Influence of Size on Movement Adaptability of a Front-Open Shirt

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The objective of this study was to develop guidelines for clothing sizes, and to develop designs for ready-made clothes which are comfortable for the wearer. The movements of the cloth of wearers’ shirts as well as the measurements of the wearers’ bodies were measured simultaneously and then analyzed with a three-dimensional motion analysis system to determine the ease of movement was examined with respect to clothes of various sizes. A wearing test using a front-opening shirt was conducted on 22 young women. Subjects wore five sizes from one small size to three big size than their standard clothing size. The effects of the sizes were investigated in terms of their “ease of movement” and “sensory evaluation of wearing.” The results showed that the subjects who wore shirts from one big size to three big size felt larger range of motion of the shoulder joint than the wearers of the one small size and the standard clothing size. It may be said, then, that it is not necessary for people to wear larger shirt than one big size. Wearers prefer clothing which exposes part of their body when they move and clothing which they have to adjust after moving. The research found that this type and size of clothing is optimal for wearers.

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INTRODUCTION

The authors have investigated judgments of size by both the wearer and the observer in a wearing test of a front-open shirt conducted with young women. Assessments of the observer differed from those of the wearer with regard to the best fitting size, with the observer selecting the best fitting size in accordance with the standard clothing size (which was JIS clothes size chosen according to bust measurements). In other words, the subjects appeared the most beautiful when wearing the standard clothing size. The wearer included aspects of comfort such as movement adaptability in the evaluation and, consequently, judged sizes larger than the standard clothing size to be better. Based on these findings, “the selection of the best fitting size for the wearer” requires the inclusion of aspects of the wearing condition in order to produce ready-made clothes of designs in which the wearer will be comfortable.

A precedent study has aspects of “the choice of clothes by size,” “the wear ease of clothing relation between the body and clothes,” and “the evaluation of movement adaptability by using EMG.” However, the study has not been conducted to evaluate movement adaptability (this is “ease of movement”) and wearing evaluation of different sizes. Therefore, in this report, the measurement of the linking movement of shirt and body was analyzed with a three-dimensional motion analysis system, so ease of movement was examined with respect to clothes of various sizes. And these data were compiled to develop guidelines on sizes and to develop clothes for comfort.

SUBJECTS AND METHODS

The subjects were 22 young women (average age, 23.7 years old). In addition to height, measurements at the bust, waist, and hip were taken. The means (with SD) were as follows: height, 157.6±5.7 cm; bust, 83.8±4.4 cm; waist, 66.6±4.2 cm; and hip, 92.4±4.5 cm. The sizes of clothing that subjects usually purchased and their standard clothing sizes are shown in Table 1.
The item of test clothing was a front-open shirt, which the authors made from a prototype\(^{12}\) in all sizes from 3 to 21. With this prototype, “width across body” was “(bust measurements size)/2 + 6” cm, “width across chest” was “(bust measurements size)/8 + 6.2” cm, and width across back was “(bust measurements size)/8 + 7.4” cm. The back-waist length and length of sleeve were held constant, with bust dimensions varied for each size (bust measurement size of JIS clothes size: 3, 74 cm; 5, 77 cm; 7, 80 cm; 9, 83 cm; 11, 86 cm; 13, 89 cm; 15, 92 cm; 17, 96 cm; 19, 100 cm; 21, 104 cm). The test shirts were made from dark blue 100% cotton broadcloth (thread density: warp, 60.7 threads/cm, weft, 28.3 threads/cm; thickness: 0.22 mm; expansion rate: warp, 13.6%, weft, 13.8%). The subjects wore an undershirt of 100% silk under the test shirt. Each subject wore 5 sizes of the test shirt with the standard clothing size corresponding to bust size as follows: 1 size smaller (−1 size), standard clothing size, 1 size bigger (+1 size), 2 sizes bigger (+2 size), and 3 sizes bigger (+3 size). For example, for a subject whose size is 7, 5 is −1 size, and 9 is +1 size. Sizes were not indicated on each shirt, and the wearing order was randomized so that each subject would evaluate the shirt based only on sensation without the influence of size information.

