Title	Making the steps count: Adult stair use: Hindsight, insight & foresight
Author(s)	Tung C K C, Aziz A R, Ong S T H and Chia M Y H

This is the published version of the following article:

Tung, C. K. C., Abdul Rashid Aziz, Ong, S. T. H., & Chia, M. Y. H. (2023). Making the steps count: Adult stair use: Hindsight, insight & foresight. *Physical Activity, 1*(1), 3-17.

Physical Activity 1(1) 2023: 3—17 | https://doi.org/00.00000/0000000

OPEN ACCESS Check for updates

REVIEW PAPER

Making the Steps Count: Adult Stair Use-Hindsight, Insight & Foresight

Tung CKC[1], Aziz AR[2], Ong STH[3], Chia MYH[1]*

[1] Physical Education & Sports Science, National Institute of Education, Nanyang Technological University, Singapore
[2] Singapore Sports Institute, Sports Singapore
[3] Changi General Hospital, Singapore

ABSTRACT

The primary aim of the review is to present a balanced narrative of adult stair use. Healthy young and older adults can expect to reap multiple anthropometric, neuromuscular, physiological, and metabolic health benefits following adherence and accomplishment of stair use that is sustained over 2 to 12 weeks, at least 3 times a week, at a moderate-to-vigorous intensity, either within exercise designs of continuous and sustained exercise, or within a timesaving, low volume, and high-intensity interval training set up. There are inherent risks of falls in stair use and participants should adhere to safety tips when navigating stairs in daily life as a form of commute or as intentional exercise. Additional steps for safety and inclusiveness to adult stair use exercise include customizing stair use to suit individual health, fitness, and the exercise context including those with special needs and medical conditions by working with medical practitioners.

Keywords:
care,
demerits,
merits,
stair-walk

Received:
June 18, 2022
Accepted:
September 28, 2023
Published online:
November 20, 2023

Introduction

The conceptual frame of the narrative review on stair-climbing is through the lens of hindsight, insight, and foresight. Hindsight informs future actions by examining data on what, how, and why things happened in different contexts. Insight is the nexus between past findings and future possibilities and is the discernment of useful data and openness to different forms of knowledge. Foresight is the extrapolation of insight to what it might be and wonderment about why things are the way they are and what that means for what things might be. As such, the review (1) addresses multiple benefits and the safety concerns of stair- climbing, (2) provides information on precautionary measures from the 'fall' literature, and (3) summarizes information about exercise modifications suited to different fitness levels of young and older adults. Stair use can feature as part of daily commute or as a form of deliberate exercise. The review focuses primarily on stair use in healthy young and older participants.

Methods

Hindsight

Hindsight informs future actions by examining data on what, how, and why things occurred in different contexts.

Adult stair use exercise

The last 20 years have seen interest in stair use as a mode of exercise multiply as evidenced by the increase in publications with the keywords "stair use", "stair-climbing" and "exercise" [92].

***CORRESPONDENCE:** Professor Michael CHIA, PhD, PPA, FMCCY; Physical Education and Sports Science Academic Group, National Institute of Education; 1 Nanyang Walk, Singapore; Email: michael.chia@nie.edu.sg

© Physical Activity (PA) is the official journal of the Asian Society of Kinesiology (ASK).

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

Stair- climbing, taken to describe ascending and descending stairs, is an affordable, accessible, and convenient exercise for aerobic training that can be performed in various settings such as in public staircases at home or work, or using stair climbers at fitness facilities. The promotion of stair use in health promotion is that it is a low impact and of short duration energy expenditure activity during daily commutes or travels [42,96,22,35]. Aside from tower- or vertical running, it appears that the public has yet to adopt or accept stair use as a convenient form of exercise. Public apprehensions about the safety and applicability of stair use for fitness or for health enhancement exist. These public perceptions of stair use are exacerbated by a lack of understanding about how stair use can be modified to suit people of different levels of fitness could also explain some inertia in its adoption.

Benefits of stair use exercise in healthy young and older adults

Stair-climbing, at the appropriate training volumes and intensities, appears efficacious in improving $\dot{V}O_2$ max resting heart rate, peak power output, post-exercise blood lactate concentration, blood pressure, lipid profiles, blood glucose levels, other metabolic blood markers, ratings of perceived exertion, and energy levels in healthy populations <Table 1, studies 1-12>. In the main, in the compiled studies, the samples of healthy participants were women (aged 18-30 years), adults (aged 19-39 years), middle-aged adults (aged 40-50 years) and senior adults (aged 65 years), and where beneficial outcomes were reported in timed- series or pre-to-post training studies (2-12 weeks; 2-7 times a week; at moderate-to-vigorous intensities) on the effects of stair use exercise. Nonetheless, some of the studies did not detect significant changes in body mass, body composition, lipid profiles, and strength after stair-climbing training <Table 1, studies 2, 3, 4, 6 & 7> due to stair use.

Fall risk in adult stair use exercise

Falls during stair use is a primary concern for exercise prescription. Epidemiological studies on the prevalence and severity of injuries due to falls in stair use suggest that falls are a result of the interactions among factors that are associated with the person, the environment, and the task at hand [91,48,68]. These interactions among these factors are discussed in greater detail in the segment on precautionary measures to take in stair use exercise.

Among older adults, falls during stair use represents a leading cause of accidental death, making up 10% of all fatal fall accidents [82]. For middle-aged adults, fatal falls are most evident in work settings [86]. Many of the falls in stair use are attributed to the risky behaviors of users such as using mobile phones [36,19], carrying items while taking the stairs [82], and not using the handrails in stair use [30]. 91% of young adults and 57% of older adults reported that they engage in at least some risky behaviors when taking the stairs [82]. Furthermore, kinesiological studies on stair use showed that foot clearance is variable and is often less than a centimetre from the stair surface, especially on the first and second steps [62,88] and the low foot clearance can increase the probability of tripping. Furthermore, the coefficient of friction generated during stair use is also variable compared to level walking, and it is much higher during stair descent and when there is an increase in walking speed in the stair use [14,31,32 ,23, 12].

Falls during stair use when compared to level walking, represent a disproportionately high risk for mortality, or major injuries like traumatic brain injury and hip fracture [82,34,6]. Common types of stair use injuries are sprains and strains, soft tissue injuries, and fractures [6]. The body regions most frequently injured are the lower extremities and head/neck and older adults are more likely to sustain fractures [6]. Such injuries can lead to long-term disability and have high economic costs to the country owing to loss of manpower days for work. Given that stairway falls are a common occurrence throughout the adult lifespan, more can be done to better educate adults about the safety and care in stair use with point-of-decision prompts to use the stairs safely with posters, signages near or on staircases, and to discourage risky behaviors in stair use.

Summary of hindsight to adult stair use exercise

The health benefits of regular stair use for healthy young and older adults are manyfold and represent an under-tapped and underutilized exercise modality. The benefits of stair-walking or stair-running must be counterbalanced by the risks for falls, where potentially the injury sustained is more serious than those sustained

in walking or running on the level. Practitioners of stair use exercise should take steps to reduce or eliminate the risks of falls so as to maximize the benefits of stair use exercise to health and wellbeing.

Insight

Insight is the nexus between past findings and future possibilities and is the discernment of useful data and openness to different forms of knowledge.

