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Position and Movement of Centre of Force During Propulsion of 3 Different one Arm Drive Wheelchairs by Hemiplegic Users

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Abstract

Purpose: This pilot study used a CONFORmat® Pressure mat to measure the position and movement of the centre of force measured at the buttock/seat interface of users whilst seated in three different one arm drive wheelchairs during propulsion. The manual wheelchairs included were: a dual handrim, a lever drive and a Neater Uni-wheelchair.

Methods: 15 hemiplegic user's propelled each wheelchair around an indoor course during which the centre of force was continuously recorded. Position and movements of the centre of force in the anteroposterior and mediolateral directions were recorded. The time taken to complete the circuit was also recorded. Standard deviations and 95% confidence intervals for each participant in each wheelchair were calculated to determine statistically significant differences.

Results: Movement of the centre of force was greatest in the dual handrim wheelchair, both antero-posteriorly [$F(2,39)= 21.696$, $p<0.001$] and medio-laterally [$F(2,39)= 44.273$, $p<0.001$]. Position of the centre of force was also anteriorly displaced in the dual handrim wheelchair, [$F(2,39) =15.57$, $p<0.001$]. There were no significant differences in the position of the centre of force in the medio-lateral direction. [$F(2,39)= 2.488$, $p=0.096$]

Conclusions: The dual handrim wheelchair produced the greatest movement of centre of force and the lever wheelchair produced the least. This may be indicative of the symmetry and stability of seated posture in hemiplegic one arm drive wheelchair users.

Keywords: Wheelchairs; Force; Posture; Symmetry

Introduction

The standard manual wheelchair is an effective, but inefficient means of transport [1]. Mandy et al [2] summarized the literature regarding wheelchair provision, for hemiplegic subjects and identified a lack of suitable provision. Kirby et al [3] specifically identified the difficulties faced by hemiplegic wheelchair users and further suggested that improvements were needed in wheelchair provision for this group. Hemiplegic users face cognitiveand perceptual difficulties in addition to physical challenges. Whilst the cognitive and perceptual difficulties are difficult to address, the physical challenges can be ameliorated by improvements in wheelchair design. Current provision includes two different types of propulsion; the ratchet arm or lever-drivemechanism and the dual handrim mechanism. Lever arm design, such as the Nu Drive or Pivot, involves a pushing or pulling action on the end of a lever mechanism [3,4]. The dual hand rim design, has two hand rims mounted on the same side of the wheelchair. Propulsion involves gripping and rotating both rims at the same time in order to move forward in a straight line. This can be difficult for users with a small hand span or with impaired hand function. Alternatively each rim may be used in turn to propel the wheelchairforwards but this can result in a snake like movement which is inefficient and requires significant effort. Contemporary versions of this propulsive mechanisminclude the Nomad and Invacare Action 3. However, there are deficiencies associated with both of these designs particularly with respect to the user interface. The lever drive design usually has a fixed mechanical advantage, the ergonomics of simultaneous propulsion and steering can be awkwardand the operation of the brake is not intuitive. In the dual handrim designs, steering and propulsion cannot be actuated simultaneously. Braking via the dual handrims is more difficult than with a standard wheelchair since the user must simultaneously grasp both handrims to avoid turning. For a large number of users, the overall ergonomics of operation are not efficient. Literature reports that nearly 70% of wheelchair users experience upper extremity pain or overuse injury at some point [5,6]. Anecdotally UK clinicians report that current one arm drive wheelchairs do not meet the needs of hemiplegic users which may explain the high level of wheelchair abandonment. Wheelchairs have the highest level ofabandonment, more than any other mobility device [7,8,9]. Moreover, high abandonment rates leave many individuals without the technology they need to maintain their physical fitness and independence [7]. In such cases wheelchair users commonly resort to thestandard issue wheelchair which they propel through punting (the use of the non-disabled leg to move the

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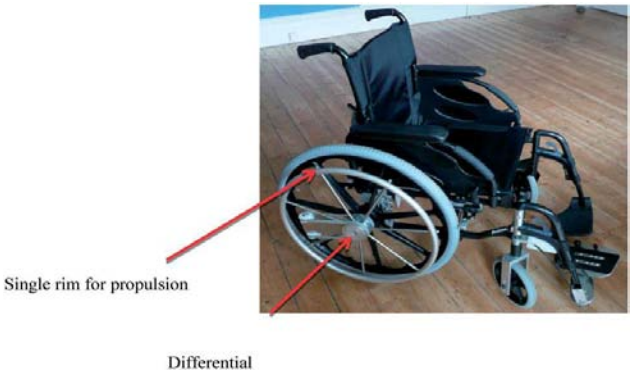


Figure 1: The Neater Uni-wheelchair.

