Comparison of Simulated Physical Load of Sidewalk Curb for Electric, Manual Wheelchair Users and Visually Impaired People

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Abstract
Physical activity, depending on work load as well as work environment, is modulated by Electrocardio-vascular activity. Activity of an electrocardiogram (ECG) may be associated with the physical load of moving for people with mobility handicaps in use of wheelchairs. The aim of this study is to investigate the relationship of ECG activity with the physical load of electric and manual wheelchair users and visually impaired people when crossing a main road with difficult access to high sidewalks. Eight voluntary students participated in the study. R-R interval times of heart beats were continuously recorded for each session of manual/electric wheelchairs and visually impaired. Experimental road conditions included places where there was a 0 cm to 10 cm drop or a steep step at both sides of the road. It is concluded that electric wheelchairs can provide stable driving for their users under conditions where there are differences in height between sidewalk and road, which are common obstacles for the users of wheelchairs. Furthermore, the influences of the sidewalk curb on heart beats when changing the method of transportation with difference conditions of curb are discussed. In addition, it was found that there are different influences of the curb heights on wheelchair users and visually impaired people.

Keywords
electric wheelchair, manual wheelchair, visually impaired, ECG, physical load,

1. INTRODUCTION
Barriers on roads limit the possibilities of carrying on daily social life for both wheelchair users and visually impaired people, increase their physical load unnecessarily and become one of the main causes worsening their impairment. [Engström, 1993, 2003; Strauss et al., 1992] For example, not only the frequency of outings by wheelchair users is limited but also the distance they go is limited, depending on how much physical load caused by the use of a wheelchair they can bear. The existence of a barrier-free environment is a key issue for reducing their physical load.

There are several types of barriers in the sidewalk environment. Especially, the height of curbs on sidewalks and steep slopes on the road become barriers for easy transportation and increase the difficulty and uneasiness of operating a wheelchair. Also, the dangers of traffic accidents are an issue. According to Japanese guidelines, based on traffic barrier-free law, the height of the curb of the sidewalk from the road requires 2 cm as a standard. However, it is desirable to decide about the structure of the curb height after understanding an evaluation between the curb structure and the characteristic actions of wheelchair users, visually impaired people, and elderly people. [Ministry of Land, Infrastructure, 2003]

As for the research regarding walking on the sidewalk for visually impaired people, their actions of discriminating between barriers on the sidewalk and raised blocks was confirmed [Ikeda et al., 2006] In the situation of a 2 cm curb on the sidewalk, it is not easy to recognize the curb for visually impaired people, and it is possible to for them to disregard it. It is easier to recognize curbs for visually impaired people by raising the height, however, this becomes a considerable barrier for transport by wheelchair users. [Yamaguchi et al., 2004] It is necessary to decide the ideal curb height for each user, however, it is important to consider that time and money are also necessary to transform all curb heights to barrier-free. It can be assumed that not only discussion about barrier-free sidewalks, but the use of additional power, for example electric wheelchairs, will also have a constant effect as a method of movement. [Ikeda et al., 2003] It is important to evaluate the physical load of manual and electric wheelchair users and visually impaired people under the same conditions, and to know the influence that the curb has on barrier-free progress on the sidewalk.

The heart rate has been used in various fields as an indicator of physical load. In addition, the heart rate has also been studied systematically as an indicator for objective assessment. The reasons for its use are because of (1) the compact nature of the measuring device, as it is light, thin and small, (2) the possibility of recording for a continuous and a long period of time, (3) the smallness of the impact on the subject of experiments, (4) the ease of any analysis using computers. For example, Kroemer and Grandjean [1997] have written about their research findings using the heart rate as an indicator.

In this paper, the comparative physical load, using R-R interval times, for traveling over an experimental sidewalk and curbs of six conditions for an electric wheelchair group, a manual wheelchair group, and a visually impaired group was measured and improvements for an ideal method of sidewalk curb are discussed. Regarding the curb height, which is one of the important points concerning barrier-free measures of the sidewalk, the characteristic point of this research was to compare and evaluate using the same subjects and the same conditions from an objective view-point with manual wheelchair users and visually impaired people, who are easily affected by the curb height, and users of electric wheelchairs, which are thought to be effective for the curb height.