Table 1. Impact of stair-climbing on physiological and metabolic markers in healthy young and older adults

No.	Study	Subjects	Exercise type	Exercise protocol description	Findings
1	Boreham et al., 2000	N = 22 sedentary young women, 18-22 y	Lifestyle-based / Ascent and Descent / Structured	7-wk daily stair-climbing program 199 steps per ascent at 88 steps·min^{-1}; progress from 1 ascent per day to 6 ascents in week 7	Stair-climbing group *vs.* Control group: Rise in HDL (P<0.05) Reduced total cholesterol/HDL ratio (P<0.01) Improved $\dot{V}O_{2max}$ (P<0.01) Decrease in resting HR (P<0.01) Reduction in post-exercise lactate (P<0.01)
HDL: High-density lipoprotein, $\dot{V}O_{2max}$: Maximal oxygen consumption, HR: Heart rate					
2	Egaña et al., 2004	N = 22 active healthy women, 29 ± 5 y	Steady-state / Structured / Ascent-only Stair climber *vs.* Elliptical trainer *vs.* Treadmill running	12-wk, 3 d·wk^{-1} Wk 1 to 4: 70% to 75% HR_{max} for 30 min per session Wk 5 to 8: 75% to 80% HR_{max} for 40 min per session Wk 9 to 12: 80% to 90% HR_{max} for 40 min per session	Stair-climbing group *vs.* Control group: Significant increases in$\dot{V}$ O_{2max} and $\dot{V}_{Emax}$ No significant between-group differences in post-training improvements No significant decrease in mean body mass and % body fat in any training group
HR_{max}: Maximal Heart Rate, $\dot{V}_{Emax}$: Maximal ventilation, $\dot{V}O_{2max}$: Maximal oxygen consumption					
3	Boreham 2005	N = 15 sedentary healthy young women, 19 ± 1 y	Steady-state / Ascent and Descent / Lifestyle-based	8-wk, 5 d·wk^{-1} 199 steps per bout at 90 steps·min^{-1}, with 60 min rest between bouts Wk 1 to 2: 2 bouts·d^{-1} Wk 3 to 4: 3 bouts·d^{-1} Wk 5 to 6: 4 bouts·d^{-1} Wk 7 to 8: 5 bouts·d^{-1}	Stair-climbing group *vs.* Control group: Significant improvements in $\dot{V}O_{2max}$ (P < 0.05) and LDL-C (P < 0.05) No significant changes in: BMI, Total cholesterol, HDL-C, TC/HDL-C, Triglycerides and Homocysteine
BMI: Body Mass Index, HDL-C: High-density lipoprotein cholesterol, TC/HDL-C: Total cholesterol/High density lipoprotein cholesterol ratio, LDL-C: Low-density lipoprotein cholesterol, $\dot{V}O_{2max}$: Maximal oxygen uptake					
4	Kennedy et al., 2007	N = 45 healthy sedentary adults, 42 ± 1 y	Steady-state / Continuous ascent / Lifestyle-based	8-wk, 5 d·wk^{-1} 145 steps per bout at 75 steps·min^{-1} with 60 min rest between bouts Wk 1 to 2: 1 bouts·d^{-1} Wk 3 to 4: 2 bouts·d^{-1} Wk 5 to 6: 3 bouts·d^{-1} Wk 7 to 8: 3 bouts·d^{-1}	Stair-climbing group *vs.* Control group: Significant improvements in $\dot{V}O_{2max}$ (P < 0.05) No significant changes in Body mass, BMI, Body composition, SBP, DBP, Total Cholesterol, HDL-C, LDL-C, TC/HDL-C ratio, Triglycerides
BMI: Body Mass Index, DBP: Diastolic blood pressure, HDL-C: High density lipoprotein cholesterol, TC/HDL-C ratio: Total cholesterol/high-density lipoprotein cholesterol, LDL-C: Low-density lipoprotein cholesterol, $\dot{V}O_{2max}$: Maximal oxygen consumption					
5	Adegoke et al., 2012	N = 40 healthy young adults, 36 ± 3 y	Ascent-descent / Forward vs Backward Walking / Structured / Steady-state / Structured	8-wk, 3 d·wk^{-1} 1 bout = 1 ascent and descent at 24 steps·min^{-1} Wooden stepladder with 4 steps 15 cm high on the ascending and 3 steps 20 cm high on the descending Wk 1 to 2: 3 repeated bouts Wk 3 to 4: 6 repeated bouts Wk 5 to 6: 9 repeated bouts Wk 7 to 8: 12 repeated bouts	Forward stair-climbing group (FSC) *vs.* Backward stair-climbing (BSC): Significant difference (P = 0.006) between changes in cardiovascular endurance for FSC group and BSC group. Significant improvement in cardiovascular endurance only in FSC group (P = 0.045)
BSC: Backward stair climbing, FSC: Forward stair climbing					

6	Allison et al., 2017	Sedentary young adults Study 1 (Acute): N = 8, 19 ± 2 y Study 1 (Chronic): N = 12, 26 ± 11 y Study 2: N = 11, 26 ± 11 y	HIIT / Continuous Ascent vs Ascent-descent / Structured	Study 1 (acute response): 3 x 20-s sprints of continuous ascent *vs.* 3 x 20 s sprint cycling Study 1 (chronic effects): 6 wk, 3 d·wk^{-1}, 3 x 20-s sprints Study 2 (acute response): 3 x 20 s sprints of continuous ascent *vs.* 3 x 60-s ascent + descent with 1 flight of stairs *vs.* 3 x 60-s ascent + descent with 2 flights of stairs 61 steps per flight Study 2 (chronic effects): 6-w, 3 d·wk^{-1}, 3 x 60-s	Study 1 (acute response): Similar mean HR (P = 0.40) Similar increase in lactate after each bout (P = 0.40) Study 1 (chronic effects): 7% increase in total stair climbed from week 1 to 6 81% ± 4% HR_{max} on average per session $\dot{V}O_{2max}$ increased by 12% (P<0.001) No training-induced changes in resting systolic BP (*P* = 0.82), diastolic BP (*P* = 0.97), mean arterial BP (*P* = 0.86), BMI (*P* = 0.39), body mass (*P* = 0.35), fat-free mass (*P* = 0.09), fat mass (*P* = 0.70), % body fat (*P* = 0.42), fasting glucose concentration (*P* = 0.15), fasting insulin concentration (*P* = 0.31), and HOMA-IS (*P* = 0.52) Study 2 (acute response): Mean HR similar across all 3 protocols Study 2 (chronic effects): $\dot{V}O_{2max}$ increased by 8% (P=0.001) Significant improvements in BMI (*P* = 0.02), Body mass (*P* = 0.05), Fat-free mass (*P* < 0.001) No change in fat mass (*P* = 0.36), % body fat (*P* = 0.10), systolic BP (*P* = 0.50), diastolic BP (*P* = 1.00), and mean arterial BP (*P* = 0.96) post-training
BMI: Body Mass Index, BP: Blood Pressure, HOMA-IS: Fasting insulin concentration, HR: Heart rate, $\dot{V}O_{2max}$: Maximal oxygen consumption					
7	Cho et al., 2018	N = 18 sedentary healthy young adults, 21 ± 2 y	Steady-state / Ascent-descent vs Walking / Structured	2-wk, 3 d·wk^{-1} 30 min continuous ascent-descent of 22 steps at moderate intensity of 50-60% HRR	Stair-climbing exercise group (1) *vs.* Walking exercise group (2): Significant improvements in FMD (P = 0.003) in (1) and (P = 0.001) in (2) c-f PWV was significantly different post-intervention in (1) but not in (2) CSBP significantly decreased in (2) but not in (1). No significant improvements in bodyweight, % body fat, brachial BP, CDBP, and $\dot{V}O_{2peak}$ in either group
BP: Blood pressure, c-f PWV: Carotid-femoral pulse wave velocity, CDBP: Central diastolic blood pressure, CSBP: Central systolic blood pressure, HRR: Heart rate reserve, $\dot{V}O_{2peak}$: Maximal oxygen consumption					
8	Jenkins et al., 2019	N = 24 inactive young adults, 20 ± 2 y	Lifestyle-based / HIIT / Exercise *vs.* Non-exercise	6-wk, 3 d·wk^{-1}, 3 bouts·d^{-1} Each bout was 3 x 20-s sprints with 2 min rest between sprints; and with 1 to 4 h rest between bouts RPE 5 ±1, ~85% HR_{mzx} Fixed training volume	Intervention group *vs.* Control group: $\dot{V}O_{2peak}$ increased (P<0.01) Peak power output increased (P<0.01)
HIIT: High intensity interval training, HR_{max}: Maximal Heart rate, $\dot{V}O_{2max}$: Maximal oxygen consumption					
9	Michael et al., 2021	N = 50 sedentary healthy women, 32 ± 1.0 y	Steady-state / Ascent only vs Ascent-descent / Lifestyle-based / Exercise *vs*. Non-exercise	8-wk, 5 d·wk^{-1}, 2 bouts·d^{-1} Home-based stair climbing (Home) was ascent-descent intervals of 200 steps Gym-based climber (Gym) was ascent-only at 143 steps per bout Climbing pace was 50-60 steps·min^{-1} and training increased by 1 bout every 2 week	Control *vs.* Gym vs Home: RPE after each fitness test was greater in Home *vs*. Gym Similar improvements in $\dot{V}O_{2max}$, post-exercise lactate, serum lipids, and body composition for Home and Gym (all P<0.03) Weaker evidence regarding improvements in changes in % body fat and leg power No improvements in resting DBP, HR, and fasting blood glucose
DBP: Diastolic blood pressure, HR: Heart rate, RPE: Rating of Perceived Exertion, $\dot{V}O_{2max}$: Maximal oxygen consumption					

