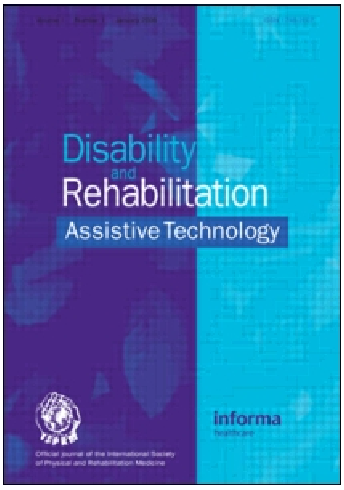

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Measures of energy expenditure and comfort in an ESP wheelchair: a controlled trial using hemiplegic users'

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Measures of energy expenditure and comfort in an ESP wheelchair: a controlled trial using hemiplegic users'

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Abstract

Aim. The aim of this pilot study using hemiplegic subjects was to measure energy expenditure, hand position and ride comfort, in a standard dual handrim Sunrise Breezy wheelchair compared to one modified with a novel ergonomic self-propelled steering (ESP) mechanism kit. A previous study by Mandy et al. (Disabil Rehabil Assist Technol 2007;2:255–260) reported that the attachment of the ESP kit to a standard Sunrise Breezy wheelchair provided a more ergonomically efficient mechanism for wheelchair steering and propulsion for non-disabled individuals.

Methods. Thirteen hemiplegic stroke users participated in a repeated measures trial by driving two manual wheelchairs – a standard manual dual handrim wheelchair and one fitted with the ESP steering conversion kit. Wheelchairs were randomly assigned, to participants who drove each wheelchair around a designated circuit. Oxygen consumption, carbon dioxide and heart rate were measured as indicators of ergonomic efficiency using a Cosmed analyser. Comfort for each wheelchair was measured using a validated questionnaire.

Results. Oxygen consumption (O_2mls/min) and exhaled carbon dioxide (CO_2mls/min) were significantly lower in the modified wheelchair ($p < 0.004$ and $p < 0.04$, respectively). Time taken to complete the course was significantly faster in the ESP ($p < 0.001$). There was no significant difference in heart rate readings between the wheelchairs. All comfort ratings were reported to be significantly greater in the ESP ($p < 0.01$).

Conclusions. The ESP conversion kit transforms a standard Sunrise Breezy wheelchair into one that is ergonomically more efficient and comfortable for hemiplegic subjects.

Keywords: *Assistive technology, ergonomic efficiency, ride comfort*

Introduction

The standard manual wheelchair is an effective, but inefficient means of transport [1] particularly for people who have experienced a stroke and have a resultant hemiplegia. Mandy et al. (2007) [2] summarised the literature regarding wheelchair provision for hemiplegic subjects and identified a lack of suitable provision. In response to this issue, and in conjunction with a stroke rehabilitation team, stroke patients and an engineer, the team designed a novel ergonomic self-propelled steering (ESP[1]) mechanism kit which could be attached to a standard manual wheelchair (Figure 1). The novel steering mechanism kits enables the user to steer with the footplate, and propel the wheelchair with only one pushrim. In addition, the kits can be attached to either side for use by either the right or left handed users and enables the wheelchair to be steered independently from the propulsion. The ESP incorporates two innovations: a gear differential built into one drive wheel and an engageable/disengageable foot steering involving one front castor. The axle is not affected and can still be removed in order that the wheelchair can be collapsed for storage. These devices are fitted to the wheelchair on the users' functional side and are operated independently by the individuals with a cerebrovascular accident (CVA) who use a wheelchair. The differential enables a single pushrim to drive both rear wheels equally resulting in the wheelchair moving in a straight line with steering that can be employed as required. The differential ensures that the load on the

