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Appropriate Stair-Step Height for Comfort, Satisfaction, and Cardiovascular Response: Implications for Design and Active Living

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ABSTRACT

Background: Ensuring appropriate step height in buildings, public spaces, and homes is crucial to public health and safety. This study aimed to determine the most comfortable and physiologically optimal step height among healthy adults. As such, this study aimed to determine the most comfortable step height among healthy adults based on heart rate (H.R.), blood pressure (B.P.), rate pressure products (RPPs), body mass index (BMI), and personal satisfaction.

Methods: Thirty healthy adults climbed 12-step stairs with 14-cm and 18-cm step heights to compare satisfaction and cardiovascular changes.

Results: A step height of 14 cm was the most comfortable and satisfying, with no significant changes in H.R., B.P., and RPP ($p < 0.077–0.19$). In contrast, the step height of 18 cm significantly increased H.R., B.P., and RPP ($p < 0.001$) and required much time to climb without satisfying participants. Meanwhile, BMI significantly negatively impacted H.R., B.P., RPP, time to climb stairs, and satisfaction when ascending the stairs with a step height of 18 cm. 14 cm is the most comfortable, satisfying, and recommended step height for healthy adults for homes, public buildings, and attractions. In contrast, an 18-cm step height could be suggested for fitness exercise to increase H.R., B.P., and RPP.

Conclusion: The results of this study provide valuable insights for risk management and healthcare policy professionals to develop guidelines and recommendations for step height in homes, public buildings, and other infrastructure. Implementing appropriate step heights can promote active living, proper stair utilization, and avoid related injuries, ultimately contributing to better population health outcomes.

Keywords: Heart rate, blood pressure, physical activity, stairs, satisfaction, building, quality of life.

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INTRODUCTION

Stairs have become a standard structure and component of many houses, offices, public and community buildings, etc., coming in various shapes, heights, widths, and sizes [1]. Regardless, all stairs must meet specific basic technical requirements, particularly concerning the safety and comfort of those climbing them. With their wide availability, stair climbing has become an everyday activity of daily living, and the ability to do so efficiently is vital to people's quality of life (QoL).

Stair climbing is a low-cost and accessible form of voluntary daily exercise offering various health benefits. It is one of the functional activities of daily living that aids individuals in maintaining mobility and independence. It offers many developmental benefits, including strengthening leg muscles, improving balance and coordination, and boosting spatial awareness [2]. It also improves dynamic balance, resting heart rate (H.R.), submaximal endurance, and cardiorespiratory performance [2,3], in addition to recovering compromised skeletal muscle microvascular phenotypes [4]. Moreover, it decreases body mass if performed as part of one's daily activities [5]. Stair climbing-based high-intensity interval training is safe, effective, and enjoyable for patients with stable coronary artery disease who have enrolled in cardiac rehabilitation [6], offering an energetic lifestyle involving physical activity, thus representing a healthy aerobic fitness option that has even been suggested as an alternative to traditional moderate-intensity continuous training [7]. Vigorous stair climbing has been reported to improve cardiorespiratory fitness in young, sedentary adults [8] and to be well tolerated in patients with type 2 diabetes [9], rendering it a useful and cost-effective aerobic exercise for smokers with dyspnea as well [10].

However, few studies have related these physiological benefits to any particular step height; for instance, Halsey et al. and Gimenez et al. linked the physiological benefits of stair climbing to step heights of 16.3 cm and 15 cm, respectively, where the former reported a lower H.R. when ascending stairs (15-cm step height) one step versus two steps at the time. However, Halsey and colleagues used different strategies to compare ascension via one step and two steps at a time rather than standard heights. This variation in stair-climbing methods may have impacted the results, in addition to not determining the most appropriate stair height for healthy individuals. Therefore, it is inappropriate to generalize the benefits of stair climbing at any step height to any population, as various stair heights are used across different community building codes.

Conversely, stair climbing has also been reported to cause knee joint pain, muscle soreness and fatigue, and stress on cardiopulmonary output [11], and it is recognized as a critical functional activity before and after knee replacement in osteoarthritis patients and individuals with patellofemoral joint pain [11-13]. Furthermore, around 30.5% of patients undergoing total knee replacement were dissatisfied with their ability to ascend and descend stairs [14]. This could increase the risk of falling among older people [15], who are acknowledged as having difficulty climbing stairs [16]. Older people take longer to ascend and descend stairs than young, healthy participants [17]. However, it is unclear whether the reported pain provocation, discomfort, dissatisfaction, and difficulty are due to pathological complications or stair-step heights.

Furthermore, no previous studies identified any stair step heights that cause patient discomfort and dissatisfaction. Only one study reported that a step height of 17 cm can increase the risk of falling among older people [15]. Therefore, it is inappropriate to generalize whether stair climbing harms or benefits the human body.

