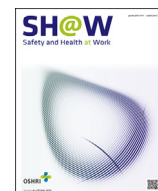


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## Original Article

# Evaluation of Interhandle Distance During Pushing and Pulling of a Four-Caster Cart for Upper Limb Exertion



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## ABSTRACT

**Background:** This study examined the relationship between interhandle distances and upper limb exertion during simply pushing and pulling of a cart with four swivel wheels, defined by a roll box pallet (RBP) in a Japanese industrial standard.

**Methods:** Six healthy young male participants were asked to push and pull an RBP at a distance of 5.2 m under six conditions corresponding to different interhandle distances (40 cm, 60 cm, and 80 cm) and weights (130 kg and 250 kg). The upper limb exertion was studied by shoulder abduction and flexion, and elbow flexion, as well as surface electromyogram (EMG) in shoulder extensor, and elbow flexor and extensor. Participants were required to provide subjective evaluations on operability after each trial.

**Results:** Subjective operability indicated that a narrower interhandle distance had a better operability for pushing. Interhandle distance was also related to upper limb exertion especially for pushing. A narrow interhandle distance caused smaller shoulder adduction but larger elbow flexion. The normalized EMG data revealed that muscular activity became smaller with a narrow interhandle distance in shoulder extensor. During the pulling task, elbow flexion was smaller at a narrow interhandle distance, although subjective operability and normalized EMG were not significantly varied.

**Conclusion:** A wider interhandle distance, such as 80 cm, was not suitable in the forwardbackward movement of the RBP. Therefore, this study concluded that an interhandle distance of 40 cm would be suitable for pushing and pulling an RBP to protect the workers' hands against the risk of injury by installing inner handles.

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## 1. Introduction

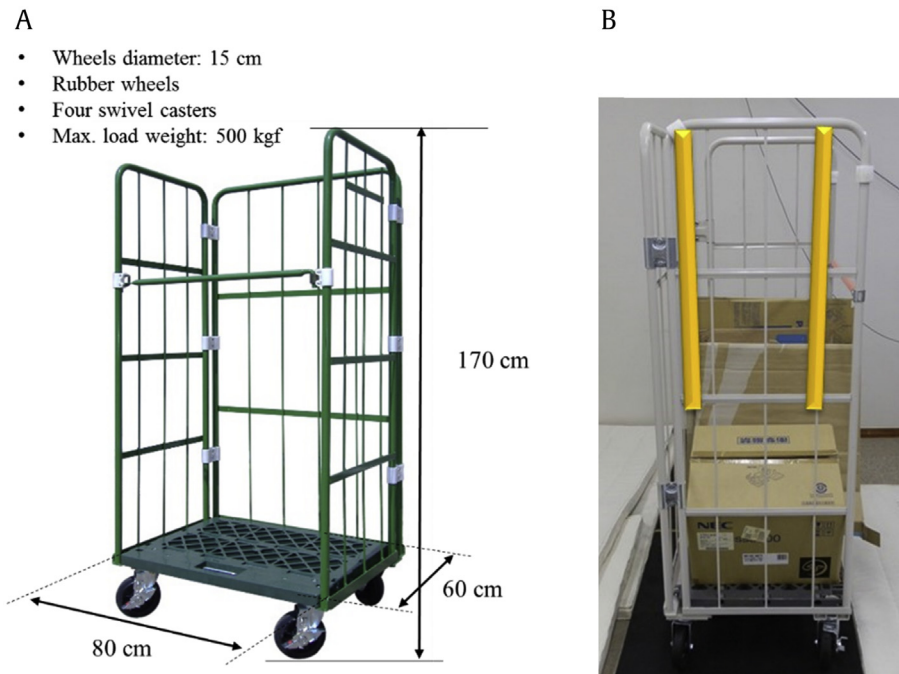
Roll box pallets (RBPs) are four-caster carts that are widely used in many industries in Japan to transport industrial goods, household utensils, groceries, luggage, and other materials. RBPs are similar to roll containers that meet the European standards [1]. A typical RBP is shown in Fig. 1A. In general, RBPs have three components: a loading pallet, a cage constructed of steel tubing (vertical bars) and steel materials, and four casters at each corner. Typically, RBP either has four swivel casters or a combination of two swivels and two rigid casters. The former arrangement shows good turning ability; therefore, it is preferred for use in Japanese workplaces, where space is often a constraint. The maximum load weight for a typical RBP is set from 300 kg to 500 kg. Because RBPs

can be used to carry or store loads, they contribute to efficient distribution services [2,3]. They are generally loaded onto trucks for transport to distribution centers or delivery to offices, and in the workplace they are moved manually or by a tail lift or a forklift.

