .041$; $\eta_p^2 = .10$. However, follow-up contrasts showed that none of the numerical increases in the number of stairs climbed during successive intervals reached significance ($p \geq .071$, $\eta_p^2 \leq .12$ in all cases). A repeated-measures ANOVA showed that the stair-climbing interval had a robust effect on both RPE prerating, $F(2.88, 77.85) = 108.34$; $p < .001$; $\eta_p^2 = .80$, and on RPE postrating, $F(2.11, 56.96) = 54.76$; $p < .001$; $\eta_p^2 = .67$. Follow-up contrasts indicated fairly large increases, albeit not necessarily statistically significant, with each successive stair-climbing interval in RPE preratings ($p \leq .056$, $\eta_p^2 \geq .13$ in all cases) and RPE postratings ($p \leq .070$, $\eta_p^2 \geq .12$ in all cases).

Cognitive Performance

The descriptive statistics for Pro, Anti, and Pro/Anti during the stair-climbing and control sessions are summarized in Table 5 and Figure 3. The repeated-measures ANOVA of correct median RTs with session (stair climbing and control) and cognitive task (Pro, Anti, and Pro/Anti) as within-subject factors showed, as expected based on past research (Bierre et al., 2017; Brett & Machado, 2017),

Table 2 Physical Activity and Heart Rate Measures for the Control and Stair-Climbing Sessions ($n = 28$)

Variable	Control		Stair climbing		Paired samples <i>t</i> test					Wilcoxon's signed-rank test		
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>t</i>	<i>df</i>	<i>p</i>	95% CI	<i>g</i>	<i>Z</i>	<i>p</i>	<i>r</i>
Physical activity												
Frequency (days/week)	4.75	2.27	4.93	2.19						0.45	.651	.08
Total (hr/week)	13.28	11.32	11.67	11.76						0.66	.509	.12
Heart rate (bpm)												
Resting baseline mean	74.53	11.11	74.82	11.58	.19	27	.850	[-2.79, 3.36]	0.02			
Resting baseline max	82.92	10.71	85.35	12.60	.87	27	.392	[-3.30, 8.15]	0.20			
Neuropsychological testing mean	75.42	11.46	90.54	13.94	7.63	27	<.001	[11.05, 19.18]	1.15			
Neuropsychological testing max	85.53	14.02	97.92	14.14	4.92	27	<.001	[7.23, 17.55]	0.85			

Note. bpm = beats per minute; *g* = Hedges' *g*; CI = confidence interval.

Table 3 Stair-Climbing Intensity Measures ($n = 28$)

Measure	SC1		SC2		SC3		SC4		SC5		SC6	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Heart rate (bpm)												
Mean	105.09	10.44	116.34	10.64	121.83	11.75	124.76	13.43	129.99	14.2	133.18	15.68
Max	116.53	11.67	125.67	11.71	131.96	13.17	135.75	14.28	140.07	14.83	142.92	16.19
%HR _{Max}	66.01	6.45	73.09	6.65	76.53	7.24	78.37	8.26	81.64	8.58	83.64	9.56
%HR _{Reserve}	54.16	11.86	63.89	12.67	70.42	13.92	74.36	15.00	79.15	14.87	82.29	16.47
RPE												
Pre	7.29	1.63	10.82	1.92	11.50	1.85	12.18	2.09	12.75	2.45	13.18	2.14
Post	12.21	2.23	13.57	2.47	14.00	2.52	15.11	2.52	15.43	2.53	15.75	2.75
Stairs climbed	12.21	2.23	13.57	2.47	14.00	2.52	15.11	2.52	15.43	2.53	15.75	2.57

Note. SC = stair-climbing interval; bpm = beats per minutes; %HR_{Max} = percentage of heart rate maximum; %HR_{Reserve} = percentage of heart rate reserve; RPE = rating of perceived exertion (minimum = 6, maximum = 20).

