Exploration of the Optimal Riding Seat Position of Recumbent Exercise Bikes

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ABSTRACT

This study used recumbent exercise bikes as the target of investigation and adopted the subjective comfort level and fatigue level assessment results for users to determine the optimal riding seat position for recumbent exercise bikes. The results showed that: (1) the riding comfort levels of the participants and the fatigue levels of their body parts at different seat positions are significantly different; (2) the shank, knee and thigh are the body parts with higher fatigue levels, and the effects of the seat position on the fatigue level and comfort level of the above body parts are significantly greater; (3)by using regression analysis, the optimal seat position for the user with various lower body lengths when riding was derived as follows: seat center position from the crankshaft center (horizontal distance; mm) is equal to 269.15+3.50×lower body length (cm), and seat center position fromthe crankshaft center (vertical distance; mm) is equal to 58.58+0.71×lower body length (cm).

Keywords: recumbent exercise bikes, seat position, fatigue level, comfort level

斜躺式健身車最佳騎乘座椅位置探討

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摘　要

本研究以斜躺式健身車為探究對象，期藉由騎乘者實際騎乘後的主觀舒適度及各身體部位之疲勞度之評量結果，據以找出騎乘者最適騎乘的座椅位置。結果顯示：（1）不同座椅位置下受測者的騎乘舒適度及各身體部位之疲勞度達顯著差異；（2）各身體部位中以小腿、膝蓋及大腿是騎乘疲勞度較高之部位，且騎乘座椅位置對上述部位之疲勞度及舒適度之影響明顯較大；(3)經由迴歸分析推導出不同下半身長度之使用者之適合騎乘的座椅位置分別為：座椅中心點位置距曲柄軸中心之水平距離(mm)= 269.15+3.50*下半身長度(cm)， 座椅中心點位置距曲柄軸中心之垂直距離(mm)= 58.58+0.71 *下半身長度(cm)。

關鍵詞：斜躺式健身車、座椅位置、舒適度、疲勞度

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I. INTRODUCTION

One health investigation report by the United States Department of Health and Human Services [1] indicated that the regular exercise can bring the following improvement for health conditions:(1) reduce early death; (2)reduce risks to cause colon cancer; (3) reduce diabetes mellitus; (4) help the elderly have ability of independent living and reduce tumble risk; (5) reduce death caused by heart disease; (6) improve emotions and ease depression and anxiety symptoms; (7)help control weight. Shephard's(1990) report [2]indicated that exercise can prevent and control the risk of chronic disease. The investigation report by Lobo [3]indicated that 20-minute exercise twice every week can decrease hospitalization rate, hospitalization time, sick leave, personal medical expenses and drug costs. In view of this, exercise can improve the health conditions and reduce personal and social medical expenses, and the state financial revenue may increase due to good health of the people.

With rapid development of information and knowledge transmission, people's views and cognition for direct effects of exercise on control of coronary thrombosis, hypertension, cancer, diabetes mellitus, dysphoria and depression had been enhanced and thus made the application of fitness equipment extend from professional persons to ordinary people, and became the equipment used for body building and health care [4]. The fitness equipment referred to various auxiliary instruments which can promote good health[5].They were also generic terms of appliances which use resistance of equipment to consume calories and train heart and lung to achieve health purpose[6].

Stationary exercise bikes are the primary equipment used for indoor cyclical pedaling and riding, which occupy a large fitness equipment market share. Although exercise bikes could not enhance or strengthen riding skills, they allowed users to appreciate the joy of exercising indoors and could increase physical strength [7].For cardiovascular disease patients with poor physical fitness and muscle or joint damage, stationary exercise bikes are a suitable rehabilitation tool; the public also favors exercise bikes.

Stationary exercise bikes could be divided into upright exercise bikes, recumbent exercise bikes, and dual action exercise bikes based on function or purpose, seat type, and structure [4] (as shown in Fig. 1).The above three stationary exercise bikes have different exercise postures, which may have different forces imposed on the body parts in exercise. Wanich et al.[8]studied bike exercise, and found that the exerciser posture and injury to knee joints and hip joints caused by excessive exercise are related to the bike frame size, and distance between seat position and the handle. The exercise bikes are evolved from normal bikes. Thus, the exercise bikes are also affected by shape and seat position of bikes. Unsuitable exercise method may cause injury to the exercisers.