Many occupational accidents occur during the manual handling of RBPs, which is associated with a risk of injury to the hands and feet [2,3]. To reduce the risk of hand injury, their handles should be designed specifically so that the inner part of the frame is handled more frequently than the outer part (Fig. 1B). The distance between the handles influences the muscular load on workers who operate the RBP. Van der Beek et al [4] investigated the forces exerted and the physiological load during pushing and pulling of a wheeled cage by postal workers. They confirmed that both the force exerted to the handles and the physiological load peaked in the initial

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**Fig. 1.** Roll box pallet. (A) Typical roll box pallet. (B) Concept of a new handle configuration, attached to an inner part of the frame, for preventing hand injury.

acceleration phase of a cage being pulled or pushed, at which point the exerted forces could exceed the maximum acceptable values established by Mital et al [5]. In their guidelines for loads > 250 kg, the authors stressed the importance of measures to reduce the risk of musculoskeletal disorders associated with wheeled cage handling [4,5].

In addition, handles are typically held at 65% of the worker's height [6] or in the range between shoulder and hip height [7]. However, the most suitable interhandle distance for handling a cart such as RBP has not been examined. Better handle design from an ergonomics point of view would be presented if the handles' tilting angle, diameter, and materials are also considered at the same time. However, the change from installing two steel tubes as handles inside the outer frames was not very difficult. In this study, we only focused on solving the method of reducing hand injuries while handling the RBP. We hypothesize that the interhandle distance influences the operability of the RBP, affecting upper-limb exertion. This study examined the shoulder and elbow joint movements and muscular activities such as upper limb exertions involved during rectilinear pushing and pulling of an RBP. Specifically, we aimed to establish a suitable interhandle distance in case the handles were set more inward to a greater extent than the outer frames to reduce the risk of hand injury.

## 2. Materials and methods

### 2.1. Participants

Six healthy young males (age,  $21.7 \pm 0.5$  years; height,  $172.6 \pm 3.5$  cm; weight,  $63.5 \pm 5.9$  kg; shoulder breadth,  $42.8 \pm 2.7$  cm) participated in the experiment. All were right-handed, and none had experienced gait disorders, severe orthopedic disorders, or musculoskeletal symptoms within the previous year. Written informed consent was obtained from all participants prior to the experiment. This study was approved by the Research Ethics Committee of the National Institute of Occupational Safety, Japan.

### 2.2. RBP and experimental conditions

The RBP used in this study (CTN-20S6; Daifuku, Osaka, Japan) had the following dimensions: height, 170 cm; depth, 80 cm; width, 60 cm (Fig. 1A). It was primarily made of metal tubes with 2.5-cm diameter and had hard rubber wheels that were 15 cm in diameter, all of them swivel casters. The RBP was placed on an experimental walkway that was 5.2 m in length and consisted of hard floor with thin rubber surface. In actual workplaces, RBPs carry goods of various sizes and weight. Therefore, the experiment was performed using two weight conditions: 130 kg and 250 kg [4]. Two vertical bars, which were 2.5 cm in diameter, were attached onto the frames of the RBP as handles (Fig. 2). These handles were laterally adjustable such that the distance between them could be varied from 15 cm to 100 cm. The standard distance between the bars specified by the JIS Z 0610 standard [8] is 60 cm to 100 cm. We therefore performed the experiment using three different interhandle distances: 60 cm (medium, the minimum standard), 40 cm (narrow), and 80 cm (wide). In addition, the experimental data were measured from RBPs with no weight (0 kg) and the 60-cm interhandle distance for the normalization of muscular activity. In previous studies, the handles were set at a height between shoulder and hip [7]. However, when the handles were at hip height, this allowed the participant to lean his body forward considerably. In the present study, we set the handles to be grasped at any height between the participant's shoulders and elbows, with the hands kept level. Fig. 2 shows the pushing task with a 130-kg weight and a 60-cm interhandle distance.

### 2.3. Experimental protocols and subjective evaluation of operability

During practice trials of pushing and pulling the RBP at each interhandle distance and each weight, the participants chose their preferred grasping points. Prior to the initiation of each trial, all swivel casters were positioned with attached handles to be parallel to the plane of the RBP. Participants were asked to push the RBP forward or to pull it backward at their preferred speed for a

