行政院國家科學委員會專題研究計畫 成果報告

以人體動作分析與生理負荷分析對橢圓滑步機作人因分析(I)

研究成果報告(精簡版)

計 畫 類 別 ： 個別型
計 畫 編 號 ： NSC 96-2221-E-040-005-
執 行 期 間 ： 96 年 08 月 01 日至 97 年 12 月 31 日
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計 畫 主 持 人 ： 羅世忠
共 同 主 持 人 ： 陳瓊玲、游家源
計畫參與人員： 碩士班研究生-兼任助理人員：孫佑榮

報 告 附 件 ： 出席國際會議研究心得報告及發表論文

公 開 資 訊 ： 本計畫可公開查詢

中 華 民 國 98 年 03 月 30 日

行政院國家科學委員會補助專題研究計畫 ■ 成 果 報 告
□期中進度報告

以人體動作分析與生理負荷分析對橢圓滑步機作人因分析

(I)

計畫類別：■個別型計畫　　□ 整合型計畫
計畫編號：NSC 96－2221－E－040－005－
執行期間： 96 年 8 月 1 日至 97 年 12 月 31 日

計畫主持人：羅世忠
共同主持人：陳瓊玲、游家源
計畫參與人員： 孫佑榮

成果報告類型(依經費核定清單規定繳交)：■精簡報告　□完整報告

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執行單位：中山醫學大學職能治療學系

中 華 民 國 98 年 3 月 30 日

行政院國家科學委員會專題研究計畫成果報告

以人體動作分析與生理負荷分析對橢圓滑步機作人因分析(I)

Human factor engineering analysis of elliptical trainer by human motion analysis and physical load analysis(I)

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摘要

近年國內運動風氣的興盛， 很多人選擇使用橢圓滑步機作為強健身體與維持基本體能的訓練工具，長時間使用橢圓滑步機後， 為有效了解橢圓滑步機對人體肌肉骨骼與生理負荷的影響，建立生物力學與生理負荷評估之人因工程分析是有其必要。本研究目的是以人體動作分析系統，來瞭解兩部不同設計等級的滑步機運動的舒適性差異。並以人體質量中心(center of mass, COM) 、肌電訊號（EMG）與關節角度變化作為橢圓滑步機相關評估之參數。本研究受測者為十位健康無神經肌肉骨骼傷痛的學生，兩種不同等級之橢圓滑步機，針對每種型號做三種不同滑動負荷實驗（70W、220W 與 370W)。實驗結果發現在兩台不同的橢圓滑步機上，人體質量中心在垂直高度（238%、211%與 199%）與前後距離（輕 156%、154%與 131%）有顯著性差異，而在同一橢圓滑步機之不同負荷比較上，只有在輕負荷與重負荷發現人體質量中心的左右移動軌跡（machine A：147%、machine B：134%）有顯著性增加。肌電訊號（EMG）峰值會隨者負荷而增加（股直肌、股二頭肌與脛前肌），以及股直肌與腓腸肌有肌電訊號提前發生的現象，除此之外，關節角度變化上，負荷間均沒有顯著影響（髖關節、膝關節與踝關節）。在下肢各關節角度變化實驗結果發現在髖關節最大角度發生在週期 40%；膝關節最大角度發生在週期 25%，此為踏板軌跡為最上方。在不同機型，負荷群體間分析比較下，關節角度變化沒有明顯的統計差異。

The exercise equipment used for strengthening muscle and shaping body is getting more prevalent due to the increased population and limited space in exercise. Elliptical trainer is regarded as a good approach with full body motion like treadmill but reduced impact force. However, unfitting exercise trainers and working over a long period of time cause musculoskeletal disorders. Little information is known for choosing the comfortable exerciser.

The purpose of this study was to understand the factors affecting the musculoskeletal uncomfortableness with motion analysis system. The factor was set to three loads and two type of elliptical trainer. The evaluated parameters of elliptical trainer include the kinemaic data, center of mass （COM） and electromyography (EMG).

Ten physically healthy male subjects volunteered for this investigation. None had ever suffered from upper extremity injuries or disorders. Three resistant loads, low（70 Watt）、middle（220 Watt）and high（370 Watt), were set to two type of elliptical trainer, home-used (machine A) and club-used (machine B). Full markers on body landmarks defined by Vicon polygon model were attached on subjects.

In the result, there was significant difference in both up/down and anteral/posterial excursion of COM in low load and high loads compared between two types of elliptical trainer. The excursion ratio of COM, Machine A/Machine B, was 238%、211% and 199% in up/down direction and 156%、154% and 131% in anteral/posterial direction respectively.

There was significant difference right/left excursion of COM in high load and low load compared between the same machine. There was no significant difference for joint angle （hip, knee and ankle）among loading group.