Figure 2: The Neater Uni-wheelchair Steering Mechanism.

wheelchair forward) or become reliant on others to propel them. This punting or hemiplegic pattern has been described by Kirby et al [3] who concurred with the difficulties identified when propelling a standard wheelchair.

In response to this problem Mandy et al [2,10] have developed an alternative one arm drive wheelchair, the Neater Uni-wheelchair. The Neater Uni-wheelchair (NUW) is an Action 3 wheelchair to which novel propulsion and steering kit is attached (see Figures 1 & 2). Both these features have been described in detail in an earlier paper by Mandy et al [10]. The NUW was designed by clinicians, users and engineers forhemiplegic users with the use of only one arm and one leg. The novel combination of the differential and a self-propulsivesteering mechanism kit enables the user to steer with the footplate, and propel the wheelchair with only one handrim. Thus the user is able to propel and steer simultaneously with no interference between the footplate and the castor. In addition the kits can be attached to either side for use by either right or left handed users.

The research by Mandy et al [2,10] to date has compared the NUW to the Invacare Action 3 dual handrim (see Figure 3) and the findings suggest that the NUWis ergonomically more efficient to drive and preferred by users in both a laboratory setting [2,10] and in an activities of daily living setting [11]. A further study evaluated users experiences of using the NUW in their own homes [12]. Four key themes of increased user independence and freedom ease of use and maneuverability, usefulness and increase in activity were reported [12]. These studies suggested that Neater Uni-wheelchair may be an alternative for the hemiplegic user group and provide them

Figure 3: The dual handrim wheelchair.

with an additional choice in their wheelchair provision. The research also advocated that the NUW was a viable alternative to the current catalogue of one arm drive wheelchairs available to rehabilitation therapists. Recent work has explored vertical reaction forces at the buttock/seat interface [13] in different wheelchairs. The findings suggested differences in the magnitude of vertical forces between the hemiplegic and non-hemiplegic side. A possible explanation of this could be that changes to postural position occurred during propulsion resulting in the participants becoming seated in an asymmetrical position. This concept has been explored by others who have established a relationship between the position of the centre of force and the posture of the torso and the head [14] in the static seated posture [15]. Buttock seat measurements have also been used to investigate the symmetry of seated posture in people who have experienced a stroke. Mudie et al [15] suggested that weight distribution in seated stroke subjects was more asymmetric and deviated significantly from a defined normal range when assessed with posturegraphy. More recently Tessem et al [16] suggest that stroke subjects show significantly more lateral displacement when reaching forwards. Clinically asymmetric seated posture is observed in patients who have experienced a stroke; however, the research evidence is limited especially in functional movements [16]. Moreover there are no studies investigating movements of the centre of force during one arm drive wheelchair propulsion.

The aim of this study was to compare the position and movement of the centre of force measured at the buttock/seat interface whilst seated in three different one arm drive wheelchairs during propulsion. In light of the findings from the study investigating vertical reaction forces [13] the research hypotheses were: The dual handrim will produce greatest changes in in the movement of the centre of force at the seat/buttock interface when propelling different one arm drive wheelchairs. The lever drive will produce the least changes in the movement of the centre of force at the seat/buttock interface.

Methods

Ethics

Ethical Approval was sought and obtained from the University of Brighton Research Ethics committee and also from North Wales Research Ethics Committee prior to commencing the study. Research

Figure 4: The lever drive wheelchair.

Governance approval from Betsi Cadwaladr University Health Board was also sought and obtained for the study.