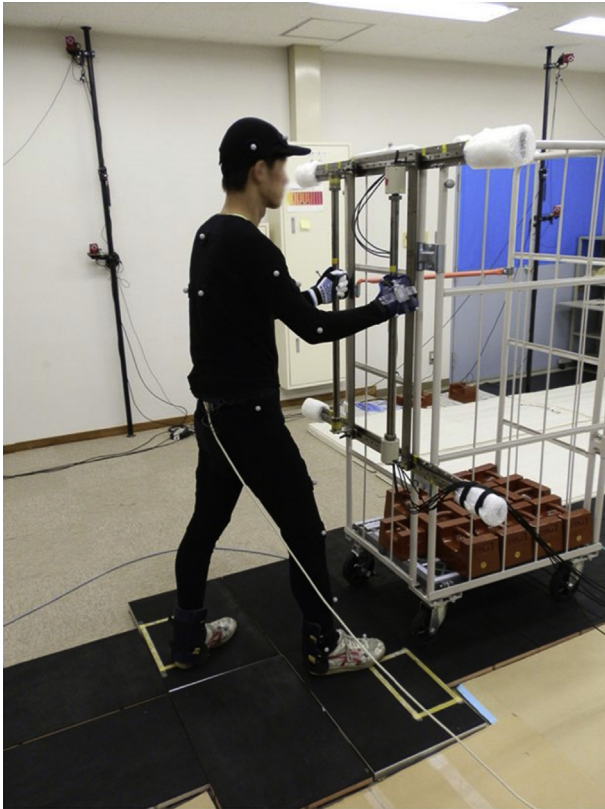


Fig. 2. The pushing task with a 250-kg load and a 40-cm interhandle distance.

distance of 3.0 m with each weight. The participants were also asked to position one foot in a half-step forward, as shown in Fig. 2, to reflect an actual worker's handling of an RBP. After each trial, participants gave their subjective evaluations of operability for pushing and pulling, graded into five levels: 1, very difficult to operate; 2, difficult to operate; 3, neutral; 4, easy to operate; and 5,

very easy to operate. The operability was defined as an easily applicable upper limb force to the handles in this study.

#### 2.4. Experimental setup and data analysis

A motion capture system (ARENA ver. 1.7.200; NaturalPoint, Corvallis, OR, USA) including 14 infrared cameras (OptiTrack FLEX: V100; NaturalPoint) was used to measure body and RBP movement at a sampling frequency of 100 Hz during pushing and pulling. The data were stored on a personal computer. A total of 37 infrared reflection markers were attached to the feet, legs, thighs, pelvis, trunk, shoulders, upper arms, forearms, hands, and head of the participant and to the RBP. Joint angles were calculated by Euler angles of a three-dimensional link segment model that estimated the movement of each body segment on the basis of the marker positions. This study focused on the peak values of three joint angles: shoulder abduction, shoulder flexion, and elbow flexion. These were chosen because interhandle distance is directly related to shoulder abduction. The participant leaned his upper body forward during pushing and backward during pulling. The participant's shoulders and elbows were flexed at the initial phase of pushing and pulling. Thus, the three joint movements were related to the operability of the RBP. Data were obtained from the beginning of movement to the first step for either foot because Van der Beek et al [4] reported that the peak forces of pushing and pulling appeared in the initial acceleration phase. The definition of these measured angles is presented in Fig. 3.

Next, to investigate muscular activity, surface electromyography (EMG) was applied bilaterally by using DL-141 (S&ME, Tokyo, Japan) for three muscles around the shoulder and elbow: the biceps brachii (the flexor in the elbow), triceps brachii (the extensor in the elbow), and anterior deltoid (the flexor in the shoulder). The three muscles were selected because they were related to the shoulder and elbow movements. Electrodes were placed on the skin over the biceps brachii and triceps brachii muscles. For the deltoid muscle, the electrode was placed on the anterior segment. The deltoid muscle had three anatomical functions for shoulder movement: (1) flexion; (2) abduction; and (3) extension. However, shoulder flexion was the most important factor for the handling of the RBP

