HUMAN MOVEMENT
2017; 18(3): 60–66

EFFECTS OF AN EIGHT-WEEK STEPLADDER EXERCISE PROTOCOL ON LOWER LIMB MUSCULAR STRENGTH OF APPARENTLY HEALTHY YOUNG ADULTS

original paper
doi: 10.1515/humo-2017-0026

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ABSTRACT
Purpose. Backward descent of stairs is associated with improved muscle strength and reduced joint stress, but the effect of backward ascent of stairs on lower limb muscle strength has not been reported. This study compared the effects of forward and backward stair climbing on lower limb muscle strength in apparently healthy young adults.
Methods. The total of 31 young volunteers were allocated to either forward or backward stair climbing group (n = 16 and 15, respectively). Dynamic quadriceps and hamstring muscle strength was assessed in addition to thigh girth at baseline and at weeks 4 and 8 with the use of the repetitive maximum method and tape measure, respectively.
Results. Between baseline and week 8, muscular strength in both groups (quadriceps: 14.4 ± 3.6 to 16.4 ± 3.4 kg; 14.0 ± 2.9 to 15.3 ± 2.7 kg; hamstring: 12.2 ± 3.2 to 13.4 ± 3.2; 11.7 ± 2.5 to 12.9 ± 2.7 kg) increased significantly ($p < 0.05$) while the increase in thigh girth was not significant ($p > 0.05$). The groups were comparable in all three measures post intervention.
Conclusions. Forward and backward stair climbing protocols are effective for improving the dynamic strength of the hamstring and quadriceps muscles of apparently healthy young adults. Thus, either protocol could be used for the improvement of lower limbs dynamic muscle strength.
Key words: stair-climbing, strength-training, quadriceps, hamstring

Introduction

Stair climbing is a component of lifestyle physical activity that has the potential for an accessible, effective, and affordable health intervention [1–3]. It has gained so much prominence that it was specifically recommended by the American College of Sports Medicine and American Heart Association for health improvement and maintenance [1, 4] It is a common functional training procedure in physiotherapy and sports science and has been reported to be highly associated with improved cardiovascular health, muscular strength, and fitness [5–8].

In spite of extensive published trials on stair climbing [5–10], its effectiveness regarding improvement of muscular strength still appears debatable. Most authors have focused on the cardiorespiratory and biomechanical effects of climbing stairs [5, 6, 8, 11]. The few available studies relating to the use of stairs in strength training have involved either individuals with mobility limitation (induced by cardiovascular disease) [7] or healthy seniors aged 65 years and above [10]. These authors have also come up with conflicting findings. For instance, researchers like Bean et al. [9] and Theodorou et al. [7] reported significant increases in muscle strength among healthy and diseased elderly men, respectively; whereas Donath et al. [10] did not find any remarkable effect of stair climbing on their participants' double leg maximal isometric force.

There is enormous evidence in literature to suggest that isometric, isotonic, and isokinetic strength training techniques increase muscle mass and strength [12–16]. One of the basic principles governing strength training is that of overload that implies tasking the muscle beyond its normal or regular capacity [14]. A muscle that is trained close to its force-generating capacity will increase in strength as strength improvement is generally governed by the intensity of overload and

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Received: March 27, 2017
Acepted for publication: July 18, 2017

Citation: Olagbegi OM, Adegoke BO, Christie CJ, Bolarinde OS, Jegede JA. Effects of an eight-week stepladder exercise protocol on lower limb muscular strength of apparently healthy young adults. Hum Mov. 2017;18(3):60–66; doi: 10.1515/humo-2017-0026.

not by the specific type of exercise used to apply that overload [13, 14]. Stair climbing is a dynamic training procedure which derives its overload from the trainee's body mass [17], although a group of researchers used weighted vests to provide additional training load [9].

