

Relationship between the Active Range of the Shoulder Joint and Necessary Ease for the putting-on motion of a Jacket for Improved Clothing Design

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肩関節の可動域と着衣に必要な背面のゆとり量の関係

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肩関節の可動域が減少して着衣が困難になった高齢者のために、上衣の背面に付与するゆとりの位置と量について検討することを目的とした。サージカルテープで肩関節の可動域を制限した若年女性の上衣の着衣動作を、デジタルビデオカメラで撮影し、3次元動作分析システムによって解析した。実験衣には背面のプリーツの3種類の位置と幅(6, 12, 18と24 cm)を組み合わせたジャケットを用いた。先行研究では、高齢者は上肢の水平進展の可動域が狭く、腕を外転して袖を通すが、外転の可動域の可動域が狭い場合、特に、動作の所要時間が長くなることが分かっている。動作時間分析の結果、被験者が上肢を外転させることなく袖ぐりを手首まで引くことができるようにするためには、袖ぐり下端の高さを含んだ位置で幅12から18 cmのゆとりが必要であることが明らかになった。それより少ない場合は袖ぐりを肩より前側に引くことができないため効果がなく、それより多い場合は逆にあまりが多くて手が引っかかるため適切ではなかった。

1. Introduction

As the elderly population continues to grow in Japan, there is an increasing need for clothes that satisfy the physiological and psychological needs of the elderly. Accordingly, data are needed to support the design of functional and aesthetically pleasing clothes for this population.

It has been pointed out that difficulties were seen in the motions of putting on and taking off clothes among elderly people. Okada (2004) examined the relationship between the amount of ease on the bust line or the height of the arm hole and the difficulties in the motions of putting on and taking off clothes. Akashi et al. (2002) conducted comparative studies on appropriate sleeve shapes in subjects with restricted range

of motion of the elbow. Tanimizu and Muramoto (2012) analyzed the maximal angles of the shoulder joints on the motion of putting on and taking off various shirts (a T-shirt, a polo shirt and a tank top). However, these studies discussed whether the motion times had been shortened or whether the result of sensitivity evaluation was better when a gore or more ease was added to the garment. They did not clarify the details of the motion or why the elderly felt that the motion of putting on/taking off clothes was difficult.

In our previous study, we recorded the motions involved in putting on and taking off jackets using three-dimensional motion capture with an infrared camera among 71 elderly women. We classified the pattern of the motions and analyzed motion-time and the locus of the

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upper limbs on which 12 light-emitting diodes (LEDs) had been pasted. The motion time in putting on the jacket in which two pleats had been added to the back to make the back width wider was significantly shorter than that in putting on normal-type jackets (Watanabe, et al., 2009a). After passing the first arm through a sleeve, the subject passed the wrist of the other arm through the other armhole. At this time point, the wrist moved in a complicated manner and the motion time was longer than when putting on a normal-type jacket. In other words, difficulty in putting on clothes occurs at this time point.

In the next study, we clarified that this difficulty was related to the active range of the shoulder joint, such as horizontal extension of the upper arm while bending the elbow vertically upward and abduction of the arm (Watanabe, et al., 2009b).

The motion time for putting on a jacket in the group whose active range of abduction was less than 120 degrees, was significantly longer than that in the group whose active range of abduction was over 146 degrees. In addition, we clarified that this problem was solved by adding two wide pleats in the back bodice of the jacket that provides wide ease.

However, we did not ascertain whether the width and position of the pleats are appropriate. The pleats were long, and the width of the pleats was 24 cm (total of right and left pleats), which are not appropriate for designing aesthetic clothes. Therefore, the aim of the present study was to clarify the minimum ease and the suitable position of the ease, which was added by pleats, in order to design jackets for people whose active range of the shoulder joints is reduced. The present study included young women in whom the active ranges of horizontal extension and abduction of the arm were

restricted by taping, and their putting-on motion of jackets was analyzed. We thought that it was not appropriate to have older people participate in this experiment as this experiment would be physically burdensome for them. In our previous study, young women moved their arm in a similar manner as elderly women with narrow active range of the shoulder joint when the active ranges of horizontal extension and abduction of the upper arm were restricted using taping. Furthermore, their motion time of putting on jackets became significantly longer than that without restricting the range of motion of their shoulder joints. We had concluded that this reduction of active range of motion of the shoulder joint using taping is effective for experiments on ease of putting on and taking off clothes (Watanabe, et al., 2009b).