10	Donath et al., 2014	N = 39 healthy seniors 71 ± 5 y	Steady-state / Ascent-only / Single-step vs Double-step / Structured / Exercise *vs.* Non-exercise	8-wk, 3 d·wk^{-1} Climbing at 75-85% HR_{max} at RPE 4-6 Wk 1 to 2: 128 to 320 steps Wk 3 to 4: 256 to 448 steps, Wk 5 to 6: 384 to 896 steps Wk 7 to 8: 448 to 1280 steps	1-step strategy group (INT_1) *vs.* 2-step strategy group (INT_2) *vs.* Control group (CON): No significant between-group differences in balance performance and unilateral/ bilateral maximal strength Decrease in resting HR (P<0.0.1), RPE (P<0.05), HR (P<0.01) & blood lactate (P<0.05) Greater degree of improvements in INT_2 for all-parameters compared to CON
HR: Heart rate, RPE: Rating of Perceived Exertion					
11	Mair et al., 2019	N = 11 inactive older women, 65 to 74 y	Step-ups / Lifestyle-based / Exercise *vs.* Non-exercise	6-wk, 3 d·wk^{-1}, 3 bouts·d^{-1} 4 sets of 10 step-ups a portable stepper of 20 cm in height Additional load (% body mass) Wk 1: 0% Wk 2 to 3: 5% Wk 4: 7.5% Wk 5 to 6: 10%	Cross-over design Significant improvement in absolute peak power (P = 0.037), normalised peak power (P = 0.036), stair climb time (P = 0.02) and normalised stair climb power (P = 0.004) No significant changes in absolute power output (P = 0.238), Normalised mean power output (P = 0.266), Quadricep muscle strength (P = 0.350), absolute stair climb power (P = 0.082), 4-m walk time (P = 0.314), and chair-rise time (P = 0.118)
ECC: Eccentric exercise, ECC+: Eccentric exercise with additional weight, CON: Concentric exercise					
12	Regnersgaard et al., 2020	N = 32 untrained healthy seniors, 70 ± 3 y	Steady-state / Ascent-only vs Descent-only vs Weighted (15% bodyweight) descent-only / Structured	Between 3-6 wk, 3 d·wk^{-1} 95 steps, exercise to exhaustion, 45 to 60 min per session RPE between 3 and 6 weeks of training (CON: 12.3 ± 0.3 and 12.5 ± 0.6; ECC: 11.6 ± 0.4 and 11.5 ± 0.4; ECC+: 11.9 ± 0.3 and 11.8 ± 0.5, respectively). Additional post-workout protein feeding	Eccentric exercise with additional weight (ECC+) *vs*. Eccentric exercise (ECC) *vs*. Concentric exercise (CON): No significant changes in leg press strength, leg extension power, or thigh muscle mass Significant changes only between ECC+ and CON in changes in leg muscle mass, calf muscle mass, and power CST Significant between-group differences in changes in body fat, and 6 min walking test performance
CST: Chair stand test, RPE: Rating of Perceived Exertion					

1. Stair use modalities

Table 1 provides a summary of the stair use exercise on physiological and performance-based outcomes in healthy young and older adults.

1.1. Stair ascent compared to stair descent

Research on stair use in healthy young and older adults feature stair ascent and descent from kinesiological perspectives. In the main, these studies demonstrated differences in joint angles and muscular forces between stair ascent and stair descent. More specifically, it appears that stair ascent places a high demand on knee extensors and hip extensors with relatively lower demand on knee flexors and hip flexors whereas stair descent appears to be more demanding on the knee extensors and knee flexors than stair ascent [70,72,77,2,11].

Teh & Aziz (2002) [87] investigated differences in cardiorespiratory demands between stair ascent and stair descent. They observed that mean oxygen uptake (33.5 ± 4.8 vs 17.0 ± 3.8mL•kg-1•min-1) and heart rate (159 ± 15 vs 107 ± 18 beats•min-1) in the last 30s of the exercise are greater during stair ascent compared to stair descent respectively, despite the increased average self-selected stepping rate (95 ± 14 vs 106 ± 14 steps•min-1) in stair descent. This suggests that stair descent is less demanding on the cardiovascular and respiratory systems and may be more appropriate for certain populations with impaired aerobic endurance. Regnersgaard et al. (2021) [73] reported similar improvements in leg muscle mass and performance in the 6-minute walk test after 6 weeks of either ascending-only or descending- only stair walking. However, there is limited comparative evidence in descent-only vs stair ascent and additional research on the physiological demands of stair descent only use will be helpful.

1.2. Continuous stair ascent compared to stair ascent-descent intervals

A typical exercise prescription for stair use involves continuous ascent on multiple levels of steps to develop fitness and improve health. However, some researchers contend that continuous stair ascent may be too challenging for adults who are unfit and older adults with an average level of fitness [85]. A viable alternative would be prescribing stair ascending or descending intervals on a reduced number of flights of stairs.

Pilot research by Takaishi et al. (2012) [84] showed that participants in the continuous ascent group reached a higher peak heart rate on average than participants in the ascending or descending group. The step rates were 90 steps/min for ascending for both modes of exercise and 75 steps•min-1 for the descending phase of the ascending or descending exercise. Although the total work done was slightly less in the stair ascent or stair descent group, the work-to-rest ratios and stepping speeds for both groups were similar. While studies directly comparing continuous ascent and stair ascent or stair descent interval exercises are limited, this demonstrates that the intensity of stair exercise can be moderated by altering the stair- descending phase in the exercise program.

1.3. Moderate-intensity continuous compared to high-intensity interval training (HIIT) in stair use

There is mounting evidence that accumulating 30-160min•week-1 of moderate-to-vigorous intensity stair climbing for 2-8 weeks can improve aspects of cardiovascular fitness in both young [7,21,8,41,58,57] and older adults [20]. Emergent studies support that stair use exercise is a safe and practical model or HIIT [3,51].

While studies that directly compare steady-state and HIIT stair use protocols are limited, a systematic review and meta-analysis on low-volume HIIT by Sultana et al. (2019) [83] concluded that despite a lower training volume, low-volume HIIT induces greater improvements in cardiorespiratory fitness compared moderate-intensity continuous training in normal weight, overweight and obese adults. This suggests that lower volumes of brief, intense stair use exercise is a time-efficient strategy to improve cardiovascular fitness.

1.4. Structured compared to lifestyle-based stair use interventions

Stair use exercise can be implemented as structured physical activity, typically accomplished in a single session during the day or as lifestyle-based physical activity, where multiple bouts of stair use are accomplished throughout the day. Due to the ease of access and abundance of private or public staircases, stair use exercise can be incorporated throughout the day as part of daily living. Current evidence suggests that both structured [21,1,20,3] and lifestyle-based stair use [7,8,41] are efficacious in improving cardiovascular fitness. Additionally, some evidence in older adults suggest that lifestyle-based physical activity allows for greater adherence to physical activity and maintenance of cardiorespiratory fitness two years post-test compared to structured physical activity [6].