Moreover, Yaguchi et al. (2022)reported that the ability to climb stairs is a health asset among older people and should be encouraged when able. However, it remains crucial to determine an appropriate step height for older people [18]. Alves et al. (2020)considered stairs in public sites a barrier and challenge to walkability among older people [19]. So, standard step heights in homes, public buildings, and walkways at city attractions should be considered to promote elderly walkability and QOL.

Climbing stairs at home or in public for therapeutic purposes is considered an alternative form of hospital-based physical rehabilitation to meet patients' preferences and overcome barriers to participation and adherence. In one study, patients showed more interest in home-based programs [20], so facilitating an alternative home therapeutic program reasonably may benefit participants, such as offering choice, increasing program commitment, reducing costs, and enabling fast recovery. However, it is wise to determine an appropriate step height that meets therapeutic needs without harming patients.

Building stairs are a key element for a safe evacuation route to reduce fatalities [21], so evacuation time using the stairs is crucial to saving lives. Low stair heights in buildings are thus necessary for increasing movement speed with little physical effort, and it has been concluded that a ramp evacuation route is better than a stair route for older adults [21]. However, it can be argued that drawing such a conclusion based on a stair height of 17.78 cm along the evacuation route is inappropriate without testing other lower stair heights, i.e., 14-cm or 15-cm step heights. Particularly, it was reported that an 18-cm stair step height requires excessive energy and presents difficulty maintaining body balance due to weak core muscles in older people. Thus, it was suggested that a stair height of 15 cm or lower is appropriate for older people [22].

Step height is coded as standard for buildings in many countries. For instance, the Saudi Code set it between 12 cm and 18 cm, [23] the Brazilian Code fixed it at 17 cm, [24] the International Code Council determined it to be between 15.24 cm and 20.32 cm, [25], Czech Republic standards range between 15 cm and 18 cm [26], and the Occupational Safety and Health Administration (OSHA) of the United States (U.S.) Department of Labor standard for step heights ranging between 6.5 inches and 9.5 inches (~16.51 cm–24 cm) [26]. Variations in step heights in building codes are indeed grounded in human considerations, as building codes aim to create stair systems that are safe, accessible, and user-friendly. By considering such factors as safety, user mobility, and accident prevention, building codes ensure that step heights are appropriate for different user groups.

Clinically, the choice of step height during exercise could have various medical implications, as it affects the cardiovascular response, joint health, balance and coordination, and psychological aspects of exercise. Individuals can optimize their workouts and minimize potential health risks by considering these factors. It is essential to consult with their healthcare professional or personal trainer before starting a new exercise program based on climbing stairs, especially if they have any existing medical conditions or limitations. In particular, various step heights were reported to alter H.R. and blood pressure (B.P.), influence peak kinematic and kinetic parameters, impact the timing of gait cycle phases, and introduce later changes to the overall kinematic and kinetic time series patterns [2, 3, 28, 29]. Moreover, it is considered an essential aspect of assessing postoperative knee function, a performance predictor before and after total knee replacement, and a criterion for successful rehabilitation in terms of returning to previous activity levels [2,3,13,20].

A baseline for investigating the effects of stair step height is needed herein to allow for a controlled examination of the isolated effects of step height without the confounding factors associated with pre-existing medical conditions or age-related limitations. By establishing a baseline understanding of healthy individuals, future research can build upon this foundation and investigate the specific effects of step height in different populations. Therefore, this study was designed to determine healthy adult participants' most comfortable step height based on H.R., B.P., rate pressure product (RPP) readings, personal satisfaction, and the time needed to climb stairs.

MATERIAL AND METHODS

In this study, healthy young adults (n= 30, males) aged between 18 and 25 years were eligible to participate and were asked to sign a written consent form. The study was conducted in accordance with the Declaration of Helsinki and reviewed and approved by the Department of Rehabilitation Health Sciences. Participants were asked to climb 12 steps of two different heights, 14 cm and 18 cm, randomly and at a comfortable speed. The participants were nonathletes and did not exercise regularly, and they had no history of injury to the lower extremities or spine for at least 12 months before the study. The 14-cm and 18-cm step heights were selected because they are within the range of the reported standards for buildings in many countries and the most commonly used step height in Saudi Arabia [23,25,26].

The participants' H.R., B.P., and RPP were measured before and after climbing 12 stairs at 14- and 18-cm step heights. The time required to complete the tasks was recorded separately for each subject, and participants' satisfaction with the 14-cm and 18-cm step heights was measured after completing the above 12-step stair-climbing task.

This study used two stair flights with step heights of 14 cm and 18 cm, a digital arm sphygmomanometer, a stopwatch, and a personal satisfaction rating scale. The 12 steps having a 14-cm step height were 31 cm deep with a 168 cm inclination, whereas the 12 steps having an 18-cm step height were 31 cm deep with a 216 cm inclination. Both step conditions were immaculate, offering handrails, good light, and proper ventilation.