Methods

(1) Measurement

The active ranges of horizontal extension of the upper arm while bending the elbow upwards and abduction of the arm in young women were restricted by taping. Experimental conditions were set as “restriction of only abduction”, and “restriction of both horizontal extension and abduction”. Two experiments were conducted in the present study as follows.

1) Experiment 1: Restriction of horizontal extension and abduction of upper arm

The subjects of Experiment 1 were 12 healthy young women (age range, 20 to 25 years old; mean age, 22.4 years old). Their mean height was 155.7 cm [standard deviation (S.D.): 2.1 cm], mean weight was 50.7 kg (S.D. 3.3 kg), and mean bust girth was 83.2 cm (S.D. 3.4 cm). The definitions of abduction of the arm and horizontal extension of the upper arm while bending one's elbow upwards are illustrated in Fig. 1. In our

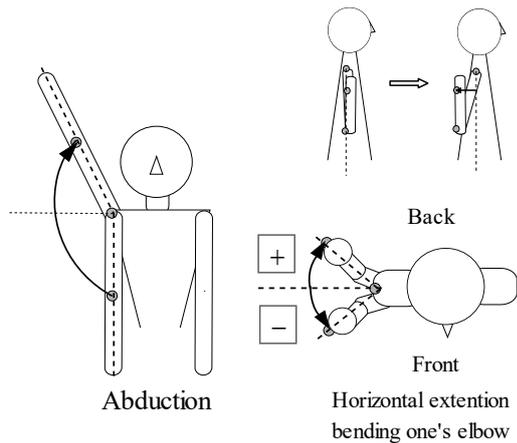


Fig. 1 Definition of motions of active range of the shoulder joint.

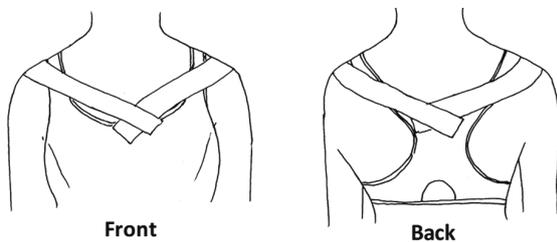


Fig. 2 The method of restricting to movement of shoulder joint using medical tape.

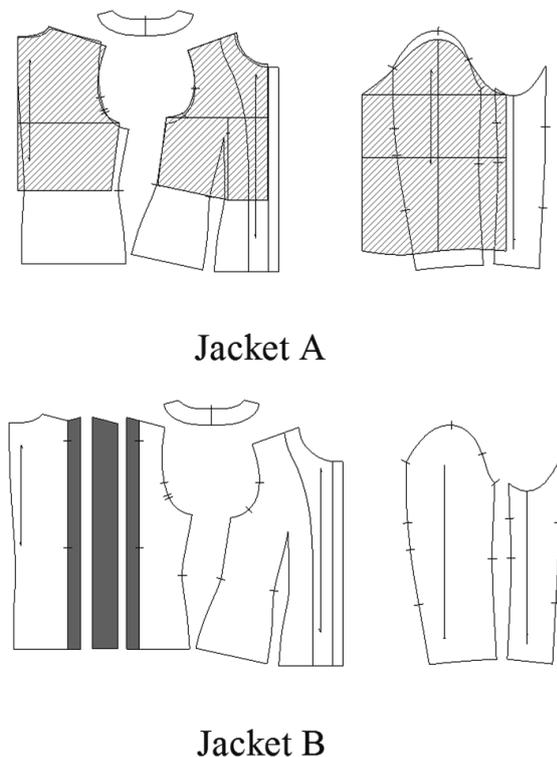


Fig. 3 The pattern of two types of jackets that was used in this study.

previous study (Watanabe, et al., 2008b), we had measured the active range of motion of the shoulder joints in 6 elderly women who could not put on a jacket smoothly. As the result, the mean value of horizontal extension was -10.8° (S.D. 13.1°) and that of abduction was 116.2° (S.D. 9.5). In the present study, the subjects were asked to round their upper back and their shoulders were fixed with surgical tape to make the active range of the shoulder joints as narrow as that in elderly women (Fig. 2). As a result, the mean value of horizontal extension in the subjects was restricted to -9.1° (S.D. 13.4°) and the mean value of abduction was restricted to 110.1° (S.D. 18.1°). The mean values of horizontal extension and abduction when the subjects did not have any restrictions were 23.1° and 163.2° , respectively. This means that the subjects could not pull their wrist backward to the shoulder point, and they were unable to raise their arms beyond about 20 degrees from the horizontal of the shoulder point after their shoulders were fixed.

