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SPEED AND PHYSIOLOGICAL COST INDEX OF HEMIPLEGIC PATIENTS PEDALLING A WHEELCHAIR WITH BOTH LEGS

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Objective: **To determine whether hemiplegic patients can propel a leg-pedalling wheelchair and whether it is easier and faster for them to pedal the wheelchair using both legs alternately than to propel an ordinary wheelchair with their unaffected hand and leg.**

Design: **Within-subject comparison.**

Subjects: **Subjects comprised 10 hemiplegic in-patients (8 males, 2 females), aged 63.7 (SD 12.7) years with severe or moderate gait disturbance due to stroke.**

Methods: **Subjects were asked to practice propelling the leg-pedalling wheelchair and ordinary wheelchair on both slalom and rectangular courses for a period of 7–10 days. Once they had become skilled in this, the wheelchair speed and patient's heart rate were measured, and a physiological cost index was calculated.**

Results: **Subjects could pedal the leg-pedalling wheelchair using both legs alternately. The speed of this wheelchair was faster than that of the ordinary wheelchair, and the physiological cost index for pedalling it was lower than that for propelling the ordinary wheelchair. However, subjects needed some help in transferring to the leg-pedalling wheelchair.**

Conclusion: **The hemiplegic patients could pedal the leg-pedalling wheelchair using both legs alternately faster and more effectively with regard to speed and physiological cost index.**

Key words: wheelchair, leg-pedalling, stroke, rehabilitation.

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INTRODUCTION

In general, patients who are hemiplegic due to stroke may propel an ordinary wheelchair (OW) by turning the hand-rim with the unaffected hand and pushing the ground backwards with the unaffected leg (1). However, this is very slow and asymmetrical forces may cause the OW to deviate towards the affected side. It is difficult and uncomfortable for hemiplegic patients to propel the OW over a long distance or when going up a slope or changing direction (1). When hemiplegic patients make an effort to propel the OW faster by swinging their trunk forwards and backwards, their posture becomes unstable.

Hemiplegic patients with severe gait disturbance can, however, pedal a recumbent ergometer using both legs alternately. Several studies have shown that the maximal workload for leg exercise is greater than that for arm exercise and cardiorespiratory responses due to arm exercise are higher than those of leg exercise at the same workload (2–4). There has been little research into propelling a wheelchair with both legs (5–8). Stein et al. (5) have studied the energy cost to paraplegic subjects propelling a wheelchair by flexing and extending both legs simultaneously. They concluded that leg propulsion required less than half the effort of arm propulsion. Therefore if the patients could pedal a leg-pedalling wheelchair (LW) alternately with both legs, it would be less difficult and more comfortable. To our knowledge, there has been little research into the effectiveness of stroke patients pedalling a wheelchair with both legs.

The aim of this study was to determine whether hemiplegic patients with severe or moderate gait disturbance could pedal the LW alternately with both legs, and whether it was easier and faster for them to pedal the LW than to propel the OW using the unaffected hand and leg.

METHODS

Subjects

The subjects were patients who were hemiplegic due to stroke and who had severe or moderate gait disturbance who had been admitted into our University Hospital. Ten hemiplegic in-patients (8 males, 2 females), mean age 63.7 (SD 12.7) years were selected according to the following inclusion criteria: (i) duration from the onset of stroke was more than 4 weeks; (ii) the subjects, in a reclining position, could flex and/or extend their affected leg without any assistance; (iii) they were able to understand how to drive the LW and OW; (iv) they had no visuo-spatial neglect; (v) they had no degenerative knee joint disease or bone fracture; (vi) they had no severe cardiopulmonary disease; and (vii) they were not taking any medicine that affected their heart rate (e.g. beta-blockers). The time elapsed from stroke onset was 57.6 ± 110.4 months (range 2–336 months). The causes of hemiplegia were cerebral infarction in 4 subjects and cerebral haemorrhage in 6. Six of the subjects were right hemiplegic and 4 were left hemiplegic (Table I). The mean score for the Barthel Index was 89.4 (SD 12.0) (range 58–98) (9). All subjects had severe or moderate gait disturbance. Nine subjects needed an ankle-foot orthosis when they walked, 1 subject required a knee-ankle-foot orthosis and continuous support. The purpose and procedures of this study were fully explained to all patients and informed consent was obtained from them.