Most researchers that used stair climbing for strength training have routinely employed forward climbing of stairs [9, 10] since it appears practically easier and more acceptable to the public. Backward stair descent was reported as the safer approach for people with knee osteoarthritis who also present with reduced strength and joint laxity [11]. Forward stair descent was shown to impose greater work load on the lower limb joint, which aggravates the patients' symptoms [11]. Further, studies on the effectiveness of climbing stairs for strength training among young adults who are active in sports or other activities of daily living are rather scarce. Besides, there has been no known previous attempt to investigate the efficacy of backward ascent of stairs in strength training although it was reported as having similar cardiovascular effects as forward approach [8]. Since backward stair descent is beneficial in terms of reduced joint stress and loading [11], it is pertinent to determine if combined backward stair ascent and decent will be useful for improvement of strength among healthy population with the view of extrapolating findings to people with knee joint complaints. Further, cost-effective interventions which require only stairs are important in poorer, developing countries like Nigeria. Therefore, the purpose of this study was to investigate and compare the effects of forward and backward stair climbing on hamstring and quadriceps muscles strength, as well as thigh muscle girth of apparently healthy young adults.

Material and methods

Participants

The protocol involved 31 apparently healthy male and female volunteers aged 18–30 years who were recruited from the University of Ibadan and University College Hospital communities in Nigeria. Oral interviews and physical examination of the participants' lower limbs were conducted to ensure they had no history of major injury or surgery (in the preceding 12 months), paralysis or weakness in their lower extremities. None of the participants was involved in any active sporting activity at the time. The subjects were assigned either to the forward stair climbing (FSC) or to the backward stair climbing (BSC) group in order of their availability [8].

Research design

A pre-test/post-test quasi-experimental design was applied in the study. The participants were allocated to the treatment groups (FSC or BSC) for an 8-week period, with sessions occurring 3 times per week.

Research venue

The study was conducted at the gymnasium of the Department of Physiotherapy, University College Hospital, Ibadan, Nigeria.

Procedure

The approval of the University of Ibadan / University College Hospital Joint Institutional Review Committee (UI/IRC/04/0050) was sought and obtained before the commencement of the study. Written informed consent was obtained from the participants after the experimental procedures had been explained. The participants' age was recorded in years, while their stature and body mass were measured with a stadiometer (with combined metric and mass scales) (Gulfex, Germany). For the purpose of uniformity, the subjects' dominant limbs were chosen for strength testing. The dominant limb was determined by instructing the participants to kick a ball thrown at them thrice. The limb used to kick the ball at least twice was chosen for the assessment [18].

Outcome measures

The assessment of dynamic quadriceps and hamstring muscle strength was performed by predicting a participant's one repetition maximum (1-RM) with the use of Berger's equation [19, 20]. The equation was reported to be valid for predicting 1-RM of lower limb muscles strength in adults and demonstrated good correlation with the conventional 1-RM test ($r = 0.97$; $p < 0.05$) [20]. Thigh girth was evaluated with a tape measure (Butterfly, China). Lower extremity girth measurements have demonstrated high reliability, both intra- and inter-tester, with the intraclass correlation coefficients (ICC) ranging 0.82–1.0 and 0.72–0.97, respectively [21].

Muscle strength testing

(a) *Dynamic quadriceps muscle strength*

Dynamic quadriceps strength was assessed with the Delorme boot (Oxford, England) and plastic weights (Oxford, England), with the participant in a high sitting position on a specially designed seat that had its backrest tilting at the angle of 120° to the horizontal. The position placed a stretch on the rectus femoris aspect of the quadriceps femoris muscle, thereby causing the force of the extensors of the knee to be increased [22]. The subject's back was strapped to the backrest of the testing seat, while the upper third of the thigh was strapped to the sitting platform to prevent extraneous movements of the thigh during tests. The legs were free to move in space from the knee. The Delorme boot was

strapped to the foot of the leg to be tested, and the plastic weights corresponding to a certain repetition maximum of the participant (W kg) were randomly selected and attached to the boot. The participant was instructed to lift the load by extending the knee of the limb to which the load was attached. The number of times they performed the lift from 90° of knee flexion to full knee extension before fatigue set in was also recorded as R [23].