Patient criteria

Potential participant's were identified by the head occupational therapists from the data base of patients at The Posture and Mobility Service. The search identified hemiplegic users who were one arm wheelchair drivers with at least 1 years' experience. Twenty potential users were identified and screened by the rehabilitation team for suitability for inclusion into the study. Of these 15 agreed to participate in the study.

Recruitment and screening

The inclusion criteria were: deemed able to consent by the Posture & Mobility Service rehabilitation team, willingness to participate, hemiplegic experienced one arm drive wheelchair users. The exclusion criteria were: musculoskeletal pain or injury to the non-hemiplegic upper limb, unstable medical conditions, cognitive or perceptual difficulties, height and weight restrictions of 163-185 cm and 54-90kg.

All subjects who wished to participate completed a health declaration sheet and informed consent sheet.

Study design

The study was designed as a controlled, same subject study to measure the movements of the centre of force at the buttock/seat interface for each user during propulsion in three different one arm drive wheelchairs.

All participants were given familiarization training in the use of all the wheelchairs until they felt competent to undertake the trial. Propulsion of the dual handrim wheelchair required the user to grasp and compress both handrims together to propel in a straight line and grasp the individual handrims alternately when steering and maneuvering (see Figure 3). When maneuvering the Neater Uni-wheelchair the users' grasped the single rim for propulsion and the foot steering plate for directional control. Propelling the lever wheelchair involved flexion and extension of the shoulder and a forwards and backwards motion. Steering occurred by rotating the lever handle, using abduction and adduction of the wrist (see Figure 4).

The study was conducted at an indoor circuit at the Artificial Limb and Appliance Centre in Wrexham (Figure 5). The participants familiarized themselves with the indoor circuit which consisted of maneuvering along a carpeted covered corridor, through a door

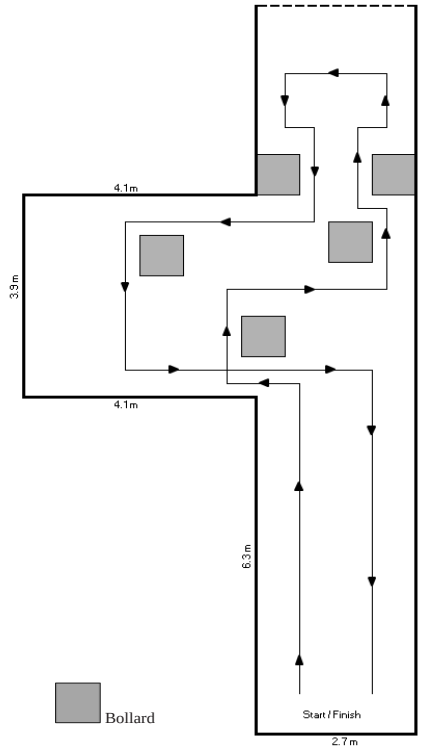


Figure 5: The Indoor Circuit.

jamb, around a circular course of obstacles and then returning back down the corridor to the start. The course included both right and left hand turns. Subjects were randomly allocated the wheelchairs using random numbers.

Measurement

Demographic data including age, gender and side of impairment were recorded for all subjects. Prior to commencing the course, the CONFORMat® was placed on the users own pressure cushion which was then placed in turn in each of the wheelchairs. Care was taken to standardize the position of the mat in each of the wheelchairs. Each participant was positioned in a symmetrical sitting posture in each wheelchair and initial data capture was undertaken in this static position prior to driving each wheelchair around the course. The participants were asked to drive the wheelchair round the course at their own speed. The movement of the centre of force was measured using the CONFORMat® Pressure Measurement System, a portable interface pressure mapping system, which records pressure distribution under the contact area. The system includes pressure sensing hardware and software. CONFORMat® is an instrumented mat of approximately 0.5m square containing 1024 sensors which sample direct loading at 10Hz. The CONFORmat® software version 6.20 was used to record and process the data. The system was calibrated for each subject prior to data collection as recommended by the manufacturer [17]. Data was captured continuously throughout each circuit. The course was repeated once per wheelchair with a 30 minute gap, or however much time was necessary, for the users to feel recovered. Refreshments and comfort breaks were available at all times.

