Abstract

The aim of this pilot study was to compare EMG activity in six muscles surrounding the shoulder joint during propulsion of three different Action3 manual one arm drive wheelchairs: a Nu Drive lever attached to one wheel, the Neater Uni-wheelchair and a standard Action3 wheelchair. Each wheelchair was steered using the Neater Uni-wheelchair steering mechanism attachment. Surface EMG was measured during dynamic propulsion of each wheelchair during propulsion around an indoor circuit and obstacle course.

Methods:

17 non-disabled users were randomly assigned each wheelchair. During propulsion a multiple sensor, continuous measurement of force was recorded. 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 positioned according to Seniam guidelines. Time taken to complete different sections of the circuit were recorded.

Mean activity levels for each muscle were calculated per user per wheelchair.

Results:

The NuDrive produced the highest levels of activity in triceps muscle in straight running.

The NuDrive produced the highest levels of activity biceps and Pectoralis major over mats and around corners.

The Neater produced the lowest levels of activity in biceps and Pectoralis major over mats and around corners. There was no significant difference in activity in the other muscles in the different wheelchairs.

Conclusions:

The evidence suggests that the NuDrive required the greatest levels of muscle activity for propulsion. The Neater generated the least muscle activity during the slalom and over mats. The evidence would suggest the need to replicate the study in a user population is warranted. 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.

Introduction:

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 due to 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

(Insert Fig 1 and 2). 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 propulsive mechanism being used.

Shoulder muscle activity levels, upper limb kinetics and kinematics have been reported during manual wheelchair propulsion on level and inclined surfaces. Shoulder flexion and elbow extension are the two primary movements required during wheelchair propulsion (Mulroy et al., 1996; Sabick et al., 2004). Pectoralis major, anterior deltoid and triceps brachii are consistently reported as the primary muscles involved during the push phase on level surfaces (Mulroy et al., 1996; de Groot et al., 2003; Dubowsky et al., 2008). Meanwhile, the posterior deltoid and upper trapezius have been identified as the primary muscles that are active during the recovery phase (Mulroy et al., 1996; de Groot et al., 2003). Recent findings have shown that the primary muscles required for the push and recovery cycles of manual wheelchair propulsion during ramp ascent (triceps brachii, anterior deltoid and pectoralis major for the push phase and posterior deltoid for the recovery phase) were the same as for level propulsion (Chow et al., 2009). The goal of this investigation was to quantify changes in the activity of muscles surrounding the shoulder in three different one arm drive wheelchairs. The research hypothesis was: There will be differences in EMG activity around 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 muscle activity using EMG in six muscles around the shoulder. Muscle activity was measured in each user during propulsion of three different one arm drive wheelchairs. The Neater Uni-wheelchair (Fig 1), an Action3 wheelchair with one NuDrive lever drive attachment to the right hand wheel only and the Neater uni-wheelchair steering attached to the right caster (Fig 2), and an Action3 wheelchair with a standard handrim and the Neater Uni-wheelchair steering mechanism attached to the right hand footplate only (Fig 3).

Figure 1: The Neater Uni-wheelchair

Figure 2: The NuDrive Lever

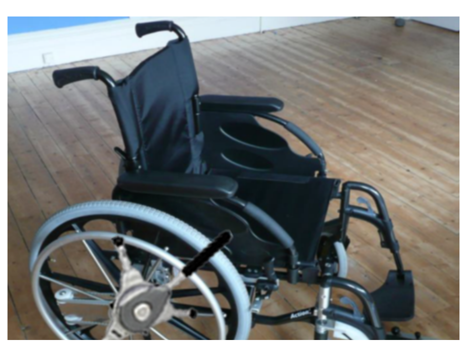


Figure 3: The Standard Action3 wheelchair with Neater Uni-wheelchair steering.