(b) *Dynamic hamstring muscle strength*

Dynamic hamstring strength was determined with the Delorme boot and plastic weights. The participant was made to lie prone, with their feet hanging over the edge of the plinth. A pillow was placed under the knees to prevent compression of the patella between the femur and the plinth. The trunk and thighs were also strapped to the plinth to prevent extraneous movements of other parts of the body. The Delorme boot was strapped to the dominant foot, and the plastic weights corresponding to a certain repetition maximum of the participant (W kg) were attached to the boot. The participant was then instructed to flex their knee against the resistance offered by the load and lifted the weights within their limits of pain and muscle fatigue, as suggested by Puett and Griffin [23]. The number of times the individual lifted the load through the full range of motion (from knee extension to knee flexion) before getting fatigued was recorded as R.

Computations. The 1-RM for the hamstrings and quadriceps femoris muscles was estimated with Berger's equation:

$$1\text{-RM} = W\ (\text{kg})/(1.0261\ e^{-0.0262 \times R}) \text{ [19]}$$

The calculated 1-RM values were taken as the subject's dynamic quadriceps and hamstring strengths, measured in kilograms, to the nearest two decimal places.

(c) *Thigh girth*

The participants' thigh girth was assessed with an inelastic tape measure. The subject lay supine on the plinth with their lower extremities relaxed and straight. The landmarks of greater trochanter and the apex of the patella were located. The mid-point between the landmarks was marked with an erasable marker, and the thigh circumference was taken from the point and recorded in centimetres [24]. The measurements were obtained at baseline, week 4 and the end of the intervention period.

Stair climbing training programme (intervention)

The lead researcher practically demonstrated the training protocols to the participants before they were allowed to commence training.

A wooden stepladder with 4 steps (each 15 cm high) on the ascent side, and 3 steps (each 20 cm high) on the descent side, was used for the stair climbing training programme. Its highest platform was 60 cm high and its gradient on the ascent and descent sides was 0.67 and 0.91, respectively. All steps were 50 cm wide [8].

(a) *Forward stair climbing*

The participants in the forward stair climbing group faced the stairs with their arms hanging freely by their sides. They then ascended and descended the stairs in the forward direction. The ascent and descent lasted 8 seconds, with the participant's alternate foot stepping on each stair every second to a count of 1, 2 up to 8. The subjects ascended at the same side of the stairs and descended through the opposite set of steps without holding the rails, and performed 3 complete ascents and descents per session during weeks 1 and 2 of the training. A progression was built into the training as follows:

– weeks 3 and 4: 6 ascents and descents per session;
– weeks 5 and 6: 9 ascents and descents per session;
– weeks 7 and 8: 12 ascents and descents per session [8].

(b) *Backward stair climbing*

The format and progression for backward stair climbing training were as for the forward stair climbing training, except that the participants were now required to climb and descend the stairs in the backward direction (backing the stepladder) [8].

The training for both groups took place thrice weekly.

Statistical analysis

The data were analysed with the use of the SPSS 20.0 version software (SPSS Inc., Chicago, Illinois, USA). The descriptive statistics of mean, standard deviation, and 95% confidence intervals were computed. The independent *t*-test was applied to compare the participants' demographic characteristics and baseline muscle strength variables. Repeated measures ANOVA allowed within-group comparison of FSC and BSC participants' dynamic quadriceps muscle strength, dynamic hamstring muscle strength, and thigh girth across baseline, week 4, and week 8 of the study, while Bonferroni adjustment was performed for post-hoc analysis. One-way ANCOVA was also used to compare the parameters of the groups, with age as a covariate. (The groups were significantly different in their ages at baseline). The level of significance was set at $\alpha = 0.05$.

Results

A total of 31 apparently healthy young adults [FSC group: $n = 16$ (11 males, 5 females); BSC group: $n = 15$

(9 males, 6 females)] participated in the study. Their demographic characteristics and baseline muscle strength variables are presented and compared in Table 1. The participants in the FSC group were significantly older ($p = 0.007$) than those in the BSC training group, but the groups were comparable in the stature, body mass, and body mass index of the subjects.

