〔보 문〕

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A Study on Walking Movements for Skirt Patterns with 3D Motion Analysis System
3차원 동작분석장치를 이용한 하지동작 연구

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Abstract

본 연구는 동작분석장치를 이용하여 하지동작분석을 시도함으로서 실제 동작 시 적응 할 수 있는 의복설계를 위한 기초 자료로서 하지부 실루엣 변화의 특성을 밝히고자 하였다. 대퇴돌기점을 기준으로 본 하지동작의 진행방향 이동과 상향 방향이동을 살펴보았는데 보행유형에 따라 여유량이 특히 요구되는 부위가 각기 다르며, 부위별 필요 여유 량도 각기 다르다는 것을 알수 있었으며, 이러한 보행유형별 스커트 실루엣의 특징은 기능복 설계 시 고려되어야 하겠다. 평지보행시는 발목부위가 전면방향보다 후면방향으로 이동의 범위가 크므로 트임이나 주름이 뒷면에 있는 것이 적합하고, 계단승강이나 버스승강의 경우 무릎전면에 여유량이 필요하므로 주름이나 트임을 앞쪽에 주는 것이 바람직하며 그 길이는 대퇴돌기점 높이정도에서 시작하여야 하고 무릎아래에 있는 앞트임은 하지동작에 도움이 되지 않음을 알 수 있었다.

Key words: 3D-motion analysis system, Lower limbs, Knee, Ankle; 3차원 동작분석 시스템, 하지, 무릎, 발목

I. Introduction

In order to manufacture functional clothing, it is necessary to understand somatotypes, physiological conditions and physical movements. Therefore, body measuring and biotechnology should be the foundation of clothing ergonomics, and human body size, fitness and adaptability need to be analyzed. The amount of easing in clothing should be for body movement and in the appropriate areas. Therefore, it is necessary to observe body movement and analyze it to discover the amount of ease needed and where it is required. The skirt, which covers the abdomen, the waist and lower limbs of the human body, must be able to accommodate the movement of the lower limbs.

The major activities of the lower limbs include walking, sitting and standing. Walking movements such as walking on the floor and stepping on the stairs. are actions for the transfer of human body mass. The restriction of these actions adds to physical fatigue. To cope with these activities, the skirt has to have enough width. The movement of the lower limbs should be considered in conjunction with the movement circle of the knee and ankle, during skirt manufacturing. Tight skirts are used by many women regardless of their age.

In her research concerning the effect of garment restriction on the human body for long periods of time, Inomata (1992a) examined the restriction of tight skirts and the resulting change of muscle activity causing fatigue to the wearer. Many people prefer to wear tight skirts of narrow width. If these skirts are to be functional as well as slender, it is essential to find out ways to satisfy both requirements.

Photography using a video camera is a useful method for recording body movements that change instantaneously, since observation with the naked eye is not only inaccurate and hard to analyze but also lacks objectivity. A 3-D motion analysis system makes it possible to observe and analyze the human movements, and to gather information connected to the human factor, and apply this in pattern making

Therefore, in this study, changes to the silhouette and its movement patterns caused by the motion of walking on the floor, stepping on the stairs and stepping on a bus, were measured and analyzed with a motion analysis system in order to establish formations for making functional skirts.

The objective of this study is to analyze the movement of the lower limbs and changes of silhouettes with a motion analysis system, and provide information for functional skirt patterns.

Definitions

(1) Lower limbs : the lower limbs consist of 3 parts which are the thigh, leg and foot. These are divided by hip joint, knee joint and ankle joint.

(2) Walking movement : walking movement refers to the actions that move the position of the human body using two lower limbs.

(3) Silhouette : shadow, contour or out-line,

(4) Step length : the distance between the center of the heel of one foot and the centre of the heel of the other foot.

(5) Stride length: the distance between the center of the heel on one foot and the center of the heel on the same foot after 2 steps.