Table 1: To Show Mean and 95% Confidence Intervals of movements of centre of force (cm) for each user in each wheelchair.

	Antero/posterior movement			Medio/lateral movement		
	Neater	Lever	Dual	Neater	Lever	Dual
1	0.23 (0.22,0.25)	0.15 (0.14, 0.16)	0.33 (0.32,0.35)	0.39 (0.37,0.42)	0.48 (0.46, 0.50)	0.93 (0.89,0.97)
2	0.39 (0.37,0.41)	0.18 (0.17,0.19)	0.45 (0.43,0.47)	0.49 (0.47,0.51)	0.42 (0.4,0.44)	0.8 (0.77, 0.84)
3	0.15 (0.14, 0.15)	0.16 (0.15,0.17)	0.76 (0.73,0.80)	0.38 (0.36,0.40)	0.31 (0.30,0.32)	0.71 (0.68,0.75)
5	0.15 (1.14, 1.15)	0.24 (0.23, 0.25)	0.22 (0.21, 0.23)	0.48 (0.46, 0.5)	0.29 (0.28 ,0.30)	0.7 (0.67, 0.73)
6	0.18 (0.18, 0.19)	0.14 (0.14, 0.15)	0.35 (0.33, 0.36)	0.56 (0.54, 0.59)	0.25 (0.24, 0.26)	1.15 (1.10, 1.2)
7	0.31 (0.3, 0.33)	0.26 (0.25, 0.27)	0.54 (0.52, 0.56)	0.39 (0.37,0.40)	0.33 (0.32, 0.35)	0.72 (0.69, 0.75)
8	0.23 (0.22, 0.24)	0.18 (0.17, 0.19)	0.5 (0.48, 0.52)	0.53 (0.51, 0.56)	0.31 (0.30, 0.33)	0.95 (0.91, 0.99)
9	0.24 (0.23, 0.25)	0.28 (0.26, 0.29)	0.4 (0.38, 0.42)	0.55 (0.53, 0.57)	0.44 (0.42, 0.46)	0.72 (0.69, 0.75)
10	0.16 (0.16, 0.17)	0.26 (0.25, 0.27)	0.6 (0.57, 0.62)	0.40 (0.38, 0.42)	0.31 (0.30, 0.33)	1.24 (1.19, 1.30)
11	0.15 (0.14, 0.16)	0.19 (0.18, 0.20)	0.35 (0.34, 0.37)	0.37 (0.36, 0.39)	0.27 (0.26, 0.29)	0.53 (0.51, 0.56)
12	0.1 (0.09, 0.1)	0.11 (0.11,0.12)	0.16 (0.15, 0.17)	0.42 (0.40, 0.44)	0.24 (0.23, 0.25)	0.46 (0.44, 0.48)
13	0.16 (0.15, 0.17)	0.14 (0.14, 0.15)	0.48 (0.46, 0.50)	0.37 (0.36, 0.39)	0.29 (0.28, 0.30)	0.74 (0.71, 0.77)
14	0.29 (0.28, 0.30)	0.35 (0.33, 0.36)	0.51 (0.48, 0.53)	0.59 (0.56, 0.61)	0.34 (0.33, 0.36)	0.7 (0.67, 0.74)
15	0.26 (0.25, 0.27)	0.25 (0.24, 0.26)	0.6 (0.57, 0.62)	0.47 (0.45, 0.49)	0.15 (0.14, 0.16)	0.89 (0.85, 0.93)
Mean	0.214	0.207	0.446	0.457	0.317	0.802
SD	0.079	0.066	0.159	0.078	0.086	0.214

Data processing

The raw force data was manipulated using the CONFORMat® software to generate time referenced data for the movement of centre of force. Movements in the anteroposterior and mediolateral directions were calculated for the duration of propelling each wheelchair around the indoor circuit. While the data were being processed it was noted that the data from participant 4 was corrupt and therefore not included in the analysis.

Statistical analysis

The study was designed to compare the measurements taken in each wheelchair for each individual participant, with each user acting as their own control. This was considered to be an appropriate approach due to the heterogeneity of hemiplegia within the user group and the bespoke postural and pressure equipment that they used in the wheelchairs during the study. The standard deviations (SD) and 95% confidence intervals for each participant in each wheelchair were calculated and used to determine statistically significant differences in the movement of the centre of force.

