Biomechanical Evaluation of New Type Stair Climbing Machine

I-Jung Tsai 蔡依蓉, Chien-Ju Lin 林倩如, Fong-Chin Su 蘇芳慶
Institute of Biomedical Engineering, National Cheng Kung University 成功大學醫學工程研究所
E-mail: fcsu@mail.ncku.edu.tw

摘要

本篇主要探討使用新式樓梯機（S770）的過程中，下肢關節的生物力學特性以及相關肌肉活化的表現。本研究共收取 12 位年輕受試者，分別在身體保持直立及左右移動的狀態下，以自己選擇的速度在感覺舒適的範圍及全部衝程範圍踩踏樓梯機。主要藉由動作分析系統、六軸力量與力矩感測器及表面肌電圖收取資料，比較不同情況下各關節的角度變化範圍、足底接觸力量、關節力矩、以及肌肉活化表現。結果發現，關節角度均在正常範圍內，且有較多髖關節外展和內收的動作；垂直方向的最大足底接觸力量約爲 0.8 倍的體重；髖關節與膝關節外展、伸直的力矩較大，踝關節內收、背屈的力矩較大。肌肉表現方面顯示，股四頭肌肌群以及髖關節外展肌活化程度較爲顯著。因此，新式樓梯機可增加髖關節外展的活動且不會對關節產生過大的衝擊。

關鍵字：新式樓梯機、運動學、動力學、肌肉活化

Ⅰ. INTRODUCTION

Stair climbing is an important functional activity in daily life which needs sufficient muscle strength and cardiopulmonary function. Therefore, simulated stair climbing machine is one of the popular equipments in rehabilitation center of healthy club. According to the previous studies, training with stair climbing machine or stepping machine could help to improve aerobic capacity and fitness (Loy et al., 1994; Ben-Ezra and Verstraete, 1991; Hass et al., 2001). It is also a useful equipment to strengthen quadriceps muscle (Loy et al., 1994). In addition, because that movement of simulated stair climbing is one of the close chain exercise which could reduce impact force, it might be the appropriate training equipment for subjects with joint pain or osteoarthritis.

Because most simulated stair machine or stepping machine we can get only have the movement in one plane, the new type of stair climbing machine S770 (SportsArt Fitness, Taiwan) was designed to combine movement with sagittal and coronal planes (Figure 1). In order to understand the specific efficiency and safety of a new exercising machine, it is necessary to evaluate characteristics of biomechanics during movement. Therefore, the purpose of this study was to investigate the biomechanical performance and electromyographic activities of lower extremity while subjects stepping on S770.

Figure 1 Side view of new type of stair climbing machine S770. The trajectory of foot plate combined anteroposterior and mediolateral directions.

Ⅱ. METHODS

12 voluntary young people (2 women and 10 man, 24.5±1.2 y/o) participated in this study. The average body height was 171.1±5.5 cm, and the average body weight was 64.0±9.6 kg. None of them had history of neuromuscular disease or complaint of lower extremity pain.

Before data collection, the electrodes of surface EMG and reflective markers were attached. Electrodes placed on the muscles of left leg including knee extensor (rectus femoris, vastus lateralis, vastus medialis), hip flexor (hamstring), hip abductor (gluteal medialis), hip adductors, ankle dorsiflexor (tibialis anterior), ankle plantarflexor (medial gastrocnemius), and evertor (peroneus longus). Maximal voluntary contractions of muscles were measured to be the normalized value. The Modified Helen Hayes marker set, 15 reflective markers, were used, including bilateral ASIS, thigh, knee joint, shank, heel, lateral malleous, toe, and sacrum.

Subjects were asked to stepping on S770 at self-selected speed in four conditions randomly. They needed to step at selected range or through whole stroke with trunk kept static or shifted with weight bearing. There were three trials for each condition, and 15 seconds for each trial.

The 6-axis force and torque sensor (MC3A, Advanced Mechanical Technology, Inc., Watertown, MA, USA) was embedded in central area of left pedal to collect foot contact force. The Eagle digital real-time system with 8 digital cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) was used to capture the position of reflective markers. The 6-axis force and torque sensor was synchronized with the motion capture system with sampling rates at 100Hz. Multi-channel of electromyography system (MA 300, Motion Lab Systems, Inc., Baton Rouge, LA, USA) was used to collect muscle activities during movement with sampling rate at 1000Hz

Ⅲ. RESULTS

At the initial of cycle, left leg showed hip and knee joint flexion combined knee internal rotation and ankle inversion. Then, hip and knee extension, external rotation, hip abduction, knee adduction, ankle dorsiflexion, abduction, and inversion to lower left step. The movement revised to the initial position at the end of stride cycle. Table 1 shows the angular displacement range of different activities and extremity range of lower extremity joints. Results appeared that most joint angular displacements were in the normal range except larger range in transverse plane (internal/external

rotation) of hip and knee joint, and dorsiflexion range in ankle joint. In addition, subjects performed more movement in coronal plane of hip joint (hip abduction/adduction) in simulated stair climbing than level walking and normal stair climbing.