(6) Swing : the movement that raises a foot to move forward for walking.

(7) Stance : the action of one foot standing on the floor while the other foot swings.

(8) Double support : when parts of both feet touch the floor at the same time when one foot changes from swing action to stance and the other foot changes from stance action to swing.

II. Materials And Methods

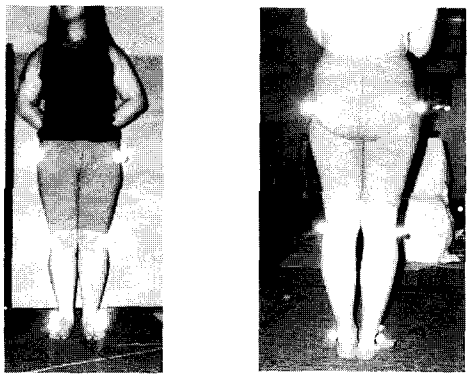
Three female subjects were selected between the ages of 18 and 24. One of the subjects was average size with a height of 160.8cm(Korea Research Institute Standards and Science, 1997). The other two were of comparatively smaller (height 152.1cm) and bigger (height 163.9cm) size.

Table 1. Subjects' anthropometric measurements

unit(cm)

item	subject A	subject B	subject C
stature	152.1	160.8	163.9
waist height	90.7	97.5	98.5
hip height	75.0	79.5	80.2
knee height	40.8	41.6	43.3
ankle height	4.9	4.9	5.8
weight(kg)	48.8	50.0	63.0
Rohrer index	1.38	1.2	1.46

In order to study the movement of the lower limbs, the subjects were marked at 9 sites which were the back waist center point, the right and left greater trochanter for the hip joint, the right and left head of the fibula for the knee joint, the right and left lateral malleolus for the ankle joint, the



Front Back

Fig. 1. Attached reflection marker on each site

right and left metatarsal 5 for instep point. Reflection makers were attached to each site, to be observed well in all 4 cameras. The subjects dressed in short tops to look well from the waist, and short nylon pants which were 10cm above knee length to move freely. After measuring each site with a Matin measuring instrument, reflection markers were attached at the measuring points.

To set up the working station for the experiments, the bus stair was set up first since the bus stair was the highest, to see whether all of the site was viewable in camera while subjects practiced the movements, and the operation of motion analysis device was tested. Subjects practiced natural walking before the experiment movements, and the experiments were repeated 2 times. A 3-D Motion analysis system, Matin' s measuring instrument, 2 stair steps (height 15cm, width 30cm for each step), bus stair (height 34cm, width 30cm) were used for this study.

1. Apparatus

A motion analysis device that was used during the research consisted of software for 3D expert vision motion analysis system, 4 CCD cameras, a video processor, a sun workstation and software for data analysis, VCR etc. Reflective markers were attached at the sites and experimental actions in workstation were performed. The action was filmed by 4 cameras and this photographing process was synchronized with a video processor device and was recorded on video tape. The result was displayed on a 3D x-y-z position for each marker, for each frame.

To analyze human body actions which change instantaneously, the disposition of each measuring site must be able to be recorded and described later. The actions which change rapidly in a short span of time, were able to be analyzed in detail with the 3D motion analysis system.

The work station (Fig. 3) was established. Four lines with reflective markers were hung down to the floor, the x-y-z position for the reflective markers were figured out, then the lines were removed. The walking was performed in the work station.