The data were also investigated to explore differences in movement of the centre of force between wheelchairs across the whole sample. The data was tested for normal distribution using the Kolmorgorov Smirnov and found to be normally distributed. Differences between the movement of the centre of force across all wheelchairs was explored using a one way ANOVA with Tukey's post hoc test.

The mean ($\bar{x}$) of the position of the centre of force of the anteroposterior and mediolateral directions was also calculated and analyzed using one way ANOVA to explore changes in the symmetry of posture.

Time taken to complete the circuit was compared using a one way ANOVA.

Results

Demographic data

The sample consisted of 6 females and 9 males. The mean age of the sample was 56.6 years (SD 17.1) with a range of 59 (24-83). The mean age of the males was 55.3 years (SD19.3) with a range of 59 (24-83).The mean age of the females was 58.5 years (SD14.8) with a range of 46 (32-78). All participants had left sided hemiplegia of at least one years' duration with no cognitive or perceptual difficulties.

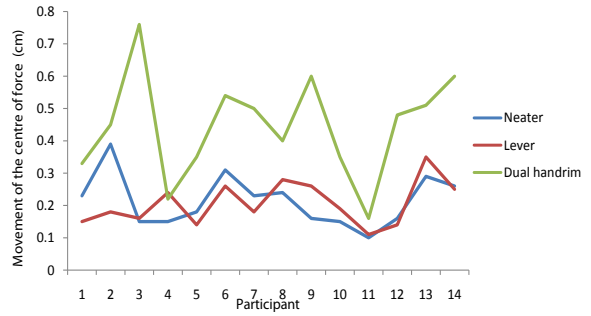
The demographics of the sample represented the heterogeneity of stroke survivors. All were experienced wheelchair users, and were considered to have representative of this patient group. Thus the findings will be considered to be an accurate reflection of hemiplegic wheelchair users.

Measurement of centre of force

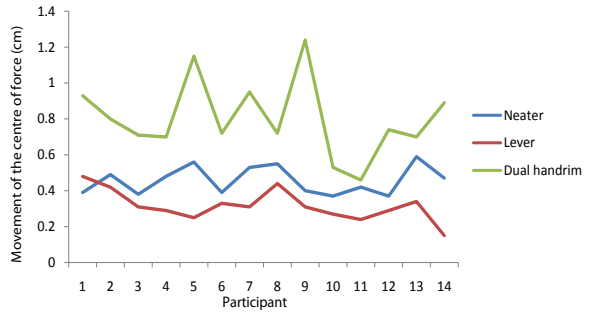
The mean and confidence interval of the movement of the centre of force from each participant for each wheelchairis shown in Table 1. This data was then used in statistical analysis to explore differences.

The mean values from Table 1 for each participant for each wheelchair were used to generate graphs to show the movement of the centre of force in the antero-posterior (Graph 1) and medio-lateral (Graph 2) directions.

The data for mediolateral and anteroposterior movements were analysed independently. The movement measured when using each wheelchairwas compared. Where there is no overlap in confidence



Graph 1: To show the movement of the centre of force antero-posteriorly in each wheelchair.



Graph 2: To show the movement of the centre of force medio-laterally in each wheelchair.

Table 2: To show the wheelchair in which least movement of the centre of force occurred.

	Antero/Posterior			Medio/Lateral		
	NvL	NvD	DvL	NvL	NvD	DvL
1	L	N	L	N	N	L
2	L	N	L	L	N	L
3	ns	N	L	L	N	L
5	N	N	D	L	N	L
6	L	N	L	L	N	L
7	L	N	L	L	N	L
8	L	N	L	L	N	L
9	L	N	L	L	N	L
10	L	N	L	L	N	L
11	L	N	L	L	N	L
12	L	D	L	L	ns	L
13	N	N	L	L	N	L
14	N	N	L	L	N	L
15	ns	N	L	L	N	L

L= Lever, D= Dual, N=Neater
Ns = non-significant difference.
*Participant 4 – corrupt data.

intervals indicates significantly different movements of centre of force ($p<0.05$). A summary of the statistical differences is shown in Table 2.