We tested ease of movement for subjects who performed 3 motions starting from the upright position when wearing the test shirt. We regarded the movement of the clothes as a body. Three motions were tested: lifting only the right arm (motion A), lifting both arms simultaneously (motion B) and an anteflexion (motion C) (Fig. 1). Images were recorded with four digital video cameras (infrared mode) through visible light cut filter and analyzed with a three-dimensional motion analysis system Mpro3D (HuTech). The measurement points on the body and on the shirt are shown in Fig. 2. A reflective marker was added to each point of measurement on the shirt and an IR-LED marker was placed at the corresponding measurement points on the body. IR-LED markers that are affixed directly to the skin can allow making measurements of body movement while fully clothed. But when IR-LED markers were used without requiring IR-light to pass through cloth the measurement error was generated. So, reflective markers were used on the shirt where it is not necessary for the IR-light to pass through cloth. By using two kinds of markers together, the measurement of the linking movement of shirt and body at the same time was enabled.

The ease of movement for the shirt was evaluated by examining the movement of the shirt corresponding to the movements of the body. When wearing a shirt of the standard clothing size, with the standing position before the motion, the centerline of front and back matched the center of the body, and the BL/WL/hem line was level. From this condition, the

<table>
<thead>
<tr>
<th>Clothing size purchased by wearer (cm)</th>
<th>78(cm)</th>
<th>90(cm)</th>
<th>102(cm)</th>
<th>114(cm)</th>
<th>126(cm)</th>
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<tr>
<td>Total</td>
<td>5</td>
<td>6</td>
<td>8</td>
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<td>22</td>
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*Fig. 1. Three motions for testing ease of movement

![Fig. 1: Three motions for testing ease of movement](image)

![Fig. 2: Measurement points on the body and on the shirt](image)
differences in coordinates and the distance between “the measurement point of the shirt” and “the corresponding measurement point on the body” were also computed. These measured values show the condition worn beautifully, and the amount of change by the motion and the amount of change after the motion from this condition were measured. “The measurement point of the shirt” and “the corresponding measurement point on the body” were NLP(f, b)–NP(f, b), BLF(f, b)–BP(f, b), WLP(f, s, b)–WP(f, s, b), HLP(f, s, b)–WP(f, b) or HP(s) on the same side (for example: front, right side, or back) and SP (on the shirt)–SP (on the body). Changes in the difference in Z coordinate of WPF–WLPf at motion A in one subject are shown in Fig. 3. At the start, the distances between the measurement points were assumed to be the zero. The degrees of change in the time of maximum motion (maximum frame) and motion end time (last frame) differed with those of the first frame. Thus, the degree of change of each of the coordinates was calculated and used in examination: X, right and left direction; Y, front and back direction; Z, top and bottom direction;

\[
\text{the difference in coordinate between body and shirt) = (coordinate on the shirt) - (coordinate on the body)}.
\]

In addition, the degree of change of the distance was calculated and used in examination: the calculation method of distance:

\[
\text{the distance between body and shirt) = \sqrt{(\text{difference in X coordinate})^2 + (\text{difference in Y coordinate})^2 + (\text{difference in Z coordinate})^2}}.
\]

“The difference at the maximum frame” represented the change from the first to the maximum, and “the difference at the last frame” represented the change from the first to the last. In addition, the shoulder joint point of view was expressed as the \( \angle \text{EP} \cdot \text{SP} \cdot \text{WPs} \).

Sensory evaluation was also investigated. For each shirt, the subject made an evaluation on a scale of 1 to 5 points; very small, 1; slightly small, 2; just right, 3; slightly big, 4; very big. 5. In addition, after trying all 5 shirts, they chose “a shirt evaluated as fitting the best (named “best fitting size selection”)” from among the five shirts.