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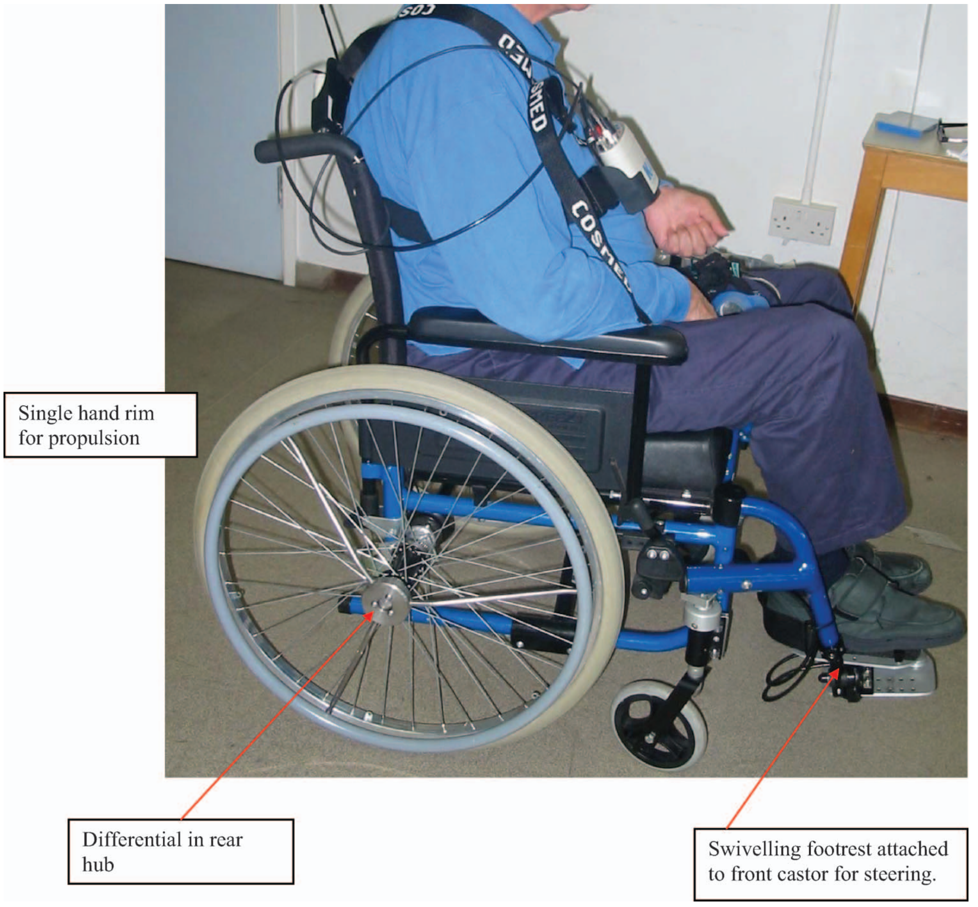

Figure 1. The ESP kit attached to a Sunrise Breezy Wheelchair.

pushrim stays constant whatever be the direction of steering. Steering is intuitive: rotating the foot to the right turns the wheelchair to the right; rotate the foot to the left and chair turns left. The steering has a built in safety feature allowing it to disengage if it hits an obstacle. It is re-engaged by lifting the able foot of the footplate and then replacing the foot on the footplate which locks the steering mechanism in place. A belt drive between the front castor and the footplate ensures that small rotational movements of the footplate result in large movements of the front castor in a ratio of 2:1. This feature enables the wheelchair to make tight turns. The resultant prototype product [3], appeared to meet these criteria, had been demonstrated to be efficient in a non-disabled sample but required clinical testing with hemiplegic subjects. An earlier trial [2] involving non-disabled male users has reported a significant reduction in energy expenditure, hand position and ride comfort by the users, driving a Sunrise Breezy wheelchair with the ESP conversion kit attached to it compared with a standard Sunrise Breezy dual handrim wheelchair.

The aim of this study was to replicate the earlier study using hemiplegic subjects.

Methods

Ethical Approval was sought and obtained from the University of Brighton Research Ethics committee and also from Brighton, Mid Sussex and East Sussex NHS Trust was sought prior to commencing the study. Research Governance approval from East Sussex Hospitals NHS Trust was also sought and obtained for the study.

Participants

A power analysis, using an α value of 0.05 to detect 25% difference in both heart rate and oxygen uptake indicated that a sample size of 12 would be sufficient at a power of 0.8. This was further supported by Cooper et al. [4] who demonstrated a significant change in both oxygen uptake and heart rate using a sample of 10 subjects using a similar same subject repeated measures design.

Study design

This was a controlled same subject study that compared wheelchair skills performance of a group of hemiplegic participants in a standard dual handrim Sunrise Breezy wheelchair to the skills performed in the modified Sunrise Breezy wheelchair.