The most frequent motions of the lower limbs in daily life are walking on the floor, ascenting and descenting stairs, getting on and off buses. The size

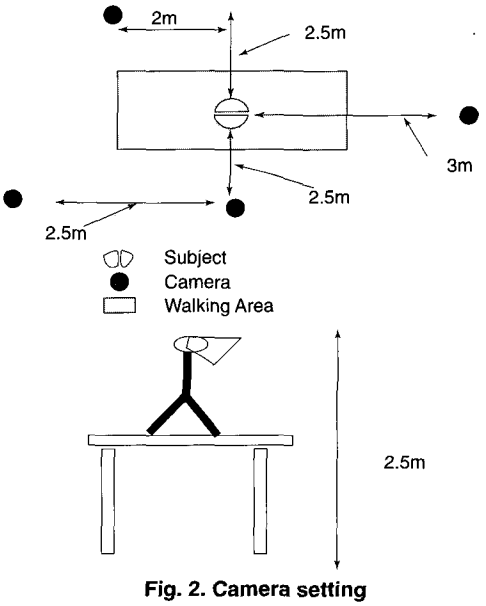


Fig. 2. Camera setting

of the stair was 15cm high and 30cm wide which was the same size as the subway and school stair The size of the bus stair was 34cm high and 30cm wide. Since the walking motion occurs continuously, the experiments were repeated as far as the work station permitted, 3 steps for the stairs and 2 steps for the bus stairs.

Walking consists of a stance which is moving the body with the feet stationary on the ground or the stairs, and swing which is detaching the feet from the ground and moving them to the next step. Swing and stance happen alternatively left and right, the swing action is held on right, the stance on left. Next, the swing action is held on left and then stance on the right. There is double support at the time that the stance changes to swing or swing changes to stance.

The movement of the knee joint and the ankle joint was described with a graph on the basis of the hip joint, and the action of the swing and stance was studied. Analysis of variance was conducted for the range of movement of the thigh and leg.

Ⅲ. Results and Discussion

In order to observe silhouette changes of the lower limbs, the movement of the hip joint, the knee joint, and the ankle joint were marked with reflective markers. The amount of displacement for each joint was indicated by a numerical value and forward and upward movement of each joint, was displayed by a graph to recognize the whole displacement of the lower limbs. To obtain the information for the movement of the lower limbs in the skirt, the range of motion for the knee joint and the ankle joint in relation to the hip joint was analyzed. Swing and stance was able to be measured by the x-y-z position of the knee and ankle joint.

The swing motion appears to be proceeding forward, and the stance motion appears to be proceeding backward in relation to the hip joint.

The moment when both lower limbs appeared to move backwards was the state of double support. The body moves forward by repeating forward and backward movements for the knee joint and the ankle joint in relation to the hip joint.

The difference in swing and stance can be seen by the movement of the ankle joint, the ankle joint moves forward in relation to the hip joint for swinging and the ankle joint moves backward in relation to the hip joint for stance. Because of the

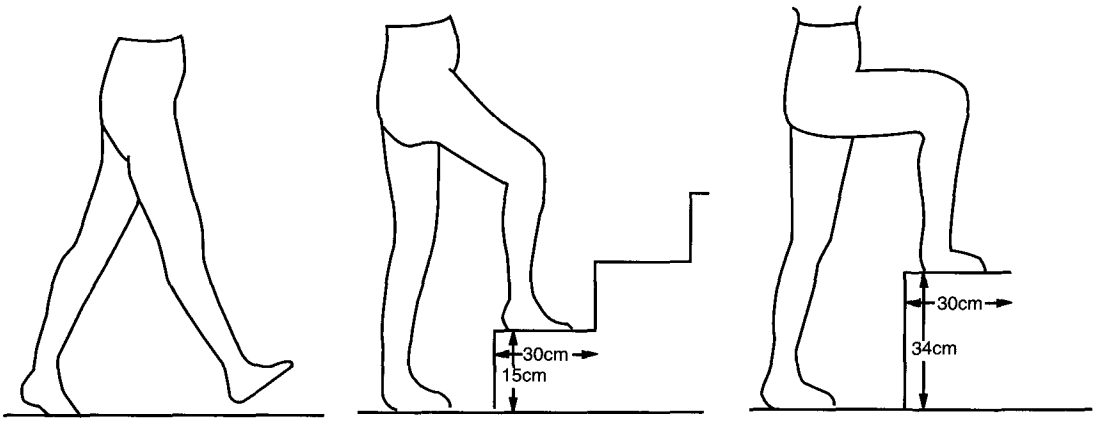


Fig. 3. Three types of walking movements

time people step on their feet and move the body forwards, the lower limbs in relation to the hip joint move backwards. For double support, both lower limbs moved backward in relation to the hip joint.