As presented in Table 2, quadriceps muscle strength (FSC: 14.4 ± 3.6 to 16.4 ± 3.4 kg; BSC: 14.0 ± 2.9 to 15.3 ± 2.7 kg) and hamstring muscle strength (FSC:

Table 1. Comparison of the participants' demographic and muscle strength variables at baseline

Variable	Training groups		*t*-value	*p*-value
	FSC	BSC		
	Mean ± *SD*	Mean ± *SD*		
Age (years)	26.06 ± 3.09	23.13 ± 2.58	2.877	0.007*
Stature (m)	1.71 ± 0.13	1.69 ± 0.06	0.459	0.650
BM (kg)	61.13 ± 12.76	58.53 ± 4.85	0.737	0.467
BMI (kg/m^2)	20.85 ± 3.67	20.44 ± 1.70	0.391	0.699
DQS (kg)	14.39 ± 3.62	13.99 ± 2.86	0.340	0.736
DHS (kg)	12.17 ± 3.24	11.71 ± 2.51	0.442	0.662
TG (cm)	47.69 ± 5.74	47.13 ± 3.62	0.362	0.752

* significance at α = 0.05
FSC – forward stair climbing, BSC – backward stair climbing, SD – standard deviation, BM – body mass, BMI – body mass index, DQS – dynamic quadriceps muscle strength, DHS – dynamic hamstring muscle strength, TG – thigh girth

Table 2. Repeated measures ANOVA within-group comparison of FSC and BSC participants' variables across baseline, weeks 4 and 8 of study

Variable	Baseline	Week 4	Week 8	*p*	Cohen *d*
	Mean ± *SD* (95% *CI*)	Mean ± *SD* (95% *CI*)	Mean ± *SD* (95% *CI*)		
FSC GROUP					
DQS (kg)	14.39 ± 3.62^a (12.46–16.32)	15.70 ± 3.44^b (13.87–17.53)	16.38 ± 3.35^c (14.59–18.16)	< 0.001	1.52
DHS (kg)	12.17 ± 3.24^a (10.44–13.89)	12.99 ± 3.20^b (11.23–14.69)	13.43 ± 3.24^c (11.71–15.15)	< 0.001	1.48
TG (cm)	47.38 ± 6.42^a (44.63–50.74)	48.25 ± 6.50^a (44.79–51.79)	48.38 ± 6.42^a (44.96–51.79)	0.227	0.24
BSC GROUP					
DQS (kg)	13.99 ± 2.86^a (12.41–15.58)	14.92 ± 2.87^b (13.33–16.51)	15.32 ± 2.70^c (13.82–16.82)	< 0.001	1.19
DHS (kg)	11.71 ± 2.51^a (10.32–13.09)	12.41 ± 2.56^b (11.00–13.83)	12.94 ± 2.73^b (11.43–14.45)	< 0.001	1.12
TG (cm)	47.13 ± 3.62^a (45.12–49.14)	47.20 ± 3.69^a (45.16–49.24)	47.60 ± 3.36^a (45.74–49.46)	0.488	0.21

$^{a, b, c}$ – represent post-hoc analysis. Mean values with different superscripts are significantly ($p < 0.05$) different.
Mean values with same superscripts are not significantly ($p > 0.05$) different.
SD – standard deviation, CI – confidence interval, FSC – forward stair climbing, BSC – backward stair climbing, DQS – dynamic quadriceps muscle strength, DHS – dynamic hamstring muscle strength, TG – thigh girth

Table 3. Analysis of covariance comparison of the participants' parameters adjusting for age

Variable	R^2	Adjusted R^2	Mean difference (95% *CI*)	*F*	*p*
DQS (kg)	0.59	–0.09	0.52 (–2.04 to 3.08)	0.173	0.680
DHS (kg)	0.008	–0.06	0.60 (–1.95 to 3.15)	0.231	0.634
TG (cm)	0.021	–0.049	0.13 (–4.23 to 4.44)	0.004	0.953

Mean difference – difference between mean FSC and mean BSC, CI – confidence interval,
DQS – dynamic quadriceps muscle strength, DHS – dynamic hamstring muscle strength, TG – thigh girth

12.2 ± 3.2 to 13.4 ± 3.2 kg; BSC: 11.7 ± 2.5 to 12.9 ± 2.7 kg) increased significantly ($p < 0.05$) between baseline and week 8. Large effect sizes (ES) were observed for the increase in both measures for the two groups (FSC quadriceps: ES = 1.52; hamstring: ES = 1.48; BSC quadriceps: ES = 1.19; hamstring: ES = 1.12). The increase in thigh girth was not significant ($p = 0.227$) across the 3 time points of the study.