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Table I. *Characteristics of subjects*

Gender/age (years)	Type of stroke	Side of hemiplegia	Time elapsed since stroke (months)	BI	SIAS HF	SIAS KE	SIAS FP
F/55	Haemorrhage	Right	3	86	2	2	2
M/62	Infarction	Left	19	98	2	1	0
M/88	Infarction	Right	336	87	3	2	1
M/65	Haemorrhage	Left	168	96	2	3	0
M/79	Infarction	Right	37	96	3	3	2
M/55	Haemorrhage	Right	3	91	2	2	1
M/48	Haemorrhage	Left	3	88	3	3	1
M/70	Infarction	Right	2	58	2	1	0
F/65	Haemorrhage	Right	2	96	4	4	3
M/50	Haemorrhage	Left	3	98	3	2	0

M = male; F = female; BI = Barthel Index (9); SIAS = stroke impairment assessment set; HF = hip flexion test; KE = knee extension test; FP = foot patting test.

Wheelchairs

We used an EZchair® (Premier Designs, CA, USA) as the LW (Fig. 1). The pedals were connected to the rear wheels by a chain and the subjects pedalled the LW using both legs alternately, as though pedalling a recumbent bicycle. The subjects operated a steering bar attached to the front caster on the unaffected side in order to change direction. Though the LW had a toggle brake (for parking), it had no brake system to reduce the speed.

We prepared 4 LWs, 2 medium-sized and 2 small ones, with a steering bar on either side. We chose 1 suitable LW from the 4 LWs for each subject and then adjusted the seat height and crank length. Both feet were fixed to the pedals with a band to prevent the affected foot from falling off the pedals. Three sizes of standard wheelchairs were also prepared as the OWs to be used in the study.

Measurements

A physical therapist instructed the subjects on how to pedal the LW using both legs alternately and to propel the OW with the unaffected hand and leg; they practiced propelling each type of wheelchair (LW and OW) for 20 minutes/day/wheelchair for 7–10 days under the supervision of the physical therapist. Once they had became skilled in propelling the wheelchairs, we measured the wheelchair speed while they propelled the LW and OW as fast as they could for 3 minutes on a 40 metre rectangular course (Fig. 2) and on a slalom course (Fig. 3) (8). Each subject underwent 4 measurements (the LW and OW on the slalom course, and the LW and OW on the rectangular course) in the order based on the results of picking cards. Both courses were set out on the level floor of a gymnasium.

The distance the wheelchair travelled was measured using a cycle counter (CC-CD100N, CAT EYE Co. Osaka, Japan), which detected the rotation of 4 magnets attached to the left wheel at a crossed position. The accuracy of the measurement was confirmed in advance by comparing the distance indicated by the cycle counter during the wheelchair drive with the actual length of the straight course (8).

The subjects heart rate, while propelling the wheelchair, was monitored continuously using a telemetric cardiograph (Bioview1000®, NEC Co. Tokyo, Japan). The physiological cost index (PCI) was obtained by subtracting the heart rate at rest from the heart rate at 3 minutes of propelling and dividing the result by the wheelchair speed (10). A physical therapist watched the subjects propelling a wheelchair and counted the number of times they hit a pole during propelling on the slalom and rectangular courses. After the measurement, the physical therapist asked subjects their impression of propelling the OW and LW. These methods were based on our preliminary research into the effectiveness of the LW (8).

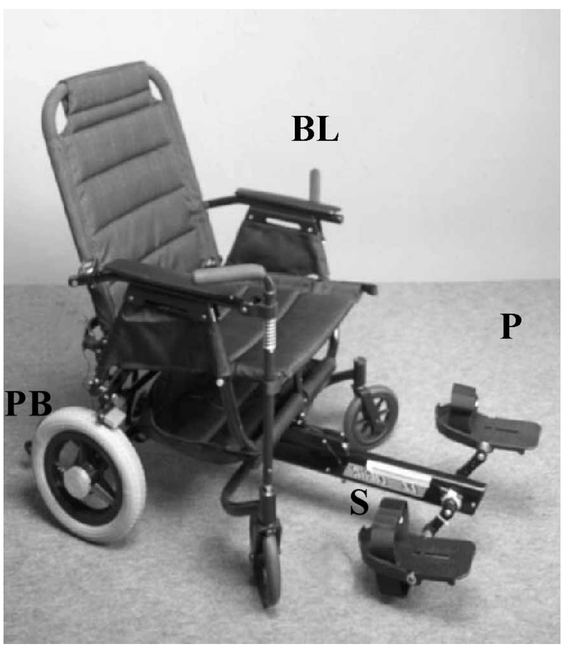

Fig. 1. Leg-pedalling wheelchair for a left hemiplegic patient (EZchair®). PB = parking brake; BL = brake lever; S = shaft connecting the pedals and wheelchair; P = pedals.