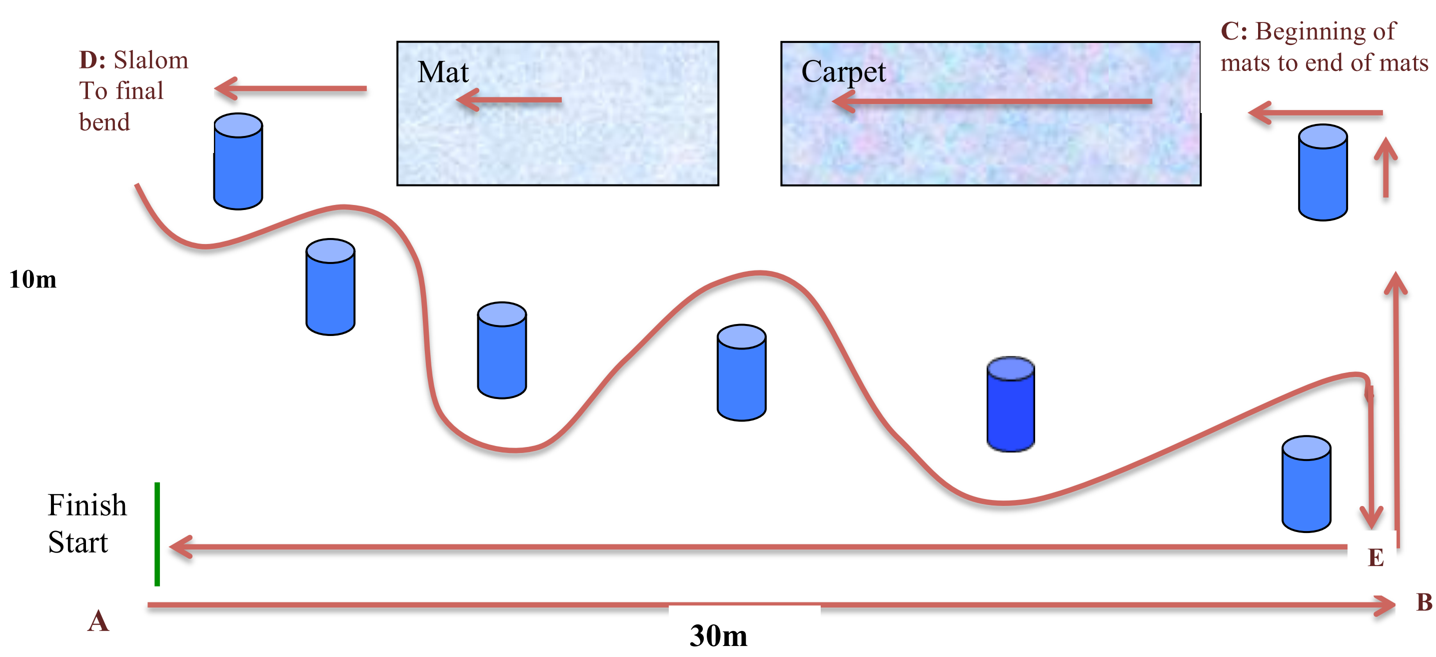
EMG Measurement System

EMG activity in biceps, triceps, pectoralis major, anterior and posterior deltoid and infraspinatus muscles was collected using the Biometrics DLK 900 system with version 7.5 software. The data was sampled at 1000Hz. The skin under the electrodes was cleaned using alcohol wipes prior to attachment of the electrodes using double sided tape. The EMG electrodes were positioned according to Seniam guidelines. The reference electrode was positioned over the left wrist.

The study was conducted at an indoor circuit at the University of Brighton (Fig 4). 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 Action3 with steering, to which the NuDrive lever was attached, involved flexion and extension of the shoulder in a forwards and backwards motion. Maneuvering the Neater Uni-wheelchair involved the use of the single rim which was attached to the rear wheel differential for propulsion. Maneuvering the normal Action3 involved propulsion only using 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 4: The driving course



A: start and straight running to first bend B

Procedure

Demographic data including age, and gender were recorded for all subjects. The users had the electrodes positioned over each of the six muscles on the right shoulder and arm prior, to commencement of the trial. Subjects were randomly allocated the wheelchairs using random numbers.

The participants were asked to drive the wheelchair round the course (Fig 4) 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 raw EMG data was processed using Matlab v R2012a. The data was high pass and low pass filtered (with cut off frequencies of 20 and 300 Hz) 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 activities: straight running, over mats 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 muscle activity around the shoulder in the different wheelchairs.

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

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.