一、緒 論

對於維持身體基本體適能訓練一直受到社會大眾的重視，而由於工作時間或是居家環境等因素，許多人選擇使用運動器材作為強健身體的重要項目之一。但有許多案例指出對於長時間使用運動器材後，會產生不舒適或甚至有可能發生肌肉骨骼性傷害。目前運動器材漸

漸由原本機構設計，慢慢增加人因工程方面考量，所以除了機構設計外，測試上加入人體運動分析，其分析項目有動作分析與生理肌電訊號評估，追求運動器材設計達到舒適的健身[1-6]。

為能瞭解橢圓滑步機在設計上對人體運動時的相關性，選擇兩台不同類型市售橢圓滑步機，包括大賣場販售低階機型與俱樂部使用高階機型，使用動作分析系統，以建立人體在橢圓滑步機運動分析與評估模式。本研究將結合三維動作分析系統與肌電訊號量測系統作為評估兩台不同類型市售橢圓滑步機，以瞭解在輕、中與重負荷下對人體肌肉骨骼系統的影響，並期待從研究中找出設計符合人體舒適度之橢圓滑步機之重要參數：(一）人體運動學方面：主要探討人體質量中心(COM)的變化；(二）肌肉骨骼系統則以肌電訊號（EMG）的肌肉活動起點（onset)、肌肉活動終點（offset)、肌肉活動期間（duration)、肌肉出力大小（%MVC）及是否有肌肉拮抗現象等方面進行研究。

二、研究方法

受試者為十位均無神經肌肉骨骼傷害之年輕受測者，皆為在學大學生與研究生。使用動作分析系統 Vicon460 (Vicon Motion System Corp., Oxford, UK)、肌電訊號收集器 MP150 (Biopac Inc)及兩部橢圓運動機進行相關實驗。包括六台 CCD 攝影機，資料收集頻率 120Hz，收集人體在空間中的運動；反光球黏貼的位置以 Vcion 內建的 PolygonRT 模型，EMG 收集頻率為 1000HZ，肌電訊號採用皮膚表面收集方式，使用兩極貼片(3.5cm × 5cm)，收集受測者右腳之股直肌(rectus femoris RF)、股二頭肌(biceps femoris)、脛前肌(tibialis anterior)與腓腸肌(gastrocnemius)四條肌。

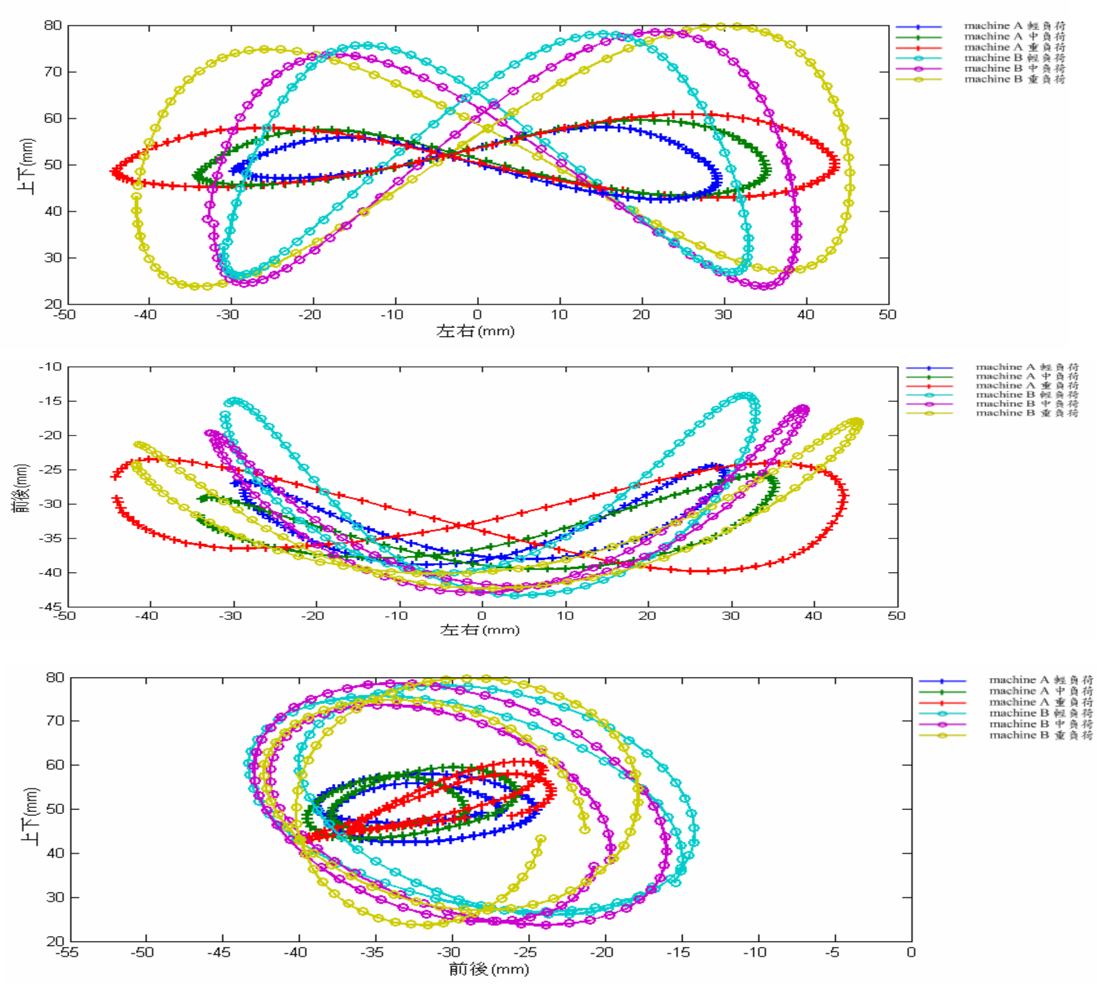
兩種不同橢圓滑步機型，均為目前市面上均可購置的運動器材商品，本實驗中設定的兩機型分別為 mahcine A（類似力山運動器材橢圓滑步機 600E）與 machine B（類似力山運動器材橢圓滑步機 Q35）兩種。