Table 1 Comparison of angular displacement (unit: degree)

	Extreme range	S770	Stair
Hip			
Flex/Ext	110-120/ 10-15	78-89 / 0-3	60 / 5
Abd/Add	30-50 / 30	16-21 / 17-22	4.1 / 9.7
IR/ER	30-40/ 40-60	15-47 /0	
Knee			
Flex/Ext	135 / 15	72-89 / 0	93 / 10
Abd/Add		4-7 / 0.8-3.8	5.0 / 10.4
IR/ER	20-30 / 30-40	25-40/ 13-26	
Ankle			
PF/DF	50 / 20	0/ 28-32	9.4 /29.8
Abd/Add		7-9 / 2	12 /14
Inversion /eversion	45-60 / 15-30	19-29 /10-16	

Peak vertical foot contact forces of four conditions were about 0.8 times of body weight. Compared with other activities such as walking or normal stair climbing, simulated stair climbing showed less foot contact force during movement.

In stepping S770 machine, subjects had larger abductor, extensor, and external rotator moment in hip joint. In knee joint, subjects had larger abductor and extensor moment, but not much difference between internal rotator and external rotator moment. In ankle joint, subjects had larger adductor, dorsiflexor, and inversion moment.

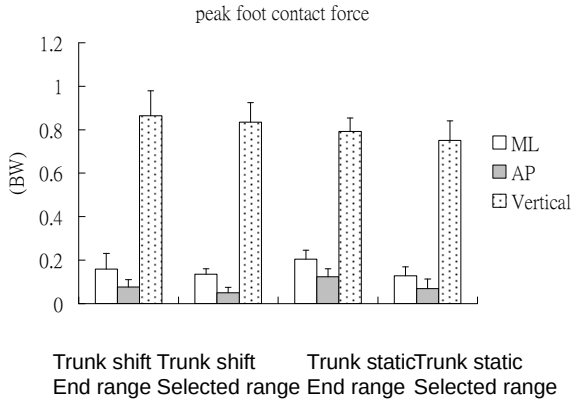

Figure 2 Peak foot contact force of four conditions (ML: medial-lateral, AP: anterior-posterior)

At the initial position, extensor (VM, VL) and flexor (Hamstring) muscles of knee joint co-contraction to maintain stability and prepare to step. Following by hip abductor, knee extensor (VM, VL, RF), ankle plantar flexor (MG) activated to lower the pedal.

Ⅳ. DISCUSSION

The results show that stepping on S770 could have normal displacement range in three movement planes and got lower impact force. Compared to other exercising machine, such as stepping or elliptical trainer, S770 shows several advantages with particular design. S770 combines arm rests connected with pedal, so that almost whole body segments were involved during stepping on S770. It not only could strengthen lower extremity muscles, but upper extremity muscles by modulating the stepping power produced by legs. On the other hand, stepping with arm movements would be benefit to the improvement of cardiopulmonary function and coordination of interlimb.

In addition to the movement in sagittal plane (hip and knee joint flexion), S770 have large movement in coronal plane, especially hip joint. EMG data also showed that hip abductor and quadriceps activated during movement. Most traditional stepping machines or elliptical trainers strengthen more on quadriceps, but not hip abductor. In older people, weakness of hip abductor and quadriceps is a common problem to affect functional ability level. Hip abductor is one of the key muscles to determine functional ability level in daily life because it would contract to maintain stability during single-leg standing. Therefore, strengthening hip abductor and quadriceps muscles is important for the elderly.

Furthermore, the result of foot contact force showed that lower force during movement. Compared with other activities such as running on treadmill or level walking, stepping on S770 is a close-chain exercise with less impact force. It may be more suitable for subjects with osteoarthritis or joint pain. In addition, according to the results of internal moment that subject had larger knee abductor moment than adductor moment, S770 might also be appropriate for patients with OA knee.

In conclusion, stepping on S770 is a whole body exercise especially adds movement in coronal plane. It can help improve muscle strength with lower foot contact force. With suitable resistance and stepping speed, it could be appropriate for health adults who wants to increase muscle strength and cardiopulmonary, and also good for elderly or patients with joint pain, osteoarthritis, hip abductor weakness.

Ⅴ. REFERENCES

Loy, S.F., et al., Med Sci Sports Exerc, 1994. 26(2): p. 241-7.

Ben-Ezra, V. and R. Verstraete, Eur J Appl Physiol Occup Physiol, 1991. 63(3-4): p. 261-4.

Hass, C.J., et al., Eur J Appl Physiol, 2001. 85(1-2): p. 157-63.

Zimmermann, C.L., et al., J Orthop Sports Phys Ther, 1994. 19(3): p. 173-80.

Stoloff, R.H., et al., Exp Brain Res, 2007. 178(4): p. 427-38.

Brask, B., R.H. et al., Phys Ther, 1984. 64(3): p. 324-9.

Costigan, P.A., et al., Gait Posture, 2002. 16(1): p. 31-7.

Ⅵ. Acknowledgement

The authors thank SportsArt Fitness for financial supported of the current study.