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Effect of Rear-Wheel Operation of a Manual Wheelchair on User's Riding Comfort and Helper's Physical Strain while Navigating Steps

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Abstract: *Steps are one of the main factors that affect the physical strain of wheelchair helpers and the safety and comfort of wheelchair users. In this study, we examined the effect of the movement of the rear wheels of the wheelchair while navigating steps on the physical strain of helpers and the riding comfort of users. Although the maximum height that the rear wheels were lifted was controlled according to the step height, the distance driven during lifting of the rear wheels was not related to the step height. The helper's physical strain increased with the distance driven while the rear wheels were lifted. The correlation coefficients among indexes for the rear-wheel locomotion revealed that the distance between the rear wheels and step just before lifting significantly, positively correlated with the distance driven while the rear wheels were lifted. These findings suggest that the distance between the rear wheels and step just before lifting can be used as an operation index in the development of suitable techniques for lifting the rear wheels and thereby relieving the physical strain of helpers.*
Keywords *Wheelchair, Step, Transportation, Riding comfort, Physical strain*

1. Introduction

Wheelchairs are the most widely used assistive devices for improving the mobility of those needing care. In order for helpers, especially elderly helpers, to operate wheelchairs safely, road and floor environments that are safe for wheelchair mobility and suitable wheelchair operation techniques for improving user comfort and reducing helper physical strain are essential, in addition to the functional improvement of wheelchairs. In particular, steps on the floor and road are barriers that prevent the movement of wheelchairs indoors and outdoors, because helpers must be physically strong and knowledgeable of proper techniques for operating wheelchairs when navigating steps.

Therefore, to enable wheelchair users to participate in social activities and elderly helpers to operate the wheelchair safely, design standards for step height are needed. There are some design standards for the living environment, including roads, buildings, and houses, in Japan [1]. However, there is no standard for step height that takes helpers operating a wheelchair into consideration, and there are only a few studies on reducing the helper's physical strain when navigating a wheelchair over steps [2, 3, 4].

Our previous studies have focused on the wheelchair user's riding comfort and helper's physical strain when navigating steps. To reduce the shock to the user in the wheelchair, helpers need to lift the front wheels when navigating convex steps with heights ≥ 10 mm [4]. In addition, higher steps force the helper to raise the front and rear wheels higher, which increases the helper's physical strain [4, 5]. Inexperienced helpers would benefit greatly from knowing suitable wheelchair

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operation techniques for navigating steps that consider not only standards for the heights of the steps, but also the mutual safety and comfort of both the user and the elderly helper.

The purpose of the present study was to propose suitable wheelchair operation techniques for navigating steps from two perspectives: 1) the movement of the rear wheels of the wheelchair when navigating steps, and 2) the subjective evaluation of whole-body physical strain of elderly female helpers during the navigation of steps.

2. Experimental method

2.1 Participants

In consideration of the most of caregivers in Japan are elderly women [6], eleven females in their 60s (mean age 64.6 ± 3.5 years, mean height 153.6 ± 4.1 cm, mean weight 52.2 ± 4.8 kg, mean grasping power 25.2 ± 4.2 kgf) were chosen as wheelchair helpers. Two young females (A: age 22 years, height 159.7 cm, weight 47.3 kg; B: age 22 years, height 161.3 cm, weight 53.0 kg) participated as wheelchair users. The weight of user A was adjusted to 53 kg (mean weight of a Japanese female in her 60s) using additional weight. No subjects had a history of hypertension, cardiac, or motor dysfunction. Written informed consent was obtained from all subjects before starting the study. This study was approved by the Research Ethics Committee of the Kyushu University.

2.2 Wheelchair and step conditions

The users sat in the assistive manual wheelchair (Table 1), and the helpers operated it using the handles on the rear seat. We installed staircase steps using eight height conditions (5, 10, 20, 40, 60, 90, 120, and 150 mm) on a wooden passageway (6 m in length and 1.5 m in width).