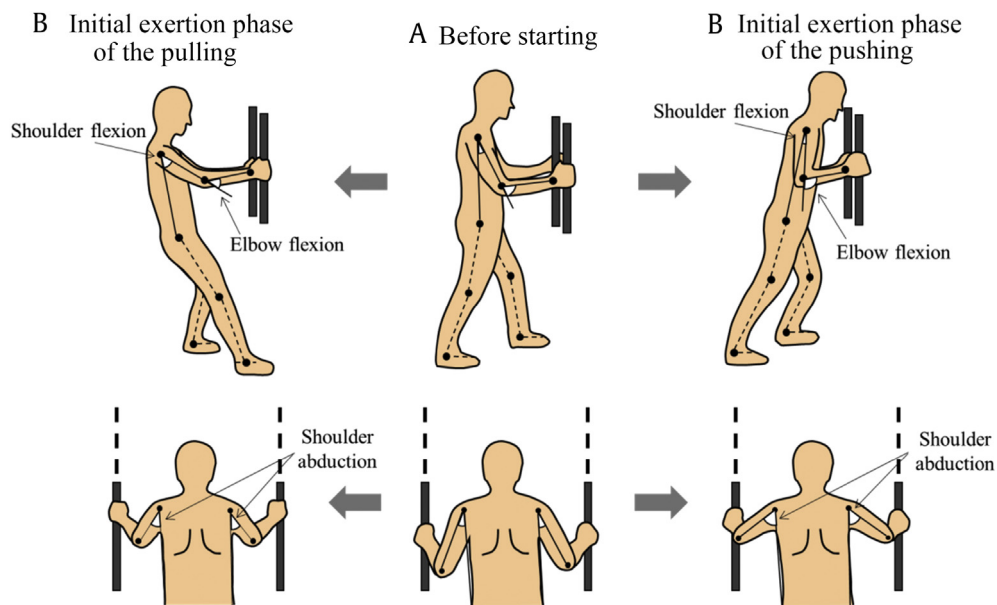


Fig. 3. Definition of the measured shoulder abduction, shoulder flexion, and elbow flexion during pushing and pulling tasks. (A) Before starting. (B) Initial exertion phase.

**Table 1**  
Mean  $\pm$  standard deviation (SD) of subjective operability evaluation during pushing and pulling tasks in each condition

|         | 130 kg        |               |               | 250 kg        |               |               | Multiple comparison                      |
|---------|---------------|---------------|---------------|---------------|---------------|---------------|--|
|         | 40 cm         | 60 cm         | 80 cm         | 40 cm         | 60 cm         | 80 cm         |  |
|         | Mean $\pm$ SD | Mean $\pm$ SD | Mean $\pm$ SD | Mean $\pm$ SD | Mean $\pm$ SD | Mean $\pm$ SD |  |
| Pushing | 4.0 $\pm$ 0.9 | 4.0 $\pm$ 0.9 | 3.7 $\pm$ 0.8 | 2.4 $\pm$ 1.1 | 2.5 $\pm$ 1.0 | 1.8 $\pm$ 0.7 | 40 cm > 60 cm/80 cm*<br>130 kg > 250 kg* |
| Pulling | 4.2 $\pm$ 0.9 | 4.3 $\pm$ 0.8 | 4.3 $\pm$ 0.9 | 2.3 $\pm$ 0.8 | 2.5 $\pm$ 0.5 | 2.5 $\pm$ 0.8 | 130 kg > 250 kg*                         |

\*  $p < 0.01$ .

because the participant's shoulders were flexed in the initial phase of pushing and pulling. Therefore, shoulder flexion was measured in the anterior part of the deltoid muscle. All electrodes were attached bilaterally. The signals were digitized using an AD converter (TRIAS; DKH, Tokyo, Japan) at 1 kHz and stored on a personal computer. EMG data were analyzed from two points of view: the time series and the amount of muscular activity. For the former, we rectified and smoothed the raw data using the moving average method at 2 Hz. Patterns and magnitude of muscular activity were compared with the position data for the RBP. For the latter, we quantified the amount of muscular activity by the root mean square (RMS) value of the EMG data [9,10]. The RMS value was normalized to that of a no-load weight condition (0 kg) with a 60-cm interhandle distance. Joint movements were observed to reach peak values just after the beginning of movements; however, muscular activity varied according to the role in pushing or pulling the RBP. One muscle activated around the beginning of the movement, whereas the other produced its muscular activity after the peak value of joint movement. The RMS values of muscular activities were obtained from the start position of the RBP to a position 70 cm ahead of it. Thus, the analysis period for the EMG data was somewhat longer than that for the joint movement. Additionally, the traveling time when the participant pushed or pulled 70 cm was measured by markers of displacement of the RBP.

### 2.5. Statistical analysis

Repeated-measures analysis of variance (ANOVA) for within-participant factors was used to evaluate suitable interhandle distance conditions using Ekuseru-toukei 2013 software (Social Survey Research Information Co., Ltd., Tokyo, Japan). The ANOVA was performed using the following design: interhandle distance (40 cm, 60 cm, or 80 cm)  $\times$  weight (130 kg or 250 kg). A Bonferroni correction was used for multiple  $t$  test comparisons between the interhandle distances. The significance limit was  $p < 0.05$ .

## 3. Results

### 3.1. Subjective evaluation and traveling time of the pushing and pulling tasks

After each trial, participants provided subjective evaluations on the operability of pushing or pulling the RBP. The resulting mean values and standard deviations are presented in Table 1. ANOVA

indicated that the main effect of weight was significant during both pushing and pulling. The participants found an RBP with a 250-kg weight more difficult to operate than one with a weight of 130 kg. In terms of interhandle distance, significant variation was observed only in pushing, where the interhandle distance of 40 cm was easier for the participants to operate than distances of 60 cm and 80 cm.