Table 4 Planned Contrasts for %HR_{Max} and %HR_{Reserve} (*n* = 28)

Interval	%HR _{Max}				%HR _{Reserve}			
	df	F	p	η_p^2	df	F	p	η_p^2
SC1 vs. SC2	1,27	60.27	<.001	.69	1,27	41.08	<.001	.60
SC2 vs. SC3	1,27	21.90	<.001	.45	1,27	26.47	<.001	.49
SC3 vs. SC4	1,27	15.59	.001	.37	1,27	21.51	<.001	.44
SC4 vs. SC5	1,27	14.27	.001	.35	1,27	10.66	.003	.28
SC5 vs. SC6	1,27	06.71	.015	.20	1,27	05.82	.023	.18

Note. SC = stair-climbing interval; %HR_{Max} = percentage of heart rate maximum; %HR_{Reserve} = percentage of heart rate reserve.

a large main effect of cognitive task, $F(1.45, 39.19) = 511.12$; $p < .001$; $\eta_p^2 = .95$, and planned contrasts confirmed large increases in RTs between the Pro and Anti tasks, as well as between the Anti and Pro/Anti tasks ($p < .001$, $\eta_p^2 \geq .87$ in both cases), indicating an increase in difficulty across the tasks. With regard to the main purpose of this study, a medium to large effect of session, $F(1, 27) = 3.594$; $p = .069$; $\eta_p^2 = .12$, indicated improvement in cognitive performance following the exercise intervention; however, the effect was only marginally significant. The interaction between the session and cognitive test showed a small effect size and did not approach significance, $F(2, 54) = 0.435$; $p = .649$; $\eta_p^2 = .02$.

Mood States

Table 5 shows descriptive statistics for the VAMS in each session. Paired sample *t* tests assessing differences in mood states between the two sessions revealed that the participants reported feeling more tired after stair climbing compared with the control session, $t(27) = 2.26$; $p = .032$; $g = 0.51$. None of the other mood state comparisons between the two sessions indicated a difference ($p \geq .236$, $g \leq 0.21$).

Discussion

The purpose of the current study was to trial in healthy older adults a brief and readily accessible exercise intervention that could translate to everyday life. To our knowledge, this is the first study to investigate the effect of a stair-climbing intervention on cognitive performance and mood states in older adults. As hypothesized, cognitive performance was better following the interval stair-climbing intervention relative to the control session, as evidenced by a fairly large effect ($\eta_p^2 = .12$) on RTs, albeit only marginally significant ($p = .069$). However, contrary to our hypotheses, improvements in cognitive performance did not increase with the difficulty of the task, and there were no mood benefits. Instead, the participants reported feeling more tired following the stair-climbing intervention.

The evidence of improved cognitive performance following the interval stair-climbing intervention in the present study is consistent with past studies reporting beneficial effects of an acute bout of continuous aerobic exercise on cognitive performance in older adults (Córdova et al., 2009; Kamijo et al., 2009; McSween et al., 2019; Petrella et al., 2019). However, the pattern of results (Figure 3) is not consistent, with previous studies reporting that performance on more challenging cognitive tasks benefits most from acute exercise (Ludyga et al., 2016; Pesce & Audiffren, 2011), as the pattern of benefits in the current study was not greatest for the most difficult task (Pro/Anti). One possible explanation for these findings is that the majority of our

Table 5 Cognitive Performance and Mood States in the Control and Stair-Climbing Sessions (*n* = 28)

Measure	Control		Stair climbing	
	M	SD	M	SD
Pro task				
Median RT (ms)	373	47	366	53
Accuracy (%)	99.82	0.01	99.46	0.01
Anti task				
Median RT (ms)	499	89	479	75
Accuracy (%)	98.12	0.01	98.12	0.02
Pro/Anti task				
Median RT (ms)	756	106	742	103
Accuracy (%)	94.37	0.05	93.83	0.06
Mood state				
Sad	6.00	8.60	8.00	12.61
Energetic	60.64	21.64	57.17	22.59
Tense	23.21	22.82	21.46	22.11
Happy	72.03	14.42	75.57	17.77
Tired*	17.89	18.22	28.57	22.13
Calm	73.50	21.19	74.78	23.25

Note. RT = reaction time.

* $p < .05$.