2. METHOD

An electric wheelchair and a manual wheelchair were used in this experiment. On six conditions, where the curb height was against the operation of wheelchairs, the R-R interval time of heart beats, perceived rating as an index of physical load required, were measured. Visually impaired people were also measured at the same time. In this experiment, the subjects were normally sighted people and the visual impairment was assumed by the use of an eye mask and a white cane to walk as referred to in the experiments by Yokoyama et al. [2007] and Kawashima et al. [2003]. In Yokoyama's research, normally sighted people wearing an eye mask were used because even some visually impaired people are inexperienced to recognize with a white cane. Therefore, the subjects selected were people who have equal sensitivity to inexperienced visually impaired people. Also, in the research of a walking experiment with and without a white cane by Kawashima, difference walking performances were shown. Therefore, in this paper, it was considered important, at the first stage of research, to know the tendencies of the three groups through comparison of the same subjects. The subjects' eye sight was completely taken away, therefore, for safety reasons, another person assisted the subjects. In addition, each group, electric wheelchair, manual wheelchair, and visually impaired people, consisted of the same subjects.

Table 1 shows the main features of the electric wheelchair. Figure 1 and Figure 2 show the two wheelchairs which were used. The operation of the electric wheelchair was controlled by the use of a joy-stick. The manual wheelchair was a Japanese Industrial Standard (JIS) type.

Fig. 1 Electric wheelchair

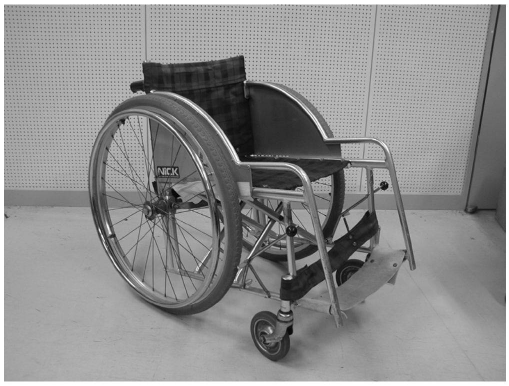

Fig. 2 Manual wheelchair

Table 1 Specifications of the electric wheelchair

Model/type	EMC-101 OE
Drive system	Front-wheel power-steering, rear-wheel direct-driven system
Wheel	220 mm-diameter front-wheel and 388 mm-diameter rear-wheel
Motor	30-minutes rated output 24 V 220 W × 2
Size	Length 1070 mm × width 600 mm × height 900 mm
Weight	83 kgs (including batteries)
Speed	Low: 2.5 km/h, middle: 4.5 km/h, high: 6.0 km/h
Minimum turning radius	850 mm

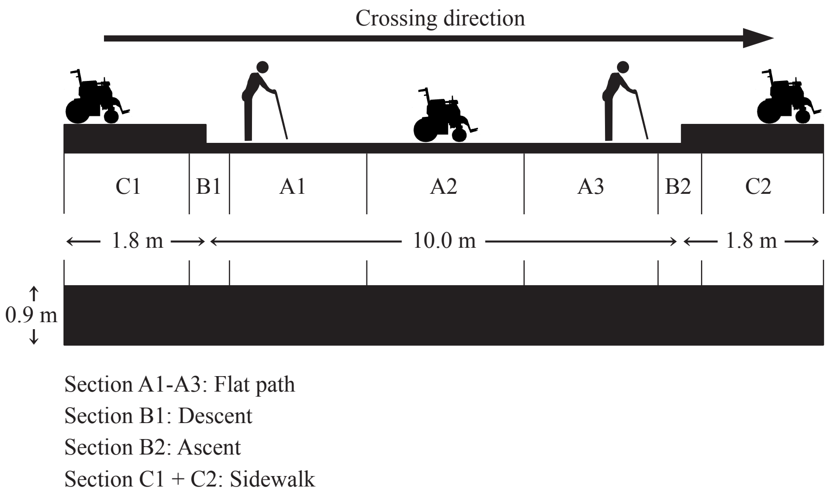

Fig. 3 Sectional view of setting in the experimental road

As Figure 3 shows, the wheelchair crossed the road from one sidewalk to the sidewalk on the other side. The experiment was conducted over six different curb heights between sidewalk and road. The heights ranged from 0 cm to 10 cm difference, and the road was single-lane. The width of the road was 10 m in total from A1 to A3, and the width of the sidewalk was 1.8 m.