With regard to the traveling time of 70-cm movement, the resulting mean values and standard deviations are presented in Table 2. ANOVA indicated that the main effect of weight was significant during both pushing and pulling. The participants who moved an RBP with a weight of 250 kg took more time than the one with a weight of 130 kg. In terms of interhandle distance, there was no statistically significant difference in pushing and pulling.

### 3.2. Shoulder and elbow movements and surrounding muscle activities during pushing

Because maximum shoulder abduction, minimum shoulder flexion, and maximum elbow flexion reflected the upper limb exertion in the initial phase of the pushing task, we used these joint angles to analyze their peak value. Because participants were asked simply to push or pull the RBP with both hands, we did not focus on any differences in right–left movement. Data for both the right and left joint angles were combined prior to analysis because it could simply explain the characteristics of the upper limb motions. The resulting combined values for right and left shoulder abduction, shoulder flexion, and elbow flexion during the pushing task are shown in Table 2. Shoulder abduction increased significantly with a heavier weight and a wider interhandle distance. In addition, the shoulder flexion and the elbow flexion decreased significantly with a wider interhandle distance, although the latter did not vary between the 40-cm and 60-cm distances.

In all muscles, the combined RMS value for EMG activity increased with increasing weight, indicating that muscular load was affected by the external load on the RBP. Table 3 shows the combined RMS values for the anterior deltoid, biceps brachii, and triceps brachii muscles during the pushing task. Fig. 4 shows an example of muscular activity on the right side of the body during the pushing task. The anterior deltoid and biceps brachii muscles were strongly activated during the initial phase of pushing. Propulsion power, which was produced by the lower limbs, was transferred to the RBP through the shoulders and elbows. While the participant operated the RBP with a 40-cm interhandle distance, the combined RMS value was smaller for the anterior deltoid

**Table 2**  
Mean  $\pm$  standard deviation (SD) of traveling time in 70-cm distance for pushing and pulling tasks in each condition

|         | 130 kg          |                 |                 | 250 kg          |                 |                 | Multiple comparison |
|---------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|---------------------|
|         | 40 cm           | 60 cm           | 80 cm           | 40 cm           | 60 cm           | 80 cm           |                     |
|         | Mean $\pm$ SD   | Mean $\pm$ SD   | Mean $\pm$ SD   | Mean $\pm$ SD   | Mean $\pm$ SD   | Mean $\pm$ SD   |                     |
| Pushing | 1.56 $\pm$ 0.22 | 1.59 $\pm$ 0.31 | 1.64 $\pm$ 0.32 | 1.95 $\pm$ 0.31 | 1.87 $\pm$ 0.35 | 2.03 $\pm$ 0.51 | 130 kg < 250 kg*    |
| Pulling | 1.63 $\pm$ 0.33 | 1.72 $\pm$ 0.29 | 1.68 $\pm$ 0.43 | 2.14 $\pm$ 0.43 | 1.97 $\pm$ 0.26 | 2.00 $\pm$ 0.27 | 130 kg < 250 kg*    |

\*  $p < 0.01$ .

**Table 3**

Mean  $\pm$  standard deviation (SD) of the combined values for right and left shoulder abduction, shoulder flexion, and elbow flexion during the initial phase of pushing and pulling tasks in each condition