Between-group comparison did not reveal significant differences in any of the three measures (Table 3).

Discussion

Effects of forward and backward stair climbing on muscle strength and thigh girth

The results of the study suggest that both forward and backward stair climbing positively impact on dynamic strength expression despite no changes in the thigh girth. It is a known fact that a muscle that is trained close to its force-generating capacity will increase in strength, and the strength improvement is determined by the level of tension placed on such a muscle [13, 14]. The impact of body weight on the leg muscles during stair climbing provides overload which generates tension in the selected muscles and some other muscles of the lower limb [17]. This further suggests that the demand placed on the participants' hamstring and quadriceps muscles by the stepladder protocol was good enough to stimulate strength gain, hence the observed finding. The result regarding strength gain is consistent with the reports of Loy et al. [25], who observed a significant increase in the isokinetic quadriceps strength of 9 middle-aged women after a 12-week strength training with a treadmill stair climber.

The results suggest that both stair climbing protocols did not bring about the expected strength-induced hypertrophy as reflected by the inappreciable increase in the participants' thigh girth. Although strength training can cause muscle hypertrophy, the findings of some previous investigators [26–28] suggest that circumferential measurement is a poor predictor of muscle strength in spite of its wide usage. Bohannon [28] argued that other muscles, subcutaneous adipose tissue, blood vessels, and bones also contributed to the circumferential measurements results. Unfortunately, modern techniques of assessing muscle size, such as ultrasonography or computer tomography, were not readily available for use in this trial. An increase in muscle bulk is not a necessary pre-requisite for improvement in strength and power with training since important neurological factors significantly affect the expression of human strength [29]. Hence, rapid gains in strength in early phases of strength training have indeed been ascribed to recruitment of motor units (neural) factors [15, 16, 29].

Studies testing stair climbing protocol influence on thigh girth are rather scarce. Meyers et al. [30], however, observed a significant effect of 12-week stair climbing on gastrocnemius muscle girth (in both injured and uninjured limbs) in athletes who had undergone anterior cruciate ligament repair. Besides the methods of girth measurement and the difference of muscles, the observed variability of findings might be attributable to the training equipment involved in both studies. A short stair frame (with 4 steps and 60 cm high) was used for training in the present study, while Meyers et al. [30] employed a hydraulic stair climber. Thus, while the training load was the body weight in this study, the resistance in the other one came from the hydraulic system of the stepper. Eccentric contractions of the plantar flexors are needed to overcome the resistance of the stair climber [30]. Stair dimensions were also reported to influence the temporal and angular kinematics of the lower limb during stair climbing [31], which may in turn determine the overload provided by the stairs during the training. The findings of Kennedy et al. [5] and Boreham et al. [6], who trained their participants using public stairs, cannot be compared directly with the present study outcomes since they did not refer to the effects of stair climbing on muscle strength or bulk.

Forward versus backward stair climbing in strength training

The two stair climbing protocols appear comparable in their effects on muscle strength and bulk, as revealed by the findings of this study. Exercise experts and the public may not be favourably disposed towards adopting the backward stair climbing protocol. It is less appealing, practically more difficult, and does not really represent the common public approach. However, the backward method has been reported better and safer for descending stairs in terms of reduced joint stress and loading [11]. One may be inclined to suggest, with the present findings, that backward stair climbing will offer combined benefits of improved strength and reduced joint stress in individuals with knee joint problems. We are aware of the difficulty associated with ascending stairs with the backward approach, and this largely influenced our choice to adopt a short stepladder for training in our study.

To our knowledge, this is the first study testing the effects of combined ascent and descent of stairs in strength training, and also among a young healthy population. Theodorou et al. [7] found greater improvement in eccentric (12.3% vs. 7.1%) and isometric (8.8% vs. 5.9%) peak torque for the stair descent group as compared with the ascent group. However, the extent of comparing their findings with this study is limited. Their participants were much older (60–70 vs. 18–30 years of age) and also physically impaired by chronic heart failure; moreover, there were obvious differences in methods of stair climbing and muscle strength assessment. Similar differences also exist between our

study and the research by Donath et al. [10], who did not find significant differences in the effects of one-step and two-step stair ascent on the maximal strength of healthy seniors (mean age, 70.5 years). There seems to be dearth of studies on the comparative efficacy and effects of FSC and BSC exercises on muscle activity and strength.