三、 結果與討論

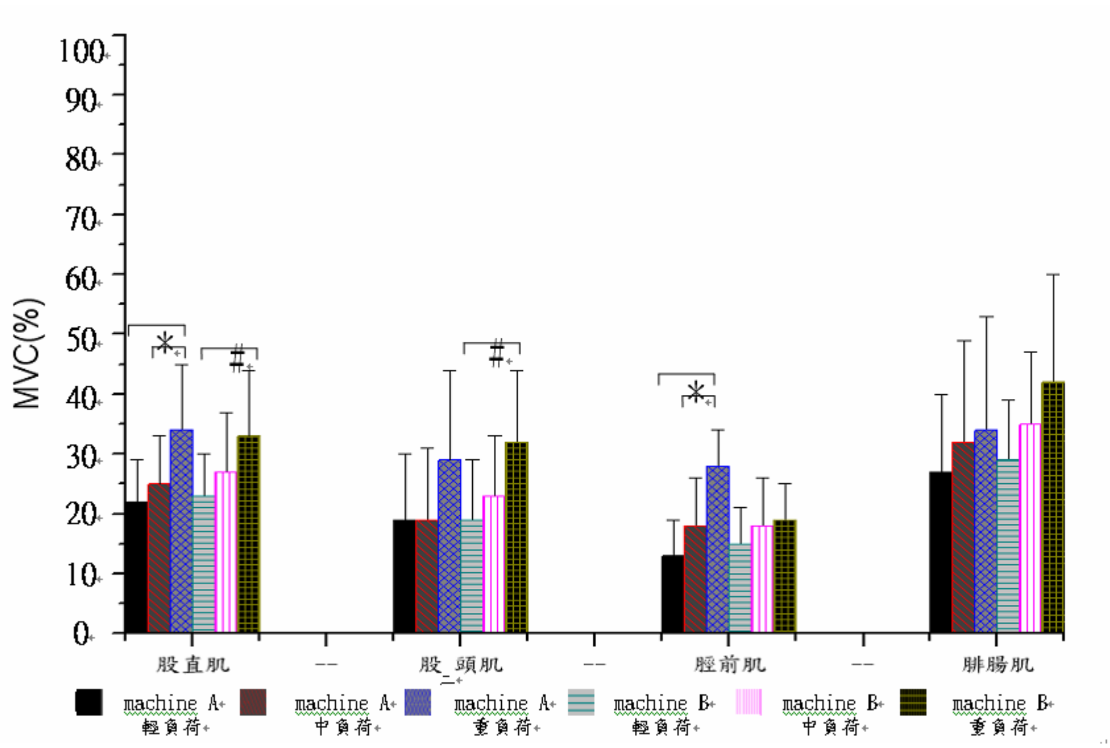
machine A 在圖形上要比 machine B 扁平（圖一上)，在橫切面的圖形中，兩台機型的軌跡變化相似，呈 U 形狀，且隨者負荷的增加，U 型角度會有向外擴張的趨勢（圖一中)，最後在矢狀面的平面圖，兩台機型所呈現的軌跡變化相似橢圓形狀，其中以 machine B 的橢圓

面積明顯比 machine A 大，而從圖中可以發現 machine B 的橢圓長軸比較接近垂直軸方向（圖一下）。

四條肌肉分別達到峰值的先後順序為脛前肌（週期範圍 90%至 120%）、股直肌（週期範圍 30%至 50%），股二頭肌與腓腸肌（週期範圍 50%至 80%），因此從實驗數據結果觀察，其中以股直肌在相同橢圓滑步機下，隨負荷增加有顯著的增加趨勢（$p<0.05$;圖二），而股二頭肌只有在 machine B 機型下，有顯著性的增加（$p<0.05$;圖二），脛前肌則是在 machine A 有明顯的趨勢（$p<0.05$;圖 4-16）。