To analyze the range of movements, the percentages of forward direction and backward direction in relation to the hip joint were compared and the swing action and the stance action were studied.

Table 2. Range of forward and backward movement in relation to the hip joint

Type	Subject	Step	Knee(%)		Anker(%)	
			Forward	backward	Forward	backward
Walking on the floor	Subject A	1	42	58	26	73
		2	43	57	34	66
		3	45	55	33	67
		Average	43.3	56.6	31	68.6
	Subject B	1	38	62	26	74
		2	45	55	28	72
		3	44	56	26	72
		Average	42.3	57.6	27.3	72.6
	Subject C	1	35	65	28	72
		2	36	64	30	72
		3	34	66	26	74
		Average	35	65	28	72
Stepping on the stairs	Subject A	1	75	25	48	52
		2	76	24	46	54
		3	85	15	51	49
		Average	78.6	21.3	48.3	51.6
	Subject B	1	64	36	44	56
		2	72	28	37	63
		3	69	31	39	61
		Average	68	32	40	60
	Subject C	1	62	38	27	73
		2	66	34	22	78
		3	63	37	-	-
		Average	63.6	36.3	24.5	75.5
Getting on the bus	Subject A	1	94	6	60	40
		2	88	12	63	37
		Average	91	9	61.5	38.5
	Subject B	1	97	3	59	41
		2	81	19	49	51
		Average	89	11	54	46
	Subject C	1	93	7	61	39
		2	93	7	80	20
		Average	93	7	70.5	29.5

1. Silhouette changes of the lower limbs

1) Walking on the floor

For walking on the floor, the knee joint in relation to hip joint moved 35%~43% forward, 57% ~65% backward, and the ankle joint in relation to hip joint moved 27%-28% forward and 72% backward. At the forward direction movement in relation to hip joint, the range of leg movement was bigger than the thigh movement at forward direction, and greater at backward direction,

The range of movement for the ankle joint was about 2 times more than that of the knee joint. When the lower limbs changed the motion from swing to stance and stance to swing, the stance ankle was mostly backward and there was double support. From this time double support lasted until the other foot took up from the ground, and was followed by single support. The ankle protruded forward after the knee reached maximum height. The upward movement of the knee joint in relation to the hip joint was paralleled with the ground with irregular small ups and downs. Walking movement occurred in coordination with many parts of the body.

2) Stepping on stairs

For the forward movement, the knee joint moved parallel with the ankle joint, and the knee joint was more forward than the ankle joint when stepping on the stairs. when stepping on the stairs, the knee and the ankle changed motion almost at the same time from swing to stance. The knee tended to move first when changing from swing to stance.