Some iterations of stair use exercise include "exercise snacks" as a novel strategy for increasing daily physical activity by incorporating a lifestyle-based HIIT. Exercise snacks are defined as isolated $\leq$ 1-min bouts of vigorous exercise performed throughout the day to break up periods of prolonged sedentary living. First implemented using cycling protocols [26] and then later adopted by Allison et al (2017) [3], the exercise protocols, involved either 3x20sec bouts of continuously ascending stairs interspersed with 2min rest or 3x60sec bouts of ascending and descending 1 flight of stairs interspersed with 60sec rest, were similarly adopted in several proof-of-concept studies on exercise snacks [20,9,10,39,71,37].

1.5. Single-step compared to double-step stair use

Two practical strategies are utilized when climbing stairs- contact with alternating feet on each step (single) or every other step (double). Longitudinal studies investigating the physiological effects of dual step stair-climb are very limited, however, kinesiological trials that document participants who climbed with the double-step strategy tend to climb at higher vertical speeds compared to the single-step strategy, resulting in greater metabolic and possibly muscular demands at hip flexors, vastus lateralis, and lateral gastrocnemius for participants who stair-climb using a double-step approach [28,29]. Thus, it is reasonable to assume that using a double-step stair climb is likely to be a more effective form of aerobic exercise

compared to stair climbing using a single-step. [20] observed significantly greater improvements in resting HR, RPE, postexercise HR, and blood lactate in healthy seniors in the double-step group compared to the single-step group after 8 weeks of progressive stair-climbing. However, no significant between-group differences were found on balance performance and unilateral/bilateral maximal strength. This suggests that a double-step stair climbing exercise is not only safe for healthy and active older adults but might also be a more effective form of stair use exercise.

1.6. Other modalities and progressions of stair use

Stair use is not solely limited to stairwells. In biomechanical terms, similar movements can be achieved using different stair-climbing equipment. Egaña and Donne (2004) [21] investigated cardiorespiratory changes after a 12-week exercise training with subjects assigned to stair- climber, elliptical trainer, or treadmill running and found similar significant improvements in $\dot{V}O_{2max}$ and $\dot{V}E_{max}$. Similar metabolic improvements were observed when directly comparing stair-climbing at home and with gym-based stair-climbers [57]. Home-based steppers also appear to be a safe and viable modality for accumulating steps in older adults [53]. A preliminary study by Regnersgaard et al. (2020) [73] suggests that incrementally increasing load in stair use in the form of wearing weighted vests may be an alternative form of progression to increase the muscular demands of stair- climbing.

2. Keeping safe during stair use exercise

An examination of the stair use exercise literature in healthy young and old adults, which included unsupervised or supervised training, in group or individual settings, revealed no reports of adverse events due to stair use. This suggests that stair use is relatively safe and tolerable for healthy young and older adults and can be done independently without increased risk of harm, insofar as participants are medically cleared for the stair use exercise. The absence of injury during supervised stair use exercise could be due to increased vigilance under supervised conditions and reduced risk-taking behavior in participants in the stair use exercise compared to unsupervised stair use in everyday commute. It is noted that the research trials only lasted between 2 and 12 weeks, and there is apparently no longitudinal monitoring of the incidence of stair use exercise-related injuries. Nonetheless, a synthesis of the fall and the exercise-related injury literature distils the following recommendations in stair use exercises to minimize injury risks, and these are covered in the next segment.

2.1. Choose a well-lit public staircase

Vision provides vital information to guide stair navigation. While tread fixation is common behavior during stair-walking to guide foot placement and postural control [100,18], it may not be a requirement [60,61], due to the visual input from peripheral vision, more specifically from the lower visual field. The tread is the top portion of the step that the foot comes into contact with when ascending or descending stairs [5]. However, evidence on the importance of tread fixation and peripheral vision at higher speeds remains lacking.

Dimly lit staircases with poor illuminance significantly reduce the visual stimulus from the surrounding, and this is associated with reduced levels of static [93] and dynamic stability [33]. Previous studies show that older people tend to adopt a precautionary gait (reduced speed and increased stance time) without any change in step clearance in stair negotiation [81,31,32,101,78]. Even so, such precautionary gait in stair negotiation do not necessarily reduce the risk of falling because of dim ambient lighting. Furthermore, during moderate-to-vigorous intensity stair use at faster walking speeds, low ambient lighting would exacerbate and increase the risk of injurious falls. To reduce risk of harm, stair use in poor lighting should be avoided at all costs.

2.2. Avoid wet staircases and wear appropriate footwear

Frictional demands, at the same walking speed, increase during stair navigation as compared to level walking, with frictional demands for stair-descent higher than for stair-ascent. When steps on stairs are wet, the friction between the surface of the footwear and the stair surface decreases, and this increases the risk of slipping. This also applies to shoes with worn outsoles. Furthermore, studies comparing stair navigation and level walking have identified a greater range of motion (ROM) at the hips during stair-ascent and

greater ROM at the ankles during stair-descent [47,76,74,63]. While knee ROM is comparable between level walking and stair- climbing, experimentally restricting knee ROM with a brace significantly increased stance time, step width, and hip abduction angle, which are positively associated with fall risk [17]. The use of high heel shoes during stair-ascent and stair-descent also results in compensatory changes to lower limb joint angles such as increases in ankle inversion, hip abduction, and lateral pelvic tilt, which pose risks of pain and low stability due to changes in the movement of lower limb joints [67,56,79]. Therefore, for safe stair use, take additional care when wearing lower limb braces that limit joint range of motion, heavy shoes, flip-flops, or shoes with worn outsoles. Avoid choosing wet staircases and wearing high heels during stair use exercises.

2.3. Hold on to hand railings and avoid carrying additional load

Handrail use during stair ambulation significantly enhances recovery from balance loss and helps with the avoidance of falls. The benefits of handrail use are likely more substantial for older adults than for young adults given that decreased levels of stability and increased attentional demands is more likely in older adults in stair use. [38] Some research on handrail use is noteworthy. Gosine et al. (2019) [27] observed that of 5 of the 12 subjects who used the handrail to assist with balance recovery, 4 did so inadequately and did not fully grasp the handrail. Likewise, King et al. (2011) [43], showed that only 6 out of 18 participants fully grasped the handrails after an unexpected balance loss, while 5 touched it but could not fully grasp it. Conversely, Maki et al. (1998) observed no error in grasping among all 4 subjects when they were given clear instructions to apply "reach for grasp" strategies after an unexpected fall. Overall, this suggests that it may be more challenging to achieve a functional grasp on the handrail in the event of an unpredictable fall in stair use exercise. Proactive handrail use appears to be a promising strategy as it is shown to allow participants to withstand a higher magnitude of destabilization with reduced latency, and in-balance recovery time [45]. It is worthy to note that most users do not use a handrail even when it is available, will descend stairs beyond an arm's length from the handrail, and often carry items such that both hands are not free during everyday stair use [16,30,27,11]. It seems that the use of handrails is associated with lower stair self-efficacy scores in older adults [30], even then, there are safety benefits to be had for elderly adults, and promoting handrail use in stair navigation in everyday use can help decrease fall risk. Taken in context, it is recommended that young and older adults use stair-ascent and stair-descent within an arm's reach of a handrail, with older adults or individuals with lower stair self-efficacy continuously making use of the handrails. Carrying additional loads, such as water bottles that require the use of one or two hands is discouraged.