圖一 人體質量中心在人體冠狀面、橫切面、矢狀面運動軌跡



圖二 股直肌、股二頭肌、脛前肌與腓腸肌在不同機型與負荷之峰值

四、結論與建議

本研究結果中兩種機型的人體質量中心軌跡，machine A 在三種負荷情況下，其水平與垂直位移比為 8:3，所以主要還是依靠左右的擺動來完成動作，另一方面，machine B 的水平與垂直位移接近 4：3 比例，從本研究觀察人體質量中心在冠狀面與矢狀面運動軌跡，machine B 比 machine A 活動範圍大，比較能產生動作協調空間，或許在速度變化上，人體質量中心在比較大的位移量之下，可能影響到下肢協調的整體動作，因此可以說人體質量中心的變化似乎可以作為評估橢圓滑步機設計的重要參數。

在 EMG 研究結果發現，在相同負荷，不同機型對四條肌肉的活動影響（肌肉峰值、活動起點、終點與期間）作統計分析，大部分均無明顯差異，顯然肌電訊號以線性峰波的處理方式無法對本實驗兩台滑步機作評估比較，但可作為橢圓滑步機週期軌跡下，肌肉活動功能之評估

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出席國際學術會議心得報告

計畫編號	NSC 96-2221-E-040-005
計畫名稱	以人體動作分析與生理負荷分析對橢圓滑步機作人因分析(I)
出國人員姓名服務機關及職稱	羅世忠中山醫學大學職能治療學系助理教授
會議時間地點	July 14~17, 2008； Las Vegas, USA
會議名稱	2^{nd} International Conference on Applied Human Factors
發表論文題目	Human factors analysis for operators using stairclimbing device

一、參加會議經過

台灣時間 7 月 13 日晚上由桃園國際機場飛往 LA，再由 LA 轉機至 Las Vegas，於美國時間 7 月 14 日清晨下榻 Flamingo 旅館，一早就到 Caesars Palace 會場報到，領取相關資料，下午參加教育訓練課程，晚上則有主辦單位舉辦的晚宴，遇到許多國內外的人因工程先進，互相寒暄交換名片，隔日便展開一連串的論文報告。

二、與會心得

本次研討會主要分為 七大主題包括生理人因（Physical Ergonomics）, 認知人因(Cognitive Ergonomics), 社會與組織人因 Social & Organizational Ergonomics, 人因與可用性評估（Ergonomics & Usability Evaluation）, 保健與特別族群（Healthcare & Special Populations）, 安全（Safety）, 工業人因（Ergonomics in Manufacturing），包含領域廣泛，也讓參與者獲益良多，另外主辦單位也舉辦許多的訓練課程包括 Multimodal and Adaptive Display Design 與 Conducting cognitive work analysis: supporting novices and experts with a software tool 等，讓較為生疏且有意參與的學者能迅速進入相關領域研究。

我報告的議程是 session 16: Universal Access to Novel Interaction Environments: Challenges and Opportunities，裡面有許多相關使用環境的人因研究包括桌椅、智慧型環境、電子商務交易環境以及爬梯機等，廣泛的題目，深入的介紹與討論，真的受益良多。

由於主辦單位給台灣參與的學術人員兩個 session，也看出台灣在建立與國際學術交流的努力。許多人因先進也都熱烈參與國際學術交流，讓後學有所學習與傳承，這些傳承也將為往後新進學者帶來學習的模式。

三、建議

多鼓勵參與國際學術交流，增進研究視野。

四、攜回資料名稱及內容

1. 大會議程及各類宣傳手冊
2. 研討會論文光碟
3. 參展廠商資料

Human Factors Analysis for Operators Using Stairclimbing Device

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ABSTRACT

To transport the elder or handicapped people climb up upstairs is difficult without the elevator or stairclimbing device. In Taiwan, local manufactory wants to develop the stairclimbing device to help the uneasily moved people but the operator information is little. To fit the gap, the purpose of this study was to understand the effect of stairclimbing device on the musculoskeletal system of the operator. Twenty healthy young people without any neuromuscular disorders were recruited. They were 22.8±4.1 in age, 165±7.5 in body height and 60±14 in body weight. A stairclimbing device, Scalamobil, five level wood stairs and three kind of height of stairclimbing device including shoulder height, shoulder height plus 10 cm and shoulder height minus 10 cm were set up in the experiment. The sequence of three sets of height was selected randomly. RULA, OWAS and motion analysis system (Vicon) with two force plate (Kistler) were used for human factors analysis. Data was analyzed statistically by repeated one-way ANOVA with $p<0.05$ as statistical significance.