For stepping on stairs, 21%~36% of knee joint

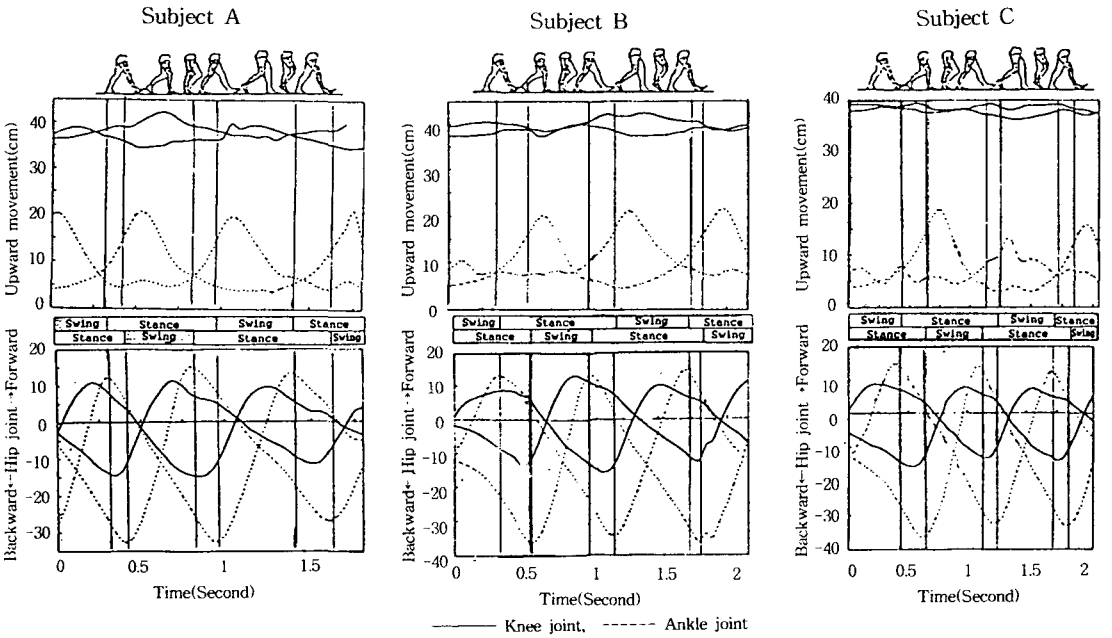


Fig. 4. The movement of the lower limbs in relation to the hip joint when walking on the floor

movement was forward direction and 64%~76% backward direction, and 49% ~61% of ankle joint movement was forward and 39%~48% backward direction in relation to the hip joint. When the knee joint was most advanced, the height was also greatest, and double support began while the body kept on moving forward. After double support, when the stance feet began the swing action, the feet of stance made a forward movement without any upward movement.

In order to make the swing action, the lower limb was lifted upward, and the body moved upward as well. For stance action, the knee and the ankle moved backwards in relation to the hip joint. Then, the other foot began swinging, with the body moving forward without upward movement, by the time one cycle was completed. During this action the body kept on moving forward.

3) Getting on the bus

For getting on the bus, forward movement of the lower limbs occurred in front of the hip joint. Especially, 88%~97% of the knee movement was held at the front and 3%~19% was held at back. The forward movement of the ankle joint was held 37%~40% at the front and 60%~ 63% at the back side of the hip joint. Similar to getting on stairs, the knee joint moved parallel with the ankle joint, but the movement was further forward in relation to the hip joint.

The swinging lower limb lifted up the leg and reached to the highest point and changed to the stance motion, then turned to double support. At the beginning of the single support, the body moved forward and upward, but simultaneously both knees crossed and the body moved forward without upward movement. The swinging foot touched the step, then turned to double support