Clinical implication of the findings

The outcome of the study reveals that both stair climbing protocols produced similar strength improvement. Physiotherapists and other exercise experts are hence encouraged by the findings to recommend backward stair climbing for combined benefits of reduced joint stress and loading for patients with knee joint problems.

Limitations

The present study is not without limitations. The major one is the fact that the male/female variables of the groups were not separated in the data analysis. This tends to limit the information conveyed in our findings in terms of ideal group comparison. Males are generally known to outstrip females in terms of strength [13]. A larger sample size might have boosted the external validity of the study. Additionally, using an isokinetic dynamometer for strength measurement could have made the findings more objective.

Conclusion

In conclusion, the study found that the 8-week forward and backward stair climbing protocols resulted in similar strength benefits. Individuals with knee joint complaints may benefit from backward stair climbing in relation to improved strength and reduced joint stress and loading. Testing these protocols in people with knee joint complaints may be an interesting perspective for future research.

Acknowledgements
The authors acknowledge the technical support received from the physiotherapists at the Department of Physiotherapy, University College Hospital, Ibadan, Nigeria.

References

1. Olander EK, Eves FF. Effectiveness and cost of two stair-climbing interventions – less is more. Am J Health Promot. 2011;25(4):231–236; doi: 10.4278/ajhp.090325-QUAN-119.
2. Engbers LH, van Poppel MN, Paw MJ, van Mechelen W. Worksite health promotion programs with environmental changes: a systematic review. Am J Prev Med. 2005;29(1): 61–70; doi: 10.1016/j.amepre.2005.03.001.
3. Eves FF, Webb OJ. Worksite interventions to increase stair climbing: reasons for caution. Prev Med. 2006;43(1):4–7; doi: 10.1016/j.ypmed.2006.03.011.
4. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Med Sci Sports Exerc. 2007;39(8):1423–1434; doi: 10.1249/mss.0b013e3180616b27.
5. Kennedy RA, Boreham CAG, Murphy MH, Young IS, Mutrie N. Evaluating the effects of a low volume stair-climbing programme on measures of health-related fitness in sedentary office workers. J Sports Sci Med. 2007; 6(4):448–454.
6. Boreham CA, Kennedy RA, Murphy MH, Tully M, Wallace WF, Young I. Training effects of short bouts of stair climbing on cardiorespiratory fitness, blood lipids, and homocysteine in sedentary young women. Br J Sports Med. 2005;39(9):590–593; doi: 10.1136/bjsm.2002.001131.
7. Theodorou AA, Panayiotou G, Paschalis V, Nikolaidis MG, Kyparos A, Mademli L, et al. Stair descending exercise increases muscle strength in elderly males with chronic heart failure. BMC Res Notes. 2013;6:87; doi: 10.1186/1756-0500-6-87.
8. Adegoke BOA, Olagbegi OM. Comparative effect of forward and backward stair climbing on cardio-respiratory parameters of apparently healthy young adults. Afr J Physiother Rehab Sci. 2012;4(1–2):34–39; doi: 10.4314/ajprs.v4i1-2.6.
9. Bean J, Herman S, Kiely DK, Callahan D, Mizer K, Frontera WR, et al. Weighted stair climbing in mobility-limited older people: a pilot study. J Am Geriatr Soc. 2002;50(4): 663–670; doi: 10.1046/j.1532-5415.2002.50160.x.
10. 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 Med Sci Sports. 2014;24(2):e93–e101; doi: 10.1111/sms.12113.
11. Hasegawa M, Chin T, Oki S, Kanai S, Shimatani K, Shimada T. Effects of methods of descending stairs forwards versus backwards on knee joint force in patients with osteoarthritis of the knee: a clinical controlled study. Sports Med Arthrosc Rehabil Ther Technol. 2010;2:14; doi: 10.1186/1758-2555-2-14.
12. Anwer S, Alghadir A. Effect of isometric quadriceps exercise on muscle strength, pain, and function in patients with knee osteoarthritis: a randomized controlled study. J Phys Ther Sci. 2014;26(5):745–748; doi: 10.1589/jpts.26.745.
13. Kisner C, Colby LA. Therapeutic exercise: foundations and techniques. Philadelphia: F.A. Davis Company; 2007.
14. McArdle WD, Katch FI, Katch VL. Exercise physiology: nutrition, energy, and human performance, 7th ed. Baltimore: Lippincott Williams and Wilkins; 2010.
15. Sale DG. Neural adaptation to resistance training. Med Sci Sports Exerc. 1988;20(Suppl. 5):S135–S145; doi: 10.1249/00005768-198810001-00009.
16. Sale DG. Neural adaptation to strength training. In: Komi PV (ed.), Strength and power in sport, 2nd ed. Oxford: Blackwell Science; 2003; 281–315.
17. Medina L. Does stair climbing build muscle? Available from: http://www.livestrong.com/article/371245-does-stair-climbing-build-muscle/.
18. Butler P, Kempson G. Quadriceps strengthening. A comparative study of the three types of apparatus for strengthening the quadriceps femoris muscle dynamically. Physiother. 1980;66(3):82–85.
19. Mayhew JL, Kerksick CD, Lentz D, Ware JS, Mayhew DL. Using repetitions to fatigue to predict one-repetition maximum bench press in male high school athletes. Pediatr Exerc Sci. 2004;16(3):265–276; doi: 10.1123/pes.16.3.265.