 (Source:PROTEUS SPORTS INC.)	 (Source:PROTEUS SPORTS INC.)	 (Source:SCHWINN)
Upright exercise bike	Recumbent exercise bike	Dual-action exercise bike

Fig.1 Three basic types of stationary exercise bikes.

Recumbent exercise bikes were created as an improvement over upright exercise bikes. Riding on a recumbent exercise bike is similar to sitting on a recliner. Riders are not only fully seated but they can also relax against the bike backrest and rest their heads. Riders are no longer required to position their bodies on the narrow saddle (seat), which can lead to numbness and skin inflammation. The recumbent exercise bike altered the traditional riding position that relies on the hips, waist, and arms as support points, and significantly reduced the body weight that is placed on the waist and the sacrum [9]. Recumbent exercise bikes are the most comfortable exercising bikes currently on the market primarily because they provide wide backrests and seats that stabilize the pelvis and improve the weight distribution of the waist, thereby avoiding lower back pain, and furthermore the low center of gravity and reduced horizontal distance between the feet and heart during exercise lowers the load placed on the heart suitable for extended use for increasing muscle endurance and strength or for elderly people or patients that require physical therapy or rehabilitation. As a rehabilitation tool, they were safer than upright exercise bikes[10]. Thus, recumbent exercise bikes not only possess the same functions as upright exercise bikes, but are also an appropriate rehabilitation and strength-building tool for older adults and those with mobility limitations. Because of these advantages, recumbent exercise bikes are currently widely used as experimental tools in clinical biomechanics, sports science, and other relevant areas of studies.

Although few studies have examined exercise bike riding, however, due to that exercise bikes evolved from bicycles, they have the same exercise patterns as bicycles. Past literatures on bike riding have identified that comfort is directly related to body size, bike types, and riding posture. From this perspective, the riding comfort level and load level of exercise bikes are closely related to seat positions (e.g., forward, backward, high, and low). In addition, people of varying heights or lower body lengths have different suitable seat positions for riding and the comfort of riding is related to the time and frequency of usage. Thus, the comfort of riding is a crucial issue for manufacturers. However, most current bike frame-development and design are dependent on computer simulations using anthropometric measurements, and have not considered design based on the comfort level of actual riding. Furthermore, relevant reference information regarding the ergonomic design of recumbent exercise bikes is lacking. Therefore, defining the optimal riding seat positions for recumbent exercise bikes to enhance rider comfort levels and usage times is a worthwhile topic requiring further investigation.

This study used recumbent exercise bikes as the target of investigation and employed a subjective assessment approach to evaluate the comfort level of riding and the fatigue level of the body, and cross-referencing the former assessment results with the later ones. It aims to determine the optimal riding seat position of recumbent exercise bikes for different lower body length users to provide a reference for manufacturers regarding future development and design of recumbent exercise bikes, and to assist riders of recumbent exercise bikes to adjust seats to an optimal riding position, thereby ensuring comfort during use.

II. EXPERIMENTAL DESIGN

2.1 Participants

A total of 48 healthy male participants between the ages of 20 to 45 years (mean age 27.6 years), with heights between 156 and 185 cm (almost 95% Taiwanese adult males, i.e., Chinese adult males, are within this height range) and the lower body lengths ranging from 101to125cm,took part in this study. All participants were at a normal weight (i.e., they were not overweight), with no record of musculoskeletal injuries or serious illnesses. The participants were divided into three groups according to height (compared to the lower body length, it is easy to be divided into groups because most participants only know their own height): (1) 156 – 165 cm; (2) 166 – 175 cm; (3) 176 – 185 cm. Through purposive sampling, 16 participants from each group were selected to undergo the experiments. The overall anthropometric measurements of the participants are shown in Table 1.Among them the lower body length was measured in a sitting position and was equal to the horizontal distance between back of the buttocks and the knee midpoint plus the vertical distance between the ground and the knee midpoint, which was different from the common way measured from the belly button to sole of the foot. This was due to that the participants of this experiment rode the exercise bike in a posture like sitting on a chair. It was really necessary to measure the lower body length based on the actual riding posture for more consistently matching with the actual riding condition.