**RESULTS AND DISCUSSION**

Adaptability of the standard clothing size shirt for each motion

1. Lifting only the right arm (motion A)

The differences in the coordinates from first frame of each measurement point to the maximum frame and the last frame for lifting only the right arm (motion A) are shown in Fig. 4. In the X coordinate, there was movement to the right. In the Z coordinate, there was upward movement. However, there was little movement in the Y coordinate. The measurement
points at the front and the right sides of the subject showed the biggest movements. In addition, the greatest movement was observed in the fall down to a hem from the neckband/shoulder. At the maximum frame, NLP/SP/BLP showed the least changes. Therefore, the shirt moves with movement along the body at the neck and the bust. However, at the maximum frame, WLP/HLP showed the large changes. So, it became clear that regardless of the movement of the position of the waist on the body, the waist and the hem on the shirt moved conspicuously. This result suggests that the woman supports the shirt with her shoulder, neck, and bust. The value of the last frame shows how the shirt changed its shape as a result of conducting motion A. If this value is big, the shirt becomes widely disheveled. The difference between the maximum frame and the last frame shows how the clothes move back to its original position when resuming the original posture. In the last frame, the measurement point showing the greatest difference corresponded with the maximum frame.

In Fig. 5, the differences in distance from first frame of each measurement point to the maximum frame and the last frame for lifting only the right arm (motion A) are shown. If this value is large, the shirt becomes widely disheveled. As for the distances, the movement is larger for measurement points closer to the hem. Furthermore, WLP and HLP of the front and the right sides showed the biggest differences between the maximum frame and the last frame. In other words, at the maximum frame, the motion of the body did not match that of the shirt, but the appearance was almost restored after the motion ended. However, there was about 5 cm difference at the hem. In this case, it is not necessarily good that the shirt does not move (does not get disheveled). The shirt links to the movement of the body and must move. But when the motion is completed, the original position is not restored, and the look is disheveled, which is a problem.

Fig. 5. Difference in distance at the maximum frame and the last frame for lifting only the right arm (motion A)

2. Lifting both arms simultaneously

In Fig. 6, the differences in the coordinates from the first frame of each measurement point to the maximum frame and to the last frame are shown for the motion of lifting both arms simultaneously (motion B). In Fig. 7, the differences in distance from the first frame of each measurement point to the maximum frame and the last frame for lifting both arms simultaneously (motion B) are shown. The Y and Z coordinates and distance were similar to those observed for...
motion A. On the other hand, for the X coordinate, the movement to the right associated with motion A disappeared. In addition, a larger value for the Z coordinate was observed than for motion A, and the distance was almost identical with that for motion A. This was a difference between lifting only the right arm (motion A) and lifting both arms simultaneously (motion B).

3. Anteflexion

In Fig. 8, the differences in coordinates from the first frame of each measurement point to the maximum frame and the last frame for anteflexion (motion C) are shown. In Fig. 9, the differences in distance from the first frame of each measurement point to the maximum frame and the last frame for anteflexion (motion C) are shown. Because the measurement points of the front of the body with the maximum frame for anteflexion were not able to be taken, there are no data. At the back hem, the movement was characteristic of the maximum frame. As for the posture assumed in the maximum frame, the skin of the back stretched widely and larger values resulted due to the fact that the interval of measurement points on the body lengthened. However, in the last frame, the shirt returned to its original position.

Based upon these findings, different movements of the shirt were observed for each motion when the standard clothing size was worn. The shirt became disheveled (sliding up around 5 cm at hem) when each motion was completed. When the standard clothing size was worn, it was necessary to reposition the shirt after every movement.

Comparison for size differences

1. Evaluation of fit

The score evaluating for fit differed with size ($F(4, 105)=30.90, p<0.001$). In Fig. 10, the mean evaluation of fit is shown for each size. These results

![Comparison for size differences](image)

Fig. 10. The evaluation of fit by the wearers

Table 2. Multiple comparison of best fitting size selection and the standard clothing size

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Least significant difference

* $p < 0.05$, n.s. no significant difference

-1:1size, 0:standard clothing size, +1:+1size, +2:+2size, +3:+3size

(983)
are shown as a multiple comparison in Table 2. +1 size and +2 size did not have significant difference, but subjects recognized differences in fit with size: +3 size > +2 size > +1 size > standard clothing size > −1 size. The evaluation that was almost “3” to express “just fit” was from the standard clothing size to +2 size.