In result of RULA and OWAS, the risk levels of working posture were on the acceptable. In the result of motion analysis, the flexion of trunk was significantly different among three heights of stairclimbing device. The max range of motion and loading were occurred on the knee joint, especially for the leading leg during upstairs and following leg during downstairs but the joint loading was not significantly different among heights of stairclimbing device. The joint loading was significantly different between leading and following leg during ascending and descending.

Keywords

stairclimbing device, RULA, OWAS, motion analysis

INTRODUCTION

Going upstairs has been described as an activity which causes high joint forces and torsional moments. Stairclimbing causes a more severe loading situation than walking(Bergmann, 1995). Upstairs the torsional moment is about twice as high as during slow walking(Bergmann, 1995). Climbing with both feet on each step, VO2 and HR were significantly higher (on average 10%) than the usual climb(Shiomi, 1994). For comparison with tall and short group, Less variation was observed in stance (50% to 60%) and swing (40% to 50%) values during tasks of stair ascent. Individuals appeared to adjust to stair dimensions by varying the flexion/extension patterns of the knee rather than those of the ankle or hip(Livingston, 1991).

Stairclimbing device is also useful for people who have problems with climbing stairs of all kinds. Little is known about the physical challenge of musculoskeletal system of operators in stairclimbing device. The purpose was to understand the effect of heights of stairclimbing device on the musculoskeletal system of the operator.

METHOD

The present study evaluated the musculoskeletal system of operators in stairclimbing device using two methods of human factors engineering, including posture analysis and biomechanics method.

Subject and Experimental Protocol

Twenty healthy young people without any neuromuscular disorders were recruited. They were 22.8±4.1 in age, 165±7.5 in body height and 60±14 in body weight. A stairclimbing device, Scalamobil, five step wood stairs and three kind of height of stairclimbing device including shoulder height, shoulder height plus 10 cm and shoulder height minus 10 cm were set up in the experiment. The sequence of three sets of height was selected randomly.

Subjects were asked to completely perform stair ascending and descending in three heights of stairclimbing device (see Figure 1). Before the start of climbing stair, subjects were asked to keep their body in the "neutral anatomic position" with arms at their sides and palms facing forward as neutral reference position. Five minutes was allowed for rest between sets, in order to avoid muscle fatigue. Simultaneous digital cam recorder and Six CCD cameras were used to record the image of motion and 3-D position of the markers respectively during the experiment.

Data reduction

The stairclimbing cycle (SC) was defined as the first toe contact to next toe contact. Eight pictures were taken for every SC. Generally one picture was for ten seconds. These pictures was used in posture analysis with Ovako working posture analyzing system (OWAS) (Lee, 1995), Rapid Upper limb Assessment (RULA)(Massaccesi, 2003).

The motion analysis system with Six CCD cameras and two piezoelectric force plate to measure vertical and two shear forces as well as the location of the center of pressure were used for calculation of kinematics and kinetics of trunk and knee joint by using an inverse dynamic procedure with the Newton-Euler equations(Haug, 1989; Winter, 1990).

Figure 1 experiment setup for stairclimbing device

Data analysis

In checklist data, the mean score of climbing cycle was done between three heights of stairclimbing device during upstairs and downstairs. The repeated one-way ANOVA with $p<0.05$ as statistical significance was used for the effect of heights of stairclimbing device.

In motion analysis data, the kinematic data of trunk and knee joint, and the kinetic data of knee joint among three kind of height of stairclimbing device was analyzed statistically by repeated one-way ANOVA with $p<0.05$ as statistical significance. The independent variables are three kind of height of stairclimbing device and dependent variables are joint angle, resultant force and resultant moment in data analysis. The post-hoc analysis for the differences between heights of stairclimbing device was done with the help of the Bonferroni method. An analysis for differences between leading and following legs was also made.

RESULTS

Checklist data

In the result of OWAS, even though the score of high height of stairclimbing device was smaller in mean, there was not significant difference between three heights during upstairs and downstairs. The mean score of OWAS was 2 that were on the acceptable(see Figure 2). In the result of RULA, there was not significant difference between three heights during stair ascent and descent. The mean score of RULA was 3 that were on the acceptable(see Figure 2).