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

Table 2: To show differences in muscle activity during the different activities

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 Muscle

Measurement in Straight running

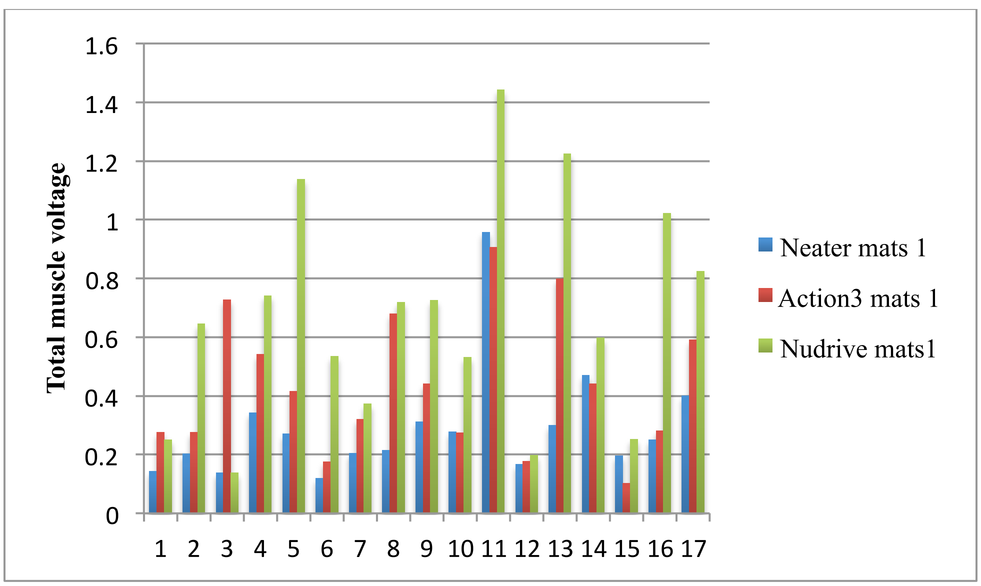
There was no significant difference in the total activity generated during straight running between the three different wheelchairs (Friedmans X^2=5.045, n=17, df=2, p=0.08).

Measurement over Mats:

There was a significant difference in activity between the three wheelchairs (Friedmans X^2=22.11, n=17, df=2, p=0.001).

Post-hoc analysis with Wilcoxon signed-rank tests, conducted with a Bonferroni correction, indicated that the activity generated in the NuDrive wheelchair was significantly greater than the activity generated in the Action3 with steering (Z= -3.516, n=17, df=2, p<0.005). The least activity was generated in the Neater Uni-wheelchair (Z= -2.817, n=17, df=2, p<0.005).

Graph 1: to Show Biceps activity over Mats

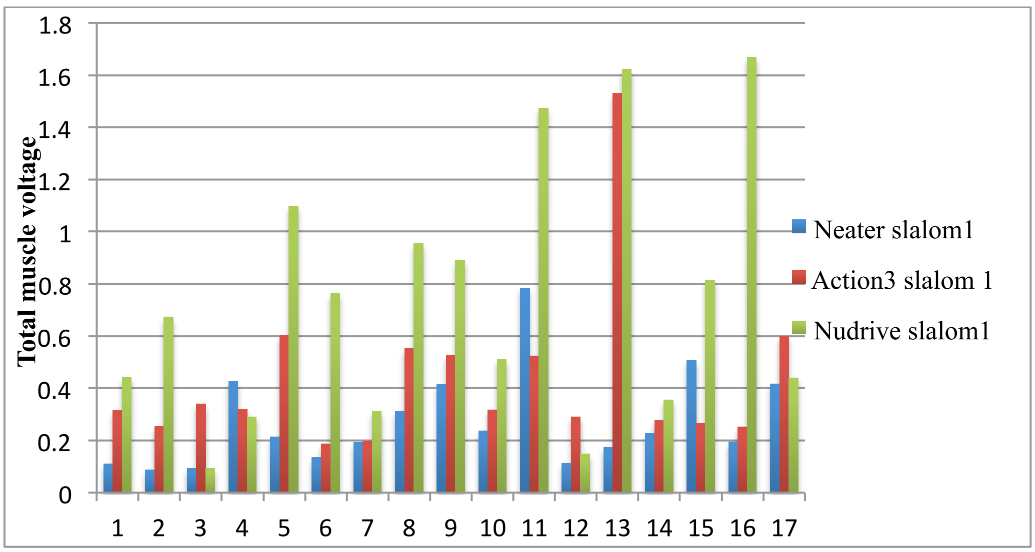


Measurement around corners and slalom driving:

There was a significant difference in the activity generated in biceps when driven around corners between the three different wheelchairs (Freidmans $X^2 = 17.28$, n=17, df=2, p< 0.001).

Post-hoc analysis with Wilcoxon signed-rank tests, conducted with a Bonferroni correction, indicated that the activity generated in the NuDrive wheelchair was significantly greater than the activity generated in the Action3 with steering (Z= -3.258, n=17, df=2, p<0.001). The least activity was generated in the Neater Uni-wheelchair (Z= -2.059, n=17, df=2, p<0.003).