Table 1 Overall anthropometric measurements of the participants

Height group		Age (year)	Height (cm)	Weight (kg)	Horizontal distance from back of the buttocks to the knee midpoint(cm)	Vertical distance from the ground surface to the knee midpoint (cm)
1	*M*	28.1	161.1	57.6	56.9	49.8
	SD	5.8	2.4	7.2	3.6	1.8
2	*M*	27.1	171.8	70. 6	61.5	53.6
	SD	6.5	2.5	10.0	3.7	2.2
3	*M*	27.6	179.3	77.6	64.5	55.9
	SD	5.5	2.6	9.6	3.1	1.8

2.2 Experimental apparatus

A Proteus Focus PEC-4770 recumbent exercise bike (as shown in Fig. 1) produced by Proteus Sports Inc. (Taiwan, ROC) was used as the tool for the riding test. The bike dimensions are 1,300 × 640 × 1,200 mm. The seat track, on which the seat is assembled and allows for seat adjustment, is at a 12° angle with the horizon. The crankshaft center of the pedal is 335 mm away from the ground. When the seat is placed at the lowest test position, the horizontal distance between the seat center and the crankshaft center is 600 mm and the seat center has a vertical distance of 460 mm from the ground (i.e., the vertical distance between the seat center and the crankshaft center is 125 mm) (as shown in Fig. 2).

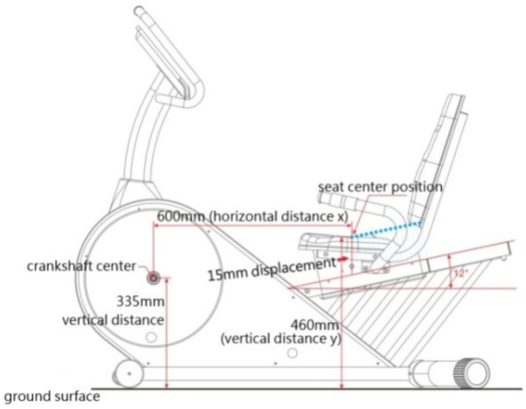

Fig.2 Position adjustment schematic for the experiment.

2.3 Seat positions

From the starting point where the horizontal distance between the seat center and the crankshaft center was 600 mm and the vertical distance was 125 mm. Each height group conducted tests at six different seat positions by adjusting the seat backwards along the seat track at a 15 mm increment unit (as shown in Fig. 2). To ensure the comprehensiveness of the test results, each height group used four positions that overlapped with the other height groups. Overall, 10seat positions were set and the horizontal and vertical distances between the seat center and the crankshaft center of them are shown in Table 2.

Table 2 The horizontal (H) and vertical (V) distances (mm) between the seat center and the crankshaft center at the six seat positions for the three height group

Position	Height group					
	1		2		3	
	H	V	H	V	H	V
1	600.0	125.0	629.3	131.2	658.7	137.5
2	614.7	128.1	644.0	134.4	673.4	140.6
3	629.3	131.2	658.7	137.5	688.0	143.7
4	644.0	134.4	673.4	140.6	702.7	146.8
5	658.7	137.5	688.0	143.7	717.4	149.9
6	673.4	140.6	702.7	146.8	732.0	153.1

2.4 Procedures

Prior to the experiment, the participants were informed of the experimental procedures and objectives, enabling the participants to understand the entire experimental process, and relevant body or anthropometric measurements were measured. The participants were asked to wear light clothing and shorts. After the participants were seated on the recumbent exercise bike, they were asked to adjust the plastic pedal ring to the most appropriate position. Their hands were placed on the two handles positioned at the sides of the seat. The participants were asked to use their most natural posture to ride the bike during the experiment.

Gaesser and Brooks [11] and Coast and Welch [12] stated that the most economical pedaling frequency was between 50–80 rpm for stationary bikes. Huo, Maruyama, and Liu's study[13]revealed that the optimal pedaling rate in bicycle ergometer (a stationary bicycle dynamometer) exercise was approximately 60 rpm for cycling. Furthermore, numerous related studies used a pedaling frequency of between

60–80 rpm[10, 14, 15]. Thus, the pedaling frequency used in this study was set at 65 rpm. The participants were asked to ride for 3 minutes at the lowest resistance mode (torque = 0.5 kg-m), i.e., load = 33.4watts（= 2 π × 9.8 × 0.5 (torque, Kg-m) × 65 (revolution, rpm)/60) for each seat position and each participant conducted tests at six different seat positions.

