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Effects of ramp slope, ramp height and users' pushing force on performance, muscular activity and subjective ratings during wheelchair driving on a ramp

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ABSTRACT

We set and examined two hypotheses about effects of ramp slope (1:6, 1:8, 1:10, 1:12, and 1:14) by varying ramp height (0.15 m, 0.30 m, and 0.45 m) and pushing force of wheelchair users (weak, medium, and strong group). Thirty participants were recruited for the experiment, and they have ascended a ramp using a manual wheelchair. Three categories of dependent variables were measured: performance measures (total time and velocity), muscular activity measures (EMG of four upper extremity muscles) and subjective rating measures (physical discomfort and acceptability). Only the strong group used muscles constantly regardless of the ramp slope. Accessibility of the ramp decreased as the slope increased, and accessibility difference between slopes increased as the height increased. Based on the result, we suggest maximum allowable slope by ramp height: 1:8, 1:10 and 1:12 were recommended for the heights of 0.15 m, 0.30 m, and 0.45 m, respectively.

Relevance to industry: This study can provide enhanced understanding concerning effects of ramp slope, ramp height and users' pushing force on accessibility of a ramp. Based on this understanding we suggested ramp slope guidelines by ramp heights. It is possible to design ramp more accessible and safe using this guidelines.

1. Introduction

Wheelchair users experience lower quality of life due to their lower mobility (Ding et al., 2007; Howarth et al., 2010; Kilkens et al., 2003; McClain et al., 1993; Meyers et al., 2002; Thapar et al., 2004). Particularly, vertical movement is one of the main problems they have (Arva et al., 2009; Canale et al., 1991; Ding et al., 2007; Horiuchi et al., 2014; Imamura et al., 2004; Pierret et al., 2014; Price, 2010). For example, in building or bus entrances, they cannot easily move vertically without an extra assistance such as an elevator, a wheelchair lift, or a ramp. A ramp is a basic type of assistive device that is used to aid wheelchair users' vertical movement (Cappozzo et al., 1991; Lemaire et al., 2010; Mann et al., 1995; McCreadie and Tinker, 2005; McMillen and Söderberg, 2002; Roelands et al., 2002; Sutton et al., 2002). However, there had been accessibility and safety problems at ramps due to their inappropriate design (Bennett et al., 2009; McClain, 2000; Rivano-Fischer, 2004; Useh et al., 2001; Xiang et al., 2006). Many previous studies have focused on ramps to improve the quality of life for wheelchair users by investigating and suggesting maximum allowable ramp slopes (Canale et al., 1991; Cappozzo et al., 1991; Department for Transport, 2005; Elmer, 1957; Lehmann et al., 1974; Sanford et al., 1997; Steinfeld et al., 1979; Sweeney et al., 1989; Sweeney and Clark, 1991; Templer et al., 1984; U.S. Access Board, 1998, 2006; U.S. Department of Housing and Urban Development, 1991; van der Voordt, 1981; Voigt and Bahn, 1969; Walter, 1971).

Previous studies have mainly focused on suggesting maximum allowable ramp slopes to improve the accessibility and safety of the ramp among various design factors such as slope, height, width and surface length because slope is one of the most important design factors. However, the suggested ramp slopes varied in different studies. The Americans with Disabilities Act Accessibility Guidelines (ADAAG) suggested 1:12 as the maximum allowable ramp

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slope (U.S. Access Board, 1998). The Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines (ABAAG), a modified version of ADAAG, suggested 1:8~1:10 for ramps with a maximum rise of 75 mm, 1:10~1:12 for ramps with a maximum rise of 75 mm to 150 mm and 1:12 for ramps with a maximum rise of 760 mm (U.S. Access Board, 2006). Canale et al. (1991) and Elmer (1957) recommended 1:6~1:6.7, which are relatively steep slopes, and Templer et al. (1984) and Walter (1971) has suggested that 1:10 is suitable. Sanford et al. (1997) and Steinfeld et al. (1979) recommended relatively gentle slopes of 1:12 and 1:16~1:20, respectively.

The reason that previous studies suggested different ramp slopes might be attributed to different experimental settings they have used. First, previous studies have used different ramp surface lengths. Canale et al. (1991) have used two ramps with 3 m and 6 m surface lengths, and Walter (1971) and Lehmann et al. (1974) have used a 3 m (10 foot) ramp. Sanford et al. (1997) have used a 9 m (30 foot) ramp, and Steinfeld et al. (1979) have used a 12 m (40 foot) ramp. From these studies, we could assume that the suggested ramp slope increased with decreasing ramp length. In addition, some researchers advanced a hypothesis that even older wheelchair users could ascend ramps steeper than 1:12 in shorter ramps, and this might be one of the evidences of our assumption (Canale et al., 1991; Cappozzo et al., 1991; Sanford et al., 1997; Sweeney et al., 1989; Sweeney and Clark, 1991). However, due to dissimilarity of experimental design such as sample frame and ramp settings (i.e. height, surface length), it is difficult to find exact relationship between maximum allowable ramp slope and ramp length, and to reach a consensus for appropriate ramp design merely by reviewing the previous studies.