2.1 Experimental procedure

The experiment was conducted through the random combination of two types of wheelchairs and six setting conditions consisting of the differences in curb height. However, the experiment involving a 5 cm curb height was not possible using the manual wheelchair, and 10 cm curb height was not possible using both the manual and the electric wheelchair, so only four conditions were used with the manual wheelchair and five for the electric wheelchair. Also, the visually impaired people were measured from 0 cm to 10 cm. After, the users' heart rate was measured while they were resting (under conditions while their eyes were closed), ten trials of road-crossing under each condition were conducted.

A wristwatch type of portable heart rate monitor S810 (Polar Electro Oy) was used for measuring heart rates, as shown in Figure 4. While the R-R interval time continued, a measurement of the heart rate was fed from the transmitter in the heart rate induction electrode to the memory in the wristwatch receiver in order to record the rate.

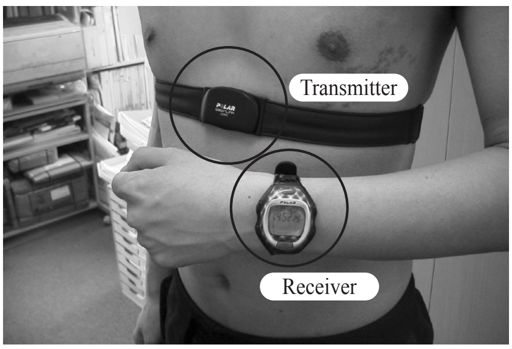

Fig. 4 Heart rate monitor and how to wear

2.2 Subjects

Table 2 shows information on the subjects. Eight male post-graduate and under-graduate students volunteered to participate in the experiment. The subjects were all healthy, and none of them had any physical problems with their upper limbs, backs and hips. Their average age was 23.5, from 21 to 31 years old. Their average body height was 173.6 cm, from 166 to 183 cm, and their average body weight was 63.5 kg, from 56.0 to 72.0 kg.

Also, the subjects were given sufficient explanation regarding this experiment and agreed, on paper, to join the experiment.

Table 2 Information of subjects

Subject	Sex	Age	Height (cm)	Weight (kg)
No. 1	Male	22	174.0	72.0
No. 2	Male	23	183.0	64.0
No. 3	Male	21	174.0	65.0
No. 4	Male	24	174.0	59.0
No. 5	Male	21	166.0	56.0
No. 6	Male	23	173.0	64.0
No. 7	Male	23	177.0	64.0
No. 8	Male	31	168.0	64.0

3. RESULTS

As shown in Figure 5, the average R-R interval times

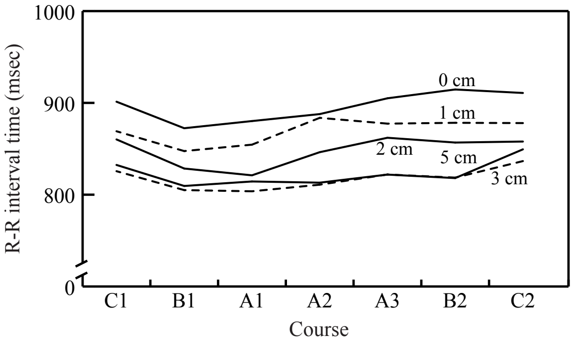

Fig. 5 R-R interval times for using an electric wheelchair

of heart beats for using an electric wheelchair on the section C1-C2 were: 0 cm = 896.0 (*SD* = 16.1), 1 cm = 869.8 (13.7), 2 cm = 847.5 (16.5), 3 cm = 817.5 (11.8), 5 cm = 822.7 (13.9) msec. In spite of the difference in height between road and sidewalk, the R-R interval time was shorter when descending the curb than when ascending, therefore, the heart rate of the user also increased. The electric wheelchair could not ascend a 10 cm curb.