2. Range of motion of the shoulder joint

In Fig. 11, according to the size, the mean angle of the shoulder joint at the maximum frame for lifting only the right arm (motion A) is shown. The mean angle of the maximum range of motion was 135.8 ± 13.3° when wearing no shirt. When a shirt was not worn, range of motion was larger than the cases with all sizes, and the differences were significant. Therefore, the range of motion of the shoulder joint was limited by wearing any size shirt. The analysis of the variance among different sizes showed a significant difference (F(4,102) = 9.49, p < .001). Range of motion was limited by smaller sizes and the limitation increased according to the size decrease. Moreover, the multiple comparison (Table 3) showed that there were no significant differences for “−1 size and the standard clothing size” and “from +1 size to +3 size.” Therefore, we can say that the range of motion of the shoulder joint was limited more in the case of the “−1 size and the standard clothing size” than in the “+3 size from +1 size” group.

3. Ease of movement of the shirt

In Fig. 12, the differences in distance of each measurement point for motion A about all sizes are shown. An analysis of the variance of different sizes at every measurement point showed significant differences for HLPf, WLPs, and HLPs. The differences in distance were greater for larger sizes. We speculated that these changes were influenced by the movement of the shoulder joint at the maximum frame and the ease of garments. Regarding the last frame, different patterns were observed for every measurement point, and the distance changes were not so large for the larger sizes. In other words, the shirts tend to alter more to adjust to the physical motion when wearing bigger sizes, but the shirts after motion got disheveled (sliding up) the same regardless of size.
Influence of Size on Movement Adaptability of a Front-Open Shirt

Relationship of the ease of movement and the size evaluation by the wearer

1. Wearer selection of the best fitting size

In Fig. 13, the results of the best fitting size which wearers chose from five shirts are shown. As shown, the “best fitting size selection” did not necessarily correspond with the standard clothing size. Thus, wearers’ choices were classified as “best fitting size selection in agreement with the standard clothing size group (Group A, n=10)” and “best fitting size selection bigger than the standard clothing size group (Group B, n=11).” And Group B was compared with Group A about the ease of movement.

2. Comparison between Group A and B, about wearing “the standard clothing size”

a. Range of motion of the shoulder joint

The average maximum motion for Group A was 117.6 ± 19.0° and 117.9 ± 8.1° for Group B. There was no significant difference (t-test) between the groups. The sensory evaluation (best fitting size selection) did not affect the range of motion of the shoulder joint. And when wearing the standard clothing size, the range of motion on the shoulder joint did not vary for anyone.

b. Ease of movement

In Fig. 14, the difference in distance from the first frame of each measurement point to the last frame is shown when wearing a shirt at the standard clothing size. The difference in distance for Group A was larger than for Group B. Next, the subjects were made physique classification on a scale of 1 to 3 points: “Y figure type (the figure of the person who had a smaller hips 4 cm than A figure type),” 1: “A figure type (the standard figure),” 2: “AB figure type (The figure of the person who had a bigger hips 4 cm than A figure type),” 3. Then, as for the mean of each group, Group A was 1.70, and Group B was 2.73. So, because Group B was the figure type that the hips were bigger than Group A, there was little ease of the hem and may not have moved. Therefore, it was related to the feeling that the standard clothing size is small because the distance was small.

Fig. 13. The best fitting size selection by wearers

Fig. 14. Comparison between Groups A and B; difference in distance at the last frame when wearing the standard clothing size

3. Comparison between Groups A and B, about wearing “the best fitting size selection”

a. Range of motion of the shoulder joint

The average maximum range of motion for Group A was 117.6 ± 19.0°, and for Group B was 129.5 ± 8.0°. There was no significant difference (by t-test) between the groups. So there was no difference in the range of motion of the shoulder joint in choosing the best fitting size selection by wearers.

b. Ease of movement

In Fig. 15, the differences in distance from the first frame of each measurement point to the last frame for the best fitting size selection by wearers are shown. There was a big difference in WLPf and WLPb, and the value was greater for Group A than for Group B (significant only for WLPb). However, for other measurement points, the values for Group B were slightly larger than those for Group A.
4. Comparison between "the standard clothing size" and "the best fitting size selection" in Group B

a. Range of motion of the shoulder joint

The average range of motion wearing the "standard clothing size" was 117.9±8.1° and the average wearing the "best fitting size selection" was 129.5±8.0°. This difference was significant (t(20)=3.40, p<0.01).