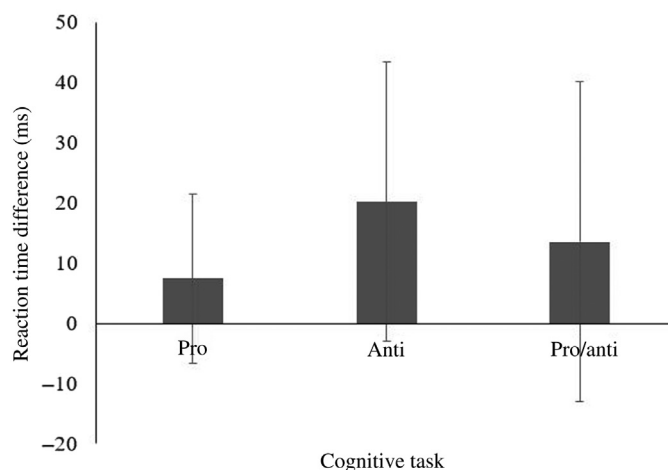


Figure 3 — Cognitive differences (stair-climbing vs. control session) for each test in 28 older adults. The main effect of session showed a fairly large effect size. Reaction time difference was calculated by subtracting median correct response latencies during the interval stair-climbing session from the control. Positive values indicate better performance following interval stair climbing. Error bars represent 95% confidence intervals.

participants did not meet the thresholds for high-intensity exercise during the stair-climbing protocol. Although compared with the Stenling et al. (2019) stair-climbing protocol of 3×1 -min intervals, we increased the number of stair-climbing intervals to six in an effort to ensure a high-level exercise intensity, only 25% of our participants reached the threshold for high-intensity exercise (i.e., 90% HR_{max}; Norton et al., 2010). In addition, the participants' average perceived exertion rate on the RPE scale was only 15.73, which is lower than the threshold for high exertion (RPE = 17; Norton et al., 2010). According to the intensity classification system recommended by Norton et al.

(2010), all of our participants reached at least moderate-intensity exercise (threshold 55% HR_{Max}) during the stair-climbing intervals, and the number of stairs climbed during each interval tended to increase across the intervals, which suggests they were putting in effort. Nonetheless, insufficient exercise intensity could have been a factor limiting cognitive benefits.

Regarding mood ratings, our finding that the stair-climbing intervention was associated with participants' reporting feeling more tired is consistent with a previous report that an acute bout of moderate-intensity aerobic exercise is associated with increases in physical exhaustion in older adults (Focht et al., 2007). These findings contrast with reports of improvements in mood states following acute light to moderate-intensity exercise in older adults (Hogan et al., 2013; Hyodo et al., 2019; Nouchi et al., 2020; Pierce & Pate, 1994). The higher exercise intensity (~80% HR_{Max}) achieved by participants in Focht et al. (2007) and the current study compared with participants in studies that reported improvements in mood states after exercise (~70% HR_{Max}) may explain the different mood outcomes, with higher intensity exercise making older adults feel more tired. The contrasting mood outcomes in the current study relative to the shorter stair-climbing intervention in young adults (Stenling et al., 2019), which showed an increase in positive mood states (i.e., feeling more energetic) and a decrease in negative mood states (i.e., feeling less tense and tired), may relate to a combination of the current demographic being older and the stair climbing involving more intervals. In addition, it should be noted that older adults show a more positive (i.e., feeling happier, calmer, and more energetic) and less negative (i.e., feeling less sad, tense, and sleepy) mood profile relative to younger adults on VAMS (Machado et al., 2019). In relation to this, and given that the current sample showed a mood profile consistent with the older adults in Machado et al. (2019), when making comparisons with a young adult population, one should keep in mind that older adults may be less likely to show increases in their positive and decreases in their negative mood profile due to there being less room for change. In any case, the current stair-climbing protocol is clearly not optimal for improving mood states in older adult populations.

It has been suggested that postexercise assessment time may be an important moderator in studies investigating the effect of exercise on mood in younger adults (Reed & Ones, 2006). Logically, one might assume that this would be particularly true for older adults, given that they tend to be more easily fatigued. As such, to observe an improvement in mood states in older adults, particularly in the context of high-intensity protocols, it may be necessary to increase the duration of the postexercise period preceding neuropsychological testing. This may help older adults feel less fatigued during neuropsychological testing, which could potentially benefit cognitive performance as well (Santos et al., 2013).