The Omron M6 Comfort was used as the digital arm sphygmomanometer to measure B.P., H.R., and RRP before and after stair climbing. This valid instrument underwent calibration before the study to minimize instrument variation and measurement bias [27], and new batteries were used to ensure measurement accuracy and reliability. The Omron M6 Comfort is a fully automatic B.P. monitor operating on the oscillometer principle, with a range of 0–299 mmHg for B.P. and 40–180 beats per minute (bpm) for H.R. Further, its cuff is inflated using an electric pump and deflated using a pressure-release valve. In addition to B.P. and H.R., RPP is a reliable clinical indicator of myocardial oxygen demand, defined as the product of resting H.R. and systolic B.P. (SBP) (RPP = SBP ×H.R.). Finally, a digital stopwatch measured the durations spent climbing 12 stairs of 14-cm and 18-cm step heights.

This satisfaction rating scale is a self-reporting 10-point scale that includes ten emotional faces with a rating number next to each. Participants were asked to look at the faces and rate their overall satisfaction, where higher points mean greater satisfaction. A rating ranging from an angry face at point one indicated no satisfaction, while a happy face at point 10 represented complete satisfaction. It has been documented that the 10-point scale is more suitable for measuring satisfaction [28], and all participants were familiar with these two-step heights and used them daily.

Statistical analysis

IBM SPSS Statistics for Windows, version 28 (IBM Corp., Armonk, N.Y., U.S.), was used for data analysis, and descriptive analyses were presented as mean and standard deviation (S.D.), where a p-value of < 0.05 was considered significant. In addition, a paired sample t-test was used to compare the variables before and after climbing the two different step heights. Pearson's (r) correlation coefficient was used to determine the degree of the relationship between BMI and HR, RPPs, and personal satisfaction with each step height.

RESULTS

Thirty young adults were recruited from the Rehabilitation Sciences Department at King Saud University. Their mean age was 22 ± 1 years, and their mean height and weight were 173 ± 7 cm and 72.7 ± 9 kg, respectively. The results of H.R., SPB, diastolic B.P., and RPP tests before and after climbing stairs with 14 and 18 cm step heights are presented in Table 1.

Table 1: Heart rate (H.R.), Systolic blood pressure (SBP), Diastolic blood pressure (DBP), and Rate pressure products (RPPs) before and after climbing 14 cm and 18 cm step heights.

	Climbing 14-cm step height			Climbing 18-cm step height		
	Before Mean ± SD	After Mean ± SD	*p-value	Before Mean ± SD	After Mean ± SD	*p-value
H.R. (bpm)	82.17 ± 8.6	88.47 ± 8.84	0.15	82.77 ± 9.71	96.20 ± 8.93	**0.001***
SBP (mmHg)	116.87 ± 9.09	119.27 ± 7.16	0.077	117.50 ± 9.27	129.33 ± 7.28	**0.001***
DBP (mmHg)	79.60 ± 05.55	80.60 ± 04.47	1.00	81.93 ± 06.80	84.63 ± 6.46	0.96
RPPs	9,628.5 ± 1,472.7	10,508.4 ± 1,408.1	0.19	9,771.6 ± 1,729.2	11,723.0 ± 1,409.2	**0.001***

**Paired sample t-test, Significant differences ($p < 0.05$)*

The H.R. values of the participants at rest before climbing stairs of 14-cm and 18-cm step heights were similar, at 82.17 ± 8.60 and 82.77 ± 9.71 pulsations/min, respectively. However, this value increased significantly to 96.20 ± 8.93 pulsations/min after climbing stairs having an 18-cm step height ($p < 0.001$), but it was only 88.47 ± 8.84 pulsations/min after climbing stairs having a 14-cm step height ($p < 0.15$).

The participants' SBP values at rest before climbing stairs with 14- and 18-cm step heights were comparable, at 116.87 ± 9.09 and 117.50 ± 9.27 mmHg, respectively, increasing significantly to 129.33 ± 7.28 mmHg after climbing stairs with an 18-cm step height ($p < 0.001$). Still, it was 119.27 ± 7.16 mmHg after climbing stairs with a 14-cm step height ($p < 0.077$).

The diastolic blood pressure (DBP) values of the participants at rest before climbing the stairs with 14- and 18-cm step heights were almost similar, at 79.60 ± 05.55 and 81.93 ± 06.80 mmHg, respectively, and there was no significant change (84.63 ± 06.46 mmHg) after climbing the stairs with 18- ($p < 0.96$) and 14-cm (80.60 ± 04.47 mmHg) step heights ($p < 1.00$).