The participants were asked to pedal according to the rhythm and frequency of a metronome. If the pedaling rhythm and frequency of a participant did not match the experimental requirements, the experiment would be repeated. To prevent fatigue from affecting the accuracy of the results, the participants were randomly assigned to a seat position. In addition, at each riding seat position, the participants were asked not to rest to achieve consistent results throughout the experiment. Furthermore, immediately after each ride, the participants were asked to complete a questionnaire regarding their riding comfort and body parts fatigue levels and then the participants were asked to undergo the next riding position test after resting for 3 minutes until they completed all six positions.

2.5 Assessment tools

The subjective assessment questionnaires were used and the questionnaire was divided into two parts. The first part is to evaluate fatigue levels of the body parts, including eight body parts: back, waist, buttocks, hip, thigh, knee, shank and ankle (as shown in Figure 3). A7-point scale was used, ranging from 1 (lowest fatigue) to 7 (highest fatigue). The second part is to evaluate riding comfort levels. Similarly, a7-point scale was used, ranging from 1 (lowest comfort) to 7 (highest comfort).

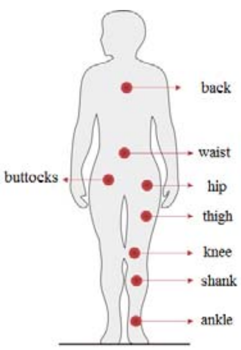

Fig.3 Body parts for fatigue level assessment.

2.6 Data Processing and Analysis

The experimental results were firstly summarized by using Microsoft Excel. SPSS statistical software was then used for the following statistical analysis:

(1) Descriptive statistics: including mean value and standard deviation.

(2) Difference analysis: repeated measures analysis of variance (ANOVA)was conducted to see if there is any significant difference between seat positions on the riding comfort levels and fatigue levels of the 8 body parts (back, waist, buttocks, hip, thigh, leg, knee, leg and ankle)of the three height groups. If significant difference existed, the LSD(Least Significant Difference)approach was then used for post-hoc comparison.

(3) Regression analysis: to build the predictive model of optimal seat positions for different lower body length users.

III. RESULTS

3.1 Riding comfort levels

Table 3 shows that the riding comfort levels at various seat positions for each height group were as follows:

(1) Height group 1 (156–165 cm): Position 3 had the highest comfort level (M = 5.06) and Position 6 had the lowest comfortable level (M = 2.33). The comfort level increased with increasing seat height (seat position towards the back) from Position 1. It reached the highest at Position 3, and then decreased with increasing seat height.

(2) Height group 2 (166–175 cm): Position 3 was the most comfortable position (M = 4.69), Position 2 was at a medium comfort level (M = 4.63), and Position 1 was the least comfortable position (M = 2.63). The comfort level increased with increasing seat height from Position 1. It reached the highest at Position 3, and then decreased with increasing seat height.

(3) Height group 3 (176–185 cm): Position 4 was the most comfortable position ($M = 4.88$) and Position 1 had the lowest comfort level ($M = 1.88$). The comfort level increased with increasing seat height from Position 1. It reached the highest at Position 4, and then decreased with increasing seat height.

Table 3 Riding comfort levels and ANOVA results for each height group (n=16 for each group)

Height group	Position	M	SD	F	P	η^2	LSD Post hoc test
1	1	2.88	1.26	9.893	<.001*	0.397	2,4>1,6 3>1,4,5,6 5>6
	2	4.19	1.28				
	3	5.06	1.34				
	4	4.06	1.39				
	5	3.50	1.59				
	6	2.37	1.20				
2	1	3.00	0.82	6.930	<.001*	0.316	2＞1 3＞1,2,5,6 4＞1,5,6
	2	3.94	1.12				
	3	4.69	1.20				
	4	4.63	1.09				
	5	3.69	1.54				
	6	3.13	1.82				
3	1	1.88	0.72	14.185	<.001*	0.486	2,3,6＞1 4＞1,2,3,6 5＞1,2,6
	2	3.13	1.02				
	3	3.44	1.15				
	4	4.88	1.36				
	5	4.44	1.59				
	6	2.75	1.18				

*Significant at 0.001 level.

