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Original Article

Effects of ramp slope on physiological characteristic and performance time of healthy adults propelling and pushing wheelchairs

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Abstract. [Purpose] This study examined the effects of ramp slope (1:12, 1:10, 1:8, and 1:6) on physiological characteristics and performance times of wheelchair users and the performance times of caregivers to determine which slope would be the best for wheelchairs, in order to propose a ramp slope that incorporates a universal design. [Subjects and Methods] Twenty-four healthy subjects were enrolled in this study. Fifteen of these subjects also volunteered to participate as caregivers. A wooden ramp with an adjustable slope was constructed. As manual wheelchair users, the participants performed propulsion of a wheelchair up the ramp at a self-selected pace. Four ramp slopes (1:12, 1:10, 1:8, and 1:6) were used, and the participants sequentially ascended them in order from the gentlest to the steepest slope. The caregivers also pushed a wheelchair up the ramp at a self-selected pace. The blood pressure and pulse of participants after the ascent, as well as the performance times of the caregivers and manual wheelchair users, were measured on each of the different ramp slopes. The measured data, pulse, blood pressure, and performance time, were analyzed using repeated ANOVA. [Results] Systolic blood pressure was significantly higher after ascending the 1:6 slope than after ascending the 1:12 and 1:8 slopes. Diastolic blood pressure was significantly higher after ascending the 1:6 slope than after ascending the 1:12 and 1:8 slopes. The participants' pulses tended to increase significantly with an increase in slope. An assessment of the propulsion performance times revealed significant differences among the slopes. [Conclusion] Considering the results of the wheelchair users and caregivers, the 1:12 and 1:10 slopes are suitable ramp slopes for wheelchairs.
Key words: Wheelchair, Ramp slope, Physiological characteristics

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INTRODUCTION

Most people with disabilities depend on a wheelchair for their mobility. For these people, a wheelchair is an important way of achieving independent locomotion . Environmental obstacles, increase wheelchair users' mobility restrictions, because they require greater effort to overcome[1, 2)]. Ramp ascent is an example of an environmental obstacle that wheelchair users often encounter. Wheelchair users frequently report ramps as being barriers to navigate and overcome during their daily activities[3)]. Edlich et al. reported that an inappropriate ramp design can cause serious musculoskeletal damage[4)].

The Americans with Disabilities Act Accessibility Guidelines (ADAAG, 1998), which gives a representative design guideline addressing the needs of wheelchair users, suggests a 1:12 slope as being the most suitable gradient for a ramp[5)]. In Korea, the Welfare Act for the Disabled, Elderly, and Pregnant Women also stipulates a 1:12 slope[6)]. Many studies have focused on determining the most suitable ramp slope for wheelchair users. Amomg these, Canale et al.[7)] found 1:6–1:6.7 slopes to be the most suitable, and Sanford et al.[8)] proposed a 1:12 slope as the most suitable gradient.

Because both caregivers who assist the disabled and manual wheelchair users handle wheelchairs, the slope of the ramp is important to both. In general, the characteristics of a wheelchair affect the musculoskeletal health of caregivers, and a previous study reported that the height of the wheelchair handle, has an impact[9)]. Also, previous researcher have studied the effects of heights of step obstacles on caregiver[10)]. However, few studies have considered the characteristics of both the manual wheelchair user and caregiver. Therefore, this study aimed to consider the characteristics of both in order to propose a ramp slope that incorporates a universal design.

SUBJECTS AND METHODS

Twenty-four healthy adult volunteers (9 males and 15 females; mean ages, 41.40±14.46 and 41.93±14.82) with

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Table 1. Comparison of the blood pressure, pulse, and performance times for the different ramp slopes

		Ramp slope			
		1:12	1:10	1:8	1:6
Manual wheelchair user	Systolic blood pressure (mmHg)	126.5±18.9	130.9±20.7	129.3±21.0	134.2±18.8
	Diastolic blood pressure* (mmHg)	66.9±12.7	72.4±14.0	68.9±10.6	73.0±11.5
	Pulse* (bpm)	51.0±4.4	52.2±4.2	53.3±4.2	55.2±4.4
	Performance time* (sec)	19.0±4.2	15.8±4.9	23.9±11.1	28.8±13.8
Caregiver	Performance time* (sec)	8.2±1.9	7.5±1.5	9.3±2.5	11.1±4.6

Results of repeated ANOVA are indicated by superscripts. *: significance, $p<0.05$.

no musculoskeletal problems, no metabolic disease, and no prior wheelchair experience were enrolled in this study as manual wheelchair users. Fifteen of these subjects also participated as caregivers. A sufficient explanation of the experimental procedures was provided to the subjects, who gave their written consent to voluntary participate in this study. This study was approved by the Institutional Review Board of the local ethics committee, in accordance with the ethical principles of the Declaration of Helsinki.