Tab.1. Wheelchair Specifications

DIMENSIONS	96L × 55W × 84H cm
FRONT WHEEL SIZE	7 inches
REAR WHEEL SIZE	16 inches
WEIGHT	16.5 kg
FRAME MATERIAL	steel

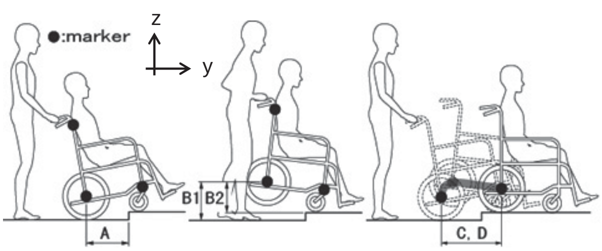
2.3 Experimental procedure and wheelchair operation

First, helpers stopped the wheelchairs at a position 180 cm from the edge of the step. Second, after a signal, they pushed the wheelchair forward. Third, they stopped the wheelchair at a preferable position before the front wheels passed over the edge of the stair step. Fourth, they lifted the front wheels up by stepping on the tipping lever, pushed the wheelchair forward to pass the edge of the steps, and set the front wheels down on the higher surface of the step. Fifth, the rear wheels were lifted and pushed onto the step, or the rear wheels were pushed forward while lifting them onto the step, and then the wheelchair was pushed forward again after the rear wheels advanced over the step. All subjects have right of withdrawal from operation at any time.

2.4 Measurements

We captured the movements of the wheelchair and helpers at 60 Hz with an optical three-dimensional measurement system (Motion Analysis, EvaRT 5.0), and used three-dimensional motion analysis software (KISSEI COMTEC, KineAnalyzer) to analyze wheelchair behavior. We calculated wheelchair locomotion indexes (rear wheels), as indicated in Figure 1.

After navigation, the users subjectively evaluated their riding comfort on a 5-point scale; a higher numerical value indicated better comfort. The helpers subjectively assessed how much strain they felt in their neck, shoulders, arms, wrists, hands and fingers, hips, legs and feet during operation of the front and rear wheels separately on a 3-point scale: “no strain felt” was 0, “some strain felt” was 1, and “strain felt” was 2. The sums of the scores for the eight positions were calculated as an index of whole-body physical strain.



A: distance (y) between rear wheels and step just before lifting
B1: maximum height (z) of lifted rear wheels (from ground)
B2: maximum height (z) of lifted rear wheels (from steps)
C: distance (y) driven while rear wheels were lifted
D: duration that rear wheels were lifted

Fig.1. Measurement variables for the wheelchair locomotion (rear wheels)

2.5 Statistical analysis

We carried out a repeated one-way statistical analysis of variance with the step height as a factor. In cases where the main effects were seen, we performed a multiple comparison test using Dunnett's method, and made comparisons with the lowest height of 5 mm. The Pearson correlation coefficient was calculated to examine the relationships between each wheelchair locomotion index and the subjective evaluation (user's riding comfort and index of whole-body physical strain). The level of significance was set at <5%.

3. Results

3.1 Navigating limit and posture for operating rear wheels

The height limit for navigating the steps was 90 mm for two participants (18%), 120 mm for six participants (55%), and 150 mm for three participants (27%). The height limits of the steps were significantly, positively correlated with grasping power ($r = 0.762$, $p < 0.01$). However, at step heights ≥ 90 mm, there were 10 cases in which some helpers who were able to navigate the steps lost their balance while operating the wheelchair (4 cases when operating the front wheels; 6 cases when operating the rear wheels).

Examples of postures when operating the wheelchair are shown in Figure 2. During the rear-wheel operation, there were two main postures, tilting forward while lifting (Figure 2-(A)) and standing on tiptoes (Figure 2-(B)).

