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Classification Efficiency in Wheelchair Rugby: Wheelchair Propulsion Power Analysis

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Abstract: This study determines the ability of people with tetraplegia, specifically wheelchair rugby players, to propel themselves in their rugby wheelchair. The paper makes a comparison between three groups of athletes: those who had undergone a Deltoid - Triceps Transfer (DTT) procedure; those who had some triceps function; and those with no triceps function. It is intended that this analysis will assist in informing current wheelchair classification processes, specifically for those athletes with DTT. A total of 17 athletes were tested and their data analysed using numerical differentiation and modeling to derive a quantitative performance indicator of maximum wheelchair propulsion power. Results showed that the no triceps and DTT groups performed similarly with a mean of 26W and 19W respectively. Both of these groups were under half the power output of the triceps group who achieved a mean propulsion power of 65.5W.

1. INTRODUCTION

1.1 Motivation

Tetraplegia is complete or partial paralysis of a person from the neck down and including all four limbs. Participation in wheelchair rugby is a serious pursuit of many players and can greatly improve their quality of life (Smith 2005). Quantification of function for athletes is important to ensure fairness and maximum participation for all levels.

1.2 Wheelchair Rugby

Wheelchair rugby, also known as “Murderball” (2005), is a game played on a hard floor surface between two teams of four players in wheelchairs. The objective of each team is for a player to cross a line at each opposing end of the court with a ball in their possession. The game involves passing, manoeuvring, blocking, acceleration and speed, and tactical play. Players are classified by their level of impairment, as with many other disabled sports, to ensure an even playing field regardless of disability.

In wheelchair rugby an athlete can be classified from 0.5 points to 3.5 points depending on their functional ability to perform technical aspects of the sport. “The 0.5 class includes those athletes with the most disability and the 3.5 class includes those athletes with the least disability or ‘minimal’ disability eligible for the sport of wheelchair rugby” (*A Layperson’s Guide to Wheelchair Rugby Classification*, 2013). Each four person team must have no more than 8.0 total points on the court at a time.

At present, classification involves an assessment of a player’s functional muscle strength and an on-court analysis. Classification does not involve reproducible quantitative testing (*A Layperson’s Guide to Wheelchair Rugby Classification*, 2013).

1.3 Deltoid-Triceps Surgery

In New Zealand, assistive surgeries for people with tetraplegia have been performed for over 30 years including the Deltoid-Triceps Transfer (DTT) procedures. This surgery enables people with tetraplegia to have active elbow extension when previously they had no, or very weak, natural triceps function. Currently there is conjecture around the classification of athletes who have had this surgery as to whether their triceps-like functionality obtained from their DTT should place them as a 0.5 or a 1.0 point athlete.

1.4 Propulsion Power

In a wheelchair rugby game context, power is an indicator of a player’s acceleration and top speed. Both are important in outmanoeuvring an opponent. This study uses wheelchair dynamometer testing to provide a performance indicator for wheelchair propulsion power.

The aim of this study is to determine if there is a difference in the propulsion power of wheelchair rugby players with tetraplegia who: a) have triceps; b) have no triceps; c) have had DTT surgery.

2. RESEARCH

2.1 Muscles used during Wheelchair Propulsion

Wheelchair propulsion involves two phases: the stroke phase, where force is applied to the wheel rim, and recovery phase where the hands have left the rim and are pulled back in preparation for the next stroke. The stroke phase can be split into the pull phase and the push phase.

The pull phase exists from when the stroke starts and hands are applied to the rim until the TDC (top dead centre) where the hands are at the top of their arc. This phase involves elbow flexion as the hands are brought towards the body and requires bicep contraction.

The push phase exists from when the TDC until the stroke phase ends when the hands leave the wheel rim. This phase involves elbow extension as the hands move away from the body and requires contraction of the triceps. (Yao 2007)

3. PROCEDURE

3.1 Ethics

Ethical approval was gained from University of Otago Ethics committee (ref 13/042). Participants were recruited at two wheelchair rugby tournaments and one local wheelchair rugby training location in New Zealand. Participants were eligible to participate if they were classified wheelchair rugby athletes.

3.2 Participants

This study utilised a uniquely available and diverse pool of wheelchair rugby athletes to draw conclusions on an aspect of their overall ability, their wheelchair propulsion, based on wheelchair propulsion power; importantly, a quantitative means of analysis.

