PMG Final Report

Measurement of (1) shoulder muscle activity and (2) hand/handrim contact force used in one arm drive wheelchairs: A comparison of the Neater Uni-wheelchair to other contemporary one arm drive wheelchairs.

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Abstract

Purpose: The aim of this study was twofold:

1. To compare the hand/handrim forces generated in three different manual one arm drive wheelchairs: a NuDrive lever drive, the Neater Uni-wheelchair and an Action3. All three wheelchairs used the Neater Uni-wheelchair steering mechanism to permit one armed propulsion. The *Grip*™ system was used to measure dynamic interface grip force between the propelling hand palm, thumb and fingers and the wheelchair handrim.
2. To measure muscle activity using EMG in six muscles around the shoulder during propulsion of the same three different one arm drive wheelchairs.

Methods: 17 non-disabled users were randomly assigned each wheelchair to drive around an indoor obstacle course. During propulsion a multiple sensor, continuous measurement of force was recorded at the hand/handrim interface. Time taken to complete each part of the circuit was recorded. Mean force for each segment of the hand and total force were calculated per user per wheelchair. The EMG data was measured using the biometrics data link system v 7.5 and the data was measured at 1000 Hz. The EMG electrodes were attached according to Seniam guidelines.

Results from the Grip Study: The greatest total hand/handrim interface force was generated during propulsion of the NuDrive lever wheelchair in straight running (Friedmans X^2=15.647, n=17, df=2, $p<0.001$) and in the slalom (Friedmans X^2 = 7.882, n=17, df=2, $p<0.019$). There was no difference in force generation over the mats.

Results exploring the force distribution within the hand indicated that there was a significant difference in force exerted in different regions of the hand in different wheelchairs in straight running. The Neater uni-wheelchair generated the lowest forces across the palm, fingers and thumb $F(4,26)=11.489$, MSE=0.993, $p<0.001$. The NuDrive generated a significantly higher force in the fingers ($p<0.032$) and palm ($p<0.019$) than the other two wheelchairs.

Results from the EMG Study:

The table identifies within which muscles and during which activity, differences in muscle activity occurred.

Activity	**Biceps**	**Triceps**	**Ant Deltoid**	**Post Deltoid**	**Pectoralis Major**	**Infraspinatus**
Running	NSD	p<0.01	NSD	NSD	NSD	NSD
Mats	p<0.001	NSD	NSD	NSD	p<0.001	NSD

Slalom	p<0.001	NSD	NSD	NSD	p<0.01	NSD

Conclusions for The Grip Study: Total force generation was greatest in the NuDrive lever wheelchair during propulsion in straight running ($p<0.019$) and also when propelling around the slalom ($p<0.006$). Analysis of the component forces suggested that the NuDrive wheelchairs generated significantly higher force in the palm ($p<0.05$) and the fingers ($p<0.03$) than the other two wheelchairs.

This suggests that the grip used in propelling using a handrim and using the levers is different resulting in a different application of force. Propulsive force may be related to repetitive strain and overuse injury which may be a factor to consider in wheelchair prescription.

Conclusions for the EMG Study: The NuDrive produces the greatest levels of activity in Biceps and Pectoralis Major over mats and during the slalom. The Neater Uni-wheelchair produces the least levels of activity in Biceps and Pectoralis Major over mats and during the slalom. The Action 3 produced the greatest levels of activity in Triceps during straight running.

Implications for Practice:

To review the clinical reasoning in prescribing lever drive wheelchairs.

To improve clinicians understanding of forces incurred in wheelchair propulsion

To illuminate clinicians understanding of the causation of repetitive strain injury in the upper limb of hemiplegic wheelchair users

Background to the Research Questions:

Manual wheelchair propulsion is known to be an inefficient means of ambulation which has been associated with high a prevalence of upper limb injuries [1,2]. Such injuries are thought to occur from a combination of repetitive movements, heavy loads on the extremities, upper limb weakness and inefficient propulsive technique [3,4]. Hemiplegic users are particularly vulnerable to upper limb injury because of being reliant on only one arm for propulsion [5]. Literature reports that nearly 70% of wheelchair users experience upper extremity pain or overuse injury at some point [6,1]. Currently the most common one arm drive manual wheelchairs include the ratchet arm or lever-drive mechanism, the dual handrim mechanism and the Neater Uni-wheelchair. Lever arm design, such as the NuDrive or Pivot, involves a pushing or pulling action on the end of a lever mechanism [7,8]. The lever drive design usually has a fixed mechanical advantage, the ergonomics of simultaneous propulsion and steering can be awkward and the operation of the brake is not intuitive. The dual hand rim 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. There are deficiencies associated with both of these designs, particularly with respect to the user interface. In the dual handrim designs, steering and propulsion cannot be actuated simultaneously, and braking via the dual handrim 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. A recent alternative to these has been the development of the Neater Uni-wheelchair (NUW) which has been designed specifically for hemiplegic users. The NUW is an Action 3 wheelchair to which a novel propulsion and steering kit is attached. These features have been described in detail in an earlier papers by Mandy et al [9,10,11,12,13].The novel combination of the differential and a self-propulsive steering 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 body of work to date suggest that the NUW is ergonomically more efficient to drive and preferred by users in both a laboratory setting [9,10] and in a simulated activities of daily living setting [12]. A further study evaluated users experiences of using the NUW in their own homes [11] from which four key themes of increased user independence and freedom, ease of use and maneuverability, usefulness and increase in activity were reported [11]. These studies suggested that NUW could meet the unmet needs of the hemiplegic user group and provide them with additional choice in their wheelchair provision. More recent work has explored vertical reaction forces under both buttocks in each of the one arm drive wheelchairs. Results from the the non-hemiplegic side indicated that the lever wheelchair required the least vertical reaction force during the propulsion and that the dual handrim wheelchair required the greatest force. The NUW required less force than the dual handrim but more force than the lever wheelchair. For the hemiplegic side, the NUW required less force for the propulsion than either of the other two wheelchairs and the dual handrim again produced the greatest force. The results indicate that the dual-handrim wheelchair required the user to produce the greatest forces under both sides of the body during propulsion. Thus, these results suggest that the dual handrim wheelchair is the most inefficient of the three. In gait analysis ground reaction forces are related to the force generated for propulsion [14,15]. The force measured through the buttocks is indirectly a result of force applied at the hand/handrim interface [16]. Therefore it could be speculated that propulsive effort may vary according to the type of propulsive mechanism being used. There is some research that has explored push and recovery phases of shoulder muscle activity during manual wheelchair propulsion and also wheelchair configuration [17, 18]. There is also limited research exploring handrim pressures in standard wheelchairs [19,20,21] and some exploring component forces within the hand in wheelchair propulsion [22,23,24,25,26,27,28,29]. However, there is no research investigating propulsion and forces in one arm drive wheelchairs. In light of this equivocal literature, and also the reported incidence of upper limb over use injury, the aim of this study was to explore force exerted at the hand/handrim interface and also muscle activity in the shoulder whilst propelling different one arm drive wheelchairs.