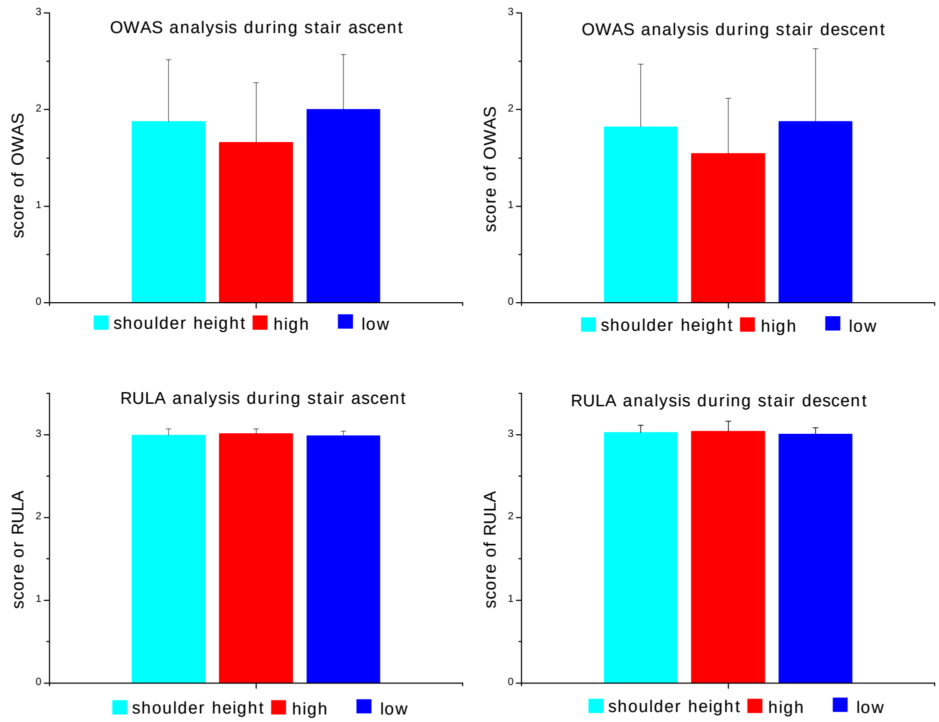

Figure 2 the risk score of posture with OWAS and RULA methods

Biomechanical data

Trunk angle

The mean peak flexion angles of trunk were range from 23 to 31 degrees for three heights of stairclimbing device(see Figure 3). There was significant difference of the peak flexion of trunk among three heights of stairclimbing device ($p<0.05$, Figure 3). The mean peak right/left flexion was about 10 degrees. The mean peak right/left rotation was about 8 degrees.

Knee angle

During stair ascent, the mean peak flexion angle of knee joint for leading and following legs were about 80 and 60 degrees respectively (see Figure 4). There was significant difference of peak flexion angle between leading and following leg. The mean peak abduction/adduction angles of knee joint for leading and following legs were about 6 degrees. The mean peak internal/external rotation angles of knee joint for leading and following legs were about 8 degrees. There was not significant difference of knee joint angle between three heights of stairclimbing device (Figure 4).

During stair descent, the mean peak flexion angle of knee joint for leading and following legs were about 60 and 80 degrees respectively. There was significant difference of peak flexion angle between leading and following leg (Figure 4).

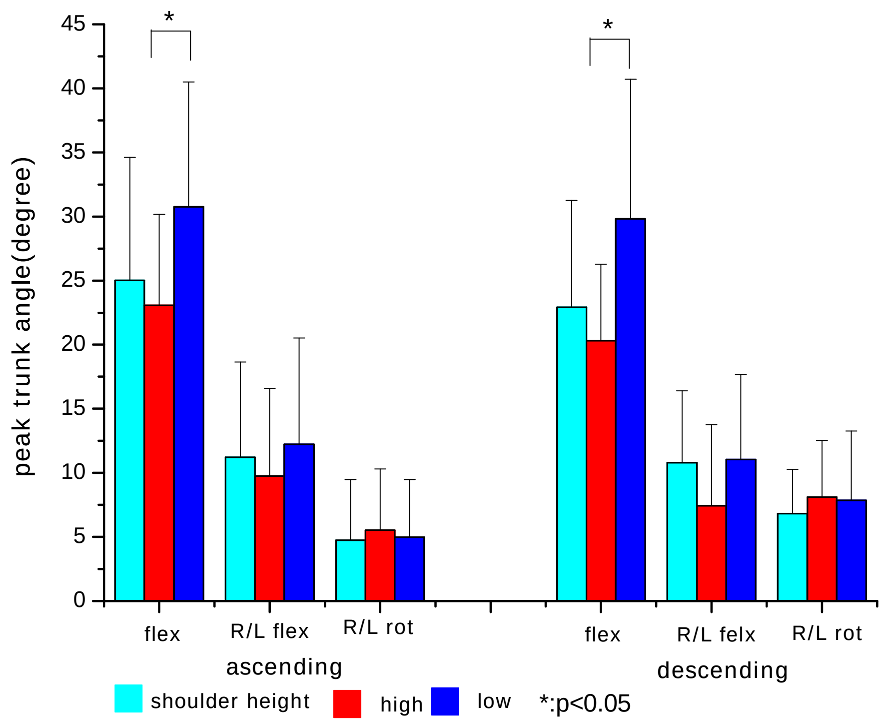

Figure 3 Mean and standard deviation of the peak trunk angle of stair ascending and descending with three height of stairclimbing device (* value significantly greater, *p<0.05*, than that of shoulder height group.)