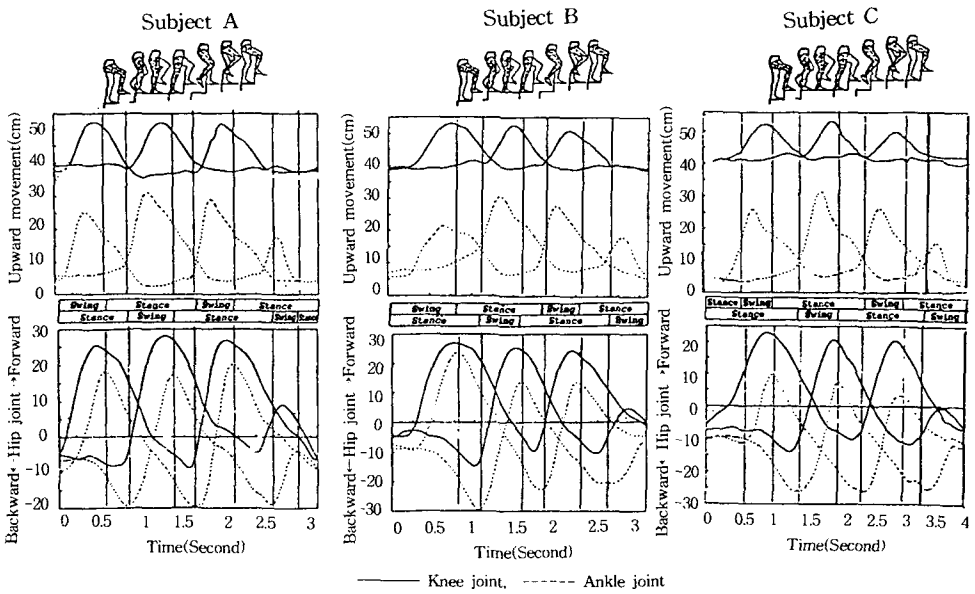


Fig. 5. The movement of the lower limbs in relation to the hip joint when stepping on the stairs

and the body moved upward and forward, completing one cycle.

2. The range of lower limbs movement in relation to the hip joint

The range of lower limbs movement was recorded and in order to find out if there were any significant differences among the subjects and types of walking, Anova was conducted.

1) The range of knee movement

The range of knee movement in relation to the hip joint was obtained by the difference of knee joint to hip joint specifically, x-y-z position of knee joint was subtracted from the x-y-z position of hip joint. The range of knee movement for walking on the floor was 21.0cm~28.8cm, The crossing point of both knees was on a vertical line of the hip joint.

The range of upward movement of the knee was 1.2cm~5.9cm, which was the smallest among the 3 walking types. In particular the average of subject C's was only 1.8cm. The range of forward movement of stepping on the stairs was 31.1cm~36.8cm and the point that both knees crossed was a little in front of the hip joint. For the range of upward movement of stepping on the stairs, Subject A was approximately 13.1cm~16.4cm, subject B was 11.9cm - 14.1cm and subject C was smallest at 8cm~10.6 cm

The range of forward movement for getting on the bus was 33.9cm~41.4cm. It was approximately 4cm bigger than getting on stairs which was 31.1cm~36.8cm, because the width of stairs was about the same 30cm as the bus step. For the upward direction, subject A and subject C moved about 23.1cm~26.9cm and subject B moved 28.2cm~33.9cm which was more than others. If the crossing point of both knees was a longer distance from the hip joint, it would mean that the knee was bent. There was no significant difference among subjects in terms of forward movement for the knee, but there were significant differences at