Table 3 also shows that the ANOVA results on riding comfort levels at the various seat positions for each height group were as follows:

(1) Height group 1 (156–165 cm): A significant difference was achieved ($F\ (5,75) = 9.893$, $p<.001$), which indicated that the comfort level was significantly affected by seat positions. The LSD post hoc test results showed that the riding comfort levels of Positions 1 and 6 were significantly lower than those of the other seat positions, and except for Position 2, the riding comfort level of Position 3 was significantly higher than those of the other seat positions.

(2) Height group 2 (166–175 cm): A significant difference was achieved ($F(5,75) = 6.930$, p ＜.001), which indicated that the comfort level was significantly affected by seat positions. The LSD post hoc test results showed that, except for Position 4, the riding comfort level of Position 3 was significantly higher than those of the other seat positions.

(3) Height group 3 (176–185 cm): A significant difference was achieved ($F(5,75)$=14.185, p ＜.001), which indicated that the comfort level was significantly affected by seat positions. The LSD post hoc test results showed that, the riding comfort level of Position 1 was significantly lower than those of the other seat positions, and except for Position 5, the riding comfort level of Position 4 was significantly higher than those of the other seat positions.

3.2 Riding fatigue levels

Tables 4, 5 and6 show the fatigue levels of the body parts of different height groups at different seat positions. For the first height group, the fatigue levels of the most body parts had the lowest value at position 3 (Table 4), and too high or too low seat positions could cause increasing the fatigue levels of the all body parts. Among them, the shank, keen and thigh had higher fatigue levels, and the back and waist had lower fatigue levels. For the second height group, the fatigue levels of the most body parts had the lowest at position 4 (Table 5), and too high or too low seat positions could cause increasing the fatigue levels of the all body parts. Among them, the shank, thigh and knee had higher fatigue levels, and the back and waist had lower fatigue levels. For the third height group, the fatigue levels of the most body parts had the lowest at position 5 (Table 6), and too high or too low seat positions could cause increasing the fatigue levels of the all body parts. Among them, the thigh, shank, and keen had higher fatigue levels, and the back and ankle had lower fatigue levels.

In Table 7, the difference test results showed that too high or too low seat positions significantly increased fatigue levels of the body parts. Among the three height groups, the third group had the most significant increase. In addition, the thigh was mostly affected by seat positions, followed by the shank.

Table 4 Subjective assessment results of fatigue levels of the first height group(*n*=16)

position	Mean (*SD*)								
	back	waist	buttocks	hip	thigh	knee	shank	ankle	whole
1	2.81(1.38)	2.81(1.28)	3.38(1.71)	3.38(1.89)	3.69(1.45)	3.38(1.41)	3.56(1.71)	**2.63**(1.20)	3.20
2	**2.25**(1.24)	**2.25**(0.86)	2.75(1.39)	2.69(1.70)	3.00(1.59)	3.50(1.67)	3.38(1.89)	2.69(1.25)	2.81
3	2.44(1.03)	2.63(1.26)	**2.69**(1.45)	**2.69**(1.49)	**2.75**(1.44)	**2.88**(1.26)	**3.13**(1.41)	2.75(1.53)	**2.74**
4	2.50(1.32)	2.44(0.89)	2.88(1.50)	2.94(1.84)	3.19(1.68)	3.31(1.54)	3.63(1.89)	3.13(1.71)	3.00
5	2.50(1.55)	2.50(1.59)	3.19(1.56)	2.75(1.24)	3.56(1.21)	3.94(1.44)	4.25(1.65)	3.69(1.49)	3.30
6	2.56(1.36)	2.81(1.17)	3.75(1.44	3.44(1.50)	4.25(1.61)	4.13(1.36)	5.06(1.12)	4.38(1.41)	3.80
whole	2.51	2.57	3.10	2.98	3.41	3.52	**3.83**	3.21	