Graph 2: to Show Biceps activity during the slalom



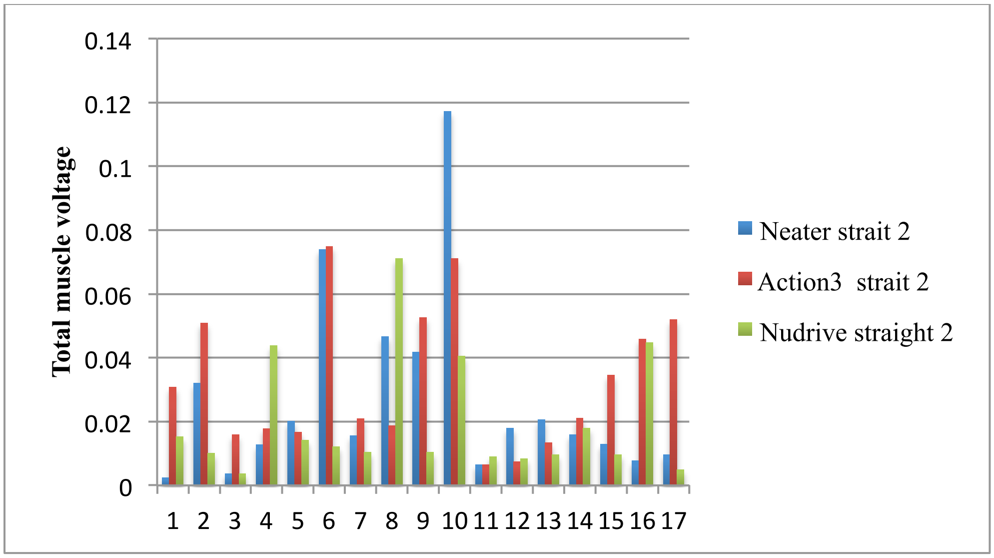
Triceps Muscle

Measurement in Straight running

There was a significant difference in the total activity generated during straight running between the three different wheelchairs (Friedmans X^2=8.98, n=17, df=2, p=0.01).

Post-hoc analysis with Wilcoxon signed-rank tests, conducted with a Bonferroni correction, indicated that that the activity generated in the Action3 with steering was significantly higher than the other two wheelchairs (Z=-2.15, p<0.03).

Graph 3: To Show Triceps straight running activity



There was no significant difference between the wheelchairs across mats (Friedmans $X^2 = 0.209$, n=17, df=2, p0.90) or during slalom corner driving (Friedmans $X^2 = 2.41$, n=17, df=2, p0.2).

Pectoralis Major

Measurement in Straight running:

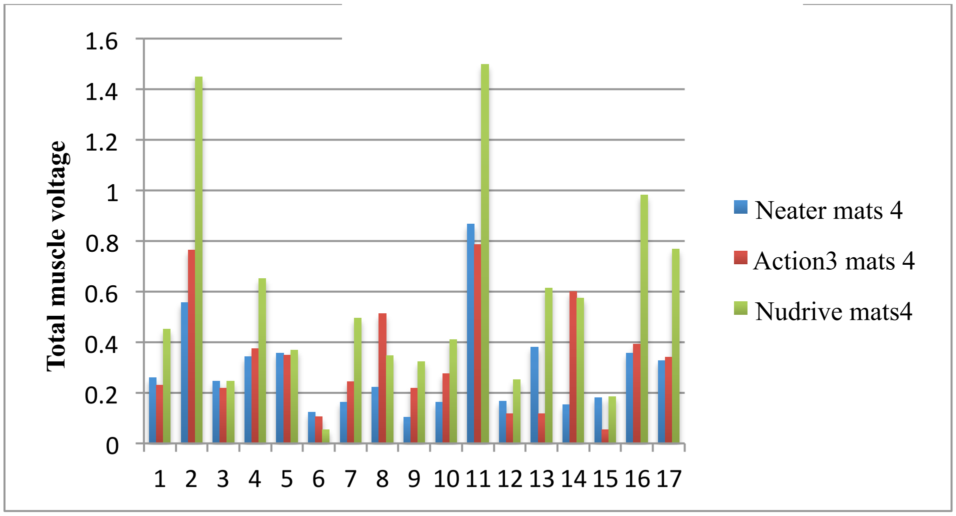
There was no significant difference in muscle activity between the wheelchairs (Friedmans $X^2=4.38$, n=17, df=2, p=0.11).