The two research hypotheses were:

1. There will be differences in hand/handrim forces in the hand/handrim interface when propelling different one arm drive wheelchairs.
2. There will be differences muscle forces at the shoulder when propelling different one arm drive wheelchairs.

Methods:

Ethical Approval was sought and obtained from the University of Brighton Research Ethics committee for the study.

Subjects were recruited from the University of Brighton Campus using posters. The inclusion criteria were: willingness to participate, no cardiac or respiratory disorder, no functional impairment, right hand dominant and to be within the height and weight restrictions of 163-185 cm high and 54-90 kg weight. Exclusion criteria: inability to learn how to propel safely. 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.

The study was designed as a controlled, same subject study that measured force generated by each user during propulsion in three different one arm drive wheelchairs. Force was measured at the hand/handrim interface using the Grip Pressure measurement system. Muscle activity at the shoulder was measured using EMG attached to: triceps, biceps, anterior and posterior deltoid, infraspinatus, and pectoralis major muscles. The one arm drive wheelchairs used were:

1. The Neater uni-wheelchair which has a differential fitted to the rear wheel and an independent steering mechanism (9). The same steering mechanism was attached to the other two wheelchairs.
2. A standard Action 3 wheelchair with the Neater Uni steering mechanism attached to the right hand castor only.

3. An Action3 wheelchair with one NuDrive lever drive attachment fitted to the right hand wheel only with the Neater uni steering mechanism attached to the right caster.

Figure 1: The Neater Uni-wheelchair

The Neater Uni steering mechanism

Rear differential

Figure 2: The NuDrive Wheelchair

The Neater Uni steering mechanism

The NuDrive lever Attachment

Figure 3: The Action3 Wheelchair

The Neater Uni steering mechanism

The *Grip*™ Pressure Measurement System

The data being measured was static and dynamic force at the hand/handrim interface using the Tekscan the *Grip*™ Pressure Measurement System, a portable interface pressure mapping system which records force distribution under the contact area. The system includes a series of force transducers mounted on a flexible force plate which can moulded to the shape of the hand. Software is provided which can generate force data or pressure mapping of the contact area. The *Grip*™ is an instrumented series of high resolution sensors that has 18 sensing regions that are positioned over the fingers and palm. Gaps between the sensing areas allow the joints to move freely, and not interfere with grip measurement. Each sensing region has multiple force transducers (sensels) for localized identification of contact points on the hand. There are a total of 349 sensels in the array.

Figure 4: The *Grip*™ Sensors prior to attachment to a vinyl glove [30].

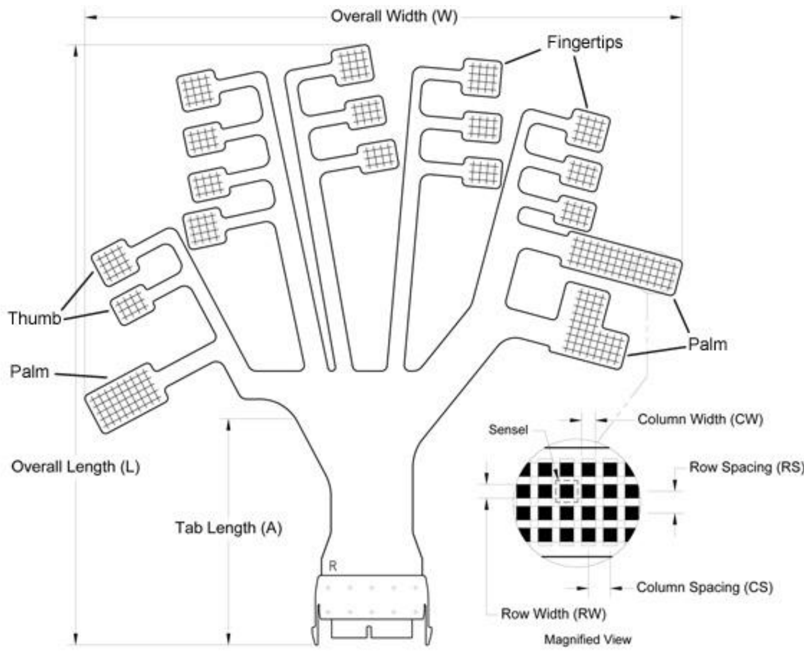
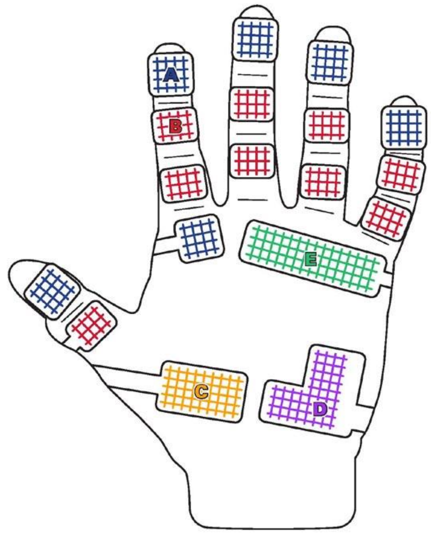


