Effect of rear wheel operation for manual wheelchair by helpers on user's riding comfort and helper's physical strain, navigating steps

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Abstract: Steps are one of the main factors that have an effect on the physical strain of wheelchair helpers and the safety of wheelchair users. In this study, we examined the relationship between the movement of the rear wheels of the wheelchair during the navigation of steps and we examined the relationship between the movement of the rear wheels of the wheelchair during the navigation of steps, and the physical strain of helpers and user's riding comfort. Although the maximum height that the rear wheels were lifted was controlled according to the step height, the distance driven during lifting rear wheels was not related to the step height. Helper’s physical strain increased with the distance driven while rear wheels were lifted. When we analyzed the correlation coefficients among indexes for the rear-wheel locomotion, distance between rear wheels and step just before lifting had significant positive correlation with the distance driven while 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 preferred 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 to operate the wheelchairs safely, including elderly helpers, road and floor environments that are safe for wheelchair mobility and suitable wheelchair operation techniques are essential, in addition to the functional improvement of the wheelchairs. In particular, steps on the road and floor are barriers that prevent the movement of wheelchairs indoors and outdoors, because helpers must be physically strong and be knowledgeable of techniques for operating wheelchairs when navigating steps. Therefore, to enable wheelchair users to participate in social activities and elderly helpers to operate the wheelchair safety, 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 few papers 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 for navigating steps. To reduce the shock to the user in the wheelchair, helpers need to lift the front wheels when navigating convex step heights ≥ 10 mm [4]. In addition, the higher step forced 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 the preferred wheelchair operation techniques for navigating steps that consider standards for the heights of the steps as well as the mutual safety and comfort of the user and the elderly helper.
The purposes of the present study were to propose the preferred wheelchair operation techniques for navigating the steps from two perspectives; 1) the movement of the rear wheels of the wheelchair during the navigation of steps, and 2) the subjective evaluation regarding the physical strain of elderly female helpers during the navigation of stair steps.

2. Experimental method

2.1 Participants, wheelchair and step conditions

Eleven females in their 60s (grasping power 25.2 ±4.2 kgf) participated as wheelchair helpers, and two young females 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.

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 at eight height conditions (5, 10, 20, 40, 60, 90, 120, and 150 mm) on a wooden passageway.

<table>
<thead>
<tr>
<th>Table 1. Wheelchair Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIMENSIONS</td>
</tr>
<tr>
<td>FRONT WHEEL SIZE</td>
</tr>
<tr>
<td>REAR WHEEL SIZE</td>
</tr>
<tr>
<td>WEIGHT</td>
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<tr>
<td>FRAME MATERIAL</td>
</tr>
</tbody>
</table>

2.2 Experimental procedure and wheelchair operation

First, helpers stopped the wheelchairs at a position 180 cm from the edge of the step. Second, after our 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 them down on the higher surface of the step then the rear wheels are lifted and pushed onto the step, and then pushed it forward again after the rear wheels advanced over the step.

2.3 Measurements and statistical analysis

We captured the measurements at 60 Hz with an optical three-dimensional measurement system (Motion Analysis, EvaRT 5.0), and we used the three-dimensional motion analysis software (KISSEI COMTEC, KineAnalyzer) for the analysis of wheelchair behavior. We calculated the following as the wheelchair locomotion indexes as indicated by Figure 1.

After navigation, the helpers subjectively assessed how much strain (the they felt in their neck, shoulders, arms, wrists, hands and fingers, hips, legs and feet) on a 3-point scale for the front and rear wheels separately. We then calculated the sum of scores of eight positions as an index of whole-body physical strain.

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 did a comparison with the lowest height of 5 mm. We calculated the Pearson correlation coefficient to examine the relationships between each wheelchair locomotion indexes and the subjective evaluation. The level of significance was set at < 5%.

Fig. 1. Measurement variables from the wheelchair locomotion (rear wheel)

3. Results

3.1 Navigating situation and rear wheels operational form

The height limit for navigating the steps was 90 mm for two people (18%), 120 mm for six people (55%), and 150 mm for three people (27%). The height limits of the steps showed significantly positive correlation with grasping power (r = 0.762, p < 0.01). We observed 23 cases of wheelchair navigation in which both wheels could pass over a step height ≥ 90 mm. While lifting the front and rear wheels, 4 and 6 cases showed loss of helper’s balance.