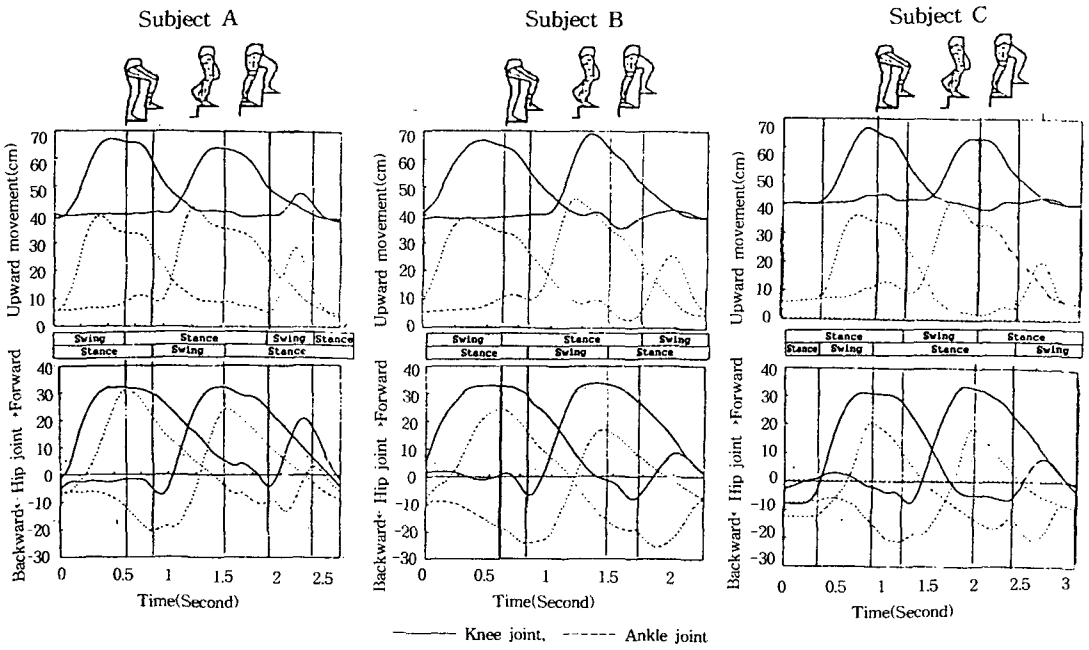


Fig. 6. The movement of the lower limbs in relation to the hip joint when getting on the bus

the level of 0.001 among the types of walking, walking on the floor, stepping on the stairs, and getting on the bus〈Table. 4〉. The range of upward movement of the knee joint had significant difference among subjects as well as types of walking〈Table. 5〉.

2) The range of ankle movement

The range of the ankle movement in relation to the hip joint was more or less the same as the range of the lower limb movement, and it was related to skirt width.

The range of ankle movement in relation to the

Table 3. The range of knee movement in relation to the hip joint Unit(cm)

Subject	Step	Walking on the floor		Stepping on the stair		getting on the bus	
		Forward	Upward	Forward	Upward	Forward	Upward
Subject A	1	25.3	2.0	33.8	13.1	33.9	26.9
	2	26.2	5.9	36.8	15.0	36.4	24.4
	3	21.0	2.9	31.2	16.4	-	-
	Average	24.1	3.6	33.9	14.8	35.1	25.6
Subject B	1	21.7	3.2	36.5	14.1	33.9	28.2
	2	28.8	2.1	35.2	13.3	41.4	33.9
	3	22.4	4.9	35.0	11.9	-	-
	Average	24.3	3.4	35.6	13.1	37.6	31.0
Subject C	1	24.5	1.3	36.8	9.3	38.5	23.1
	2	21.0	1.2	31.1	10.6	40.4	24.9
	3	21.4	3.1	32.0	8.0	-	-
	Average	22.3	1.8	33.3	9.3	39.2	24

Table 4. Anova for forward movement of knee

Source	DF	sum of squares	Mean squares	F value	Pr>F
α	2	832.27	416.1	51.3	0.0001
β	2	8.3	4.1	0.51	0.6
$\alpha\times\beta$	4	24.5	6.1	0.76	0.57

α; Types of walking, β; Subject, A, B, C

Table 5. Anova for upward movement of knee

Source	DF	sum of squares	Mean squares	F value	Pr>F
α	2	2064.1	1032.0	320.8	0.0001
β	2	65.0	32.5	10.39	0.0015
$\alpha\times\beta$	4	42.8	10.7	3.42	0.036

α; Types of walking, β; Subject, A, B, C

hip joint was obtained by the difference of the ankle joint to the hip joint, the x-y-z position of the ankle joint was subtracted from the x-y-z position of the hip joint.

The range of forward movement of the ankle for walking on the floor was 40cm~51cm, and the range of upward movement of the ankle was 10cm ~16.8cm.

The range of forward movement of stepping on the stairs was 28.5cm~43.2cm, and the range of upward movement of stepping on the stairs was 13.8cm~28.5cm.