Limitations and Future Research

One key limitation of the present study is that, due to the large number of exclusions, we did not have sufficient power to investigate the effect of sex on cognitive performance and mood states following the stair-climbing intervention. There is some evidence in the literature that sex is an important moderator of the effect of exercise on cognitive functioning (Barha & Liu-Ambrose, 2018; Stenling et al., 2019). The main reason for our small final sample size was that a large number of potential participants failed the PAR-Q due to being on blood pressure medication ($n = 19$). It has been suggested that the PAR-Q may not be ideal for use in older populations, as it overestimates the risk of exercising while on

blood pressure medication (Shephard, 2015; Thomas et al., 1992). Therefore, future studies should consider an alternative way of screening older adults for physical readiness to engage in exercise. It should also be noted that approximately 11% of participants in the current study were taking HR-altering medications; Thus, future studies might investigate HR-altering medications as a potential moderator of the effects of acute exercise on neuropsychological functioning.

Another limitation is that we did not have enough power to analyze the participants' habitual physical activity levels in relation to the neuropsychological measures in the current study. Past research indicates that higher levels of habitual physical activity are associated with superior cognitive performance in healthy older adults (Guiney et al., 2019; Orland et al., 2020), and better mood profiles (Monteiro-Junior et al., 2017). Moreover, past research indicates that unfit individuals may experience more fatigue compared with more fit individuals (Reed & Ones, 2006). According to NZ physical activity guideline reports (Van et al., 2003), approximately 93% of the participants in the current study are categorized "very active," as they reported engaging in more than 5 hr/week of physical activity (physical activity level on NZPAQ = 12.48 hr/week on average across the two sessions), thus indicating that the sample of older adults who participated in the current study were unusually habitually active, which could potentially impact their responsiveness to acute bouts of physical activity. Regardless, the unusually active sample calls into question whether the current results generalize to the wider older adult population, which on average is far less active. Therefore, in addition to making efforts to recruit a sample that is more representative of the general population with respect to physical activity habits, future studies should analyze the level of habitual physical activity as a potential moderator of the effects of a stair-climbing intervention on cognitive function and mood in older adults.

Furthermore, the current study only considered acute effects of exercise and thus cannot inform with regard to chronic effects of a stair-climbing intervention in older adults. Given the improvements in cognitive performance after other forms of chronic high-intensity interval training in older adults (Coetsee & Terblanche, 2017; Kovacevic et al., 2019; Mekari et al., 2020), it would be beneficial to investigate chronic effects of the stair-climbing intervention in older adults, although the protocol may first need to be adjusted to better suit older adults. In addition, the fact that the trials were randomized each time the cognitive tests ran introduced unnecessary variation that could be minimized by prerandomizing the trial sequence and then using that sequence for all participants (perhaps one randomized sequence for the first visit and another for the second visit, to avoid reexposing individuals to the same sequence while also counterbalancing with respect to session order). Finally, we did not investigate potential mechanisms underlying improved cognitive functioning, such as increased cerebral blood flow and oxygen uptake and supply to the brain (Kujach et al., 2018), and increased brain-derived neurotrophic factor concentration (Griffin et al., 2011; Hwang et al., 2016; Vaynman et al., 2004), which have been linked to cognitive benefits in relation to other forms of acute exercise.

Conclusions

The present study yielded initial evidence that a brief stair-climbing intervention has the potential to improve cognitive performance in older adults, thus providing indications that this accessible and time-efficient mode of exercise that can easily be translated to

naturalistic settings (e.g., households and workplaces) may prove to be a promising intervention strategy to improve cognitive performance and, consequently, quality of life in older adults. However, it should be noted that in addition to the final sample size being small, the older adults sampled were unusually active, and thus further research will be needed to confirm the benefits in more typically sedentary older adults, who should have more room for neuropsychological improvement but, on the other hand, may be less capable of the rapid stair climbing involved. Furthermore, because the current stair-climbing protocol was associated with reports of higher levels of tiredness in older adults, more research may be needed to develop a stair-climbing intervention protocol optimally suited to older adult populations.

Acknowledgments

This study was preregistered (ACTRN12619001690145). The data will be available from the corresponding author upon request. This work was supported by a University of Otago Doctoral Scholarship and a Brain Research New Zealand Pacific Summer Research Scholarship.

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