Figure 5: Location of the Sensors after attachment to a glove [30]



Region A (Qty 6) Distal phalanx (finger tips) / metacarpal head of index finger: 12.0 mm x 12.0 mm (0.47 in. x 0.47 in.)

Region B (Qty 9) Middle and proximal phalanx: 12.0 mm x 8.0 mm (0.47 in. x 0.31 in.)

Region C (Qty 1) Palm below the thumb: 32.0 mm x 16.0 mm (1.26 in. x 0.63 in.)

Region D (Qty 1) Palm below the fifth finger: 28.0 mm x 32.0 mm (1.10 in. x 1.26 in.)

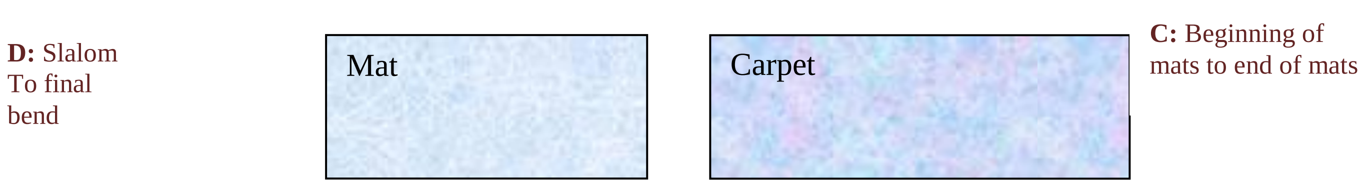
The EMG System:

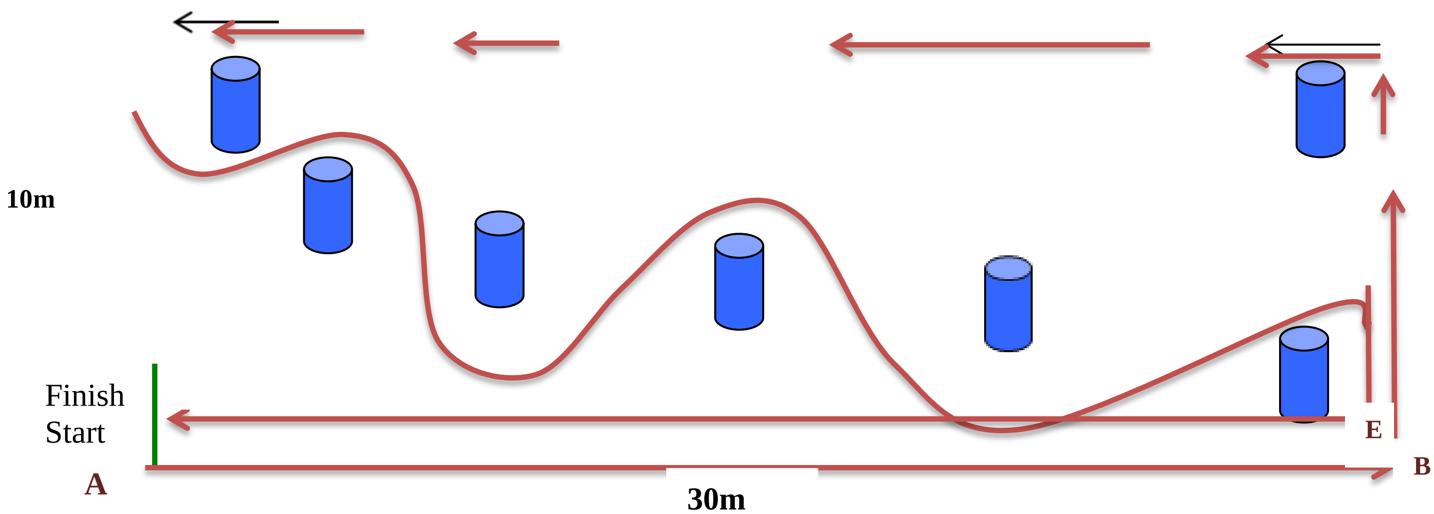
The electrodes were attached to the six muscles according to Seniam guidelines. Electrodes were attached using double sided non-allergic medical tape and skin was prepared using an alcohol wipe. EMG data was measured using the biometrics data link system v 7.5. Data was measured at 1000 Hz.