Table 5 Subjective assessment results of fatigue levels of the second height group (*n*=16)

position	Mean (*SD*)								
	back	waist	buttocks	hip	thigh	knee	shank	ankle	whole
1	3.44(1.59)	3.88(1.45)	3.69(1.20)	3.75(1.48)	4.50(1.21)	4.25(1.24)	4.44(1.67)	3.63(1.54)	3.95
2	2.75(1.34)	3.00(1.55)	**3.00**(1.41)	3.06(1.57)	4.00(1.26)	3.81(1.47)	4.19(2.00)	3.50(1.59)	3.41
3	3.13(1.67)	3.38(1.50)	3.25(1.65)	3.25(1.53)	3.63(1.20)	3.63(1.45)	**3.81**(1.42)	3.56(1.46)	3.45
4	**2.63**(1.36)	**2.88**(1.41)	3.06(1.48)	**3.00**(1.50)	**3.56**(1.55)	**3.56**(1.67)	4.06(1.65)	**3.13**(1.45)	**3.23**
5	2.81(1.47)	3.06(1.34)	3.38(1.50)	3.19(1.38)	3.75(1.48)	3.94(1.65)	4.19(1.42)	3.75(1.48)	3.51
6	3.06(1.69)	3.31(1.45)	3.56(1.67)	3.63(1.60)	4.00(1.51)	3.56(1.15)	4.31(1.35)	3.56(1.36)	3.63
whole	2.97	3.25	3.32	3.31	3.91	3.79	**4.17**	3.52	

Table6 Subjective assessment results of fatigue levels of the third height group (*n*=16)

position	Mean (*SD*)								
	back	waist	buttocks	hip	thigh	knee	shank	ankle	whole
1	3.19(1.64)	4.06(1.69)	3.56(1.36)	3.38(1.09)	4.44(1.46)	3.88(1.54)	3.88(1.15)	3.19(1.22)	3.70
2	3.13(1.31)	3.38(1.45)	3.31(1.57)	3.00(1.10)	4.06(1.24)	3.56(1.50)	3.81(1.28)	3.13(1.20)	3.41
3	**2.13**(1.31)	3.00(1.41)	2.56(0.96)	3.25(1.39)	3.38(1.63)	2.94(1.61)	3.19(1.11)	**2.25**(1.18)	2.84
4	2.63(0.89)	**2.94**(1.00)	2.75(1.29)	2.69(0.95)	**3.25**(1.06)	3.00(1.46)	3.19(1.05)	2.50(1.26)	2.87
5	2.50(1.15)	3.06(1.65)	**2.44**(1.15)	**2.25**(0.45)	3.44(1.82)	**2.69**(1.62)	**2.75**(1.24)	2.63(0.96)	**2.72**
6	2.13(0.62)	2.88(0.89)	3.19(1.22)	3.44(1.41)	3.94(1.57)	3.51(1.83)	3.69(1.20)	2.94(1.34)	3.25
whole	2.61	3.22	2.96	3.00	**3.75**	3.31	3.42	2.77	

Table 7 Difference test results of the riding fatigue levels at different body parts

Body part	Height group 1 (*n*=16)			Height group 2 (*n*=16)			Height group 3 (*n*=16)		
	F	*p*	LSD Post hoc test	*F*	*p*	LSD Post hoc test	*F*	*p*	LSD Post hoc test
back	.703	.623	--------	1.399	.235	--------	4.384	.001*	1,2＞3,6 4＞5
waist	.855	.516	--------	2.076	.078	--------	2.871	.020*	1＞2,3,4,6
buttocks	1.818	.120	--------	1.072	.383	--------	4.014	.003*	1,2,6＞3,5
hip	1.164	.335	--------	1.552	.184	--------	3.400	.008*	1,2,3,6＞5
thigh	2.828	.022*	6>2,3,4	2.353	.049*	1＞2,3,4,5	4.200	.002*	1＞3,4,5 2＞4 6＞3,4
knee	2.118	.072	--------	1.144	.345	--------	3.733	.005*	1,6＞3,5 2＞5
shank	4.442	.001*	5>3 6>1,2,3,4	.625	.681	--------	3.322	.009*	1,2,6＞5
ankle	5.676	.000*	5>1,2,3 6>1,2,3,4	.632	.676	--------	2.021	.085	--------

*P<0.05

3.3 Regression analysis for the seat positions appropriate for riding

Based on the lower body lengths and seat positions of all participants with the maximum riding comfort levels, regression analysis was used to obtain the correlation between the lower body length and seat position for optimal riding comfort level, which was used to derive the appropriate seat positions for users of various lower body lengths when riding.

Figure 4 and Table 8 show the scatter plot and the linear regression analysis results of the lower body length (independent variable, X) and the horizontal distance between the seat center and the center of the crankshaft (dependent variable, Y_h). As seen from Table 8, $R^2$was 0.598, indicating the prediction equation had high explanatory power for variables, and the regression equation was as follows: Y_h(mm)= 269.15+3.50*X(cm). In addition, Fig. 5 shows the scatter plot of the standardized predicted values and standardized residuals obtained from the above equation. As seen from Fig. 5, no pattern was present, i.e., the model fits well.