Comparison of the anteroposterior movements from the whole sample (Table 2), using a one way ANOVA, demonstrated significant differences between the wheelchairs [$F(2,39)=21.696$, $p<0.001$].

Table 3: To show mean position of the centre of force in each wheelchair.

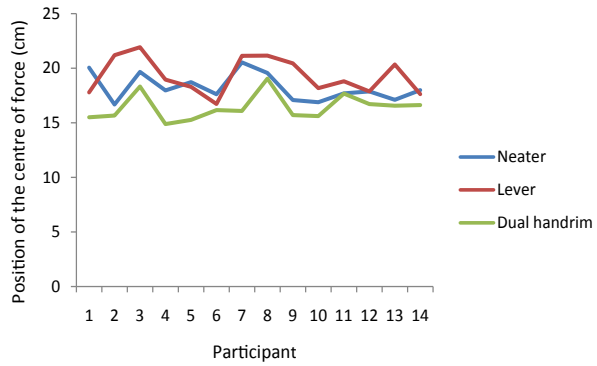
	Antero/Posterior			Medio/Lateral		
	Neater	Lever	Dual	Neater	Lever	Dual
1	20.059	17.785	15.508	16.845	18.840	16.274
2	16.671	21.194	15.662	15.661	17.775	19.145
3	19.670	21.928	18.323	15.872	16.276	17.765
4	*	*	*	*	*	*
5	17.962	18.958	14.883	16.395	15.601	14.824
6	18.726	18.295	15.268	15.142	16.107	19.235
7	17.615	16.723	16.162	17.357	14.693	16.694
8	20.538	21.139	16.087	18.647	16.950	18.900
9	19.568	21.156	19.047	13.880	14.825	19.031
10	17.086	20.442	15.708	14.765	13.706	15.235
11	16.878	18.174	15.617	15.109	13.799	15.343
12	17.692	18.804	17.676	16.087	14.249	16.303
13	17.878	17.878	16.716	15.454	15.454	16.380
14	17.099	20.348	16.568	18.093	16.199	16.056
15	17.992	17.621	16.622	14.037	15.721	15.581
Mean	18.245	19.318	16.418	15.953	15.728	16.912
SD	1.257	1.667	1.199	1.412	1.468	1.588

Post hoc comparisons using the Tukey HSD test indicated that the mean ($\overline{x}$) movement for the dual handrim ($\overline{x}$= 0.446, SD =0.159) was significantly greater than for the Neater Uni-wheelchair ($\overline{x}$ = 0.214, SD =0.079) and the lever wheelchair ($\overline{x}$ = 0.207, SD = 0.066).

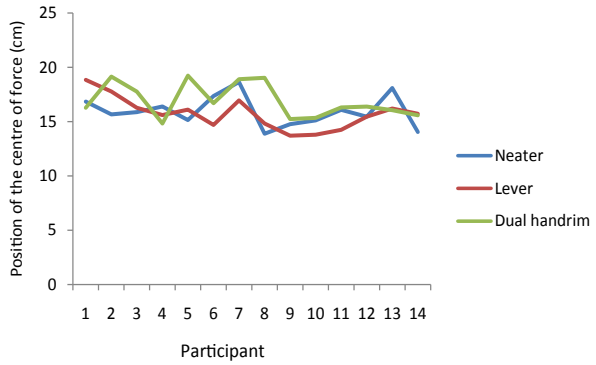
Comparison of the mediolateral movements from the whole sample (Table 2), using a one way ANOVA, demonstrated significant differences between the wheelchairs [$F(2,39)=44.273$, $p<0.0001$].

Post hoc comparisons using the Tukey HSD test indicated significant differences between every wheelchair. The dual handrim produced the greatest movement ($\overline{x}$ = 0.802, SD =0.214), and the lever wheelchair produced the least movement ($\overline{x}$ = 0.317, SD = 0.086). The measurement of movement for the Neater Uni-wheelchair was $\overline{x}$ = 0.214, SD =0.079.

Mean position of centre of force in each wheelchair were compared using a one way ANOVA (Table 3). In the anteroposterior



Graph 3: To show the position of the centre of force in the antero-posterior direction.