Measurement over Mats:

There was a significant difference in activity generated over the mats between the three different wheelchairs (Friedmans $X^2 = 14.17$, n=17, df=2, p<0.001).

Post-hoc analysis with Wilcoxon signed-rank tests, conducted with a Bonferroni correction, indicated there was significantly more activity generated whilst propelling the NuDrive than the Neater (Z=-3.36, p<0.001), and NuDrive than the Action3 with steering (Z-2.91, p<0.04).

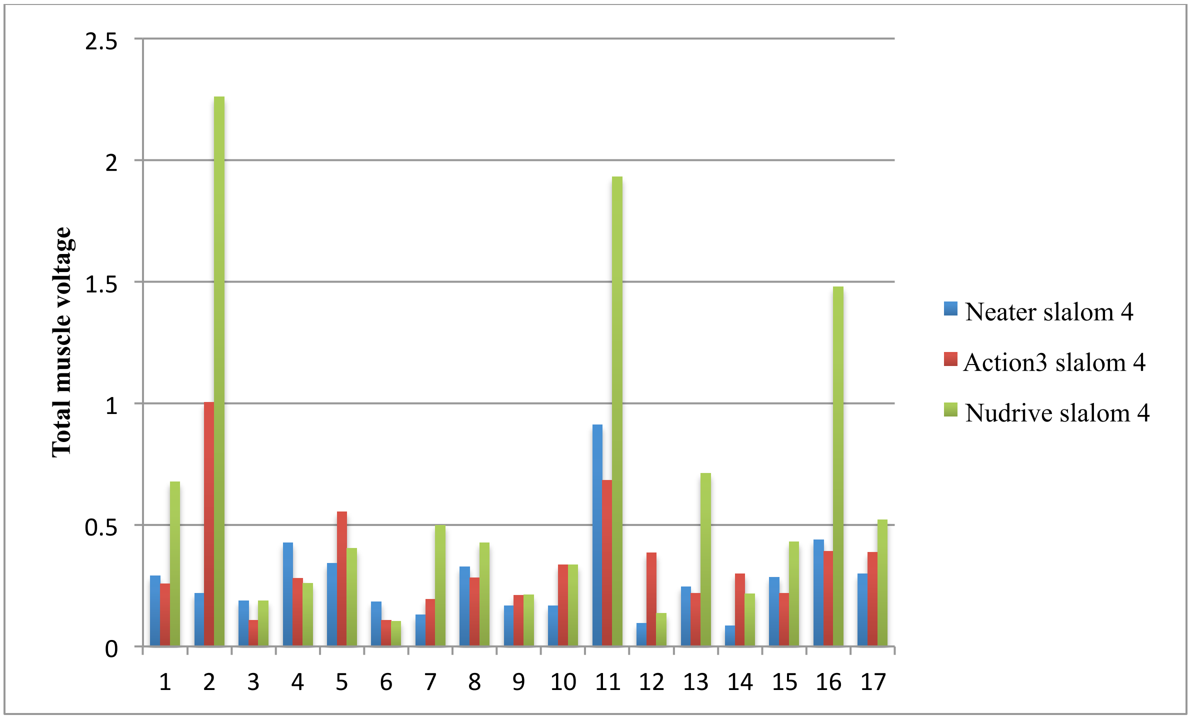
Graph 4: To Show Pectoralis Major activity over Mats



Measurement around corners and slalom driving:

There was a significant difference in activity generated around corners and slalom between the three different wheelchairs (Friedmans $X^2 = 8.149$, n=17, df=2, p=0.017). Post-hoc analysis with Wilcoxon signed-rank tests, conducted with a Bonferroni correction, indicated there was significantly less activity generated whilst propelling the Neater compared to the NuDrive (Z=-2.896, p=0.004). The Action3 with steering also produced significantly less activity than the NuDrive (Z=-2.059, p=0.035).

Graph 5: To Show Pectoralis Major activity during slalom



The following muscles did not show any significant differences between chairs in each activity.

Anterior Deltoid Muscle

Measurement in Straight running:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=81.7, n=17, df=2, p=0.42).

Measurement Over Mats:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=1.16, n=17, df=2, p=0.55).

Measurement around Corners and Slalom driving:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=5.04, n=17, df=2, p=0.08).

Posterior Deltoid Muscle

Measurement in Straight running:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=0.627, n=17, df=2, p=0.73).