Two types of jackets were used in this study (Fig. 3). *Jacket A* was a basic jacket with a plain collar and tailored sleeve. It was drafted based on the Bunka basic pattern, to which a 10 cm ease was added on the bust line. *Jacket B* was developed from *Jacket A* with two pleats added to the back to make the back width wider. The upper end and lower end of the pleat were closed by being sewn, and the parts where the pleat was open were limited (Fig. 3). In order to clarify the suitable place and amount of ease for elderly women to put the jacket on smoothly, 10 conditions were set for the place and the width of the pleat on *Jacket B*. In Position ①, the pleats are opened from 10 cm above the bottom of the armhole to 2 cm below the bottom of the armhole, and the width of the pleats was set to 4 kinds (total 24 cm, 18 cm, 12 cm, or 6 cm). In

Position ②, the pleats are opened from 10 cm above the bottom of the armhole to the bottom of the armhole. In Position ③, the pleats are opened from 5 cm above the bottom of the armhole to 5 cm below the bottom of the armhole. In Positions ② and ③, jackets with one of three pleat widths (total 18 cm, 12 cm, 6 cm) were prepared. For each condition, 3 sizes (bust 80, 84, 88 cm) of jacket were made. The appropriate size worn by each subject was selected according to the subject's bust size. The sleeve length was accommodated to each subject based on body measurement data. The specifications of the fabric of the jacket are the same as in the previous study (Watanabe et al., 2009a). In order to avoid the effect of stretchability and determine the amount, fabrics with low stretchability were selected. The clarified amount of necessary ease might be replaced elastic materials in practical use. The jackets were tailored without a lining.

Each subject was asked to put on and take off jackets in our laboratory where the air temperature was 26°C, humidity was 50%, and the intensity of illumination was over 480 lx. Twelve LED marks were placed on the subject's skin based on the anthropometric landmarks to measure the motions of the upper limb and upper body. The putting on and taking off motions were recorded by eight digital video cameras with an ultraviolet cut filter. By using the visible light cut filter and

LED-emitting infrared light, it was possible to capture the light of the LED marks even though they were under a black jacket. The subjects wore a tank top during measurements. In order not to bias the data, the order of wearing jackets was randomly assigned to each subject.

1) Experiment 2: Restriction of only abduction of shoulder

For comparison with Experiment 1, in this experiment we restricted only the active range of abduction and did not restrict horizontal extension, and conducted the same experiment as in Experiment 1. The subjects of Experiment 2 were 15 healthy young women (age, range, 20 to 25 years old; mean, 22.3 years old). Their mean height was 156.6 cm (S.D. 2.9 cm), mean weight was 50.8 kg (S.D. 2.6 kg), and mean bust girth was 83.0 cm (S.D. 2.9 cm). The subject's shoulders were fixed with surgical tape. As a result, the mean active range of abduction was restricted to 83.4° (S.D. 12.4°), but the mean active range of horizontal extension remained at 16.0° (S.D. 21.4°). In other words, they could not raise their arm higher than their shoulder joint, but they could extend their upper arm backwards from the shoulder joint.

The same types of jackets as in the previous experiment were used. As for Jacket B, three kinds of positions (Position ①, ② and ③) and two widths (6 or 12 cm) were combined, and 7 kinds of pleats were used. The same investigation