|         |                    | 130 kg           |                  |                  | 250 kg           |                  |                  | Multiple comparison                                    |
|---------|--------------------|------------------|------------------|------------------|------------------|------------------|------------------|--|
|         |                    | 40 cm            | 60 cm            | 80 cm            | 40 cm            | 60 cm            | 80 cm            |  |
|         |                    | Mean $\pm$ SD    | Mean $\pm$ SD    | Mean $\pm$ SD    | Mean $\pm$ SD    | Mean $\pm$ SD    | Mean $\pm$ SD    |  |
| Pushing | Shoulder abduction | 55.3 $\pm$ 16.0  | 90.8 $\pm$ 22.1  | 121.9 $\pm$ 28.7 | 58.7 $\pm$ 19.0  | 102.9 $\pm$ 21.7 | 135.0 $\pm$ 37.7 | 40 cm < 60 cm/80 cm*, 40 cm < 80 cm*, 130 kg < 250 kg* |
|         | Shoulder flexion   | 63.9 $\pm$ 19.4  | 36.7 $\pm$ 20.3  | 31.1 $\pm$ 13.6  | 73.1 $\pm$ 28.1  | 45.8 $\pm$ 28.7  | 24.6 $\pm$ 19.2  | 40 cm < 60 cm/80 cm*, 40 cm < 80 cm*                   |
|         | Elbow flexion      | 205.7 $\pm$ 37.1 | 210.8 $\pm$ 31.7 | 182.1 $\pm$ 23.2 | 209.9 $\pm$ 41.0 | 208.2 $\pm$ 37.1 | 189.0 $\pm$ 28.1 | 60 cm > 80 cm*   |
| Pulling | Shoulder abduction | 16.7 $\pm$ 13.4  | 37.7 $\pm$ 16.6  | 61.9 $\pm$ 26.9  | 17.1 $\pm$ 15.3  | 38.0 $\pm$ 22.7  | 61.5 $\pm$ 21.5  | 40 cm < 60 cm/80 cm*, 40 cm < 80 cm*                   |
|         | Shoulder flexion   | 131.0 $\pm$ 29.3 | 132.0 $\pm$ 32.7 | 124.0 $\pm$ 28.8 | 157.2 $\pm$ 22.6 | 151.4 $\pm$ 29.8 | 140.1 $\pm$ 38.8 | 40 cm > 80 cm*, 60 cm > 80 cm†                         |
|         | Elbow flexion      | 86.8 $\pm$ 35.9  | 83.2 $\pm$ 34.9  | 76.2 $\pm$ 30.5  | 78.8 $\pm$ 32.0  | 72.3 $\pm$ 30.0  | 70.9 $\pm$ 30.9  | 130 kg < 250 kg*, 40 cm > 80 cm*, 130 kg > 250 kg*     |

\*  $p < 0.01$ .

†  $p < 0.05$ .

muscle compared with the values for the 60-cm and 80-cm interhandle distances. The biceps brachii and triceps brachii muscles did not show a significant variation.

### 3.3. Shoulder and elbow movements and surrounding muscle activities during pulling

Because the rotation of each joint was completely opposite between pushing and pulling, minimum shoulder abduction, maximum shoulder flexion, and minimum elbow flexion were taken as their peak value in the initial phase of the pulling task. Table 3 shows combined values for right and left shoulder abduction, shoulder flexion, and elbow flexion during the pulling tasks. While the participant pulled the RBP with a 250-kg weight, shoulder flexion increased, but elbow flexion decreased significantly compared with pulling a weight of 130 kg. In addition, the shoulder abduction decreased significantly with a narrower interhandle distance, whereas the shoulder flexion and the elbow flexion increased significantly.

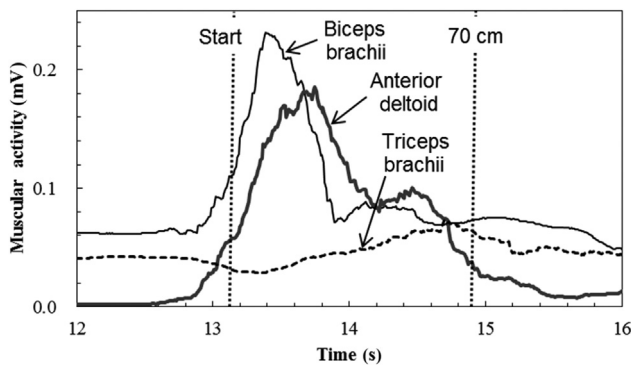
Fig. 5 shows an example of muscular activity on the right side of the body during the pulling task. The anterior deltoid and biceps brachii muscles showed lesser activity compared with that during the pushing task, but the biceps and triceps brachii muscles were active throughout the pulling task. The elbow joints were held in position by muscular activity. The anterior deltoid muscle was activated in the initial phase so that the shoulder joint was held when the participant started to pull. The combined RMS values increased with a heavier weight, but overall the muscular activity

levels during pulling were lower than those during the pushing task. As shown in Table 3, there was no statistically significant difference between the interhandle distances for all the combined RMS values for the muscles measured. However, these muscular activity levels slightly decreased when the interhandle distance was narrower.

