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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.

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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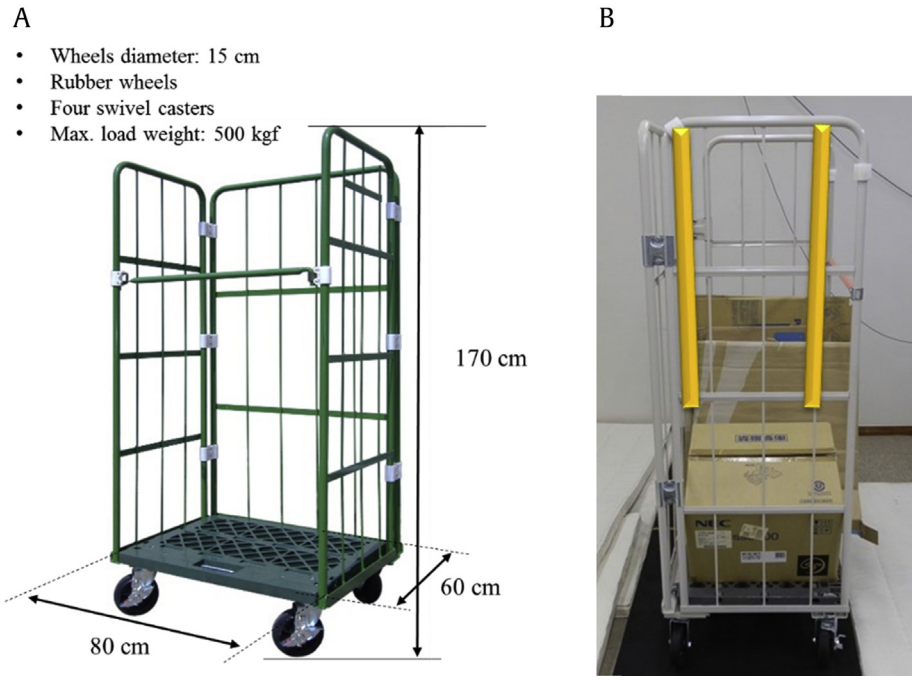

Fig. 1. Roll box pallet. (A) Typical roll box pallet. (B) Concept of a new handle configuration, attached to an inner part of the frame, for preventing hand injury.

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 ± 0.5 years; height, 172.6 ± 3.5 cm; weight, 63.5 ± 5.9 kg; shoulder breadth, 42.8 ± 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