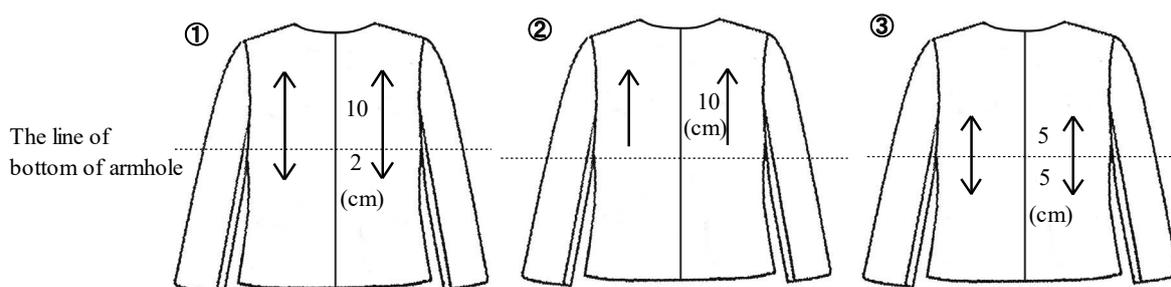


Fig. 4 The location of pleats in jacket B. The 10 position of the pleats in other words the spreading position, was limited by sewing.

was conducted using eight digital cameras.

(2) Motion time and motion analysis

Motions were analyzed with a three-dimensional (3D) motion analysis system (Hutech Co., Tokyo, Japan) and the positions of the LED landmarks were calculated three-dimensionally every 60th of a second. The locuses of the arms were observed. The putting-on motion was measured from the moment when the landmark of the first wrist (stalk point of the ulna) entered the armhole to the moment when the second wrist came out of the cuff (Fig. 5). The putting-on motion was divided into 4 phases (Phases 1-4). Then, the motion time was calculated and compared among the jackets.

Results and conclusion

(1) Experiment 1: Restriction of horizontal extension and abduction of shoulder

The subjects were asked to put on and take off Jacket A and 9 types of Jacket B, and the motion times were calculated (Fig. 6). The time taken to complete the motion from the beginning of Phase 1 to the end of Phase 4 was measured and compared among the 10 types of jackets. The motion time of Phase 3, which is the length of time to prepare to put the second wrist through the armhole, when putting on 5 types of Jacket B, i.e., <12 cm①>, <12 cm③>, <18 cm①>, <18 cm③>, and <24 cm①>, were significantly shorter than that when putting on Jacket A.

Close observation of the video and the locus of the putting-on motion showed that when putting on Jacket A, the subjects' wrist did not reach the armhole and the subjects could not put their wrist through the armhole of Jacket A because their active range of horizontal extension was restricted. Then, the subjects tried to raise their arm. In our previous study (Watanabe, et al., 2009b), the elderly women whose activity range

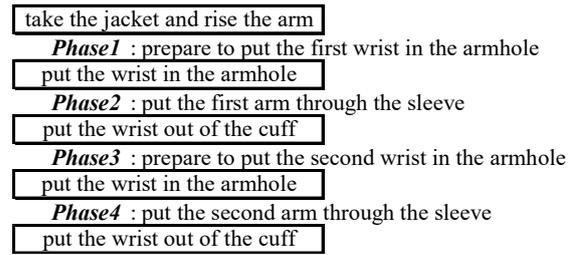


Fig. 5 Definition of motion time to put on jacket.

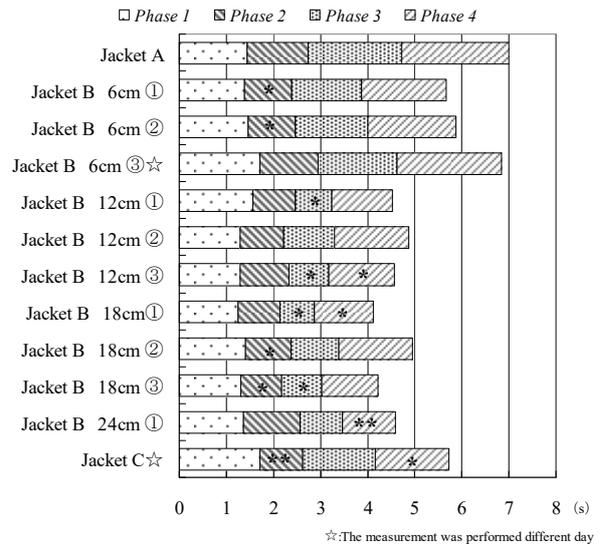


Fig. 6 Comparison of the motion time among jacket A and the other 11 jackets of young women when their active range of horizontal extension bending their elbow and abduction was restricted.

exceeded 146° were able to raise their arms and put their wrists into the armhole over their head. However, the young subjects in the present study were not able to do this because of restriction in the active range of abduction.