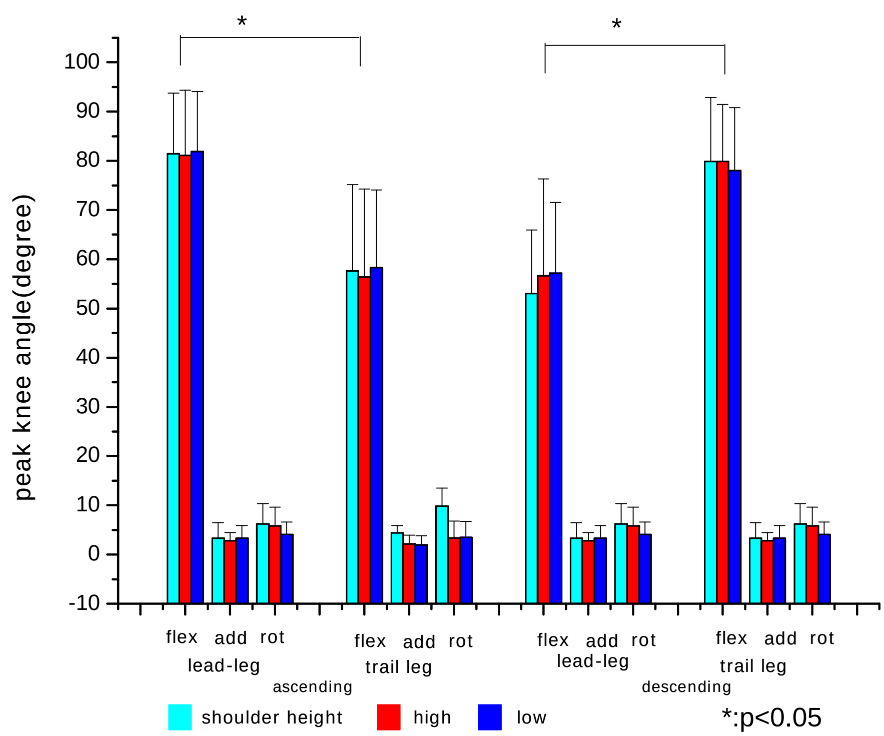

Figure 4 Mean and standard deviation of peak knee joint angle of stair ascending and descending with three height of stairclimbing device. (* value significantly greater, *p<0.05*, than that of shoulder height group.)

Knee joint force

During ascending, the mean peak axial force of knee joint for leading and trailing legs were both about 110% body weight (%BW) (see Figure 5). The anterial/posterial and medial/lateral shear force were about 20~30%BW. There was not significant difference of peak knee joint force between three heights of stairclimbing device. There was significant difference of peak anterial/posterial and medial/lateral shear force between leading and trailing legs (p<0.05, Figure 5).

During descending, the anterial/posterial shear force was significantly affected between leading and trailing legs (p<0.05, see Figure 5).

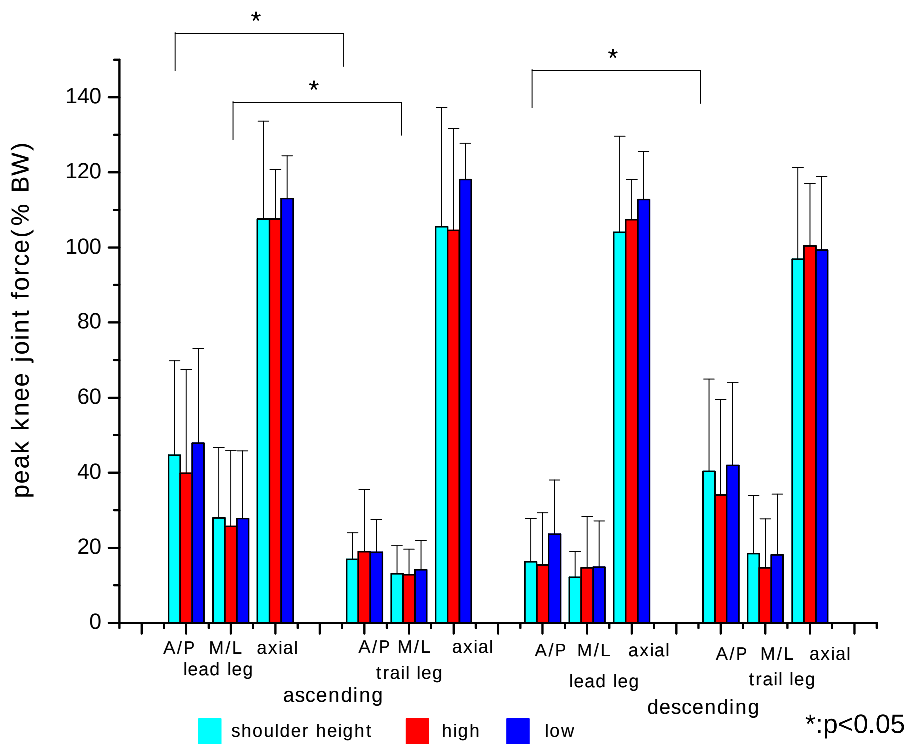

Figure 5 Mean and standard deviation of peak knee joint force of stair ascending and descending with three height of stairclimbing device. (* value significantly greater, *p<0.05*, than that of shoulder height group.)