Measurement Over Mats:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=3.85, n=17, df=2, p=0.14).

Measurement around Corners and Slalom driving:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=1.46, n=17, df=2, p=0.48).

Infraspinatus

Measurement in Straight running:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=1.88, n=17, df=2, p=0.39).

Measurement over Mats:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=2.71, n=17, df=2, p=0.25).

Measurement around Corners and Slalom driving:

There was no significant difference in muscle activity between the wheelchairs (Friedmans X^2=3.07, n=17, df=2, p=0.21).

Discussion

The aim of this study was to measure and compare the activity of six muscles involved in wheelchair propulsion in a sample of non-disabled wheelchair participants using right sided one armed propulsion mechanisms. The objective of the study was to identify which one armed wheelchair generated the least amount of activity when maneuvering in a controlled environment and around obstacles.

The results suggest that the NuDrive required the greatest amount of activity in biceps, and pectoralis major muscles in propelling over mats and around corners. The Neater Uni-wheelchair however, involved the least activity of these muscles in propulsion during these same key activities. Triceps activity was significantly greater in the Action 3 wheelchair with steering in straight running when compared to the other two wheelchairs.

Biceps is not normally considered to be a muscle used in the propulsion of wheelchairs since the action of propulsion involves extension of the elbow. The traces produced by both biceps and triceps would concur with this and indicated that biceps was active in the return of the arm following the propulsive stroke. Similarly triceps was activated during the propulsive phase.

The results for biceps may be explained through the differences in the mechanism of propulsion for the different wheelchair. The wheelchairs using a pushrim for propulsion require the users to release the pushrim at the end of the propulsive stroke, and return the arm to the starting position. During this return movement the upper muscles will be required to flex the elbow but there will be no additional load during this movement. Conversely when using the lever drive system the user is required to return both upper limb and the lever to the starting position at the end of each propulsive stroke. In this case the muscles of the upper limb will be working against the weight of the upper limb and the resistance afforded by the lever. This will increase the requirement for biceps muscle activity to flex the elbow. There was no difference in biceps activity during straight running which may be due to the fact that following the propulsive push, momentum may have assisted the forward motion of the chair which may have been supported by free-wheeling. The biceps activity during the slalom and over mats would incur additional effort due to the need to return the arm quickly to the starting position in order to cope with the lack of forward momentum as a result of the rolling resistance experienced from the mats and the tight turns associated with the corners and slalom. The differences in activity of pectoralis major would also concur with this thinking. Pectoralis major is a significant contributor to propelling wheelchairs (Rankin et al 2011). The significant differences identified in mats and corners may indicate the increased requirement on muscle activity when momentum is impeded due to increased rolling resistance. Pectoralis major is also acknowledged to be particularly susceptible to fatigue and injury due to its dual role of handrim power generation and stabilising of the glenohumeral joint (Ranking 2011). ADELT, PECM and INFSP were the primary contributors to mechanical power during the push phase, which was consistent with the large shoulder flexion moments and powers found by others (Koontz et al., 2002; Kulig et al., 1998; Morrow et al., 2010; Rodgers et al., 2003; Sabick et al., 2004) and suggests that wheelchair users likely select arm configurations that allow the shoulder flexors to function as the primary actuators during the push phase.

The involvement of triceps in straight running is not surprising because the long head is known to contribute to propulsive power (Rankin 2011). During resisted propulsion this may be explained through the greater activity of pectoralis major acting as the primary muscle of propulsion. It was evident during the trial that all participants found the mats and slalom parts of the course more challenging and appeared to change their position in the chair to enable them to cope with the increased resistance. This may have led to a change in movements of the upper limb for propulsion which in turn may have changed the primary muscle for propulsion from triceps to pectoralis major. Kinematic studies would confirm this suggestion.

The Action3 wheelchair produced higher forces than the Neater Uni-wheelchair over mats or during slalom driving but less than the NuDrive. This is not surprising because the 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 be the direction of steering [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. Ideally force measurement under the buttocks would help to explain this finding however, unfortunately the study exploring vertical reaction forces under the buttocks did not involve driving over mats. Further work to measure muscle activity at the shoulder during propulsion in the same controlled environment may also help explain these findings.

Conclusion: This study of non-disabled users suggests that

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 over use injury in propelling one arm drive wheelchairs.

Implications for 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.

Declaration of Interest

There is no conflict of interest between the participating parties. All contributors have reviewed and agreed the content of the manuscript.

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