The study was conducted at an indoor circuit at the University of Brighton (Fig 6). All participants were given familiarisation training in the use of all the wheelchairs until they felt competent to undertake the trial. The steering for all 3 wheelchairs involved the Neater Uni-wheelchair steering mechanism. Propulsion of the NuDrive involved flexion and extension of the shoulder in a forwards and backwards motion. Propelling the Neater Uni-wheelchair involved the use of the single rim which was attached to the rear wheel differential for propulsion. Propelling the normal Action3 involved using only the single handrim.

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 90^0 left turn and continue for10 m. A further 90^0 left hand turn took the user onto carpet and brush matting. The carpet and matting was 30 m long. At the end of the carpet the user made a 135^0 left hand turn into a slalom of three closely placed bollard markers which required tight 45^0 right and left hand turns. At the end of the slalom, the user completed a 135^0 right hand turn for a further 30 m of straight driving to take the user back to the start/finish line.

Figure 6: The driving course





A: start and straight running to first bend B

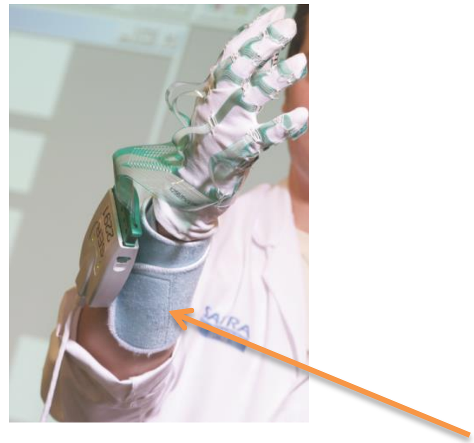
Procedure for the Grip attachment:

Demographic data including age, and gender were recorded for all subjects. The users hand was measured for size using a pre-instrumented vinyl glove to which the Grip sensors had been attached (Fig 7) according to the manufacturer instructions [30].

The user's right hand was dusted with talcum powder prior to putting on a first tight fitting non-instrumented vinyl glove. This vinyl glove was also dusted with talcum powder and then inserted into the pre-instrumented vinyl glove (Fig 7). The procedure of double gloving was for hygiene reasons. The use of talcum powder facilitated easy removal of the instrumented glove without damage to the sensors.

Figure 7: The Pre-instrumented glove showing the Grip attached to the vinyl glove [29]

Figure 8: The VersaTek cuffs [26]



The VersaTek cuffs

Photographs courtesy of SATRA Technology Centre

The pre-instrumented glove was attached to the VersaTek cuffs (Fig 8) which processed the data and relayed it to the computer via USB connection.

The system was calibrated for each subject prior to data collection as recommended by the manufacturer []. Subjects were randomly allocated the wheelchairs using random numbers.

Procedure for the EMG:

The electrodes were attached to muscles. Data captured used the Biometrics DLK900 system (Biometrics Ltd, Gwent, UK).

Figure 9: To show EMG and The Grip attached to a user

The participants were asked to drive the wheelchair round the course (Fig 6) at their own speed. Data was captured continuously throughout each circuit. Time taken to complete each section of the circuit was recorded. The key time points were:

1. A-B: start and straight running to first bend.
2. C-D: beginning of mats to end of mats and third bend
3. D-E: beginning of slalom to final bend.

The course was repeated once per wheelchair with a 30 minute gap, or however much time was necessary, for the users to feel recovered.

Data Processing

The Grip:

The raw force data was manipulated using the *Grip*™ software to generate three regions of force consisting of thumb, digit and palm fields. The force time data for each region was exported into excel. A linear trapezoidal integration of force was performed for each region. The data was divided into the three different activities: straight running, textured surfaces and slalom in each wheelchair. The total of the integrations for each activity for each region of the hand in each wheelchair were calculated.

EMG:

The raw EMG data was processed using Matlab v R2012a. The data was high pass and low pass filtered and full wave rectified. The data for each muscle was exported into excel and a moving average (MAV) function, with 30 point window, was used to linear envelope the data. A linear trapezoidal integration was performed on the data. The data was divided into the three different activites: straight running, textured surfaces and slalom and a total voltage was calculated for each muscle for each activity in each wheelchair.

Statistical Analysis

The data were statistically investigated to explore the differences in:

1.Total hand/handrim forces between the wheelchairs
2. Component force distribution within the hand in the different wheelchairs
3. Muscle activity around the shoulder in the different wheelchairs.

In all cases analyses were also performed to show differences during the different activities.

Results

Gender distribution: 10 women and 7 men.

Table 1: To show demographic variables of the participants

Male	**Mean**	**SD**	**Female**	**Mean**	**SD**

Age (yrs)	25.86	11.05	Age (yrs)	30.3	11.34
Height (cm)	183	9.70	Height(cm)	166.9	6.54
Weight(kg)	77.29	19.03	Weight(kg)	62.1	7.43

The Grip – total force measurement:

The data was tested for normal distribution using the Anderson Darling Test and found not to be normally distributed (straight running $p<0.5$; over textured surfaces $p<0.2$; slalom $p<0.3$).

A comparison of total force generated in straight running (key time point 1).

There was a significant difference in the total force generated during straight running between the three different wheelchairs (Friedmans X^2=15.647, n=17, df=2, $p<0.001$).

A Friedman's test (K-related samples test) and additional post-hoc analysis with Wilcoxon signed-rank test was performed to compare total force generated during each key section of the circuit in each of the different wheelchairs.