Meanwhile, the RPPs of the participants at rest before climbing the stairs with 14- and 18-cm step heights were statistically similar at 9,628.5 ± 1,472.7 and 9,771.6 ± 1,729.2, respectively, showing no significant change (10,508.4 ± 1,408.1) after climbing stairs with a 14-cm step height ($p < 0.19$). However, the values increased significantly to 11,723.0 ± 1,409.2 after climbing stairs with an 18-cm step height ($p < 0.001$).

Satisfaction with the experience of climbing the stairs having a 14-cm step height was significantly higher (9.03 ± 0.76) than with the experience of climbing the stairs having an 18-cm step height (7.10± 1.32) ($p < 0.05$). Further, the time needed to climb the stairs with a 14-cm step height was significantly lower (6.17 ± 0.37 sec.) than that needed to climb the stairs with an 18-cm step height (8.87 ± 0.56 sec.) ($p < 0.05$) (Table 2).

Table 2: Personal satisfaction and time required to climb 14 cm and 18 cm step heights

	Climbing stairs with a 14-cm step height	Climbing stairs with an 18-cm step height	*p-value
	Mean ± SD	Mean ± SD	
Personal satisfaction	9.03 ± 0.76	7.10±1.32	**0.05**
Time required to climb (seconds)	6.17 ± 0.37	8.87 ± 0.56	**0.05**

*Paired sample t-test, Significant differences ($p < 0.05$)

Moreover, BMI positively correlated with H.R., RPP, and time to ascend, and when BMI increased, H.R., RPP, and time to ascend increased. In addition, BMI was negatively associated with personal satisfaction, resulting in decreased satisfaction when ascending stairs with an 18-cm step height (p-value < 0.05). Further, no association was found when ascending stairs with a 14 cm step height (Table 3).

Table 3: Relationship between BMI and heart rate, RPP, time required to climb stairs, and personal satisfaction.

	Climbing stairs with a 14-cm step height	Climbing stairs with an 18-cm step height
	BMI	BMI
Heart rate	0.40	0.77*
Rate pressure products	0.39	0.84*
Time required to climb	0.31	0.76*
Personal satisfaction	-0.11	-0.79*

*p-value < 0.05

DISCUSSION

This study demonstrated that climbing 12 steps, each with a 14 cm height, is comfortable and appropriate for healthy adults. In contrast, climbing 12 stairs with an 18-cm step height stresses cardiac output and is time-consuming and unsatisfactory for healthy adults. Hence, stairs with a step height of 18 cm may be suitable for increasing cardiorespiratory fitness.

Stair climbing is considered a moderate physical activity that is enough to improve inactive people's cardiorespiratory fitness [28]. It is also reported to be effective at increasing the maximum rate of oxygen attainable during physical exercise (VO_2 max), cardiorespiratory fitness, and the strength of the lower extremities, as well as reducing cholesterol [28,29]. Therefore, it would be wise for clinicians to determine the objective of using home steps, whether for comfort and to suit different age groups with or without health problems in mobilizing around their homes safely or for therapeutic purposes and fitness uses for various health problems.

Although climbing 12 steps should be comfortable and appropriate for young, healthy adult participants, further investigations should be conducted to determine the suitability of this step height for older people and patients with knee osteoarthritis, knee pain, ambulant stroke, and cardiovascular problems. These patients may need a low-effort step height to climb safely and independently. When considering step height suitability, it is imperative to prioritize individualized approaches, especially for vulnerable populations, such as the elderly and patients with specific health conditions. We can improve the safety, accessibility, and overall QoL of these individuals by designing step heights to meet their specific needs. To ensure step heights are appropriate and compliant with applicable regulations, it is essential to consult professionals specializing in accessibility and ergonomics.

Notably, different step heights necessitated various neuromuscular strategies to achieve essential foot clearance [30], and knee flexion/extension was adjusted in response to different stair heights, where greater knee flexion is required for step heights of 21 cm than for step heights of 17 cm in the swing phase [31]. Moreover, joint power, joint moments, and the length of the gastrocnemius medialis muscle tendon are shown to vary across different step heights [30,32]. For instance, ascending stairs with an 18-cm step height required excessive force and presented difficulties in maintaining body balance due to weak core muscles in older people. Thus, step heights were suggested to be limited to 15 cm or less for older people [22].

Conversely, ascending stairs with a 15-cm step height resulted in significantly greater muscle activity among the rectus femoris, biceps femoris, and tibialis anterior of stroke patients than the 10-cm step height [33]. In contrast, a 10-cm step height was reported to be stabler and easier to manage for stroke patients, improving muscle activity and increasing balance abilities [34]. Stair climbing is an exercise commonly prescribed to patients recovering from injuries or improving their fitness. Therapists also use stair-climbing exercises to strengthen muscles, improve endurance, enhance balance, and expand coordination. Nevertheless, the types of rehabilitation exercises prescribed can be significantly influenced by step height, which plays a crucial role in the intensity and effectiveness of rehabilitation exercises. Therefore, considering the influences of step height on the neuromuscular structure and biomechanics of patients with musculoskeletal and neurological problems could enable safe and effective physical rehabilitation at home.