Knee joint moment

During ascending, the mean peak flexion moment of knee joint for leading and trailing legs were both about 1~2 body weight*leg length (BW*LL) (see Figure 6). The abduction and internal rotation moment were about 0.3 BW*LL. There was not significant difference of peak knee joint moment between three heights of stairclimbing device. There was significant difference of peak flexion and internal rotation moment between leading and trailing legs (p<0.05, Figure 6).

During descending, there was not significant difference of peak knee joint ,moment between three heights of stairclimbing device. There was significant difference of peak internal rotation moment between leading and trailing legs (p<0.05 , Figure 6).

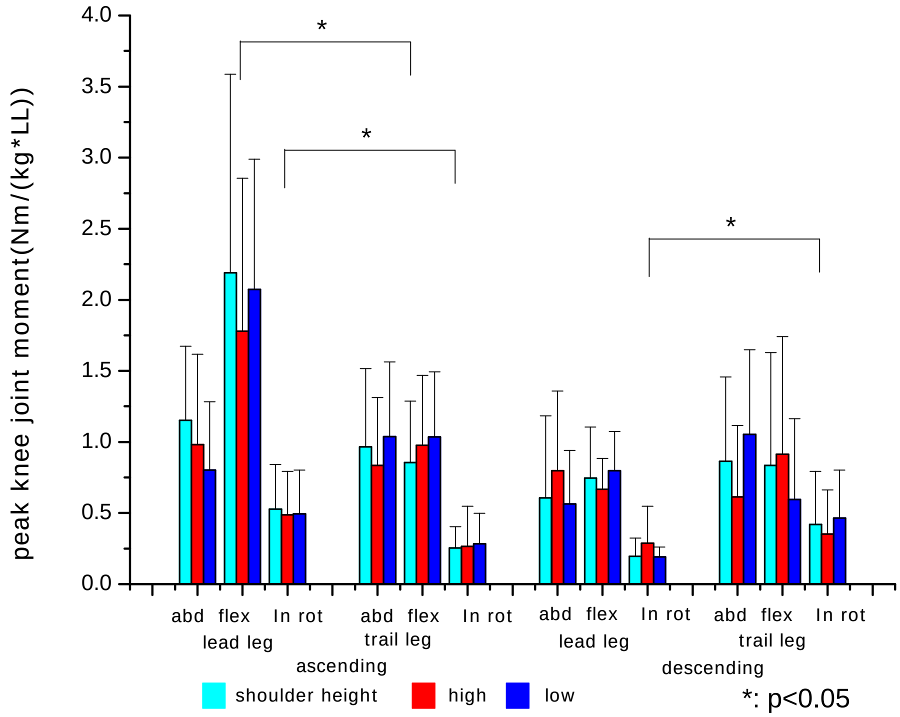

Figure 6 Mean and standard deviation of peak knee joint moment of stair ascending and descending with three height of stairclimbing device. (* value significantly greater, $p<0.05$, than that of shoulder height group.)

DISCUSSIONS

The manipulation of stairclimbing device is not difficult but practice is needed for accustomed the handling from the present experiment. The carrying loads was supported by power of stairclimbing device. The only thing the operators need to do is to balance the device with the rear wheel. Therefore, the posture analysis of OWAS and RULA was not significantly different between heights of stairclimbing device.

The significant change of trunk flexion can be expected or understood with the three heights of stairclimbing device. The high device caused the small trunk flexion. The loading on lower extremity seemed to be decreased with small flexion but the results did not show the significant difference. The possibility is the extra loads transfer from hands to device with lower height of device. Therefore, the loads on lower extremity were not different significantly between three heights. In the analysis with leading and trailing leg, the kinemaitcs and kinetics of knee joint was significantly different between two legs during stair ascent and descent. This is due to climbing with both feet on each step during ascending and descending.

CONCLUSION

From the analysis of RULA and OWAS, the risk levels of working posture were on the acceptable. From human motion analysis, the flexion of trunk was significantly different among three heights of stairclimbing device. The max range of motion and loading were occurred on the knee joint, especially for the leading leg during stair ascent and following leg during stair descent but the joint loading was not significantly different among heights of stairclimbing device. The joint loading was significantly different between leading and following leg during stair ascent and descent.

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