Post-hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied. The force generated in the Action3 wheelchair was significantly greater than the force generated in the Neater Uni-wheelchair (Z = -2.675, p = 0.007).

The force generated through propelling the NuDrive was significantly greater than compared to the force required to propel the Neater Uni-wheelchair (Z=-3.053, p =0.02).

A comparison of total force generated over mats (key time point 2)

There was no difference in the total force generated over the mats between the three different wheelchairs (Freidmans X^2 = 1.882, n=17, df=2, p = 0.390).

A comparison of total force generated during slalom driving (key time point 3).

There was a significant difference in the total force generated through the slalom between the three different wheelchairs (Friedmans X^2 = 7.882, n=17, df=2, $p<0.019$).

Post-hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied. There was a significantly greater in force generated whilst propelling the NuDrive around the slalom course. (Z=-2.77, $p<0.006$). There was no difference between the Action3 and the Neater Uni-wheelchair (Z=-497, $p<0.619$) nor the NuDrive and the Action3 (Z=-1.823, $p<0.068$).

The Grip -Component Force Distribution within the hand:

The data was not normally distributed and was transformed using a log 10 manipulation to enable a three way ANOVA with Tukeys post hoc test to be undertaken. The three independent variables were: type of wheelchair, activity and region of the hand.

1. There was no significant difference between the force distribution within the hand during the different activities. $F(4,26,)=0.886$, $MSE=0.77$, $p<0.472$.

2. There was a significant difference identified between the region of the hand in different wheelchairs. $F(4,26)=11.489$, $MSE=0.993$, $p<0.001$.

Table 2: Descriptive Data to show Mean force measurement per region per wheelchair from highest to lowest.

Region	Wheelchair	Mean	SD
Fingers	NuDrive	2.92	0.316
	Action3	2.82	0.267
	Neater	2.74	0.203
Thumb	Action3	2.19	0.283
	Neater	2.07	0.212
	NuDrive	1.95	0.410
Palm	NuDrive	2.55	0.351
	Action3	2.28	0.352
	Neater	2.28	0.256

Straight running and palm force measurement:
There was a significant difference in pressure measured in the palm in the different wheelchairs. $F(2,48)=4.612$, $MSE=0.343$, $p<0.015$.

Tukeys post hoc analysis with an alpha of 0.05 indicated that the NuDrive (M=2.52, 95% CI [-0.45,0.001]) $p<0.05$, had significantly higher force applied to the palm during straight running than the Neater. This was also the case for the NuDrive compared to the Action3 (M=2.30, 95% CI [-0.48,0.036]) $p<0.19$.

Straight running and thumb force measurement:
There was a significant difference in thumb force in the different wheelchairs. $F(2,48)=6.155$, $MSE=0.251$, $p<0.004$.

Tukeys post hoc analysis with an alpha of 0.05 indicated that the Action3 (M=2.21, 95% CI [-0.75,0.410]) $p<0.003$, had significantly higher force applied to the thumb during straight running than the NuDrive. There was no difference between the Neater and the Action3 wheelchair (M=2.106, 95% CI [-0.281,0.053]), $p=0.23$, nor the Neater and the NuDrive wheelchair (M=1.97, 95% CI [-0.384,0.296]), $p=0.16$.

Straight running and finger force measurement:

There was a significant difference in finger force in the different wheelchairs. F(2,48)=3.44, MSE=0.113, p<0.04.

Tukeys post hoc analysis with an alpha of 0.05 indicated that the NuDrive (M=2.87, 95% CI [-0.312,0.114]) p<0.032, had significantly higher force applied to the through the fingers during straight running compared to the Neater wheelchair. There was no difference between the Neater and the Action3 wheelchair (M=2.81, 95% CI [-0.2502,0.050]), p=0.254 or the Action3 and the NuDrive (M=2.81, 95% CI [-0.212,0.088]), p=0.582.

Muscle activity around the shoulder:

The data was found not be normally distributed.

Total voltage generated within the muscles was measured and compared during each activity. A Friedman's test (K-related-samples test) and additional post-hoc analysis with Wilcoxon signed-rank test was performed to compare total voltage generated during each key section of the circuit in each of the different wheelchairs.

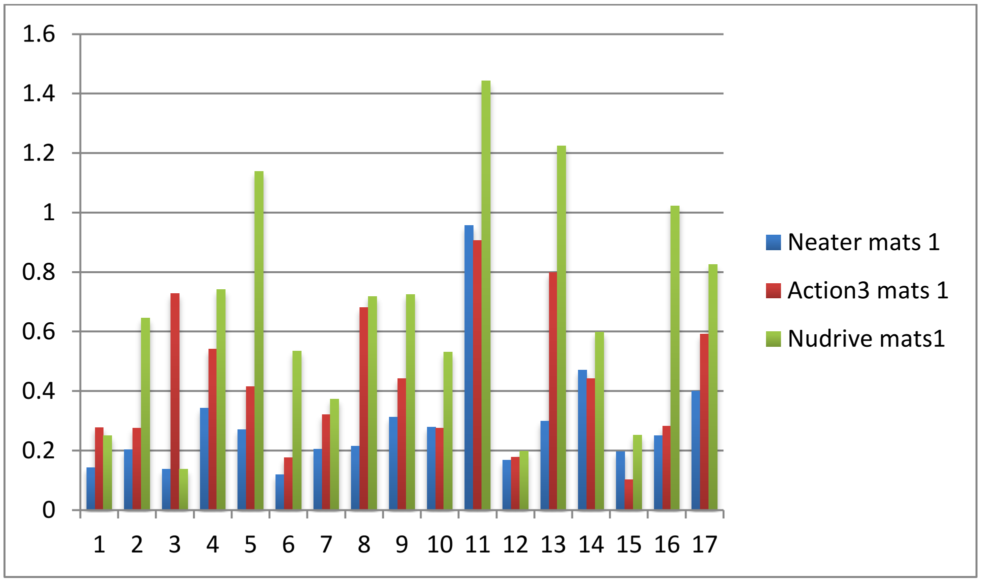
Activity	Biceps	Triceps	Ant Deltoid	Post Deltoid	Pectoralis Major	Infraspinatus
Straight running	NSD	p<0.01	NSD	NSD	NSD	NSD
Mats	p<0.001	NSD	NSD	NSD	p<0.001	NSD
Slalom	p<0.001	NSD	NSD	NSD	p<0.01	NSD