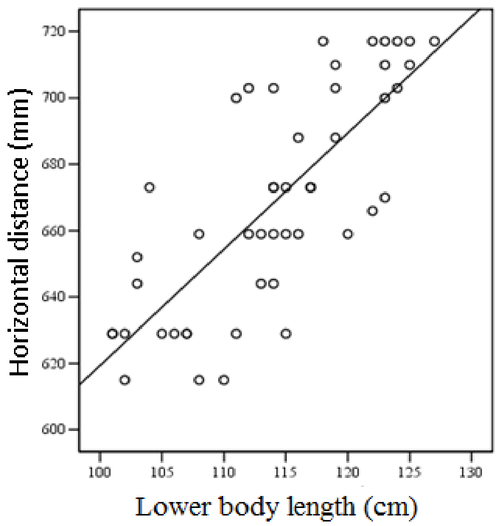

Fig.4 Scatter plot and the linear regression analysis result.

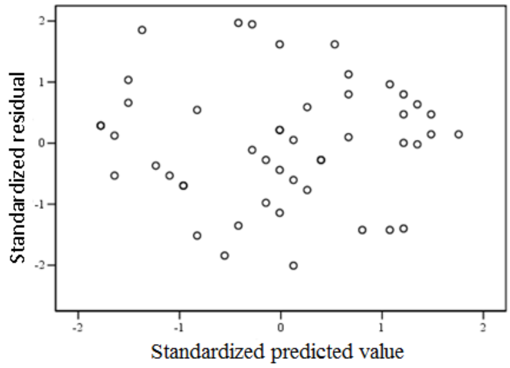

Fig.5 Scatter plot of the standardized predicted value and standardized residual.

Table 8 Linear regression analysis results of the lower body length and the horizontal distance between the seat center and the center of the crankshaft

R	R^2	Adjusted R^2	*F*		*Sig.*
0.773	0.598	0.589	68.307		<0.001*
Regression analysis results					
	Unstandardized coefficient	Standardized coefficient	*t*	*Sig.*	
Constant	269.15		5.556	<0.001*	
Lower body length	3.50	0.77	8.265	<0.001*	

*Significant at 0.001 level.

Figure 6 and Table 9 show the scatter plot and the linear regression analysis results of the lower body length (independent variable, X) and the horizontal distance between the seat center and the center of the crankshaft (dependent variable, Y_h). As seen from Table 8,$R^2$was 0.575, indicating the prediction equation had high explanatory power for variables, and the regression equation was as follows: Y_v(mm)= 58.58+0.71*X(cm). In addition, Fig. 7 shows the scatter plot of the standardized predicted values and standardized residuals obtained from the above equation. As seen from Fig. 7,no pattern was present, i.e., the model fits well.

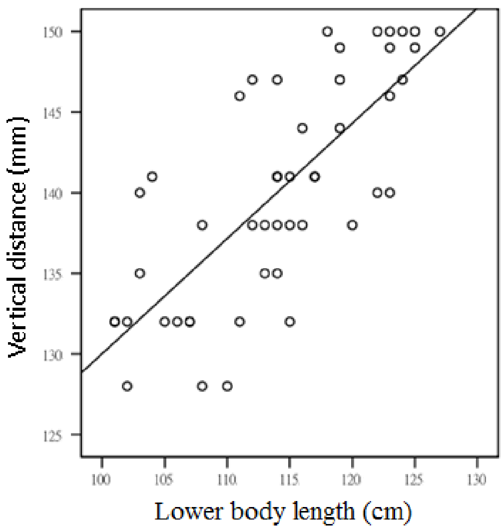

Fig.6 Scatter plot and the linear regression analysis result.

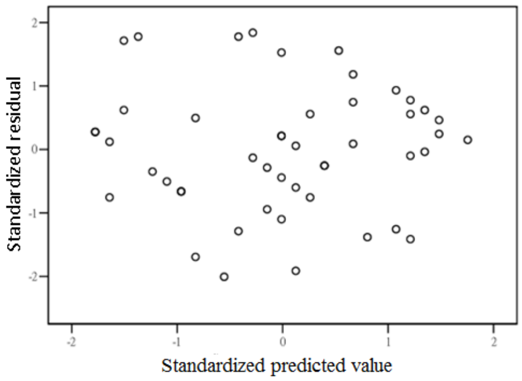

Fig.7 Scatter plot of the standardized predicted value and standardized residual.