The published literature has shown that climbing step heights of 17.5 cm, 15 cm, 17 cm, and 23 cm is an effective home training exercise that contributes to better overall fitness and health [35,36]. This agrees with the effects of climbing stairs with a step height of 18 cm in this study. However, despite the fitness benefits of climbing stairs with a step height between 15 cm and 23 cm, this range can increase the likelihood of falling. Climbing stairs with a 17-cm step height was reported to increase the possibility of falling among older people and to influence balance ability and quadricep strength in patients with operated knees [12, 25]. Such varieties and inconsistencies in step heights have led to the general assumption that the benefits of using stair climbing as a training exercise tool are inappropriate. Therefore, it is wise for building code standards officers and clinicians to cooperate in making home/office stair heights more suitable for a better QoL. Moreover, linking step height to weight, height, age, and the common biomechanics of users is a crucial factor in determining a suitable step heights for exercising and moving safely between stairs [37].

Standard codes for step heights in buildings differ among countries: it is between 12 cm and 18 cm in Saudi Arabia, 17 cm in Brazil, between 15.24 cm and 20.32 cm in the International Code Council, and between 8 cm and 15 cm in the Czech Republic [23, 25, 38]. However, whether these standard codes consider abnormal human biomechanics, cardiopulmonary comfort, and suitability as a training exercise is unclear. It is vital to remember that more than 1,000 individuals aged over 65 years are reported to die in the U.S. each year due to falling down stairs [39]. Therefore, it is imperative to identify the ideal step height for healthy adults worldwide before prescribing stair training activities for patients in physical rehabilitation programs. Both cultural and ergonomic factors are responsible for variations in standard codes for step heights, as different regions have different preferred step heights determined by historical traditions, religious beliefs, and societal norms. Conversely, ergonomic factors consider a person's physical characteristics, accessibility needs, and safety concerns. Furthermore, stairways with a lower risk of slipping, a lower rise, and a lower risk of tripping are crucial for the safety and comfort of users [26].

Increasing step heights enlarges both the joint reaction forces and joint angles of the hip, knee, and ankle during ascent, resulting in more significant stress on the joints, greater demand on the surrounding muscles, and greater pain and fatigue. Consequently, any increase in step height leads to more time and demand to climb stairs [15,30,40joint posture from weight-bearing magnetic resonance imaging, and ligament model. The three-dimension models of the patella, femur and tibia were developed with the medical image processing software, Mimics 11.1. The ligament was established by truss element of the non-linear FE solver. The equivalent gravity direction (-z direction]. This explains the lower recorded times to climb stairs and the higher satisfaction with climbing stairs having a 14-cm step height than with climbing stairs having an 18-cm step height. It is well known that people's satisfaction with stair design increases the use of stairs [41–43]. Thus, if stairs are poorly designed and fail to meet people's expectations and needs, they will likely remain unused. This is because discomfort with a staircase's step height is considered disadvantageous [38]. The lengths of the legs, calves, thighs, and feet directly affect stair descent and ascent ability, such that individuals with a height below 170 cm are recognized as finding a stair riser height of 15.2 cm as comfortable. In contrast, people above 170 cm favored a stair riser height of 17.8 cm [44].

The RPP value at rest and after climbing 12 stairs with a 14-cm step height falls within the normal zone [45]; however, it slightly exceeds the normal zone after climbing 12 stairs with an 18-cm step height. This may indicate that climbing stairs with an 18-cm step height is a low-intensity workload on the heart and can be adopted as a comfortable cardiovascular fitness exercise. This may also indicate that the higher the staircase, the higher the B.P. and H.R. Similar results have been reported for more energy and oxygen to climb stairs [29,35]. The recorded H.R., SBP, and DBP values are consistent with the range of values published for healthy adults [46], which could imply that the procedure in this study is consistent with those in other studies and that the changes detected after climbing 12 steps are real and observable.

Concerning body mass index (BMI), the significant correlations between participants' BMI and H.R., RPP, time to ascend, and personal satisfaction when ascending stairs with an 18-cm step height could be due to an abnormal alteration in the biomechanical functions of the muscles and joints in the lower limb that forces participants to exert more energy and put more stress on the heart to cope with the biomechanical alteration. The BMI of overweight and obese people substantially impacts the joint loading of the lower limbs when ascending stairs with a 17.8 cm step height, generating a more significant joint load on the lower limbs [5]. Moreover, the BMI values of obese people are reported to produce significantly higher peak hip adduction moments and peak knee anterior shear force than the BMI values of normal subjects when ascending stairs with a 20.5-cm step height, indicating that participants with a high BMI adopt different kinematic and kinetic strategies when ascending stair with a high step height, as excess body mass reduces gait velocity [47].