Randomisation of the wheelchairs

The order in which participants used the wheelchairs was determined by the use of random numbers.

Recruitment and screening

The inclusion criteria were: willingness to participate, competence to give informed consent, hemiplegia due to stroke, hemiplegic-propulsion pattern (1 arm and 1 leg on the same side) wheelchair user, tolerance of the Cosmed mask, controlled hypertension.

Exclusion criteria included unstable medical condition (e.g., angina, uncontrolled hypertension, seizures), mask phobia and height and weight restriction of 163–185 cm and 54–90 kg in order that they could fit into the wheelchairs.

Subjects were recruited from local Stroke groups. Participants were provided with an information sheet prior to be recruited into the study to enable them to make an informed decision concerning their involvement. All subjects who wished to participate completed a health declaration sheet and informed consent sheet.

Demographic data

Age, height, weight, gender and side of impairment were recorded for all subjects (Table I).

Table I. Demographic variables of participants.

	Male		Female	
Variable	Mean	SD	Mean	SD
Age	65.78	8.56	66.75	5.25
Height (cm)	176.11	8.49	154.25	4.35
Weight (kg)	79.67	10.74	61.50	6.03

Training

The study was undertaken in the University gymnasium. All participants were given familiarisation training in the use of both wheelchairs until they felt competent to undertake the trial. Propulsion of the dual handrim wheelchair required the user to use both handrims together to propel in a straight line and the handrims alternately when steering and manoeuvring. When manoeuvring the ESP wheelchair the users' used the single rim for propulsion and the foot steering plate for directional control.

The Cosmed K4b2 analyser

The Cosmed K4b2 is a portable indirect calorimeter that measures oxygen uptake over a wide range of exercise intensities and has been shown to be both valid and reliable in the general population [5,6]. The Cosmed has been used to measure oxygen consumption in published studies of neurologically impaired populations [7,8]. It comprises an analyser unit and a face mask. The analyser unit weighs ~800 g and attaches to a chest harness worn by the participant. The soft face mask is held in place with a light nylon head harness and covers the nose and mouth of the participant in order to capture the expired air. The expired air is channelled through a bidirectional digital turbine that measures the volume of the air. A sample line runs from the turbine to the analyser unit where the O_2 and CO_2 content of the expired air are measured. Before each test, the Cosmed K4b2 was calibrated according to manufacturer's guidelines. After warming up the unit for 30 min, the CO_2 and O_2 analysers were calibrated against room air as well as a reference gas of known composition (5.20% CO_2, 16.00% O_2 and 78.80% N). To compensate for the time lag between when expiration occurs and when the expired air is sampled, a delay calibration was then completed. Finally, the turbine was calibrated using a 3-L Hans-Rudolf syringe. To facilitate computation of derived values, atmospheric relative humidity, barometric pressure, ambient temperature and participant weight were all measured and entered into the Cosmed K4b2 analyser unit. To confirm that the CO_2 and O_2 analysers had not drifted during the course of the test, the unit was left running at the conclusion of the testing protocol and a reference gas of known composition was sampled for 2 min. Values measured by the Cosmed K4b2 were compared with known values and the data from the trial was deemed acceptable if measured values were sufficiently close to known values ($FECO_2 = \pm 0.1\%$; $FEO_2 = \pm 0.2\%$).

The participants were pushed around the driving course by the principle investigator initially to familiarise themselves with it. A heart rate monitor was attached to the subjects' chest. The Cosmed analyser was attached using a face mask to the subject and a baseline measure of oxygen consumption, carbon dioxide expulsion and heart rate taken once all the parameters had stabilised.

Subjects were randomly allocated either the ESP wheelchair or the standard dual handrim Sunrise Breezy with using random numbers. The total length of the driving course was 150 m. Participants were initially asked to drive across the gymnasium floor for 30 m and complete a 90° left turn and continue for 10 m. A further 45° left hand turn took the user onto carpet. The carpet was 30 m long and included a slalom of four closely placed bollard markers which required tight 10° right and left hand turns. At the end of the carpet, the user completed a 90° right hand turn back onto the gym floor for 10 m. A further drive 90° right hand turn took the user to 6 m of sponge matting. At the end of the matting was a further 90° right hand turn back onto the gymnasium floor for 10 m. A final 90° right hand turn and 10 m of driving took the user back to the start/finish line (Figure 2).