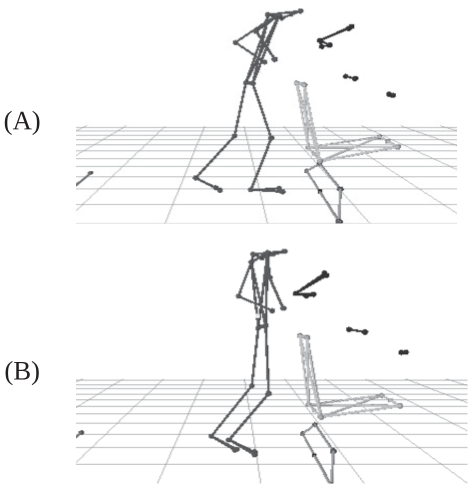


Fig.2. Example of postures for rear-wheel operation of the wheelchair (step height: 120 mm)

3.2 Relationship between the locomotion of rear wheels and subjective evaluation of strain

When navigating by lifting the rear wheels, main effects of the step height were found in the helper's whole-body physical strain ($p < 0.01$). The helper's whole-body physical strain significantly increased at step heights ≥ 60 mm, compared with a step height of 5 mm.

Figure 3 shows an example of movement of the wheelchair over a step height of 120 mm. The helper had a tendency to choose a high lifting height for the front wheels compared to the rear wheels.

In the locomotion of the wheelchair during rear-wheel operation, the main effects of step height were found in the wheelchair rear-wheel locomotion indexes B1 and D. B1 significantly increased at step heights ≥ 40mm, and D significantly increased at step heights ≥ 90 mm ($p < 0.01$), compared with a step height of 5 mm (Figure 4, Figure 5). Furthermore, C (mean: 178 ± 70 mm at all conditions, maximum value: 429 mm) was significantly, positively correlated ($r = 0.439$, $p < 0.01$) with the subjective evaluations of the helper's whole-body physical strain (Figure 6). However, significant correlation was not found between C and the user's riding comfort (Figure 7). When we analyzed the correlation coefficients among indexes for the rear-wheel locomotion (A–D), C was significantly, positively correlated with A ($r = 0.738$, $p < 0.01$) (Figure 8) and D ($r = 0.418$, $p < 0.01$) (Figure 9).

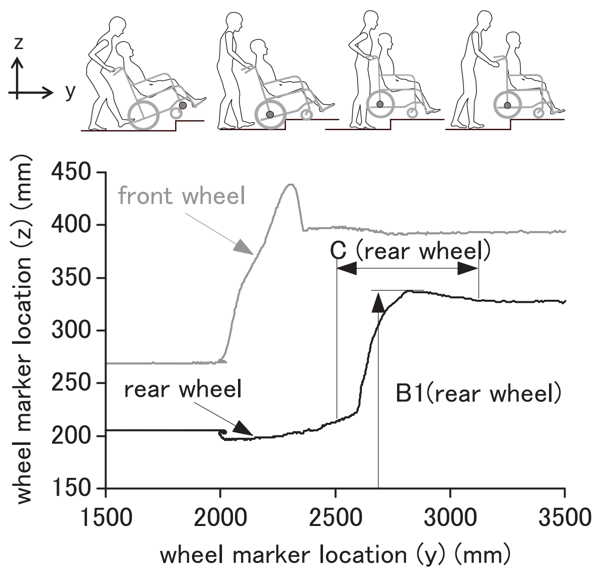


Fig.3. Example of wheelchair movement (step height: 120 mm)

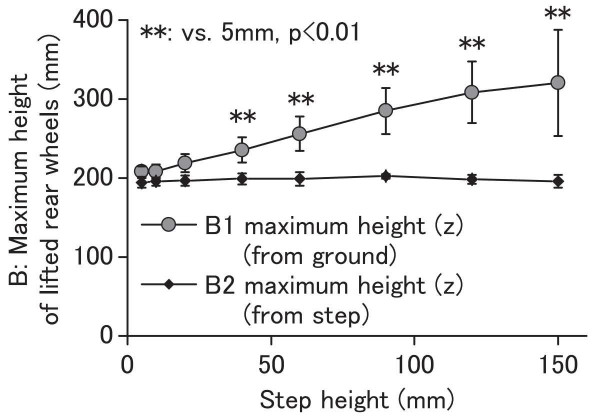


Fig.4. Relationship between step height and B (B1, B2)