In contrast, participants' BMI when ascending stairs with a 14-cm step height had no significant correlation with RPP, the time to ascend stairs, and personal satisfaction, which could be related to the fact the biomechanical changes in the lower extremities when ascending stairs with a 14-cm step height are not significant enough to influence RPP, time to ascend, or satisfaction with step height. This may imply that the higher the step height, the more negative the impact of BMI and physical performance when ascending stairs. In the same contest, it was reported that an 18-cm step height requires excessive energy and presents difficulties in maintaining body balance in older people, for whom it was thus determined that a step height of 15 cm or less is appropriate.

Moreover, stairs in buildings and public sites are critical for safe evacuation and reducing fatalities. In contrast, evacuations via stairs with low step heights are crucial to increase movement speed with low physical effort [21]. As shown in this study, a 14-cm step height could be appropriate for an evacuation route compared to a 17.78-cm step height, which agrees with the suggested step height of 15 cm or less for older people [15,22].

This study is limited by its small sample size, which prevents the generalizability of its results. We also included only healthy participants to gain a baseline understanding of the impact of step height on individuals without specific limitations or disabilities. Therefore, the sample size should be increased in the future, and the study population should be diversified to include individuals of different ages and medical conditions so researchers can enhance the robustness and validity of their conclusions and contribute to developing knowledge in the desired field.

CONCLUSION

A 14-cm step height is the most comfortable and satisfying for healthy adults, though an 18-cm step height can be used gently to increase H.R., B.P., and RPPs in healthy adults. As such, clinicians should consider the biomechanical and physiological suitability of home/public building steps for therapeutic purposes. Moreover, step height in homes, schools, or public places should not be neglected under the pretext of saving money at the expense of our health, as it is crucial to quick emergency evacuation routes to save lives. Moreover, developing safer, more efficient step heights in building practices worldwide necessitates more study to determine whether uniformity in building codes is possible.

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REFERENCES

[1] Nicoll G. Spatial Measures Associated with Stair Use. Am J Health Promot. 2007;21(4_suppl):346-352. doi:10.4278/0890-1171-21.4s.346.

[2] Andersen LL, Sundstrup E, Boysen M, Jakobsen MD, Mortensen OS, Persson R. Cardiovascular Health Effects of Internet-Based Encouragements to Do Daily Workplace Stair-Walks: Randomized Controlled Trial. J Med Internet Res. 2013;15(6):e127. doi:10.2196/jmir.2340.

[3] Donath L, Faude O, Roth R, Zahner L. Effects of stairclimbing on balance, gait, strength, resting heart rate, and submaximal endurance in healthy seniors. Scand J Med Sci Sports. 2014;24(2). doi:10.1111/sms.12113.

[4] Lim C, Dunford EC, Valentino SE, et al. Both Traditional and Stair Climbing–based HIIT Cardiac Rehabilitation Induce Beneficial Muscle Adaptations. Med Sci Sports Exerc. 2021;53(6):1114-1124. doi:10.1249/MSS.0000000000002573.

[5] Shenassa ED, Frye M, Braubach M, Daskalakis C. Routine stair climbing in place of residence and Body Mass Index: a pan-European population based study. Int J Obes. 2008;32(3):490-494. doi:10.1038/sj.ijo.0803755.

[6] Dunford EC, Valentino SE, Dubberley J, et al. Brief Vigorous Stair Climbing Effectively Improves

Cardiorespiratory Fitness in Patients With Coronary Artery Disease: A Randomized Trial. Front Sports Act Living. 2021;3:630912. doi:10.3389/fspor.2021.630912.

[7] 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. Earnest CP, ed. PLoS ONE. 2012;7(12):e51213. doi:10.1371/journal.pone.0051213

[8] Allison MK, Baglole JH, Martin BJ, Macinnis MJ, Gurd BJ, Gibala M.J. Brief Intense Stair Climbing Improves Cardiorespiratory Fitness. Med Sci Sports Exerc. 2017;49(2):298-307. doi:10.1249/MSS.0000000000001188.

[9] Godkin FE, Jenkins EM, Little JP, Nazarali Z, Percival ME, Gibala M.J. The effect of brief intermittent stair climbing on glycemic control in people with type 2 diabetes: a pilot study. Appl Physiol Nutr Metab. 2018;43(9):969-972. doi:10.1139/apnm-2018-0135.

[10] Departments of Physical Medicine and Rehabilitation and Respiratory Physiotherapy, University Hospital of Gran Canaria Dr. Negrín, Bco de la Ballena s/n, University of E-35020- Las Palmas de Gran Canaria, Spain., M G, P S, Department of Mathematics and Informatics, University Campus of Tafira, University of Las Palmas de Gran Canaria, Spain. Application of The Bi-Level Stairs Climbing as Alternative of Respiratory Rehabilitation Training in Dyspneic Smokers. Int J Respir Dis Care Med. Published online June 22, 2017:22-27. doi:10.19070/2577-4409-170005.