Prior to commencing the course a steady base line heart rate and oxygen consumption levels were achieved. The participants were asked to drive the wheelchair round the course at their own speed. At completion of the course, participants were asked to complete a ride comfort questionnaire and also a handrim comfort questionnaire. The course was repeated once per wheelchair with a 30 min gap, or however much time was necessary, between testing to restore the heart rate to its resting state. Once this had occurred they were asked to repeat the same course and complete the same hand and ride comfort questionnaires using the different wheelchair.

Statistical analysis

Oxygen consumption, carbon dioxide levels and heart rate were tested for normal distribution using the Kolmogorov-Smirnov test. The data was found not to be normally distributed. A Wilcoxon signed-rank test was used to compare the data for differences. Time taken to complete the course was found to be normally distributed and a t-test was used to measure differences.

The comfort scales included the Wheelchair Ergonomics Questionnaire [9] an Overall Ride Comfort Scale [9] and a visual analogue Ride Comfort Scale to measure manual wheelchair ride [10]. The Wheelchair Ergonomics Questionnaire [9] was measured on a 5 point ordinal scale which included the following descriptors: 'Not at all/fairly/moderately/very/extremely'. The Overall Ride Comfort Scale [4] was also 5 point ordinal scale which included the following descriptors; 'Poor/fair/moderate/good/excellent'. The Ride Comfort Scale (RCS) [10] was measured on a 10 cm VAS from 0 = Extreme discomfort to 10 = Extreme Comfort. All the comfort scales were compared using Wilcoxon signed-rank test.

Results

Gender distribution: four women and nine men.

Twelve participants had left sided weakness and one right sided weakness.

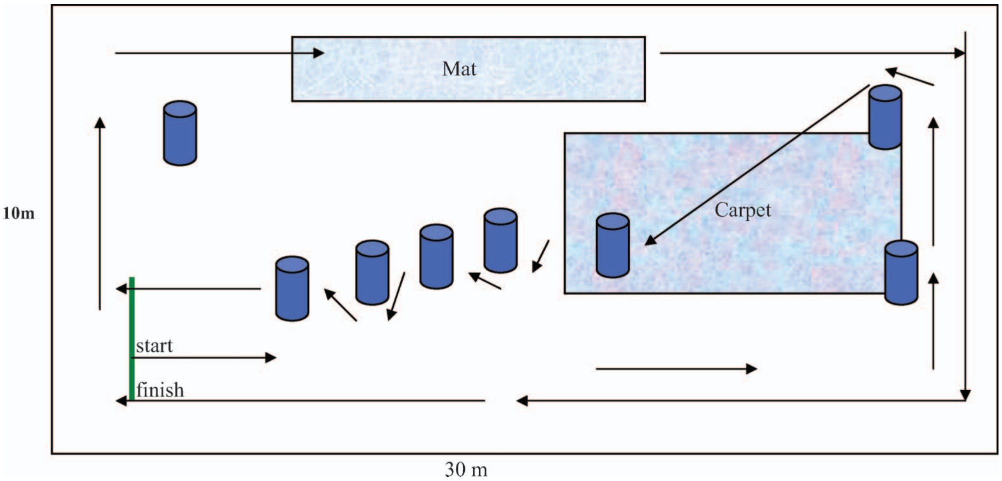

Figure 2. The driving course.

There was no difference in mean heart rate (beats/min) between the two wheelchairs. (Wilcoxon test: $Z = -1.64$, $p < 0.1$).

The oxygen consumption for the ESP (O_2/ml/min/kg) was significantly lower than the standard dual handrim Sunrise Breezy wheelchair (Wilcoxon test: $Z = -2.8$, $p < 0.004$).

The carbon dioxide levels (CO_2/ml/min/kg) were significantly lower than for the standard dual handrim Sunrise Breezy wheelchair (Wilcoxon test: $Z = -1.96$, $p < 0.049$).

The time taken to complete the course was significantly faster in the ESP wheelchair (*T*-Test: $t = 4.868$, $df = 12$, $p < 0.001$).

The Wheelchair Ergonomics Questionnaire [9] indicated the following results for the ESP (Table II).