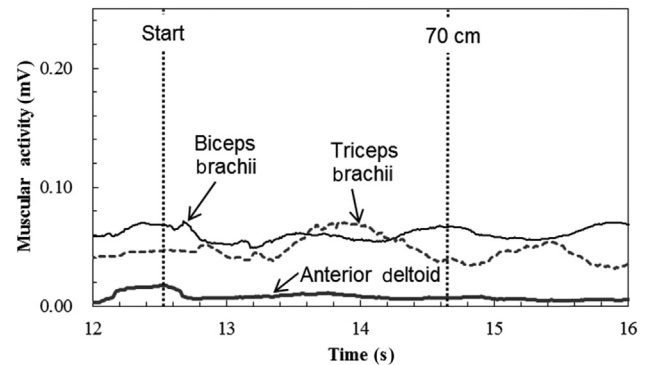
## 4. Discussion

### 4.1. Subjective operability and traveling time of the pushing and pulling tasks

The participants' evaluations showed that there was greater difficulty controlling the RBP with a 250-kg weight. This result was in accordance with Newton's laws of movement because the RBP with a heavier weight required a stronger handling force from the participant. Operability varied significantly with regard to interhandle distance only during the pushing task, with a narrower distance showing better operability. This result reflected the handling pattern of RBP. If the interhandle distance was wider than the shoulder breadth of the participant, the pushing force was divided into forward and lateral components as shown in Fig. 6. Propulsive power produced by the participant was partly transferred to the RPB because of the lateral component of force. Therefore, a wider interhandle distance showed worse operability than a narrow one. However, because the affected weight difference was too large to evaluate the operability, participants could



**Fig. 4.** An example of muscular activity measured for the right side of the upper limb during the pushing task. The interhandle distance was 60 cm. The vertical dotted lines indicate the times of the start position of the roll box pallet and the position 70 cm ahead of it.



**Fig. 5.** An example of muscular activity measured on the right side of the upper limb during the pulling task. The interhandle distance was 60 cm. The vertical dotted lines indicate the times of the start position of the roll box pallet and the position 70 cm ahead of it.

not accurately judge the difference in the interhandle distance. The result also indicated that operability differed between the pushing and pulling conditions. Operability for pulling was generally higher than that for pushing, especially with a wide interhandle distance because both the range of the upper limb motions and the muscular activities during pulling were less than those for pushing. The details of these effects are described in Sections 4.2 and 4.3.

With regard to the traveling time of the RBP, participants took between 1.8 seconds and 4.3 seconds to move the RBP a distance of 70 cm. The result of the ANOVA indicated that both pushing and pulling the RBP with a 250-kg weight required a stronger handling force from the participant and was the same as the subjective operability. The effects between interhandle distances were not found because these tasks only required simple forward–backward movements of the RBP in the initial phase. For this reason, the interhandle distance factor would be significant if other tasks, such as curving or rotation, in the steady movement phase were also measured.

#### 4.2. Shoulder and elbow movement and surrounding muscle activities during pushing

Shoulder flexion and elbow flexion decreased with widening interhandle distance, as shown in Table 2. Accordingly, participants pushed the RBP forward and laterally as shown in Fig. 6. Thus, an enlargement of the lateral components of the pushing force could explain the muscular activities. High activation of the anterior deltoid and biceps brachii muscles occurred during the initial phase of pushing, as shown in Fig. 4. The RMS value for the anterior deltoid increased when the interhandle distance was wide, as shown in Table 3. As the participant pushed the handle forward to propel the RBPs, a backward reaction force was applied to the participant. The shoulder joint was extended by this reaction force because the shoulder was higher than the hand with which the participant grasped the handle. In addition, the participant pressed hard into the floor to avoid slipping during the pushing task, which resulted in an upward force on the handle. In turn, this meant a downward reaction force was applied from the handles to the participant. The shoulder breadth of the participants ranged from 40 cm to 44 cm; the shoulder joint was therefore adducted by the downward reaction force if the interhandle distance was wider than 40 cm. The participant would push the handle outward with a wider interhandle distance. The external adduction moment was applied to the shoulder joint by the inward reaction force. Therefore, the anterior deltoid muscle produced a flexion moment against the external extension moment. The biceps brachii muscle was the elbow flexor. This muscle was activated against the external extension moment at the elbow caused by the downward reaction force. The RBP was moved forward by propulsive power

produced by the lower limbs. The shoulder and elbow joints were held in position by activation of the deltoid and biceps brachii muscles, which transferred propulsive power from the lower limbs to the RBP. The external flexion moment at the elbow joint arose from the backward reaction force. However, this moment was small because the participant grasped the handle at about the height of the elbow during the pushing task.

In this study, we analyzed the initial phases of pushing, and our results show that the participant could transmit pushing force easily if the interhandle distance was narrower. By contrast, the pushing force was not completely parallel to the direction of the RBP movement if the interhandle distance was wider, as shown in Fig. 6. The applied force to the handles was not only pushing forward in the horizontal plane, but it also had a lateral component. Therefore, the participants felt that the RBP was difficult to handle when the interhandle distance was wider, as shown in Table 1. In this study, the force applied to the handles was not measured directly by force transducers because there was a serious interference between the axes of the transducers. However, the discussion presented here is feasible from the viewpoint of physics. For example, the pushing movement was similar to push-up exercises where participants support their own weight, the difficulty of which is determined by the interhandle distance, with a wide distance being more difficult than a narrow distance [11,12]. In addition, the preferred interhandle distance of RBP was similar to the participants' average shoulder breadth. Lin et al [13] also clarified that maximal bimanual isometric pushing forces increased with the average shoulder breadth. Therefore, shoulder breadth was considered an index for the desirable interhandle distance for pushing the RBP.