2.4. Avoid dual tasking when using stairs

Distracted attention represents another task-related risk factor during stair use exercise. Dual tasking – employing a cognitive or motor task during stair-ascent and stair-descent – occurs in the form of simultaneous use of mobile phones or increasingly, texting or reading with smartwatches. Dual-tasking negatively influences both gait and cognitive performance, by increasing step times [60], gait variability [19], and decreasing toe clearance of steps [99,94]. These alterations are magnified during the initial transition steps compared to continuous stair negotiation, suggesting that there is enhanced cognitive demand during transitions [88,99]. This in turn is consistent with the increased occurrences of falls at the top or bottom of the stairway when people are distracted [82]. Mobile phone use, and other visual tasks, also strongly takes attention away from the stairs and the surrounding area [36] and reduce the frequency of looking down [60]. This could pose problems when encountering unexpected obstacles in stair use. In addition, older adults appear to require increased neural resources for stair negotiation relative to young adults, as evidenced by the greater dual-task costs [65,88]. Stair use requires focused attention while in progress and these benefits are likely more substantial for older adults than for young adults given the older adults' decreased levels of stability and increased attention demands during stair use. [38] It would be prudent to avoid mobile phone or smartwatch use during stair-ascent or stair-descent to optimize performance and reduce fall risk during exercise.

3. Summary of insight to adult stair use exercise

Stair use exercise modalities employed to investigate the exercise impact on healthy young and older adults are varied to meet the objectives of the research. Stair use exercise prescriptions can be organized in the form of frequency, intensity, duration, type, volume, and progression or FITT-VP [4]. Evidence of physiological and metabolic benefits are documented for stair use exercise programs are of (a) 2-12 weeks, at least 3 days a week (b) physical exertion is of moderate-to-vigorous intensity, (c) duration of exercise engagement per session could be either continuous or in the form of HIIT, and (d) the stair use could include regular staircases or stair-climbers in fitness facilities or in the home. These offer insights in incorporating stair use exercises in a well-rounded multi-modal exercise program for health and fitness. Safety in stair use is paramount and safe exercise tips include- be medically cleared for stair use exercise, choosing a well-ventilated, well-lit, dry, and unobstructed stairwell to exercise, wearing proper footwear with non-worn soles for grip, keeping both hands free, and be at an arm's length from handrails or using handrails where necessary, and not be dual-tasking or engaging with other tasks when using the stairs.

Foresight

Foresight is the extrapolation of insight to what it might be and wonderment about why things are the way they are and what that means for what things might be. Apart from promoting and advocating for stair use in healthy younger and older adults, there is potential and scope to use stair-climbing as an available and accessible modality for exercise in other populations. This is outlined in the next segment on future research.

Future research

Precision preventive medicine and health promotion against non-communicable diseases in young and older adults

There is scope to employ and use a social-ecological model (SEM) approach [52,50] to better understand adult stair use in daily commute or as an intentional exercise regimen to keep non-communicable diseases such as type II diabetes, obesity and certain cancers at bay. The use of the SEM approach in promoting physical activity across the lifespan is promising in obtaining sustainable results [50]. Additionally, future research should include elucidating safe, effective, and more individualized prescribed combinations of FITT-VP [4] that relate to stair use with flexible iterations that are helpful to participants in different contexts in daily life and with intentional exercise.

Stair use in adult population with challenged conditions

Stair use in various modalities has been used as an exercise intervention in populations with pre-existing health conditions- including obesity, chronic stroke, chronic heart failure, and stage 2 hypertension <Table 2, studies 1-5>. While it is beyond the scope of this paper to determine the absolute and relative contraindications for stair climbing, it should be noted that stair use exercise may not be appropriate in certain populations or may pose disproportionate risk to those with pre-existing conditions. For example, individuals with chronic knee osteoarthritis, stair use may stress the load-intolerant tibia-femoral cartilage surfaces of the knee [95]. However, there is evidence for stair use exercises to be part of a well-structured exercise program to improve self-efficacy in independent stair ambulation and reduce the risk of falls [40]. Hence, the prescription of stair use exercise should be applied with the appropriate progressions & regressions as identified previously and may include additional forms of assistance such as a walk stick to limit risks of acute injury. Stair use exercise delivery for certain populations should also be supervised by qualified medical practitioners. Additionally, within the studies identified, there were no reports of adverse events due to stair use, suggesting that stair use may be relatively safe and tolerable as a form of prescriptive exercise under clinical or medical supervision. However, more longitudinal research is needed to understand the efficacy of stair use exercise modalities in individuals with specific medical conditions.

Adult stair use and psychological effects

The literature on the psychological impact of stair use on subjective and objective measures of cognitive function is limited. A systematic review by Gay et al. (2019) [24] concluded that studies using self-reports support the positive

Table 2. Adult stair-climbing in adults with challenged conditions

No.	Study	Subjects	Exercise type	Exercise protocol description	Findings
1	Chen et al., 2017	N = 30 obese sedentary older women, 60 to 82 y	Steady state / Ascending only *vs.* Descending only / Structured	12-wk, 3 d·wk^{-1} 60 steps·min^{-1}, 110 steps 6 levels where the number of sets per session increased by 2 sets of 6 levels per week; where week 1 commenced with 2 sets Note: Elevator was used to ascend in DSW only group and to descend in ASW only group	Ascend Stair Walking group (ASW) *vs.* Descend Stair Walking group (DSW) Significant (P<0.05) difference in decreased resting HR, decreased SBP, decreased DBP, decreased HbA1C, decreased total glycerol, decreased total cholesterol, decreased LDL-C, and increased HDL-C from ASW Similar significant (P<0.05) improvements in body mass, BMI and % body fat
BMI: Body Mass Index, DBP: Diastolic blood pressure, HbA1C: Glycated haemoglobin, HDL-C: High-density lipoprotein cholesterol, LDL-C: Low-density lipoprotein cholesterol, SBP: Systolic blood pressure					
2	Neethu 2016	N = 30 obese female young adults, 20 to 25 y	Steady state / Structured / Exercise *vs.* Non-exercise	6-wk, 7 d·wk^{-1}, 3 bouts·d^{-1} 25 steps·min^{-1} for 100 steps	Experimental group *vs.* Control group Significant (P<0.05) improvement in BMI and Rosenberg self-esteem score
BMI: Body Mass Index					
3	Wong et al., 2018	N = 41 postmenopausal women with stage 2 hypertension, 59 ± 1 y	Steady state/ Ascent only/ Structured/ Exercise *vs.* Non-exercise	12-wk, 4 d·wk^{-1} 192 steps, 12 levels Borg RPE: 11-13 Wk 1 to 3: 2 bouts·d^{-1} Wk 4 to 6: 3 bouts·d^{-1} Wk 7 to 9: 4 bouts·d^{-1} Wk 10-12: 5 bouts·d^{-1}	Stair-climbing group *vs.* non-exercising Control group Significant between-group decrease (P<0.05) and significantly decreased (P<0.01) in baPWV, SBP, DBP and HR in Stair-climbing group Significant increase in Leg strength (P<0.05)
baPWV: Brachial-artery pulse wave velocity, DBP: Diastolic blood pressure, HR: Heart rate, SBP: Systolic blood pressure					
4	Lee & Seo, 2014	N = 40 chronic stroke patients, 61 ± 5 y	Steady state / Structured	4 wk, 5 d·wk^{-1} 30 min per session under supervision of a therapist	Experimental group *vs.* Control group Experimental group experienced a significant difference (P < 0.05) in: Paretic vs nonparetic sides Weight-bearing footprint Changes in anterior length in the limit of stability Decrease in surface area ellipse of Romberg Difference in posterior length in the limit of stability
5	Theodorou et al., 2013	N = 12 elderly males with chronic heart failure, 66 ± 3 y	Steady state / Ascending only vs Descending only / Structured / Specific device - SmartEscalator	6-wk, 3 d·wk^{-1} Wk 1: 45 steps·min^{-1} Wk 1: 50 steps·min^{-1} Wk 1: 55 steps·min^{-1}	Stair ascending group *vs.* Stair descending group No between-group differences in physical characteristics at baseline and at week 6 Significant increase in resting isometric torque in descending group than ascending group

associations between the perceived difficulty of stair use and symptoms of anxiety and depression, and also the non-association between stair use and reduced incidence of mental illnesses. Studies using objective measures of stair use support the negative association between elevated symptoms of anxiety and depression and stair use performance. However, the current body of evidence is replete with heterogeneous methodology, generally small sample sizes, and other study limitations. Hence, more research is needed to provide greater insights into the bidirectional relationships between stair use or stair avoidance, and psychological outcome variables. As populations in societies age, the impact of exercise, including adult stair use, as a non-pharmacological aid to treat age- associated conditions like dementia, Parkinson's and Alzheimer's diseases will grow in prominence [75].