b. Ease of movement

In Fig. 16, the difference in distance from the first frame for each measurement point to the maximum frame when wearing the standard clothing size and the best fitting size selection is shown. The best fitting size selection tended to result in larger at the maximum frame than for the standard clothing size shirt, but the differences were not significant. In Fig. 17, the differences in distance from the first frame for each measurement point to the last frame when wearing the standard clothing size and the best fitting size selection are shown. The shirt of the standard clothing size tended to move from the original positions more than in the case of the shirt of the best fitting size selection, but the difference was only significant at the HLPb. Moreover, compared to wearing the shirt of the standard clothing size, the best fitting size selection tended to "be restored nearly to the position prior to the motion" and "move freely." In other words, the wearer preferred clothes that move with her motions.

**SUMMARY**

This study was conducted to clarify the ease of movement for front-open shirts in different sizes. The measurement of the linking movement of the shirt and the body was analyzed with a three-dimensional motion analysis system. Twenty-two young women wore shirts from -1 size to +3 size. Motions of lifting only the right arm, lifting both arms simultaneously, and anteflexion were tested. As a result, the following was clarified.

1) Comparison by motions: For the standard clothing size, the movement of the shirt was different by motions. But the shirt became disheveled after each motion (sliding up from 4 to 6 cm from the original position). So when wearing the standard clothing size, it is necessary to fix getting disheveled.

2) Comparison of 5 sizes: In a comparison of shirts in "-1 size and in the standard clothing size" with those in "+1 size to +3 size," the range of motion was limited. During motions, the shirt moved more from the body for larger sizes. However, the final position did not differ from the starting position as much when the motion was completed.

3) The sensory evaluation and the relationship of the movements of the shirt: When wearing the standard clothing size, the range of motion of the shoulder joint was limited and constant, regardless of perception of the size. However, there was a difference in movement of the shirt in terms of the differences in perception. It was related to the feeling that the standard clothing size is small because the moved distance was small.

When wearing the best fitting selection, the range of motion of the shoulder joint did not differ with sizes, and there was no difference in the movements of the shirt.

Subjects who selected a size larger than the standard clothing size showed a significantly large range of motion of the shoulder joint. Further, although the shirt moved largely along with their motion, the shirt tended to be restored to the original position.

Based these findings, the wearers in the sizes from...
+1 to +3 showed larger ranges of motion of the shoulder joint than the wearers in the sizes from −1 to the standard clothing size. Thus, it is not necessary to wear shirts in more than +1 size. Wearers prefer clothing with which part of the body will be exposed with the movements of the body and which they have to adjust after the movements. The search finds that the size of such clothing is the optimal size for them.

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REFERENCES


前あきシャツの動作適応性へのサイズの影響

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快適な衣生活のために、既製服のサイズ選択に関する指標を設けることを目的とした。そこで、3次元動作分析により衣服着用時の衣服下の身体の動きと衣服の動きを同時に捉えた衣服の動作適応性について、サイズの違いから検討した。若年女性22名を被験者として、1サイズ小さいものから3サイズ大きいものまでの5サイズの前あきシャツを実験衣とした。動作適応性と着用感に関する官能評価によりサイズの影響について考察した。その結果、+1サイズ～+3サイズは−1サイズと適正サイズよりも肩関節の動作可動域が有意に大きいことが明らかとなった。しかし、+1サイズ以上大きいものを着用しても可動域が大きくなるわけではないため、動作性の効果を求めて大きなサイズを着るということであれば、+1サイズでよいことが明らかとなった。また、たとえ、動作時に衣服が動いて身体を露出する可能性があり、動作後に着崩れを直す必要があったとしても、着用者は、体の動きと連動して動くサイズのシャツを最適なサイズと評価していたことが明らかとなった。

キーワード: 若年女性, 前あきシャツ, サイズ, 適合性, 動作適応性.