On the other hand, when putting on 5 types of Jacket B, it was observed that they could pull the armhole forward and put their wrist through the armhole smoothly because the pleats spread, and the across-back width became wider.

The motion times of Phase 3 when putting on Jacket B with pleats at positions ①, ② or ③ of 6 cm were not significantly shorter than that when putting on Jacket A. Observing the video, as the subjects could not pull their elbows backward to their shoulder, they tried to pull the armhole of the jacket forward. However, the

6 cm pleats could not provide enough back width to enable them to pull the armhole forward to reach their arm. Then, the subjects tried to raise their arm, and this motion made the motion time of Phase 3 similar to that when putting on Jacket A. This result shows that a 6 cm pleat is not enough to solve the problem in elderly people, whose active range of the shoulder joint is narrower than that in young women and who feel that it is difficult to wear upper clothes. Also, the motion time of Phase 3 when putting on Jacket B with pleats at position ① of 24 cm width was not significantly shorter than that when putting on Jacket A. Some subjects could not move their arms smoothly because their hands became caught on the pleats. It is considered that if the clothes have too much ease, it might be an obstacle to move their arm. Therefore, it is concluded that the amount of ease that is appropriate is around 12 cm to 18 cm. On the other hand, for all widths of pleats at position ②, the motion time of Phase 3 was not shorter than that when putting on Jacket A.

These results are illustrated in Fig. 7. Young subjects with no restrictions can pull their elbows backward to their shoulder (i.e., extend their upper arm horizontally) and can put their wrist into the armhole easily (Fig. 7-a). However, when the subjects, like elderly women, could not pull their elbows backward to their shoulder (extend horizontally), their wrist did not reach the armhole of the jackets in cases where the across-back width was not wide enough like in Jacket A and Jacket B with 6 cm pleats. Then, the subjects tried to raise their arm (Fig. 7-b) similar to elderly subjects who did not have a narrow active range of abduction in our previous study (Watanabe, et al., 2009b.). However, in Experiment 1 of the present study, the subjects could not raise their arm because of restrictions

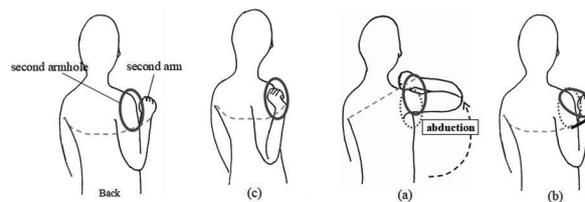


Fig. 7 The motion of second arm in phase 3.

in active range of the shoulder joint; then the motion time of Phase 3 became longer. On the other hand, when there were two pleats on the back bodice, the pleats spread, and the across-back width became wider. The subjects could pull the armhole forward to their shoulder and their second wrist could reach the armhole (Fig. 7-c). Then, the motion time of Phase 3 was shorter than that for Jacket A. In this case, the pleat needed to spread at the level of the armpit point with a width of 12 cm to 18 cm.

If the width of the pleats was 12 cm or 18 cm when the pleats were at Position ②, the motion times were not significantly shorter than that when putting on Jacket A, which has no pleats. Observing the motion of putting on Jacket A, when the subjects put their second wrist into the armhole, deep diagonal wrinkles appeared on the upper back above the armpit level of the jacket by being pulled by the wrist. This indicates that this part needs to spread. When the pleats were in Position ②, the pleats were sewn and closed at the armpit level and the pleats spread to be wider only at the upper level. Therefore, the subjects could not pull the armhole forward to their shoulder and their wrist could not reach the armhole. Thus, the width of the back needs to be 12 cm to 18 cm wider not only at the across-back level but also at the armpit point level in order for the subjects to be able to pull the armhole forward to their shoulder and put their wrist into the armhole.

On the back of Jacket A, 5 cm of ease had already been added in the bust line for breathing

and moving the upper limbs. However, the ease was not sufficient to put on a jacket for people who had narrower active ranges of abduction and horizontal extension of the upper arm. It was thought that the concept of “ease for putting on clothes” is necessary to solve the problem. In this study, we used pleats to make the back width wider; however, the pleats could be replaced with another structure or extension of the material.