Summary of foresight to adult stair use exercise

Inclusivity, empowerment, and equality of access to better health in society is one of the sustainable goals of the United Nations [89]. Therefore, it is prudent to explore further research on how safe and modified stair use in adults can be made more

accessible to populations with special needs. The efficacy and effectiveness of stair use exercise or interventions in adults are limited to 2-12 weeks, and longer-term adherence to stair-climbing, the various combinations of FITT-VP that can accrue health benefits, and the stability of these health benefits beyond the period of monitoring are still indeterminate. More research attention to this area of need is helpful.

Results

Strengths and limitations

The strength of the narrative review on adult stair use is that there is wider coverage of the issues that are associated with stair use exercise in healthy young and older adults that practitioners find more relatable and useful in improving the health and quality of life [97]. That said, the review does not adhere strictly to a set search process, and it also does not address the issue of the strength of the existing evidence or the validity of inclusion or exclusion of studies on stair use in the adult population. Additionally, this review does not offer explicit prescriptions for the different modifications of stair use exercises.

Conclusions

The narrative review on stair use in healthy adults provided useful information through the authors' perspective of hindsight, insight, and foresight. While scientific interest in adult stair use appears to be increasing, the stair ascent-descent type of exercise prescription and its use in daily life, as an accessible and low-cost health-enhancing tool, is under-exploited, under- utilized, and under-appreciated. There are inherent fall risks in adult stair use and preventive education, incentivization, and promotion of stair use among healthy younger and older adults using a socioecological approach should be explored.

References

1. Adegoke BOA, Olagbegi OM. Comparative Effect of Forward and Backward Stair Climbing on Cardio-respiratory Parameters of Apparently Healthy Young Adults. African J of Physiother and Rehabil Sci. 2012; 4(1–2):34–9.
2. Adiputra LS, Parasuraman S, Khan M. K. A. A., & Elamvazuthi, I. Bio mechanics of Desending and Ascending Walk. Procedia Computer Sci. 2015; 76: 264–9.
3. Allison MK, Baglole JH, Martin BJ, Macinnis MJ, Gurd BJ, Gibala MJ. Brief Intense Stair Climbing Improves Cardiorespiratory Fitness. Med & Sci in Sports & Exerc. 2017; 49(2):298–307.
4. American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription, 10th ed. Philadelphia (PA): Lippincott Williams & Wilkins. 2017, p 472.
5. Aziz AR, Teh KC. Physiological Responses to Single versus Double Stepping Pattern of Ascending the Stairs. J of Physiol Anthropol and Appl Hum Sci. 2005; 24(4):253–7.
6. Blazewick DH, Chounthirath T, Hodges NL, Collins CL, Smith GA. Stair-related injuries treated in United States emergency departments. The Am J of Emerg Med. 2018; 36(4):608–14.
7. Boreham CAG, Wallace WFM, Nevill A. Training Effects of Accumulated Daily Stair-Climbing Exercise in Previously Sedentary Young Women. Prev Med. 2000;30(4):277-81.
8. Boreham CAG. Training effects of short bouts of stair climbing on cardiorespiratory fitness, blood lipids, and homocysteine in sedentary young women. Br J of Sports Med. 2005; 39(9):590–3.
9. Cabral-Santos C, Rafiei H, Lira FS, Little JP. 1288-PUB: Acute Inflammatory Response of Breaking Up Prolonged Sitting with Stair Climbing Exercise Snacks. Diabetes, 70(Supplement 1). 2021.
10. Caldwell HG, Coombs GB, Rafiei H, Ainslie PN, Little JP. Hourly staircase sprinting exercise "snacks" improve femoral artery shear patterns but not flow-mediated dilation or cerebrovascular regulation: A pilot study. Appl Physiol, Nutr, and Metabolism. 2021; 46(5):521-9.
11. Camargo J, Ramanathan A, Flanagan W, Young AA comprehensive, open-source dataset of lower limb biomechanics in multiple conditions of stairs, ramps, and level-ground ambulation and transitions. J of Biomech. 2021; 119:110320.
12. Chen YT, Li KW, Chen YY. Effects of Required Coefficient of Friction for Female in Different Gait. 2016 Int Conference on Industrial Engineering, Management Sci and

Application (ICIMSA). 2016;1–4.
13. Chen, T. C., Hsieh, C.-C., Tseng, K.-W., Ho, C.-C., & Nosaka, K. Effects of Descending Stair Walking on Health and Fitness of Elderly Obese Women. Med & Sci in Sports & Exerc. 2017; 49:1.
14. Christina KA, Cavanagh PR. Ground reaction forces and frictional demands during stair descent: effects of age and illumination. Gait & posture. 2002; 15(2):153-8.
15. Cho MJ, Bunsawat K, Kim HJ, Yoon ES, Jae SY. The acute effects of interrupting prolonged sitting with stair climbing on vascular and metabolic function after a high-fat meal. Eur J Appl Physiol. 2020; 120(4):829–39.
16. Cohen J, Cohen HH. Hold On! An Observational Study of Staircase Handrail Use. Proceedings of the Hum Factors and Ergon Soc Annu Meet. 2001; 45(20):1502–6.
17. Demura T, Demura S. Influence of Restricted Vision and Knee Joint Range of Motion on Gait Properties During Level Walking and Stair Ascent and Descent. J of Mot Behav. 2011; 43(6):445–50.
18. Den Otter AR, Hoogwerf M, Van Der Woude LH. The role of tread fixations in the visual control of stair walking. Gait & Posture. 2011; 34(2):169–73.
19. Di Giulio I, McFadyen BJ, Blanchet S, Reeves ND, Baltzopoulos, V., & Maganaris, C. N. Mobile phone use impairs stair gait: A pilot study on young adults. Appl Ergon. 2020; 84:103009.
20. Donath L, Faude O, Roth R, Zahner L. Effects of stair-climbing on balance, gait, strength, resting heart rate, and submaximal endurance in healthy seniors. Scand J of Med & Sci in Sports. 2014; 24(2):e93–e101.
21. Egaña M, Donne B. Physiological changes following a 12 week gym based stair-climbing, elliptical trainer and treadmill running program in females. J of Sports Med and Phys Fit. 2004; 44(2):141-6.
22. Eves FF, Webb OJ, Griffin C, Chambers J. A multi-component stair climbing promotional campaign targeting calorific expenditure for worksites; a quasi- experimental study testing effects on behaviour, attitude and intention. BMC Public Health. 2012; 12:423.
23. Fino P, Lockhart T. Required Coefficient of Friction during Turning at Self- selected Slow, Normal, and Fast Walking Speeds. J of Biomech. 2014; 47.
24. Gay JL, Cherof SA, LaFlamme CC, O'Connor PJ. Psychological Aspects of Stair Use: A Systematic Review. Am J of Lifestyle Med. 2019; 16(1):109– 21.
25. Gibala MJ, Little JP. Physiological basis of brief vigorous exercise to improve health. The J of Physiol. 2020; 598(1):61–9.
26. Gillen JB, Percival ME, Skelly LE, Martin BJ, Tan RB, Tarnopolsky MA, Gibala MJ. Three Minutes of All-Out Intermittent Exercise per Week Increases Skeletal Muscle Oxidative Capacity and Improves Cardiometabolic Health. PLOS ONE. 2014; 9(11):e111489.
27. Gosine P, Komisar V, Novak AC. Characterizing the demands of backward balance loss and fall recovery during stair descent to prevent injury. Appl Ergon. 2019; 81:102900.
28. Gottschall JS, Aghazarian GS, Rohrbach EA. The Metabolic and Muscular Differences Between Two Stair-Climbing Strategies of Young Adults. The J of Strength & Cond Res. 2010; 24(9):2558–63.
29. Halsey LG, Watkins DAR, Duggan BM. The Energy Expenditure of Stair Climbing One Step and Two Steps at a Time: Estimations from Measures of Heart Rate. PLoS ONE. 2012; 7(12):e51213.
30. Hamel KA, Cavanagh PR. Stair performance in people aged 75 and older. J of the Am Geriatr Soc. 2004; 52(4):563–7.
31. Hamel KA, Okita N, Higginson JS, Cavanagh PR. Foot clearance during stair descent: Effects of age and illumination. Gait & Posture. 2005; 21(2):135–40.
32. Hamel K, Okita N, Bus S, Cavanagh P. A comparison of foot/ground interaction during stair negotiation and level walking in young and older women. Ergon. 2005; 48:1047–56.
33. Heasley K, Buckley JG, Scally A, Twigg P, Elliott DB. Stepping up to a new level: Effects of blurring vision in the elderly. Invest Ophthalmology and Visual Sci. 2004; 45(7):2122–8.
34. Hemenway D, Solnick SJ, Koeck C, Kytir J. The incidence of stairway injuries in Austria. Accid Anal & Prevention. 1994; 26(5):675–9.
35. Hongu N, Shimada M, Miyake R, Nakajima Y, Nakajima I, Yoshitake Y. Promoting Stair Climbing as an Exercise Routine