For forward movement of getting on the bus, the first step was 41.6cm~51.4cm, which was more than 10cm bigger than stepping on the stairs. The second step was 34.8cm~42.1cm which was about 2cm bigger than stepping on the stairs, because the starting position differed due to the height of the stairs even though the width of the stairs was the same. In the case of getting on the bus, as well as stepping on the stairs the ankle joint was behind the knee joint. The cross point of both ankle joints was on the vertical line of the hip joint. The range of forward movement for the ankle had no significant difference among subjects, but there were significant differences at the level of 0.001 among the types of walking, walking on the floor, stepping on the stairs, and getting on the bus ⟨Table. 7⟩.

For the range of upward movement for the ankle, there were no significant differences among the subjects, but there were significant differences among the types of walking, walking on the floor, stepping on the stairs, and getting on the bus ⟨Table 8⟩.

Table 6. The range of ankle movement in relation to the hip joint Unit(cm)

Subject	Step	Walking on the floor		Stepping on the stair		getting on the bus	
		Forward	Upward	Forward	Upward	Forward	Upward
Subject A	1	44.6	15.7	37.3	19.4	51.4	28.2
	2	47.4	15.6	37.0	28.5	37.3	37.3
	3	40.0	16.8	39.0	24.8	-	-
	Average	44	16.0	37.7	24.2	44.3	32.7
Subject B	1	49.0	12.1	43.2	13.8	48.6	32.9
	2	47.9	16.4	36.2	24.0	42.1	35.9
	3	50.6	13.9	34.0	19.7	-	-
	Average	49.1	14.1	37.8	19.1	45.35	34.4
Subject C	1	51.0	14.2	35.7	20.1	41.6	23.0
	2	46.2	10.1	33.5	23.8	34.8	40.0
	3	45.2	12.2	28.5	20.0	-	-
	Average	47.4	12.1	32.6	21.3	38.2	31.5

Table 7. Anova for forward movement of ankle

Source	DF	sum of squares	Mean squares	F value	Pr>F
α	2	1286.6	643.3	30.4	0.0001
β	2	35.9	18.0	0.86	0.44
$\alpha\times\beta$	4	33.8	8.4	0.41	0.80

α; Types of walking, β; Subject, A, B, C

Table 8. Anova for upward movement of ankle

Source	DF	sum of squares	Mean squares	F value	Pr>F
α	2	543.3	267.2	14.8	0.0001
β	2	77.0	38.5	2.14	0.15
$\alpha\times\beta$	4	78.9	19.7	1.10	0.39

α; Types of walking, β; Subject, A, B, C

3. Functional skirt patterns

The silhouette of the lower limb differed by the height of the stairs, walking on the floor, stepping on the stairs, and getting on the bus. Therefore, the silhouette for the movement must be considered when making functional skirt patterns.

For walking on the floor, the range of forward movement of the knee joint in relation to the hip joint was more or less the same between forward and backward, but the ankle joint was more backward than forward. Therefore, the back slit would be better than a side or front slit. When the ankle was further backward, the knee was bent, so the longer the skirt, the wider the skirt should be, and a slit would be better than a small pleat.

For stepping on the stairs, the skirt required more room for the movement circle of the knees, since the thigh moved counterclockwise and the leg moved clockwise, so the knee was bent. Stepping on the stairs, the knee and ankle moved parallel, with the knee protruding for forward movement, and the ankle had bigger movement for backwards.

Getting on the bus required more room around the knee than stepping on the stairs did, since the movement of the knee occurred at a further distance from the hip joint as the stair got higher. Also, the room should be at the front of the skirt since the movement of the knee occurred more in the front side than the back side of the hip joint. Therefore, uniforms for high school students who ride buses often should have a pleat in front and it should start from the hip joint to accommodate movement.

For stepping on the stairs and getting on the bus, the front pleats below the knee would not be helpful for walking because the movement of the thigh was bigger.

According to walking types, the area and quantity of the room required differed, and the characteristics of these walking movements should be considered for functional skirt design.

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