(2) Restriction of only abduction of shoulder

We examined whether the necessary ease for the putting-on motion is different in cases where the conditions of the active range of the shoulder joint are different. We found that the motion time upon restriction of abduction of the shoulder was shorter than that upon restriction of horizontal extension and abduction of the shoulder, and that upon restriction of abduction of the shoulder, the locus of the wrist did not undergo a complicated motion. Fig. 8 shows the results of the comparison of motion time when putting on Jacket A or 8 other kinds of jackets using the t-test. Phase 3 when putting on all types of Jacket B was still significantly shorter than that when putting on Jacket A. Even if the

active range of abduction was restricted, if the active range of horizontal extension was not restricted, the subjects could pull their wrist backwards to the shoulder and they could put their wrist to the armhole smoothly with 6 cm pleats. Comparing the results under the two physical conditions, i.e., the restriction of movement, it is clear that the degree of active range of motion of the joint caused the differences in the putting-on motion and motion time. In other words, the necessary ease for carrying out the putting-on motion is different between the physical conditions. We conclude that it is important to clarify the condition of each patient and tailor the design of clothes to each condition. In this study, we recorded the subjects' movements with eight video cameras to measure the active range of motion of the shoulder joint. However, people can check, without equipment, if they can pull their wrist backward (horizontal extension of the upper arm while bending their elbow) to their shoulder and raise their arm (abduction of arm) 30 degrees, and select or design clothes accordingly.

Summary

We examined the suitable position and the amounts of ease to place in jackets for elderly people, whose active range of the shoulder joints is reduced. Two types of jackets were used in this study: Jacket A had a basic ease, and Jacket B was developed from Jacket A with two pleats to add ease to the back bodice. Three different positions of the pleats and four widths of the pleats (6, 12, 18 or 24 cm) were combined, and ten kinds of pleats were tested. The motions of putting on jackets in young female subjects whose shoulders were fixed with tape to restrict the active range of the shoulder joints were recorded with digital video cameras and

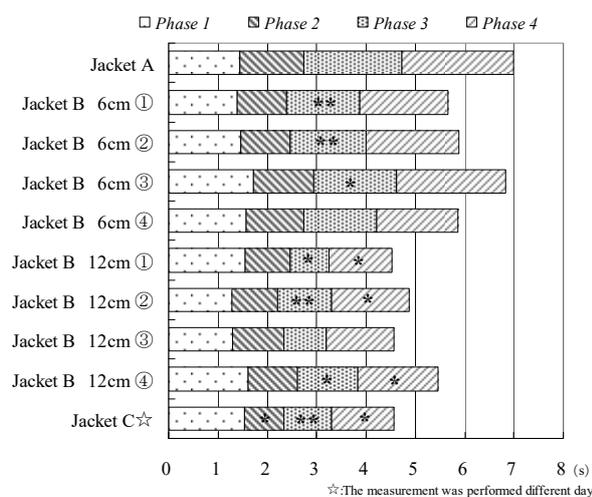


Fig. 8 Comparison of the motion time among Jacket A and the other jackets of young women when their active range of abduction was restricted.

analyzed by a 3D motion analysis system. As a result of comparison of motion time and observation of the locus of the wrist, we concluded as follows:

(1) When our subjects, similar to elderly women, could not pull their elbows backward to their shoulder (i.e., extend horizontally) and could not raise their arm (i.e., abduction), it was necessary to add ease above the armpit level and the width of the pleat needed to be from 12 to 18 cm; when these features were added, the subjects could pull the armhole of the jacket forward to their second wrist and put their wrist into the armhole without abducting their upper limb. Their wrist could not reach the armhole with less than 12 cm ease. On the other hand, too much ease was not efficient either. Therefore, identification of the appropriate amounts and positions of ease according to one's physical condition is important for clothing design.

(2) Even if the active range of abduction was restricted, if the active range of horizontal extension was sufficiently wide, i.e., the subjects could pull their arm backward to their shoulder, the addition of 6 cm ease made the putting-on motion smooth.

(3) In the case where both abduction and horizontal extension were restricted and the case where only horizontal extension was restricted, the putting-on motions were different in each physical condition. As a result, it was clarified that the amount of ease and the position of the pleats that needed to be added were different in each condition. This suggests that we need to consider each elderly person's

physical condition carefully and have the concept of "the necessary ease for the putting-on motion" in addition to "comfort ease" and "design ease". These results could be applied to clothes that are being made for people with disabilities in the shoulder joints.

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