[11] Goudakos IG, König C, Schöttle PB, et al. Stair climbing results in more challenging patellofemoral contact mechanics and kinematics than walking at early knee flexion under physiological-like quadriceps loading. J Biomech. 2009;42(15):2590-2596. doi:10.1016/j.jbiomech.2009.07.007.

[12] Lee S, Kim B, Kim S, et al. Preoperative physical factors that predict stair-climbing ability at one month after total knee arthroplasty. J Rehabil Med. Published online 2020:0. doi:10.2340/16501977-2690.

[13] Unver B, Ertekin Ö, Karatosun V. Pain, fear of falling and stair climbing ability in patients with knee osteoarthritis before and after knee replacement: 6 month follow-up study. J Back Musculoskelet Rehabil. 2014;27(1):77-84. doi:10.3233/BMR-130422.

[14] Tekin B. Expectations in patients with total knee arthroplasty. Acta Orthop Traumatol Turc. 2012;46(3):174-180. doi:10.3944/AOTT.2012.2655.

[15] Kunzler MR, Da Rocha ES, Dos Santos CS, Ceccon FG, Priario LA, Carpes FP. Should we consider steps with variable height for a safer stair negotiation in older adults? Work. 2018;59(1):15-21. doi:10.3233/WOR-172658.

[16] Verghese J, Wang C, Xue X, Holtzer R. Self-Reported Difficulty in Climbing Up or Down Stairs in Nondisabled Elderly. Arch Phys Med Rehabil. 2008;89(1):100-104. doi:10.1016/j.apmr.2007.08.129.

[17] Al-Abdulwahab SS. The Effects of Aging on Muscle Strength and Functional Ability of Healthy Saudi Arabian Males. Ann Saudi Med. 1999;19(3):211-215. doi:10.5144/0256-4947.1999.211.

[18] Yaguchi H, Sekiguchi Y, Honda K, et al. Biomechanical Characteristics of Long Stair Climbing in Healthy Young Individuals in a Real-World Study Using a Wearable Motion Analysis System. Biomechanics. 2022;2(4):601-612. doi:10.3390/biomechanics2040047.

[19] Alves F, Cruz S, Ribeiro A, Bastos Silva A, Martins J, Cunha I. Walkability Index for Elderly Health: A Proposal. Sustainability. 2020;12(18):7360. doi:10.3390/su12187360.

[20] Clark RA, Conway A, Poulsen V, Keech W, Tirimacco R, Tideman P. Alternative models of cardiac rehabilitation: A systematic review. Eur J Prev Cardiol. 2015;22(1):35-74. doi:10.1177/2047487313501093.

[21] Ahn C, Kim H, Choi I, Rie D. A Study on the Safety Evaluation of Escape Routes for Vulnerable Populations in Residential Facilities. Sustainability. 2022;14(10):5998. doi:10.3390/su14105998.

[22] Roh CG, Park BJ. A Study on the Design Criteria of Pedestrian Facility (Stairs) by Motion Analysis of Walking Parameters in the Elderly. J Korean Soc Transp. 2017;35(5):396-408. doi:10.7470/jkst.2017.35.5.396.

[23] Saudi Building Code. https://sbc.gov.sa/En/BC/Pages/buildingcode/BCHome.aspx.

[24] de Acessibilidade NTB. Acessibilidade a edificações, mobiliário, espaços e equipamentos urbanos. Rio de Janeiro. de Acessibilidade NTB. Acessibilidade a edificações, mobiliário, espaços e equipamentos urbanos. Rio de Janeiro.

[25] International Code Council, American National Standards Institute, eds. Accessible and Usable Buildings and Facilities: ICC A117.1-2009: American National Standard. International Code Council; 2010.

[26] Vesela L. Staircase - Dimensions of Stair Steps and their Deviations of Geometrical Accuracy. IOP Conf Ser Mater Sci Eng. 2019;471:022012. doi:10.1088/1757-899X/471/2/022012.

[27] Chahine, Topouchian J, Blacher J, et al. Validation of four devices: Omron M6 Comfort, Omron HEM-7420, Withings BP-800, and Polygreen KP-7670 for home blood pressure measurement according to the European Society of Hypertension International Protocol. Vasc Health Risk Manag. Published online January 2014:33. doi:10.2147/VHRM.S53968.

[28] Yadav N, Shankar R, Singh SP. Customer satisfaction – dilemma of comparing multiple scale scores. Total Qual Manag Bus Excell. 2023;34(1-2):32-56. doi:10.1080/14783363.2022.2028547.