A wooden ramp with an adjustable slope was constructed. The ramp height was adjustable between 0.83 and 1.67 m. The ramp was 10.0 m in length, and 1.5 m in width and led to a $2.0 \times 1.5\ m^2$ platform. As manual wheelchair users, the participants propelled the wheelchair (general-type) up the ramp at a self-selected pace. Four ramp slopes (1:12, 1:10, 1:8, and 1:6) were provided, and the participants sequentially ascended them in order from the gentlest to the steepest slope. The caregiver participants pushed a person sitting in the wheelchair up the ramp at a self-selected pace. To eliminate fatigue, all the participants took sufficient rest between the trials.

The blood pressure and pulse of the participants were assessed using an electronic sphygmomanometer (Manette, Hong Kong) immediately after completing the ramp ascent. The performance times of the manual wheelchair user participants and the caregiver participants was measured on each of the different ramp slopes as the time taken from the caster of the wheelchair passing the starting point of the ramp to reaching the platform using a stopwatch (general-type). Each subject was asked to perform two trials on each ramp slope and the mean measurement values were used in the analysis.

The statistical package, SPSS 18.0 for Windows, was used for the statistical analysis. The characteristic data, such as age, height, and weight, were analyzed using descriptive statistics. The blood pressure, pulse, and performance time were analyzed using repeated ANOVA. P values < 0.05 were considered significant.

RESULTS

This study involved 24 subjects. Each of the subjects propelled a wheelchair up the ramps, and 15 of them also pushed the wheelchair up the ramps. The heights and weights of the participants were 165.9±7.8 cm and 64.0±10.1 kg, respectively.

The systolic and diastolic blood pressures were significantly higher after ascent of the 1:6 slope than after ascent of the 1:12 and 1:8 slopes according to the pairwise comparison. Pulse showed significant increases with increasing ramp slope. Significant differences were observed among the four slopes (1:12, 1:10, 1:8, and 1:6).

Assessment of the propulsion performance times revealed significant differences among the slopes. Pairwise comparison found there were significant differences among all the slopes, except the pairwise comparison between the 1:8 and the 1:6 slopes. Similar to the propulsion performance times, the performance times of pushing the wheelchair were also significantly different. The pairwise comparison showed no significant difference except between the 1:8 and 1:6 slopes (Table 1).

DISCUSSION

This study examined the effects of ramp slope on the physiological characteristics and performance times of healthy adults pushing or propelling a wheelchair use. The results are expected to provide guidelines for the most suitable ramp slope for both wheelchair users and caregivers.

The pulse rate increased with increasing ramp slope. Blood pressure was higher after ascent of the 1:12 slope than after ascent of the 1:10 slope, but it generally increased with increasing ramp slope. A similar result was found for the performances times of pushing or propelling the wheelchair. The performance time was shorter on the 1:10 slope than on the 1:12 slope, but it generally increased on steeper inclines (1:8 and the 1:6 slopes). In addition, the results of performance times showed a similar trend when participants propelled the wheelchair. Most studies have reported a tendency for the physiological characteristics and performance time to increase with increasing ramp slope[8, 11], and our results are in agreement with the findings of these previous studies, except for the ramps with slopes between 1:12 and 1:10. We attribute this difference to differences in the experiment protocol and the order in which the trials on the ramp slopes were conducted. Canale et al. found 1:6–1:6.7 slopes to be the most suitable for wheelchair users[7], and another previous study reported 1:16–1:20 slopes to be the most appropriate[12]. We atrribute the differences to differences in the participants characteristics, since our subjects were selected based on the criteria that they did not have any prior experience of handling wheelchairs. Because they were unfamiliar with using a wheelchair on a ramp, they may have taken a longer time on the 1:12 slope, which was attempted first, followed by the 1:10 slope. In addition, their blood pressure may have increased due to them attempting to perform the task in too a short time on the 1:10 slope, which can be explained as a failure by the subjects to regulate their pace, because they were unfamiliar with using a wheelchair.

Kim et al.[11] conducted a ramp slope study using young healthy adults, whose physiological characteristics were similar to those of our present study. They found no significant difference between the 1:12 and 1:10 slopes, and concluded that it is acceptable to use a 1:10 slope instead of a 1:12 slope, which is the ramp slope that both the ADAAG and Korean Ministry for Health, Welfare and Family Affairs suggest. In addition, Kim et al. stated that a 1:8 slope was acceptable when a ramp connects two areas whose height differences are less than or equal to 15 cm, but that a 1:6 slope should be avoided in all cases. Our present results appear to be similar to those reported by Kim et al., considering that the systolic blood pressure and diastolic blood pressure were similar after wheelchair use on the 1:12 slope and 1:8 slope. On the other hand, the pulse rate clearly increased with increasing slope and the performance time was longer on the 1:8 slope than on the 1:12 slope. Regarding the performance times of the caregiver participants, a difference was found between the 1:12, 1:10, and 1:8 slopes but no difference was found between the 1:8 and 1:6 slopes. Therefore, the 1:8 slope appears inappropriate for a ramp slope.

Considering the results, we propose that the 1:12 slope and 1:10 slope are appropriate ramp slopes for both wheelchair users and caregivers. Nevertheless, this study was limited by the fact that the experiment protocol was not decided randomly and the subjects did not appear to have regulated their pace well. Future studies should include a more detailed study using more diverse subject groups.

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