Biceps activity over mats and slalom

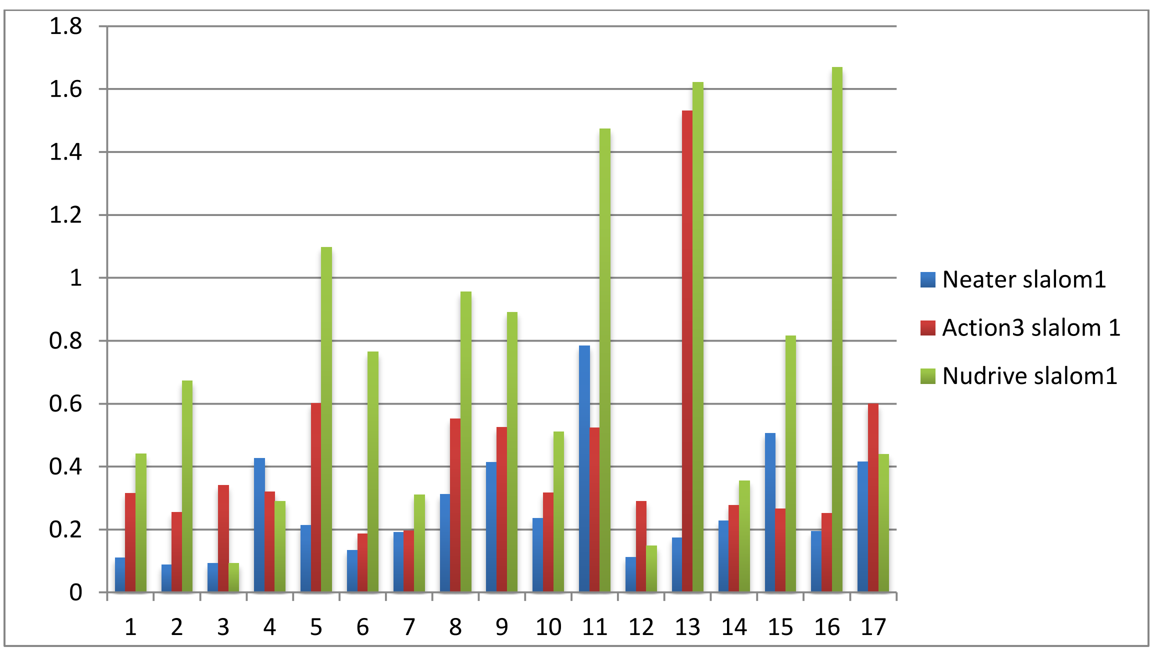
The Nudrive produced the greatest muscle activity Wilcoxon Post hoc test: Z= -2.817 p<0.005.

The Neater produced the least muscle activity Wilcoxon Post hoc test: Z= -3.51 p<0.001

Graph 1: to Show Biceps activity over Mats



Graph 2: to Show Biceps activity during the slalom

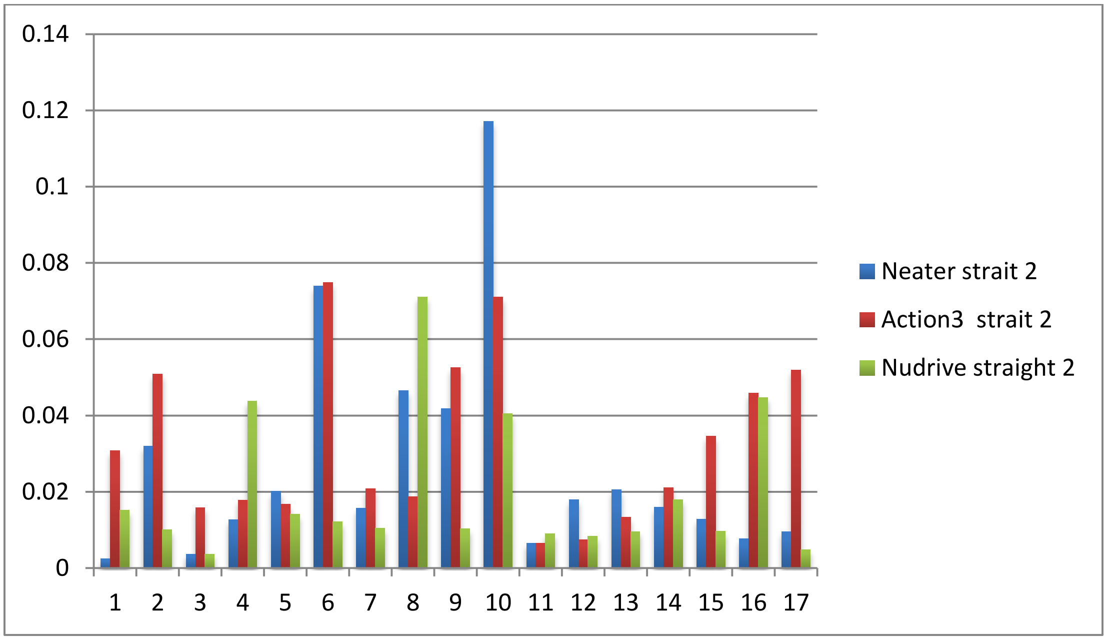


Triceps straight running activity:

The Action3 chair produced significantly **more** muscle activity than the other two chairs.

Wilcoxon Post hoc test: Z= -2.154 p<0.03

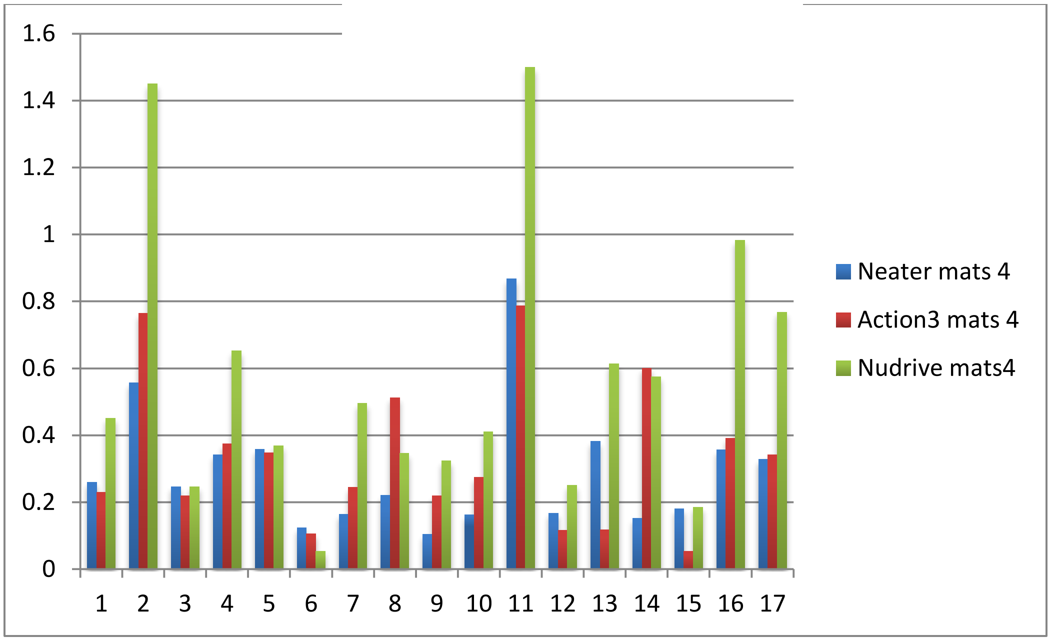
Graph 3: To Show Triceps straight running activity



Pectoralis Major activity over Mats and Slalom

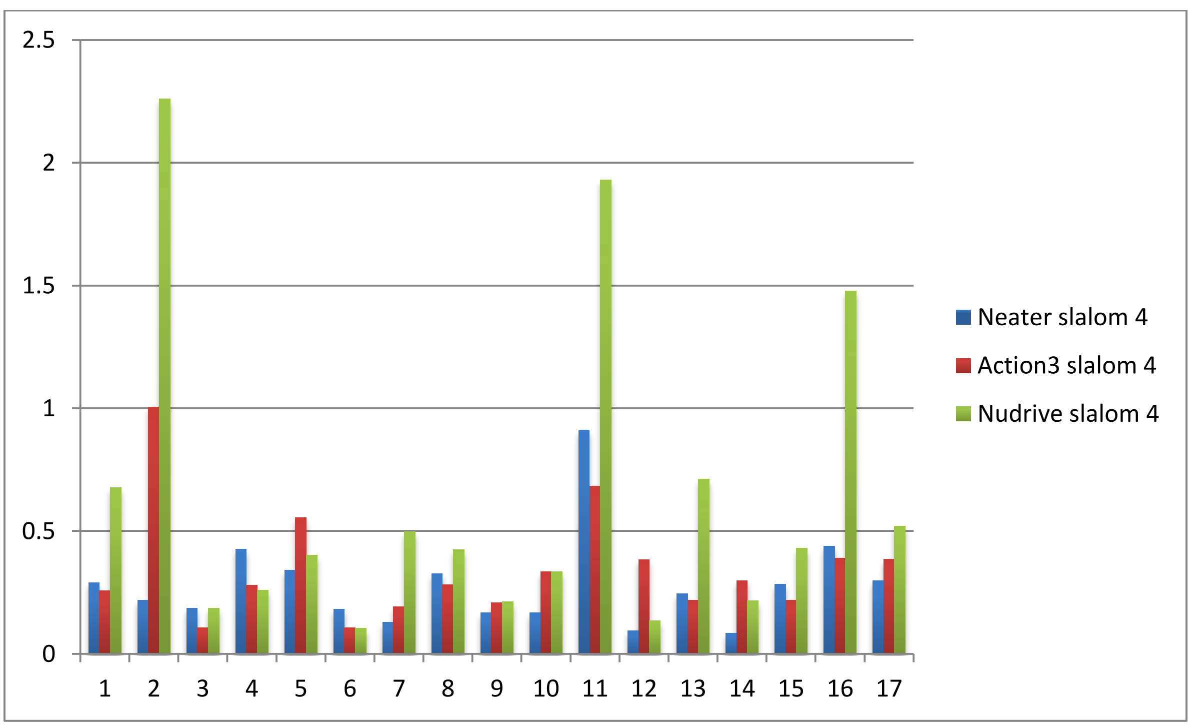
Mats: The NuDrive produced significantly more activity than the other two chairs Wilcoxon Post hoc test: Z= -2.911 p<0.004