among Healthy Older Adults Attending a Community-Based Physical Activity Program. Sports. 2019; 7(1):23.
36. Ioannidou F, Hermens F, Hodgson TL. Mind Your Step: The Effects of Mobile Phone Use on Gaze Behavior in Stair Climbing. J of Technol in Behav Sci. 2017; 2(3):109–20.
37. Islam H, Gibala MJ, Little JP. Exercise Snacks: A Novel Strategy to Improve Cardiometabolic Health. Exerc and Sport Sci Rev. 2022; 50(1):31–7.
38. Jacobs JV. A review of stairway falls and stair negotiation: Lessons learned and future needs to reduce injury. Gait & Posture. 2016; 49:159–67.
39. Jenkins EM, Nairn LN, Skelly LE, Little JP, Gibala MJ. Do stair climbing exercise "snacks" improve cardiorespiratory fitness? Appl Physiol, Nutr, and Metab. 2019; 44(6):681–4.
40. Joshi S, Kolke S. Effects of progressive neuromuscular training on pain, function, and balance in patients with knee osteoarthritis: A randomised controlled trial. Eur J of Physiother. 2023; 25(4):179–86.
41. Kennedy RA, Boreham CAG, Murphy MH, Young IS, Mutrie N. Evaluating the effects of a low volume stairclimbing programme on measures of health-related fitness in sedentary office workers. J of Sports Sci & Med. 2007; 6(4):448–54.
42. Kerr J, Eves F, Carroll D. Six-Month Observational Study of Prompted Stair Climbing. Prev Med. 2001; 33(5):422–7.
43. King EC, Lee TA, McKay SM, Scovil CY, Peters AL, Pratt J, Maki BE. Does the "eyes lead the hand" principle apply to reach-to-grasp movements evoked by unexpected balance perturbations? Hum Mov Sci. 2011; 30(2):368–83.
44. Ko DY, Lee HS. The Changes of COP and Foot Pressure after One Hour's Walking Wearing High-heeled and Flat Shoes. J of Phys Ther Sci. 2013; 25(10):1309–12.
45. Komisar V, Nirmalanathan K, King EC, Maki BE, Novak AC. Use of handrails for balance and stability: Characterizing loading profiles in younger adults. Appl Ergon. 2019; 76:20–31.
46. Kool B. Injuries in New Zealand 1985–1999. 2001.
47. Larsen AH, Sørensen H, Puggaard L, Aagaard P. Biomech determinants of maximal stair climbing capacity in healthy elderly women. Scand J of Med & Sci in Sports. 2009; 19(5):678–86.
48. Rubenstein LZ. Falls in older people: Epidemiology, risk factors and strategies for prevention. Age and Ageing. 2006; 35(suppl_2):ii37–ii41.
49. Lee J, Seo K. The Effects of Stair Walking Training on the Balance Ability of Chronic Stroke Patients. J of Phys Ther Sci. 2014; 26(4):517–20.
50. Lee Y, Park S. Understanding of Physical Activity in Social Ecological Perspective: Application of Multilevel Model. Front in Psychol. 2021; 12:622929.
51. Lim C, Dunford EC, Valentino SE, Oikawa SY, McGlory C, MacDonald MJ, Phillips SM. Skeletal Muscle Adaptation In Cardiac Rehabil Patients Undertaking Traditional Or Higher Intensity Stair-climbing Exercise: 2623 Board #84 May 29 10:30 AM - 12:00 PM. Med & Sci in Sports & Exerc. 2020; 52(7S):715.
52. Lusmägi P, Aavik K. Developing a Social-Ecological Model for Promoting Physical Activity Among Older Adults Based on the Experiences of 50+ Adults. SAGE Open. 2021; 11(3):21582440211032944.
53. Mair JL, De Vito G, Boreham CA. Low Volume, Home-Based Weighted Step Exercise Training Can Improve Lower Limb Muscle Power and Functional Ability in Community-Dwelling Older Women. J of Clin Med. 2019; 8(1):41.
54. Maki BE, Perry SD, McIlroy WE. Efficacy of handrails in preventing stairway falls: A new experimental approach. Safety Sci. 1998; 28(3):189–206.
55. Malta DC, Silva MMAD., Mascarenhas MDM, et al. The characteristics and factors of emergency service visits for falls. Revista de saude publica. 2012; 46(1):128-37.
56. Manabe K, Serita T, Hamada J, Adachi K, Fukumitsu H. Studies on the risk of fall when climbing stairs wearing high heels. Physiother. 2015; 101:e944.
57. Michael E, White MJ, Eves FF. Home-Based Stair Climbing as an Intervention for Disease Risk in Adult Females; A Controlled Study. Int J of Environ Res and Public Health. 2021; 18(2):603.
58. Min Jeong Cho, Ye Rim Park, Kanokwan Bunsawat, Hyun Jeong Kim, Eun Sun Yoon,