Examples of the operational form are shown in Figure 2. There were individual differences in
operational form. During the rear-wheel operation, there was a noticeable difference form, such as tilting forward while lifting (Figure 2-(A)) and standing on tiptoes (Figure 2-(B)).

Fig.2. Example of motion for rear wheel operation (step height: 120mm)

3.2 The relationship between the locomotion of rear wheels and subjective evaluation

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 B and D. In the results of the multiple comparison tests, B and D significantly increased at height \( \geq 90 \text{mm} \) (\( p < 0.01 \)), compared with a height of 5mm. Even more, the distance moved while lifting the rear wheels (C) (average: 178 \( \pm 70 \) mm at all conditions, the maximum value: 429 mm) had significant positive correlation (\( r = -0.439, p < 0.01 \)) with the subjective evaluations of the helper’s whole-body physical strain (Figure 3). However, significant correlation were not found between the distance driven while rear wheels were lifted (C) and user’s riding comfort. When we analyzed the correlation coefficients among indexes for the rear-wheel locomotion (A–D), A (\( r = 0.738, p < 0.01 \)) (Figure 4), and D (\( r = 0.418, p < 0.01 \)) (Figure 5) had significant positive correlation with C.

Fig.3. Relationship between C (distance driven) and Physical strain whole body

Fig.4. Relationship between C (distance driven) and A (distance between back wheel and step)

Fig.5. Relationship C (distance driven) and D (duration while lifted)

4. Discussion

4.1 The characteristics of the rear-wheel operation

The findings of our previous study imply that helpers are often forced to lift the front wheels when they help with wheelchair locomotion outdoors, which causes higher physical strain [5]. When an elderly woman operates a manual wheelchair as a helper, the degree of difficulty for the helper increases at step heights \( \geq 60 \) mm, and there were helpers who could not navigate steps at a height \( \geq 90 \) mm [5]. One different characteristic between the rear-wheel operation and the front-wheel operation is easiness to pushing the wheelchair forward without lifting of the rear wheels, because the diameter of the rear-wheel is larger. However, the helpers cannot utilize the stepping bar for lifting the rear wheels. Consequently, they have to need stronger power to push the wheelchair or to lift
the rear wheels. In the present experiment, although some helpers could lift front wheels and pass the steps over 90mm heights, some of them could not navigate rear wheels or lost their balance while operating the rear wheels. On the other hand, operation postures of the helper had individual differences, which implies that most of them were unaware of the best technique for appropriate operation of the wheelchair when navigating steps. When navigating at step heights over 90mm by elderly female helpers, our finding suggest that helpers are required power to lift rear wheel, and we need to examine the helpers postures index considering the relief of physical strain.

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

When we focused on techniques for lifting the rear wheels, the locomotion indexes B and D showed relationship to step height. This relationship was not observed in our previous study that focused on the operation of the front wheels. This means that the helpers controlled lifting height of the rear wheels, according to the step height. In our study, there is not found relationship between C and User's riding comfort. When get over the staircase step with rear wheel, need to lift up rear wheel on same level with front wheel. It shows that inclination of the wheelchair while moving is small state when lifting rear wheel, in comparison with lifting a front wheel. Therefore, it is likely that step height has more impact on user’s riding comfort than helper's operation methods. On the other hand, a longer distance (y) driven while the rear wheels were lifted (C) contributed to an increase in the helper’s physical strain. Thus, the helper’s whole-body physical strain while rear-wheel operation would be influenced by the helper’s technique for lifting the rear wheels as well as the step height. Moreover, C had significant positive correlation with indexes A and D. Namely, the decreases in A and D might be an effective method to decrease C, which results in a decrease in the helper’s physical strain. These findings suggest that there are suitable techniques for navigating steps when taking into account the helper’s physical strain. In future studies, we need to examine and verify the relationship between the operation form of the helper during wheelchair locomotion and the physical strain on the helper.

5. Conclusion

The navigating difficulty for elderly women operating a manual wheelchair as a helper increased with step heights \( \geq 90 \) mm, which might correspond to the height limit of steps where navigation is possible. Moreover, the helper’s physical strain when lifting the rear wheels was reduced by a shorter distance (y) driven while the front wheels were lifted, which was related to a shorter maximum height (z) of the lifted rear wheels. This study suggests the need for step height standards and preferred techniques for lifting the wheels of wheelchairs, for relieving the physical strain of female elderly wheelchair helpers.

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References