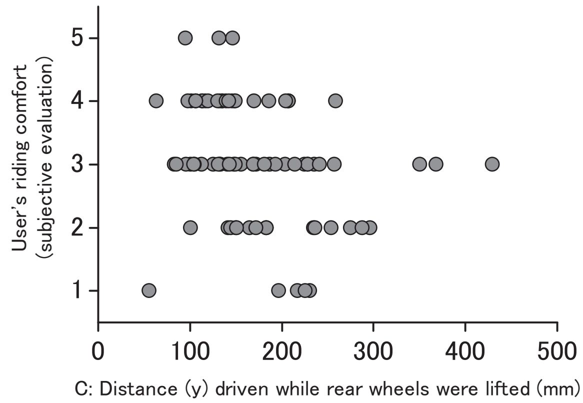


Fig.7. Relationship between C (distance driven) and riding comfort

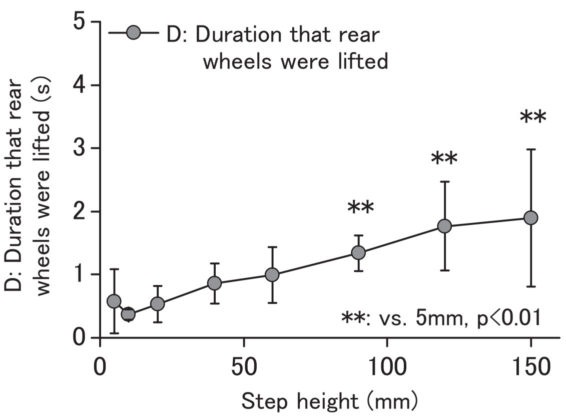


Fig.5. Relationship between step height and D

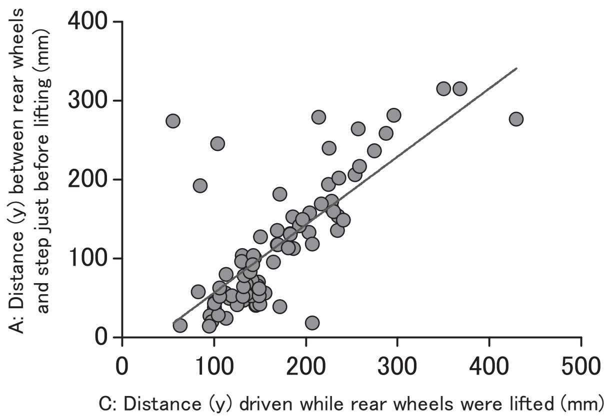


Fig. 8. Relationship between C (distance driven) and A (distance between rear wheel and step)