#### 4.3. Shoulder and elbow movements and surrounding muscle activity during pulling

The anterior deltoid and biceps brachii muscles were less active during the pulling task than during the pushing task, as shown in Fig. 4. No significant variation was observed with all the combined RMS values, as shown in Table 3. Muscular activities were less strongly associated with the RBP handling compared with the pushing task. This result indicated that the muscular activities of the upper limbs during pulling were used by the participants to keep their arms stretched only because the shoulder position could provide enough distance from their body to the RBP, allowing them to tread their feet strongly against the direction of the movement. During the pulling task, in order to move their center of mass backward at first, the participants pulled the handle backward and downward. A forward and upward reaction force was therefore applied to the participant. For the elbow, the biceps brachii and triceps brachii muscles were activated simultaneously during all

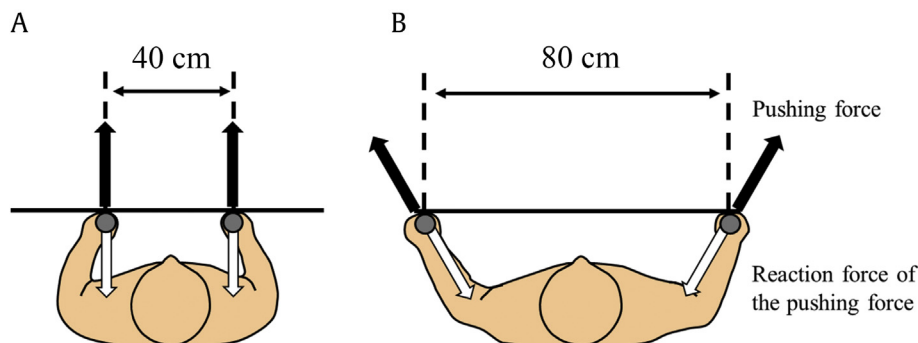


Fig. 6. Diagrams of force equilibrium. (A) 40-cm interhandle distance. (B) 80-cm interhandle distance.

phases of the pulling task, as shown in Fig. 4. Cocontraction occurred in the biceps brachii and triceps brachii muscles to lock the elbow joints against the external moment caused by the forward and upward reaction force. In contrast with the pushing task, these handling methods were not related to subjective operability evaluation. Propulsive power to the RBPs was obtained via the backward movement of the center of mass of the participants. The interhandle distance was less critical during the pulling task. However, elbow joint flexion was greater at the 40-cm distance compared with that at the 80-cm distance (Table 3). In addition, the lateral component of the pulling force was smaller with a narrower interhandle distance. There is no comparable example similar to the push-up exercise for the pushing task, however, we could explain the handling method of the RBP during the pulling task by the same articular movement model as that for the pushing task. Therefore, it was suggested that a narrower interhandle distance was also suitable for the pulling task.

#### 4.4. Application of the results

In the workplace, RBP handling is not composed only of simple pushing and pulling movements, but also involves rotational and turning movements. During such movements, the RBP would be moved by using lateral components of the handling force; therefore, a wider interhandle distance of more than 40 cm would be preferable because the shoulder and elbow joints would have a higher degree of freedom. This hypothesis is in contradiction to the present results for the pushing and pulling tasks; however, there are several opportunities for rectilinear pushing and pulling of the RBP in the workplace. In addition, there was no previous practical suggestion for hand protection when workers handle an RBP. Thus, in order to reduce the risk of hand injury, it could be beneficial to install inner handles (e.g., setting steel tubes) with a 40-cm interhandle distance.

#### 4.5. Limitations

This study only involved six young males, and the tasks of pushing and pulling were simple forward and backward movements. Further investigation will be required to consider the pushing and pulling tasks in an actual work situation, with curving, turning, or rotation movements.

## 5. Conclusion

Interhandle distance of the RBP was related to shoulder joint abduction during both pushing and pulling in this study. A wider interhandle distance caused changes in shoulder and elbow joint positions; this led to higher muscular loads only during pushing the RBP. Therefore, this study concludes that a wider interhandle distance (especially 80 cm) is not suitable for simple pushing and pulling of an RBP. In simple forward–backward movement of the RBP, a 40-cm interhandle distance, which is similar to the average shoulder breadth of the participants, would be the most favorable, and installing inner handles would also protect workers' hands against the risk of injury.

## Conflicts of interest

All authors have no conflicts of interest to declare.

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