Graph 4: To Show Pectoralis Major activity over Mats



Slalom**:** The Neater produced significantly less activity than the other two wheelchairs Wilcoxon Post hoc test: Z= -2.896 p<0.004

Graph 5: To Show Pectoralis Major activity during slalom



Discussion

The aims of this study were twofold:

1. To measure and compare the total and individual component hand/handrim forces generated during propulsion, in a sample of non-disabled wheelchair participants using right sided one armed propulsion mechanisms.
2. To measure muscle activity using EMG in six muscles around the shoulder during propulsion of the same three different one arm drive wheelchairs.

The objectives of the study were to identify which one armed drive wheelchair generated the least hand/handrim force when maneuvering in a controlled environment and around obstacles. Within this data force generation across different components of the hand was also explored. The second objective was to identify which wheelchair generated the lowest level of muscle activity around the shoulder during propulsion.

The findings will be discussed from each study independently and the overall implications summaries.

Results from the Grip study and implications.

The total force results from the Grip study suggest that in straight running the Neater Uni-wheelchair required the least propulsive force compared to the other two wheelchairs. In straight running and in slalom running the NuDrive generated the greatest propulsive hand/handrim force. There was no difference between any of the wheelchairs during propulsion over mats. Consideration of the component forces within the hand suggest that the different wheelchairs resulted in different force generation. In straight running, the NuDrive generated the greatest force across the palm and fingers. However, the Action3 generated the greatest force across the thumb. There was no difference in force generation between the Neater and the Action3.

These results may be explained through the action of propulsion for maneuvering the NuDrive wheelchair and from the type of grip applied to the lever. The grip involved in operating the lever will be similar to a hook grip whereby the hand is wrapped around the lever which would explain the higher distribution of force through the palm and fingers. The Neater and Action3 will require the thumb to be in opposition to the fingers during propulsion.

The literature suggests that rim diameter is important in force generation [22]. The handrim was the same size in both the Action3 and the Neater Uni-wheelchair however, the diameter of the lever in the NuDrive was larger than the diameter of the handrims which may have contributed to the differences measured.

The Action3 wheelchair produced higher total forces than the Neater Uni-wheelchair in straight running driving but less than the NuDrive. This is not surprising because the Action3 was only fitted with the foot steering mechanism and did not have the differential attached to the rear wheel. 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 pushrim stays constant whatever the direction of steering maybe [10]. Thus it was also speculated that the results for the force during propulsion over the mats would also be lower in the Neater Uni-wheelchair, however, this was not the case. It was observed during the study that all the users struggled to manoeuvre all the wheelchairs over the mats. It could therefore be suggested that they employed a different propulsive technique during this part of the study.

Conclusion: This study of non-disabled users suggests that the NuDrive wheelchair requires the greatest forces for propulsion at the hand/handrim interface compared to the Neater Uni-wheelchair and the Action3 wheelchair. Further work is indicated to explore propulsive effort at the shoulder in these wheelchairs in relation to forces generated at the hand/handrim interface. These findings will contribute to our understanding of overuse injury in propelling one arm drive wheelchairs.

Results from the EMG study and implications

The NuDrive produces the greatest levels of activity in biceps and pectoralis major over mats and during the slalom. The Neater Uni-wheelchair produces the least levels of activity in biceps and pectoralis major over mats and during the slalom. The increased activity in biceps in the NuDrive may be explained by the position of the elbow in greater flexion when using a lever drive mechanism. The increased activity of pectoralis major is of greater clinical concern. Pectoralis major will be an important muscle for generating propulsinve force, but an increase in activity in this muscle, in the absence of an increase in other muscles around the shoulder, is associated with shoulder pain in non-wheelchair using populations.

The Action3 produced the greatest levels of activity in triceps during straight running. This increased activity in triceps may indicate the greater effort required to propel a wheelchair that has not been adapted for single arm propulsion. The activation and involvement of different muscles again reflects the different type of effort required to propel the different wheelchairs. The evidence suggests that the NuDrive is the least efficient to propel and the Neater generated the least force during the slalom and over mats. The evidence would suggest the need to replicate the study in a user population is warranted.

It is noted that in three individuals (2,11,16) there was markedly higher muscle activity when using the NuDrive compared to the other wheelchairs. There were no obvious confounding variables to explain this pattern however, from experience and observation during the data collection it was noted that some individuals struggled with propelling the NuDrive particularly over the different surfaces. This may be explained through variation in body proportion, muscle strength, or co-ordination issues within these individuals.

Implications for Practice and Rehabilitation.

*To review the clinical reasoning in prescribing lever drive wheelchairs.

*To improve clinicians understanding of forces incurred in wheelchair propulsion

*To illuminate clinicians understanding of the causation of repetitive strain injury in the upper limb of hemiplegic wheelchair users

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