20. Hutchins M, Gearhart R Jr. Accuracy of 1-RM prediction equations for the bench press and biceps curl. J Exerc Physiol Online. 2010;13(3):32–39.
21. Soderberg LG. Kinesiology: application to pathological motion, 2nd edition. Philadelphia: Williams and Wilkins; 1997.
22. Smith LK, Weiss EL, Lehmkuhl LD. Brunnstrom's clinical kinesiology, 5th ed. New Delhi: Jaypee Brothers Medical Publishers Ltd.; 1996.
23. Puett DW, Griffin MR. Published trials of nonmedicinal and noninvasive therapies for hip and knee arthritis. Ann Intern Med. 1994;121(2):133–140; doi: 10.7326/0003-4819-121-2-199407150-00010.
24. Miyaguchi M, Kobayashi A, Kadoya Y, Ohashi H, Yamano Y, Takaoka K. Biochemical change in joint fluid after isometric quadriceps exercise for patients with osteoarthritis of the knee. Osteoarthritis Cartilage. 2003;11(4): 252–259; doi: 10.1016/S1063-4584(02)00372-2.
25. Loy SF, Conley LM, Sacco ER, Vincent WJ, Holland GJ, Sletten EG, et al. Effects of stairclimbing on VO_2max and quadriceps strength in middle-aged females. Med Sci Sports Exerc. 1994;26(2):241–247.
26. Young A, Hughes I, Russell P, Parker MJ, Nichols PJR. Measurement of quadriceps muscle wasting by ultrasonography. Rheumatol Rehabil. 1980;19(3):141–148; doi: 10.1093/rheumatology/19.3.141.
27. Wilmore JH. Alterations in strength, body composition and anthropometric measurements consequent to a 10-week weight training program. Med Sci Sports. 1974;6(2): 133–138; doi: 10.1249/00005768-197400620-00025.
28. Bohannon RW. Contribution of neural and neuromuscular factors to the short duration tension-developing capacity of skeletal muscle. J Orthop Sports Phys Ther. 1983;5(3):139–147.
29. Moritani T, deVries HA. Neural factors versus hypertrophy in the time course of muscle strength gain. Am J Phys Med. 1979;58(3):115–130.
30. Meyers MC, Sterling JC, Marley RR. Efficacy of stairclimber versus cycle ergometry in postoperative anterior cruciate ligament rehabilitation. Clin J Sports Med. 2002;12(2): 85–94; doi: 10.1097/00042752-200203000-00004.
31. Livingston LA, Stevenson JM, Olney SJ. Stairclimbing kinematics on stairs of differing dimensions. Arch Phys Med Rehabil. 1991;72(6):398–402.