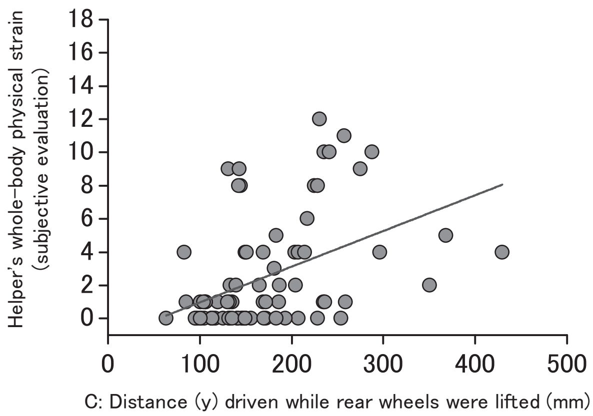


Fig.6. Relationship between C (distance driven) and whole-body physical strain

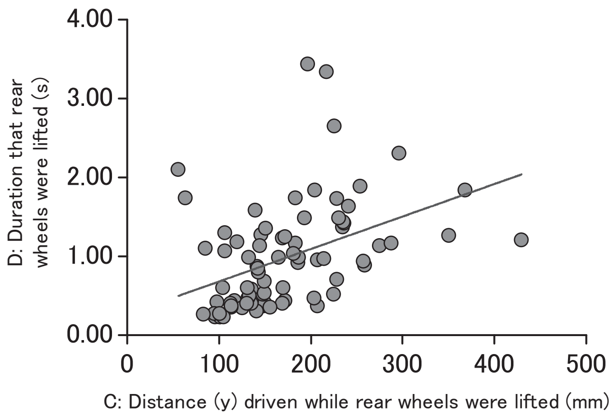


Fig.9. Relationship between C (distance driven) and D (duration that rear wheels were lifted)

4. Discussion

4.1 Characteristics of rear-wheel operation

The findings of our previous study implied that helpers are often forced to lift the front wheels when they help with wheelchair locomotion outdoors, which increases physical strain [5]. In the present study, elderly female helpers subjectively evaluated their whole-body physical strain as they operated a manual wheelchair over steps with heights ≥ 60 mm. Moreover, although some helpers could lift the front wheels and pass steps with heights over 90 mm, some of them were unable to navigate rear wheels or lost their balance while operating the rear wheels. Based on these findings, we proposed that some helpers might not be able to navigate over steps at least 90 mm high. However, it is necessary to take into account that the physical strain of helpers increases at step heights ≥ 60 mm.

There were individual differences in postures when operating the wheelchair, which implies that most of the helpers were unaware of the suitable technique for appropriately operating the wheelchair when navigating steps. One different characteristic between rear-wheel operation and front-wheel operation is that the rear wheels could be pushed over higher steps more easily than the front wheels because the diameter of the rear wheels is larger than that of the front wheels. On the other hand, under a lifting operation, helpers required more power to lift the rear wheels because, unlike the tipping lever that can be used for the front wheels, there is no lever for the rear wheels. In addition, navigational control becomes difficult as the helper's physical strain increases. When navigating over steps greater than 60 mm high, female elderly helpers required more power to lift the rear wheels. Thus, we need to examine the helper's posture index while considering safety and the relief of physical strain.

4.2 Effect of rear-wheel operation on user's riding comfort and helper's physical strain

When we focused on techniques for lifting the rear wheels, the locomotion indexes B1 and D exhibited relationships with step height. However, B2: maximum height (from step) are approximately constant (Fig. 4). This means that the helpers controlled the lifting height of the rear wheels according to the step height. In the present study, a relationship between C and user's riding comfort was not found. To get over the step with the rear wheels, helpers must lift the rear wheels to the same height as the front wheels. In this case, there is only slight inclination of the wheelchair while moving with the rear wheels lifted in comparison with movement while lifting the front wheels.

On the other hand, a longer distance (y) driven while the rear wheels were lifted (C) increased the helper's whole-body physical strain. Thus, rear-wheel operation is affected by not only the helper's technique for lifting the rear wheels, but also the step height. Namely, there are suitable techniques for navigating steps when taking into account the helper's physical strain. In this study, C was significantly, positively correlated with indexes A and D. These findings suggest that decreases in A and D might be effective methods to decrease C, which would consequently decrease the helper's physical strain.

In future studies, we will examine and verify the relationship between the operation posture and muscle activity of the helper during wheelchair locomotion.

5. Conclusion

When elderly female helpers operated the rear wheels of a manual wheelchair, their whole-body physical strain increased when navigating the wheelchair over step heights of 60 mm or more. In addition, some helpers were unable to navigate steps with heights over 90 mm while operating the rear wheels, similar to what was seen during front-wheel operation in our previous study. Moreover, the helper's physical strain when lifting the rear wheels was reduced by a shorter distance (y) driven while the rear wheels were lifted, which was related to a shorter distance (y) between the rear wheels and steps just before lifting. Results from this study indicate that a preferred technique for relieving the physical strain of elderly female helpers while navigate the rear wheels of manual wheelchair. Improvements in the physical environment will also help to alleviate the physical strain of elderly female helpers.

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