The sample base was separated into three groups: 1) Natural Triceps Function, 2) no triceps function, and 3) Troid's Assisted Triceps Function with comparisons to be made between the three.

Table 1: Participants

Group	Number
Triceps	8
No triceps	4
DTT	5
Total	17

17 Participants were tested (Table 1) and were classified into the groups as follows:

- Triceps) included all wheelchair rugby players that had active triceps muscle grade 2-5.
- No triceps) included all wheelchair rugby players that had triceps muscle grade 0-1.
- DTT) included all wheelchair rugby players who had had Deltoid-Triceps surgery performed; muscle grade 1 – 4.

3.3 Experimental Apparatus

An inertial dynamometer was built at the University of Canterbury specifically for measuring wheelchair power output. It is pictured in Figure 1 below. The rig is made of two halves that can be separated to accommodate the larger truck width of wheelchair-rugby chairs. The rig supports a chair so that the rear wheels sit on the rollers. Circular steel weights, or inertia discs, can be fixed to the protruding axle of each roller to simulate the mass of the participant. Two digital encoders connected to each roller axle measure the rotational displacement of each roller in time (100 measurements per second). This data is received via cable connection by a laptop and displayed and recorded using LabVIEW. The data is saved to the laptop for future data analysis.

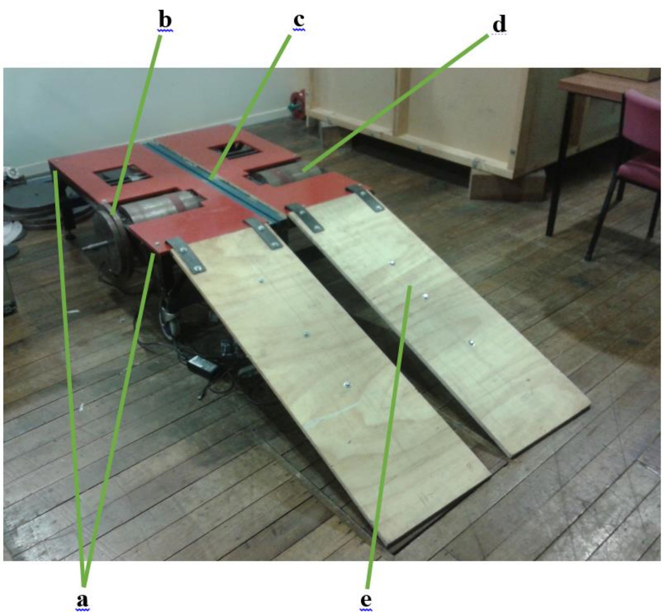

Figure 1: Wheelchair Dynamometer Test Rig:

a) Anchor Points; b) Inertia discs; c) Division between sections; d) Rollers; e) Ramps.

3.4 Experimental Procedure

The experimental procedure initially consisted of assembling the wheelchair dynamometer test rig by attaching the ramps and aligning the two dynamometer halves in parallel. The instrumentation is attached, checking to ensure a connection between the encoders and a laptop and that sample readings are appropriate.

The mass of the person is ascertained and an equivalent rotational inertia for the system is found so as to create the same inertial properties as they would experience on flat ground. Disc weights are fixed to the protruding axles to adjust the system inertia accordingly. The test participant is then placed on the rig, secured by ties to the front and back. An effort is made to achieve balance in their position such that the rolling resistance in each wheel is the same.

The test participant is then asked to complete an acceleration test. The test participant is asked to accelerate their wheelchair, with maximum exertion, from rest to a maximum speed; the acceleration phase. The participant must then immediately release the wheels and allow the system to roll down to a stop of its own accord; the deceleration phase. The deceleration phase is essential in later finding the rolling resistance of the system.

4. PROCESSING

4.1 De-identifying Data

Once participants were allocated into their groups, they were assigned a unique identifier to maintain their anonymity during data analysis.

4.2 Data Analysis

Raw data obtained from testing was used to create displacement-time curves for each participant as shown in Figure 2. The data was numerically differentiated using the centred differentiation method to create velocity-time arrays.