Statistical analysis

A paired *t*-test was performed to examine differences in wheelchair speed and PCI between the LW and the OW. A *p*-value of less than 0.05 was regarded as significant.

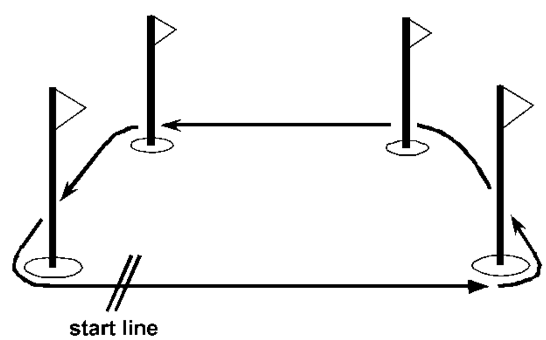

Fig. 2. Rectangular course. This was set on an indoor flat flooring surface with a perimeter of 40 metres. Subjects started from the start line and proceeded in a counter-clockwise fashion.

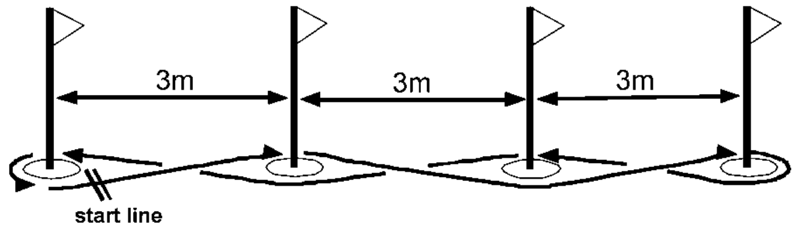

Fig. 3. Slalom course. This was on an indoor flat surface. Four poles stood in line at 3-metre intervals. Subjects started from the start line and slalomed as indicated by the arrow.

RESULTS

All subjects could understand how to pedal the LW at first practice. They could pedal the LW and propel the OW without difficulty. The speed of the LW on both courses was significantly faster than that of the OW ($p < 0.05$; Fig. 4). The PCIs of the LW on both courses were significantly lower than those of the OW ($p < 0.05$; Fig. 5). As regards controllability, the LW was superior to the OW: 1 subject using an OW hit a pole once on the slalom course. All subjects in this study mentioned that pedalling the LW alternately with both legs was easier than propelling the OW with unaffected hand and leg.

The disadvantages of using the LW were difficulties in getting into the wheelchair, speed control and starting. Ten subjects could not raise the affected leg across the shaft, which included a chain that connected the pedals and wheels, and they needed some help in transferring to the LW. The LW had no brake system to reduce speed, and all subjects needed help to stop. Six subjects claimed that the pedals were heavy, when they started to pedal the LW.

DISCUSSION

Hemiplegic patients propel the OW with the unaffected hand and leg, and the unaffected leg plays an active part in both propelling and steering. Because of this propulsive pattern, the leg rest and hand-rim of the wheelchair on the unaffected side are removed and the seat is lowered to effectively push the ground with the foot. Kirby et al. (1) reported that patients who were hemiplegic due to stroke propelled the OW slower and were more likely to deviate on an incline than normal subjects propelling with both hands. Hemiplegic patients using the LW in this study could move faster on flat ground than when using the OW, which indicates that it is more efficient for hemiplegic patients to pedal the LW with both legs alternately than to propel the OW with the unaffected hand and leg.

The controllability of the LW seems to be superior to that of the OW, because nobody hit a pole while propelling the LW on the slalom course in this study despite the high speed. It may be easier for hemiplegic patients to steer the LW by hand than to use the unaffected leg to push the ground and adjust direction when propelling the OW.