Sae Young Jae. Comparison of the effects of short-term stair climbing and walking exercise on vascular function in healthy young adults. Int J of Appl Sports Sci. 2018; 30(2):125–33.
59. Miyasike-daSilva V, Allard F, McIlroy WE. Where do we look when we walk on stairs? Gaze behaviour on stairs, transitions, and handrails. Exp Brain Res. 2011; 209(1):73–83.
60. Miyasike-daSilva V, McIlroy WE. Does It Really Matter Where You Look When Walking on Stairs? Insights from a Dual-Task Study. PLOS ONE. 2012; 7(9):e44722.
61. Miyasike-daSilva V, McIlroy WE. Gaze shifts during dual-tasking stair descent. Exp Brain Res. 2016; 234(11):3233–43.
62. Muhaidat J, Kerr A, Rafferty D, Skelton DA, Evans JJ. Measuring foot placement and clearance during stair descent. Gait & Posture. 2011; 33(3):504–6.
63. Nadeau S, McFadyen BJ, Malouin F. Frontal and sagittal plane analyses of the stair climbing task in healthy adults aged over 40 years: What are the challenges compared to level walking? Clin Biomech. 2003; 18(10):950–9.
64. Neethu PS. Effectiveness of stair climbing programme on BMI and self- esteem among obese college students. Indian J of Health & Wellbeing. 2016; 7(8):810–2.
65. Ojha HA, Kern RW, Lin CHJ, Winstein CJ. Age Affects the Attentional Demands of Stair Ambulation: Evidence From a Dual-Task Approach. Phys Ther. 2009; 89(10):1080–8.
66. Opdenacker J, Delecluse C, Boen F. A 2-Year Follow-Up of a Lifestyle Physical Activity Versus a Structured Exercise Intervention in Older Adults. J of the Am Geriatr Soc. 2011; 59(9):1602–11.
67. Park JW, Kim YJ. A Study on Changes in Lower Limb Joint Angles during Stair Walking with High Heel. The J of Korean Phys Ther. 2013; 25(6):379–85.
68. Peel N. Epidemiology of Falls in Older Age. Can J on Aging / La Revue Canadienne Du Vieillissement. 2011; 30(1):7-19.
69. Physical Activity Guidelines for Americans, 2nd edition. (n.d.). p 118.
70. Protopapadaki A, Drechsler WI, Cramp MC, Coutts FJ, Scott OM. Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals. Clin Biomech. 2007; 22(2):203–10.
71. Rafiei H, Omidian K, Myette-Côté É, Little JP. Metabolic Effect of Breaking Up Prolonged Sitting with Stair Climbing Exercise Snacks. Med and Sci in Sports and Exerc. 2021; 53(1):150–8.
72. Reeves ND, Spanjaard M, Mohagheghi AA, Baltzopoulos V, Maganaris CN. Influence of light handrail use on the biomechanics of stair negotiation in old age. Gait & Posture. 2008; 28(2):327–36.
73. Regnersgaard S, Knudsen AK, Lindskov FO, Mratinkovic M, Pressel E, Ingersen A, & Dela F. Down stair walking: A simple method to increase muscle mass and performance in 65+ year healthy people. Eur J of Sport Sci. 2020; 0(0):1–10.
74. Reid SM, Lynn SK, Musselman RP, Costigan PA. Knee biomechanics of alternate stair ambulation patterns. Med and Sci in Sports and Exerc. 2007; 39(11):2005–11.
75. Ribarič S. Physical Exercise, a Potential Non-Pharmacological Intervention for Attenuating Neuroinflammation and Cognitive Decline in Alzheimer's Disease Patients. Int J of Mol Sci. 2022; 23(6):3245.
76. Riener R, Rabuffetti M, Frigo C. Stair ascent and descent at different inclinations. Gait & Posture. 2002; 15(1):32–44.
77. Samuel D, Rowe P, Hood V, Nicol A. The biomechanical functional demand placed on knee and hip muscles of older adults during stair ascent and descent. Gait & Posture. 2011; 34(2): 239-244.
78. Shaheen AF, Sourlas A, Horton K, McLean C, Ewins D, Gould D, Ghoussayni S. Effects of lighting illuminance levels on stair negotiation performance in individuals with visual impairment. J of Electromyogr and Kinesiol. 2018; 39:8–15.
79. Shang J, Chen L, Zhang S, Zhang C, Huang J, Wang X, Yan A, Ma X. Influence of high-heeled shoe parameters on biomechanical performance of young female adults during stair ascent motion. Gait & Posture. 2021; 81:159–65.
80. Sherrington C, Whitney JC, Lord SR, Herbert RD, Cumming RG, Close JCT. Effective Exercise for the Prevention of Falls: A Systematic Review and Meta- Analysis. J of the Am Geriatr Soc. 2008; 56(12):2234–43.

81. Simoneau GG, Cavanagh PR, Ulbrecht JS, Leibowitz HW, Tyrrell RA. The Influence of Visual Factors on Fall-related Kinematic Variables During Stair Descent by Older Women. J of Gerontol. 1991; 46(6):M188–M195.
82. Startzell JK, Owens DA, Mulfinger LM, Cavanagh PR. Stair Negotiation in Older People: A Review. J of the Am Geriatr Soc. 2000; 48(5):567–80.
83. Sultana RN, Sabag A, Keating SE, Johnson NA. The Effect of Low- Volume High-Intensity Interval Training on Body Composition and Cardiorespiratory Fitness: A Systematic Review and Meta-Analysis. Sports Med (Auckland, N.Z.). 2019; 49(11):1687–721.
84. Takaishi T, Imaeda K, Tanaka T, Moritani T, Hayashi T. A short bout of stair climbing-descending exercise attenuates postprandial hyperglycemia in middle- aged males with impaired glucose tolerance. Appl Physiol, Nutr & Metab. 2012; 37(1):193–6.
85. Takaishi T, Ishihara K, Shima N, Hayashi T. Health promotion with stair exercise. The J of Phys Fit and Sports Med. 2014; 3(2):173–9.
86. Talbot LA, Musiol RJ, Witham EK, Metter EJ. Falls in young, middle-aged and older community dwelling adults: Perceived cause, environmental factors and injury. BMC Public Health. 2005; 5(1):86.
87. Teh KC, Aziz AR. Heart rate, oxygen uptake, and energy cost of ascending and descending the stairs. Med. Sci. Sports Exerc. 2002; 695–9.
88. Telonio A., Blanchet S, Maganaris CN, Baltzopoulos V, Villeneuve S, McFadyen BJ. The division of visual attention affects the transition point from level walking to stair descent in healthy, active older adults. Exp Gerontol. 2014; 50:26–33.
89. THE 17 GOALS | Sustainable Development. (n.d.). https://sdgs.un.org/goals (Accessed April 28, 2022)
90. Theodorou AA, Panayiotou G, Paschalis V, Nikolaidis MG, Kyparos A, Mademli L, Grivas GV, Vrabas IS. Stair descending exercise increases muscle strength in elderly males with chronic heart failure. BMC Res Notes. 2013; 6(1):87.
91. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N. Engl J of Med. 1988; 319(26):1701-7.
92. Timeline—Overview for stair climbing ... In Publications—Dimensions. (n.d.). 2022; https://app.dimensions.ai/analytics/publication/overview/timeline?search_mode=content&search_text=stair%20climbing%20exercise&search_type=kws&search_field=full_search&year_from=1980&year_to=2022 (Accessed March 27, 2022)
93. Turano K, Rubin GS, Herdman SJ, Chee E, Fried LP. Visual Stabilization of Posture in the Elderly: Fallers vs. Nonfallers. Optom and Vision Sci. 1994; 71(12):761–769.
94. Vallabhajosula S, Tan CW, Mukherjee M, Davidson AJ, Stergiou N. Biomechanical analyses of stair-climbing while dual-tasking. J of biomech. 2015; 48(6):921-929.
95. Vincent KR, Vincent HK. Resistance Exercise for Knee Osteoarthritis. PM&R. 2012; 4(5, Supplement):S45–S52.
96. Webb OJ, Eves FF. Promoting stair climbing: Intervention effects generalize to a subsequent stair ascent. Am J of Health Promot: AJHP. 2007; 22(2):114–9.
97. Winett RA, Ogletree AM. Evidence-based, high-intensity exercise and physical activity for compressing morbidity in older adults: a narrative review. Innov in Aging. 2019; 3(2):igz020.
98. Wong A, Figueroa A, Son WM, Chernykh O, Park SY. The effects of stair climbing on arterial stiffness, blood pressure, and leg strength in postmenopausal women with stage 2 hypertension. Menopause. 2018; 25(7):731–7.
99. Zhang C, Sun W, Song Q, Gu H, Mao D. Performance of older adults under dual task during stair descent. J of Exerc Sci & Fit. 2018; 16(3):99– 105.
100. Zietz D, Hollands M. Gaze Behavior of Young and Older Adults During Stair Walking. J of Mot Behav. 2009; 41(4):357–66.
101. Zietz D, Johannsen L, Hollands M. Stepping characteristics and Centre of Mass control during stair descent: Effects of age, fall risk and visual factors. Gait & Posture. 2011; 34(2):279–84.