Note that for a given ramp slope, if one of either ramp length or height is set, the other one is also determined. Therefore, manipulating height is identical to manipulating surface length. The height rather than length is given in a typical ramp installation and is closely related to the purpose of the ramp; therefore, the ramp height could be considered as a more intuitive design factor than the ramp length.

Second, the physical characteristics of the participants were different. Canale et al. (1991) and Elmer (1957), which suggested relatively steep slope, has recruited young and healthy people. On the other hand, Sanford et al. (1997) and Steinfeld et al. (1979), which suggested relatively gentle slope, have recruited physically weak people such as the aged and the disabled. We infer that the younger or physically healthier a participant group is, the steeper suggested ramp slope becomes. In addition, there was a mathematical relationship between the pushing force and maximum allowable ramp slope (Cappozzo et al., 1991). Thus, we could assume that maximum allowable ramp slope would be different among wheelchair users with different physical characteristics.

To sum up, we could assume by reviewing previous studies that maximum allowable ramp slope could be affected by the ramp height and the physical characteristics of the wheelchair users. However, we cannot identify the exact effects of these two factors by reviewing the previous studies only thus could not suggest ramp slope guidelines by reflecting the effects of them. Ramp slope guidelines would remain inadequate without considering effects of them, and it could induce accessibility and safety problems. Thus, we started this study to identify the effects of them under the following two hypotheses deduced by reviewing literature and suggest ramp slope guidelines by reflecting effects of those two factors.

- H1: The lower ramp height is, the steeper ramp slope can be allowed
- H2: The stronger wheelchair users are, the steeper ramp slope can be allowed

In this study, we experimentally have analyzed the effects of the ramp slope, the ramp height, and participants' pushing force on the accessibility of ramps, and suggested maximum allowable ramp slope by ramp heights. It should be noted that ramp height was considered instead of ramp length in our study. We have considered three categories of dependent variables: the total time and velocity as performance measures; total EMG of extensor carpi radialis (ECR), triceps brachii (TB), anterior deltoid (AD) and posterior deltoid (PD) as a surrogate measure of muscular activity; and physical discomfort and acceptability as subjective rating measures.

2. Methods

2.1. Participants

A total of 30 undergraduate and graduate students (11 males and 19 females) have participated in this study (Table 1). Since the participants' pushing force was considered as a between-subject factor, they were selected after performing participant screening. As a part of the screening process, the maximum pushing force of the dominant hand of each user was measured in the seated posture by a strength tester (Fig. 1). Participants pushed grab-bar for more than 5 s as strong as possible and the average force was calculated by strength tester. The maximum pushing force of the dominant hand was set as a criterion for screening because its measuring protocol was the most similar to wheelchair driving among various forces in the SizeKorea database (Korea Agency for Technology and Standards, 2011), which is the anthropometric database of Koreans.

The participants were recruited by dividing into three different groups – weak, medium and strong – based on the maximum pushing force. The weak group had pushing force under the 25th percentile (~77.1 N). The medium group had pushing force between the 33rd and 67th percentiles (88.9 N~119.2 N). The strong group had pushing force over the 75th percentile (127.9 N~). The 25th percentile to 33rd percentile and 67th percentile to 75th percentile excluded to distinguish between marginal values of adjacent groups.

The pushing force was considered as a representative factor of the participants' physical capabilities, and any other physical characteristics such as range of motion, and flexibility were excluded. In order to focus on the pushing force, we have excluded the aged when recruiting participants to avoid interference of effects of other physical characteristics. The disabled was also excluded because the disabled who use wheelchair were not different with ordinary people in terms of upper extremities (Brown et al., 1990; Perdios, 2003; Starrs et al., 2012); thus, distinction of the disabled and ordinary people was not important in this study. All participants did not have a history of musculoskeletal disorders. In addition, we recruited only novice

Table 1
Participant information (numbers in parentheses means standard deviation).

Participants group	Age	Pushing force	Number	
			Male	Female
Weak	24.9 (1.6)	69.3 (5.6)	0	10
Medium	25.0 (1.2)	102.7 (6.1)	1	9
Strong	26.4 (2.9)	160.3 (14.6)	10	0
Total	25.4 (2.1)	110.8 (39.4)	11	19

※Unit of age is years. Unit of pushing force is newton (N).