As Figure 6 shows, R-R interval times for using a manual wheelchair became shorter as the curb height increased, and the heart beats of the driver also increased. The R-R interval time was shortest when the height was 3 cm, and when the wheelchair was ascending, it showed the shortest R-R interval time of 682 msec. As the result of a t-test, there was a significant statistical difference ($t = 3.21$, $p < .05$) between the curb heights 2 cm and 3 cm for section B2. For the section C1-C2, the heart rate of the user increased when the wheelchair descended the curb and moved to the flat section A1-A3; and the heart rate was constant until the user ascended the curb. The manual wheelchair could not ascend a 5 cm curb.

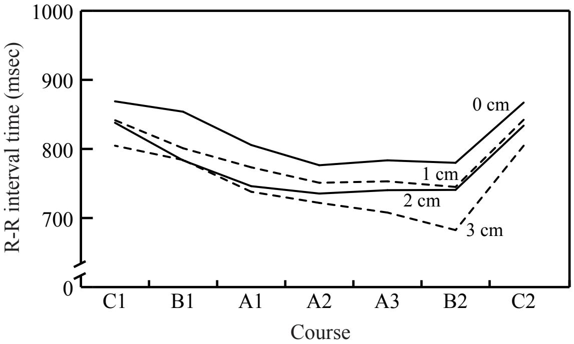

Fig. 6 R-R interval times for using a manual wheelchair

As Figure 7 shows, for the visually impaired group, R-R interval times were shorter when descending and ascending the curb. On conditions of 5 cm and 10 cm, the R-R- interval times were shorter when both ascending and descending the curbs, therefore, the heart rates increased. However, curbs from 0 cm to 3 cm showed no significant difference. As the result of a t-test, there were significant statistical differences between 3 cm and 5 cm of ascending ($t = 3.19$, $p < .05$) and descending ($t = 13.76$, $p < .01$) and 5 cm and 10 cm of ascending ($t = 10.90$, $p < .01$) and descending ($t = 12.41$, $p < .01$).

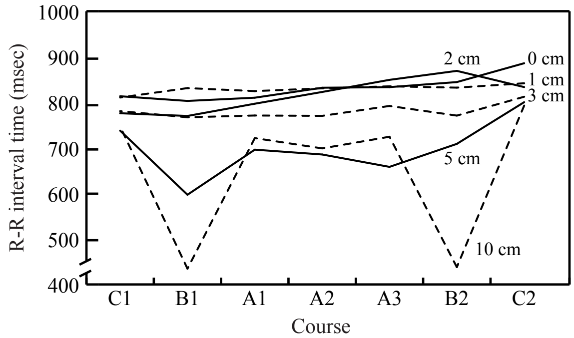

Fig. 7 R-R interval times for visually impaired group

Figure 8 shows a comparison of the average R-R interval time between the electric wheelchair group, the manual wheelchair group, and the visually impaired group for each section. Compared with the electric wheelchair, the R-R interval time when ascending the curb was shorter than when descending the curb for the manual wheelchair, and the heart rate of the user increased. However, the R-R interval time when descending the curb for the electric wheelchair was shorter than when ascending the curb, and the heart rate increased. The R-R interval time during use of both types of wheelchairs decreased in the section B1-B2. In particular, when the visually impaired group were descending the curb, the difference was recorded as 700.5 msec. In a comparison of average R-R interval times for each group, the electric wheelchair group was 850.7 msec, the manual wheelchair group