Discussion

The objective of this study was to repeat the earlier study reported by Mandy et al. (2007) [2] in a sample of hemiplegic participants. The aim was to compare energy expenditure, hand position comfort and ride comfort of a standard dual rim Sunrise Breezy wheelchair with one modified with the ESP kit.

The results indicated that that the ESP kit resulted in the wheelchair being significantly easier to drive both in terms of carbon dioxide production and oxygen consumption which were used as indicators or work. Time taken to traverse the course was also significantly faster in the ESP than in the dual handrim wheelchair. These variables would suggest that the users were operating more efficiently when using the ESP wheelchair, thereby requiring less effort for propulsion. However, there was no significant difference in heart rate. This also endorses the suggestion that the ESP wheelchair required less effort, which enabled users to work more efficiently and at their own optimum speed. If this was the case then heart rate levels would not increase.

Furthermore the comfort scales for the ESP suggested that it was significantly more comfortable in all elements than the dual handrim wheelchair with the exception of support and stability where there was no difference. The level of support result was not unexpected since the addition of the ESP kit was not expected to change the overall support provided by the wheelchairs. However, the issue of stability is of interest. The users reported no difference in stability between the two wheelchairs. This is an encouraging finding considering that the ESP kits have a novel steering mechanism whereby the weight of the leg and foot engage and disengage the footplate. When the footplate is disengaged the wheelchair can be propelled by a carer, and when it is engaged it is steered independently by the user. Although steering is intuitive, all the users had to learn how to operate the mechanism and had the potential to disengage the footplate while driving in the driving course which could have resulted in feelings of instability. However, this was clearly not the case for the users. The results would suggest that these kits provide a useful and efficient attachment to standard wheelchairs. The next phase of this work will be to provide users' with the opportunity to trial the wheelchair in their home environment and report on ease of use and maneuverability in the home environment. A further important aim in the development of the ESP is to afford independence in activities of daily living and independence from carers. If it is easier to drive than a standard dual handrim wheelchair, then greater independence is afforded. The literature would support this and has demonstrated that the environmental factors and social factors, including socialisation both within and outside the home are significant contributors to social isolation [11]. Social activity and stress in relatives/carers has also been reported to be highly correlated with individuals with a CVA who use a wheelchairs being unable to propel themselves [12]. The results of this pilot study would clearly suggest that ESP could meet the unmet needs of this user group.

Table II. Comfort Scales for the wheelchair with the attached ESP kit and the standard dual handrim sunrise breezy descriptor.

Descriptor	Result
Does the wheelchair provide adequate support?	There was no significant difference
Does the wheelchair provide adequate stability	There was no significant difference
Can the wheelchair be easily manoeuvred?	The ESP was significantly easier to manoeuvre $Z = -2.3$, $p < 0.02$
Is the hand comfortable on the pushrim?	The ESP was significantly more comfortable $Z = -3.08$, $p < 0.002$
Overall how comfortable were you driving the course?	The ESP was significantly more comfortable $Z = -2.05$, $p < 0.012$
How comfortable was the ride on the gym floor?	The ESP was significantly more comfortable $Z = -2.25$, $p < 0.024$
How comfortable was the over the carpet?	The ESP was significantly more comfortable $Z = -2.6$, $p < 0.008$
How comfortable was the ride over the mat?	The ESP was significantly more comfortable $Z = -2.5$ $p < 0.01$
Visual Analogue Ride Comfort scale	The ESP was significantly more comfortable $t = 3.2$, $df = 12$, $p < 0.007$
Visual Analogue Ease of Use scale	The ESP was significantly more comfortable $t = 4.3$, $df = 12$, $p < 0.001$

Conclusion

The results from the pilot study of hemiplegic users suggest that the ESP is a viable kit that has the potential to be a useful attachment to the standard dual handrim Sunrise Breezy wheelchair. The results suggest that the kits make propulsion of the wheelchair easier, and more comfortable to drive. The kits also potentially afford individuals with a CVA, who use a wheelchair, a satisfactory alternative to current wheelchair provision. The engineering of the prototype was robust and resulted in adequate wheelchair performance under trial conditions. There is a clear justification for the ESP Wheelchair to be tested in users' homes.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Note

1. The ESP kits are currently being patented. They are being manufactured by Neater Solutions UK and will be available commercially late 2009.

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