Graph 4: To show the position of the centre of force in the medio-lateral direction.

direction, there was a significant difference in the dual handrim wheelchair compared to the lever and the Neater Uni-wheelchairs; with the centre of force being positioned more anteriorly in the dual handrim wheelchair [F(2,39)=15.57, p <0.005] see Graph 3.

There were no significant differences found between wheelchairs in the mediolateral direction [F(2,39)=2.488, p=0.096] see Graph 4.

The mean time (seconds) taken to complete the circuit was also statistically compared using a one way ANOVA. The mean values were found to be: Neater Uni-wheelchair 81s, lever 86s, dual handrim130s. The Neater Uni-wheelchair and lever were significantly faster than the dual handrim [F(2,39)=21.21, p<0.001]. There was no significant difference between the Neater Uni-wheelchair and lever wheelchair.

Discussion

The aim of this study was to measure and compare the position and movement of the centre of force at the buttock/seat interface during one arm drive wheelchair propulsion in a sample ofleft sided hemiplegic wheelchair participants. The objective of the study was to identify which one armed wheelchair produced the least movement of the centre of force when maneuvering in a controlled environment around obstacles.

The time taken to traverse the course was significantly faster in the Neater Uni-wheelchair and lever wheelchair than in the dual handrim wheelchair. This result further endorses the work of Mandy et al [2,10] in which the Neater Uni-wheelchair was shown to be the most efficient. Later work by Mandy et al [12] also confirmed users' preference in maneuvering the Neater Uni-wheelchair because of its ease of use.

The results indicated that there were differences in both antero-posterior and medio-lateral movements of the centre of force in the different one arm drive wheelchairs. The lever drive produced the least amount of displacement in both these planes of movement. The dual handrim however, produced the greatest amount of displacement in both the planes. These data may reflect different amounts of trunk displacement as a result of the different propulsive mechanisms employed. The action of propelling the dual handrim involves pushing the hand downwards and forwards to follow the movement of the drive wheel. Conversely the lever drive requires a different hand position involving a lever that is positioned higher than the pushrim of the wheel which may necessitate less forward movement of the trunk. A further contributing factor may be the amount of effort required to propel a dual handrim wheelchair which has been shown to be the least ergonomically and physiologically efficient [10].

The data recording the mean position of the centre of force demonstrated fewer differences between the wheelchair designs. Antero-posteriorly, the mean position of force was displaced more anteriorly in the dual handrim wheelchair compared to the other two. This would further endorse the suggestion that the trunk may be displaced due to the requirements of the dual handrim propulsive mechanism. Conversely there were no significant differences in the medio-lateral position of the mean centre of force across the different wheelchairs. This may indicate that there is no difference in the asymmetry of the seated posture in the different wheelchairs. This finding does not mean that the symmetrical did not change, and it may be that similar deviations in posture occurred in all three wheelchairs. This would concur with the work of Mudie et al [16] who reported asymmetry in all stroke participants compared to non-disabled participants.

One arm drive wheelchairs necessitate an asymmetry in muscle activity in the upper body which is likely to predispose to an asymmetric sitting posture. Hemiplegic wheelchair users have also been shown to have a high incidence of asymmetric sitting posture [16]. The findings from this study indicate that some drive mechanisms are likely to displace the centre of force more than others. Current clinical practice endorses the importance of symmetrical posture in people with hemiplegia. Recent evidence indicates that asymmetric and unstable sitting postures can compromise function [18] and may also contribute to the incidence of pressure sores [19].

The dual handrim mechanism, which clinically is reported to be the most commonly prescribed in the UK, demonstrated the greatest movement of the trunk during propulsion and also an altered position of the centre of force when compared to the other two chairs. These findings may be of interest to rehabilitation teams and should be considered when prescribing one arm drive wheelchairs.

Conclusion

Differences in centre of force position and movement have been demonstrated between different one arm drive wheelchairs. The findings may have particular significance for hemiplegic one arm drive wheelchair users. Rehabilitation teams may wish to review their clinical reasoning in relation to prescribing wheelchairs for hemiplegic users on the evidence presented.

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