[29] Teh KC, Aziz AR. Heart rate, oxygen uptake, and energy cost of ascending and descending the stairs: Med Sci Sports Exerc. 2002;34(4):695-699. doi:10.1097/00005768-200204000-00021.

[30] Riener R, Rabuffetti M, Frigo C. Stair ascent and descent at different inclinations. Gait Posture. 2002;15(1):32-44. doi:10.1016/S0966-6362(01)00162-X.
[31] Livingston LA, Stevenson JM, Olney SJ. Stairclimbing kinematics on stairs of differing dimensions. Arch Phys Med Rehabil. 1991;72(6):398-402.
[32] Arima Y, Tateuchi H, Mori K, Wakida M, Kim KH, Hase K. Relationship between vertical ground reaction force and muscle strength while climbing stairs after total hip arthroplasty. Clin Biomech. 2020;78:105088. doi:10.1016/j.clinbiomech.2020.105088.
[33] Yoon-Hee C. Lower limb muscle activities and gain in balancing ability following two types of stair gait intervention in adult post-chronic stroke patients: A preliminary, randomized-controlled study. Turk J Phys Med Rehabil. 2020;66(1):17-23. doi:10.5606/tftrd.2020.3335.
[34] Choi YK, Kim K, Choi JU. Effects of stair task training on walking ability in stroke patients. J Phys Ther Sci. 2017;29(2):235-237. doi:10.1589/jpts.29.235.
[35] Mir IA, Yu VLK, Jia FS, Bhat AH. Comparison between Stair Climbing and 1 Mile Walking in Relation to Cardiorespiratory Fitness among Sedentary Adults. In: Ibrahim F, Cheong JPG, Usman J, Ahmad MY, Razman R, Selvanayagam VS, eds. 3rd International Conference on Movement, Health and Exercise. Vol 58. IFMBE Proceedings. Springer Singapore; 2017:14-18. doi:10.1007/978-981-10-3737-5_4.
[36] Michael E, White MJ, Eves FF. Home-Based Stair Climbing as an Intervention for Disease Risk in Adult Females; A Controlled Study. Int J Environ Res Public Health. 2021;18(2):603. doi:10.3390/ijerph18020603.
[37] Hong JY, Li YJ, Metcalfe RS, Chen YC. Effects of acute and chronic stair-climbing exercise on metabolic health: A systematic review. J Sports Sci. 2024;42(6):498-510. doi:10.1080/02640414.2024.2345414.
[38] Nemire K, Johnson DA, Vidal K. The science behind codes and standards for safe walkways: Changes in level, stairways, stair handrails and slip resistance. Appl Ergon. 2016;52:309-316. doi:10.1016/j.apergo.2015.07.021.
[39] Startzell JK, Owens DA, Mulfinger LM, Cavanagh PR. Stair Negotiation in Older People: A Review. J Am Geriatr Soc. 2000;48(5):567-580. doi:10.1111/j.1532-5415.2000.tb05006.x.
[40] Wang X, Liu H, Dong Z, et al. Contact area and pressure changes of patellofemoral joint during stair ascent and stair descent. BMC Musculoskelet Disord. 2023;24(1):767. doi:10.1186/s12891-023-06882-0.
[41] Dolan MS, Weiss LA, Lewis RA, Pietrobelli A, Heo M, Faith MS. 'Take the stairs instead of the escalator': effect of environmental prompts on community stair use and implications for a national 'Small Steps' campaign. Obes Rev. 2006;7(1):25-32. doi:10.1111/j.1467-789X.2006.00219.x.
[42] Warburton DER. Prescribing exercise as preventive therapy. Can Med Assoc J. 2006;174(7):961-974. doi:10.1503/cmaj.1040750.
[43] Lewis A, Eves F. Prompt before the choice is made: Effects of a stair-climbing intervention in university buildings. Br J Health Psychol. 2012;17(3):631-643. doi:10.1111/j.2044-8287.2011.02060.x.
[44] Arslan M, Erkan I. A model for evaluating the user satisfaction of human movements on stairs through the ergonomic design approach. Theor Issues Ergon Sci. 2021;22(6):651-672. doi:10.1080/1463922X.2020.1852335.
[45] Sembulingam P, Sembulingam K, Ilango S, Sridevi G. Rate Pressure Product as a Determinant of Physical Fitness in Normal Young Adults. Journal of Dental and Medical Sciences. 14(4):08-12.
[46] Stedman TL, ed. Stedman's Medical Dictionary for the Health Professions and Nursing. Illustrated 5th ed. Lippincott Williams & Wilkins; 2005.
[47] Egret C, Amasay T, Ransom A, Ludwig K. Lower Extremities Biomechanics Patterns of Obese and Normal Body Mass Adults during Stairs Ascent and Descent. Int J Anat Appl Physiol. Published online October 28, 2019:119-123. doi:10.19070/2572-7451-1900022.