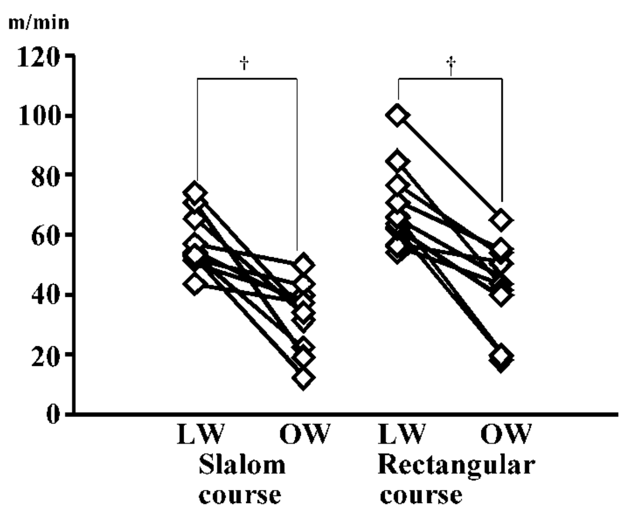

Fig. 4. Wheelchair speed. LW = leg-pedalling wheelchair; OW = ordinary wheelchair. The mean speeds of the LW and OW on the slalom course were 56.8 m/min (SD = 9.5) and 33.8 m/min (SD = 10.7), and on the rectangular course, 69.8 m/min (SD = 13.6) and 43.8 m/min (SD = 14.3), respectively. † $p < 0.05$; paired *t*-test.

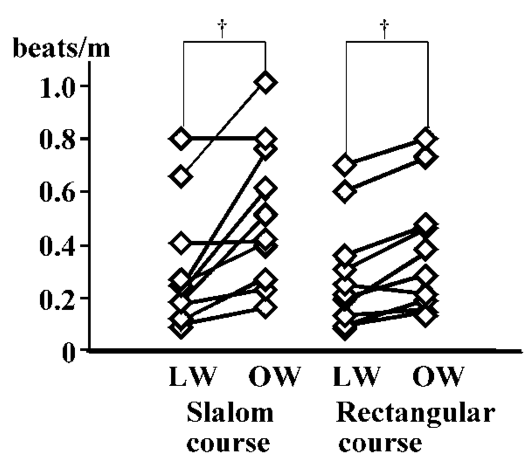

Fig. 5. Physiological cost index. LW = leg-pedalling wheelchair; OW = ordinary wheelchair. The physiological cost index of the LW and OW on the slalom course were 0.32 beats/min (SD = 0.25) and 0.53 beats/min (SD = 0.28) and on the rectangular course, 0.28 beats/min (SD = 0.23) and 0.39 beats/min (SD = 0.24), respectively. † $p < 0.05$, paired *t* test.

On the other hand, some details of the LW should be modified. The LW had a parking brake, but no brakes to reduce the wheelchair speed. The speed of the LW is high compared with the OW, and brakes are necessary to ensure the user's safety. The pedals and shaft were obstacles for patients getting into the LW. Some modifications are required for hemiplegic patients to position themselves in the LW with ease. The ratio of the pedal and rear wheel rotation was fixed, and many subjects felt that the pedalling was heavy when starting the LW. A variable gear ratio is desirable. If these details were properly modified, the LW would be a comfortable vehicle for hemiplegic patients who want to travel a long distance in a wheelchair.

Although some hemiplegic patients have been using electric wheelchairs in recent years, including a unit type such as JW-I (YAMAHA MOTOR Co. Shizuoka, Japan) which is a controllable, easy and convenient vehicle, some researchers have reported the importance of physical fitness for hemiplegic patients (11–16). We expect that propelling the LW with both legs is useful for hemiplegic patients when they go outdoors and to improve their physical fitness. Christensen et al. (17) reported that the higher motor centre, including the primary and supplementary motor cortices and the cerebellum, played an active part in the generation and control of rhythmic motor tasks such as cycling. Fujiwara et al. (18) assessed the effects of pedalling exercise in hemiplegic lower limbs and concluded that pedalling could facilitate phasic and co-ordinated muscle activities, and that it was potentially an effective mode of muscle re-education in severely hemiplegic patients. Propelling the LW using both legs alternately is similar to bicycling, and may be able to activate the brain as well as refresh the hemiplegic patients.

There are some limitations in this study. We evaluated propelling the LW and OW on only 2 courses, both of which were flat. There are other situations encountered in daily life, e.g. inclines, uneven ground, narrow corners, reversing, etc., which were not examined. Further research is needed into the effectiveness of the LW in daily use.

CONCLUSION

It was more suitable and comfortable for hemiplegic patients to pedal the LW using both legs alternately than to propel the OW with the unaffected hand and leg on the slalom and rectangular courses on a flat floor.

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