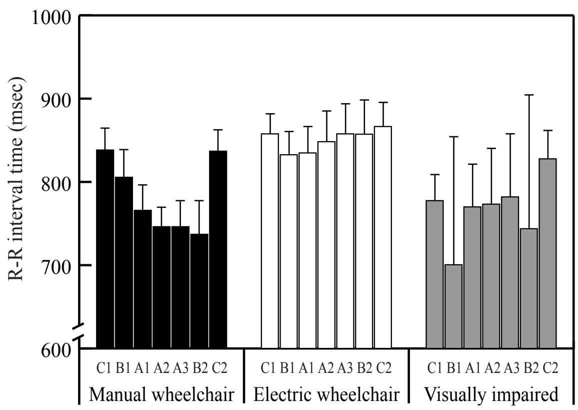

Fig. 8 Three groups of average R-R interval times of heart beats

was 782.3 msec, and the visually impaired group was 767.8 msec. As the result of a t-test to recognize differences between these three groups, there were significant statistical differences between all groups (electric wheelchair-manual wheelchair: $t = 24.63$, $p < .01$, electric wheelchair-visually impaired: $t = 3.43$, $p < .05$, manual wheelchair-visually impaired: $t = 4.51$, $p < .05$).

4. DISCUSSION

As shown in Figure 5, the R-R interval time when descending the curb for the electric wheelchair group was shorter than when ascending the curb and the heart rate increased. However, as shown in Figure 6, the R-R interval time when ascending the curb for the manual wheelchair group was shorter than when descending the curb and the heart rate increased. Especially, when ascending a curb height of 3 cm, the R-R interval time showed 682.5 msec. It is shown that there is a difference between 2 cm and 3 cm of the curb height.

Electric wheelchairs can be controlled by the simple use of a joystick. However, manual wheelchairs are operated by the power of the users' arms, so there is additional physical load on their upper limbs and shoulders. In addition, in order to maintain a stable sitting posture, load always accumulates in the back and hip and becomes a secondary problem to the users. Although the electric wheelchair runs by an electric motor, it can be said that a psychological influence is considerable and the R-R interval time becomes shorter at the curb.

The electric wheelchair group was able to ascend curbs up to 5 cm and the manual wheelchair group was able to ascend up to 3 cm, however, the visually impaired group could walk through the course even over high curbs in the same way as a physically unimpaired person. However, the visually impaired group indicated an influence on their heart rates through different results for different curb heights. The visually impaired group has to recognize curbs or barriers on the sidewalk with the use of a white cane. However, it is difficult to recognize a low curb height with a white cane and possible to walk on without being aware of the curb. As shown in Figure 7, over a curb height of 5 cm, the heart rate increased when descending and ascending curbs. Visually impaired people can recognize the curb only just before arriving at it with the use of a white cane, therefore, they can not prepare well for the curb. It can be assumed that this causes an increase of the heart rate by psychological influence, and demands mental workload for the recognition of the curb.

5. CONCLUSION

In this paper, a method with R-R interval time was used to measure and evaluate the simulated physical load for an electric wheelchair group, a manual wheelchair group, and a visually impaired group. In the results, it was made clear that an electric wheelchair was better at reducing the effects of physical load, especially when ascending the curb, than a manual wheelchair. Also, the R-R interval time of the visually impaired group was shorter when walking over high curbs. In this research, if methods of movement were different, even descending and ascending a curb on the same sidewalk, the effect on the heart rate were psychologically and kinetically different.

For manual wheelchair users, the curb height should be under 3 cm for ascent. However, visually impaired people may not recognize a difference in the curb height unless over 5 cm. The curb on the sidewalk becomes a barrier for wheelchair users, however, it is very important to recognize essential information about the walk environment. It is necessary to consider an alternative transportation environment for the future, with transportation burdens changed according to different transportation methods. As a future theme, it is necessary to consider both wheelchair users and people who have visual impairments because this holds a great connection to the design standards of sidewalk curbs which are currently recommended in Japan.

However, barrier-free is not the only maintenance of the sidewalk. According to this research, it can be said that the use of additional power, such as the electric wheelchair, is also effective. In Japan, there is a tendency to use an electric wheelchair when a manual wheelchair cannot be used from the degree of barriers. At the present time of limited sources of revenue, one effective method for barrier-free measures is the optional use of electric wheelchairs even for people who are able to operate manual wheelchairs. Therefore, it is important to produce a change in the concept of the use of wheelchairs for manual wheelchair users.

As a future theme, research should be carried out using subjects who have real visual and lower-limb handicaps, and it is necessary to measure the substantiality of the data.

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