Table 9 Linear regression analysis results of the lower body length and the vertical distance between the seat center and the center of the crankshaft

R	R^2	Adjusted R^2	*F*	*Sig.*
0.758	0.575	0.566	62.233	<0.001*

Regression analysis results

	Unstandardized coefficient	Standardized coefficient	*t*	*Sig.*
Constant	58.58		5.659	<0.001*
Lower body length	0.71	0.76	7.889	<0.001*

*Significant at 0.001 level.

IV DISCUSSION

The subjective assessment results of the riding comfort levels showed that the first height group had the highest comfort level at the position 3, the second height group had the highest comfort level at the position 3, and the third height group had the highest comfort level at the position 4.The subjective assessment results of the fatigue levels of the body parts showed that most body parts had the lowest fatigue levels at the position 3 for the first height group, at the position 4 for the second height group, and at the position 5for the third height group.

In theory, the higher the comfort level of riding, the more suitable the seat position is, and the lower the fatigue level of the body parts. To sum up, the seat position with the highest comfort level and the lowest fatigue level of the body parts for the first height group were the same at the position 3.The second height group had the highest comfort level at the position 3 and the lower fatigue level at the position 4, and the position was different. However, comfort levels at the position 3 and position 4 were almost the same (*M* is 4.69 and 4.63). Therefore, in fact, the positions with the highest comfort level and the lowest fatigue level were consistent. The third height group had the same situation as the second height group, i.e., the seat positions with the highest comfort level (position 4)and the lowest fatigue level of the body parts (position 5)were different. However, the position 5 had the second highest comfort level and the comfort levels difference between position 4 (*M* =4.88) and position 5 (*M* =4.44)was not great. Therefore, in fact, it also can be considered that the seat position with the highest comfort level was consistent with the seat position with the lowest fatigue level. In conclusion, the reliability of the subjective assessment results of the riding comfort levels can be verified by the subjective fatigue level assessment results of the body parts. It means that the results obtained in this study regarding the riding comfort level subjectively perceived by the riders are quite reasonable, and thus can be used as a reliable reference for determining the optimal riding seat position of recumbent exercise bikes for different lower body length users through regression analysis.

In addition, the shank, knee and thigh were the body parts with higher fatigue levels. It is because the above three body parts are the main force applying for riding, so it is accordingly reasonable for having higher fatigue levels.

Furthermore, too high or too low riding seat positions significantly increased fatigue levels of the body parts. From the fatigue level difference test results, it can be seen that the thigh was most easily affected by the seat position, followed by the shank. This indicated that the effects of the seat position on the fatigue level and comfort level of the main force applying body parts are significantly greater.

V. CONCLUSIONSAND RECOMMENDATIONS

The riding comfort level of the participants and fatigue level of their body parts varied significantly according to seat position. Among the body parts, the shank, knee and thigh had higher fatigue levels, and the effects of the seat position on the fatigue levels of the above three body parts were significantly greater.

Through the regression analysis, the optimal seat positions for the different lower body length users are as follows: The horizontal distance(mm) between the seat center and the crankshaft center = 269.15+3.50×lower body length(cm), and the vertical distance(mm) between the seat center and the crankshaft center= 58.58+0.71×lower body length(cm).

It is suggested that the seat adjustment information can be considered in the future recumbent exercise bike development. It means that the optimal or suitable seat positions for riding for users with various lower body lengths can be labeled on the portion of the bike used for seat adjustment to assist users in obtaining the optimal seat position for riding, enhancing riding efficiency, and reducing the risk of physical injuries.

This study only investigated the male with the lower body lengths ranging from 101-125cm (with the heights between 156 and 185 cm). Therefore, whether the results obtained in this study can make an accurate prediction for other lower body length groups or can be applied for the female users are the directions that can be studied in the future. In addition, this study used subjective comfort level and fatigue level assessments for investigation. Future studies can use an electromyography (EMG) to analyze muscle activity to achieve unbiased and objective practical predictions and assessments.

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