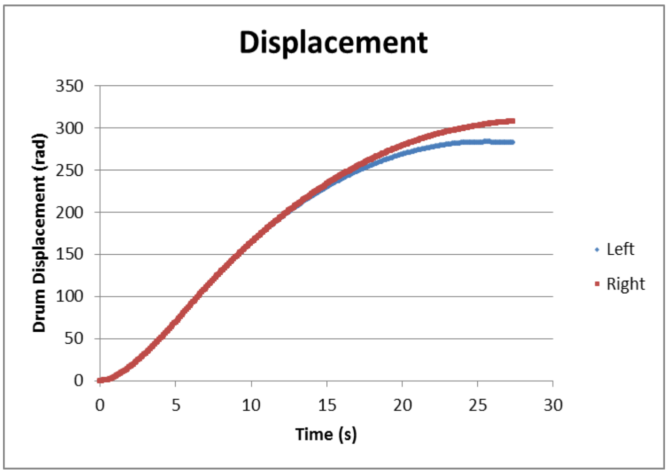

Figure 2: Example of Raw Data over the Time Period of Interest, a Displacement-Time Array

Instead, an analytical model of velocity-time arrays was created using regression curving fitting of a quadratic function to approximate the time averaged trend of velocity. This analytical model could then be analytically differentiated and regenerated into a discrete acceleration-time data series over the time range of interest. An example of the velocity-time array, including regression lines, for the acceleration phase can be seen in Figure 3 below.

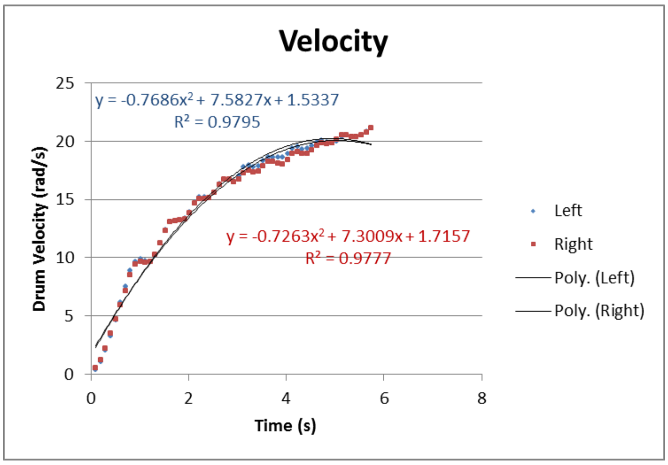

Figure 3: Example of Analytical Velocity Model Created from Discrete Data during the Aceleration Phase

From the ensuing acceleration-time arrays, net torque-time arrays are easily created knowing the system inertia. From the deceleration phase of the test, an approximate constant deceleration value can be found by linear regression of the velocity-time array, pictured in Figure 4 below. This deceleration has an equivalent torque due to the system's constant inertia. This torque is effectively the rolling resistance of the system that is also present during the acceleration phase of the test and can be added onto the net torque-time array to create a torque-time array that reflects the torque provided by the person, not just the net torque provided to the roller whose motion the encoders detect.

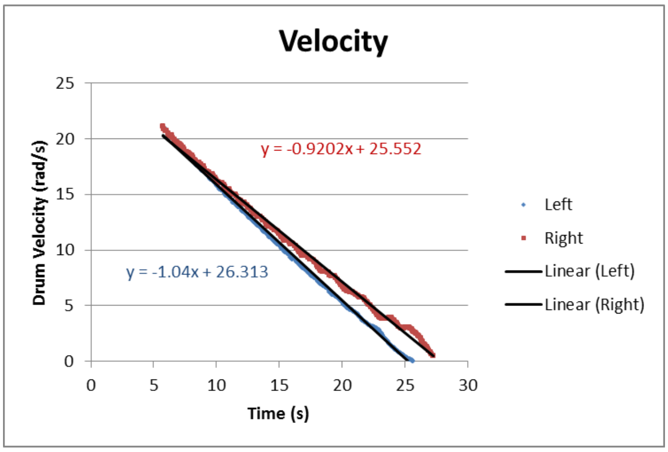

Figure 4: Example of the velocity during the deceleration, "run down", phase and accompanying analytical model

By multiplying the individual arguments at the equivalent time step of the new torque-time array and existing velocity-time array a power-time array is created. This power can be plotted against velocity instead of time to produce a human power curve.

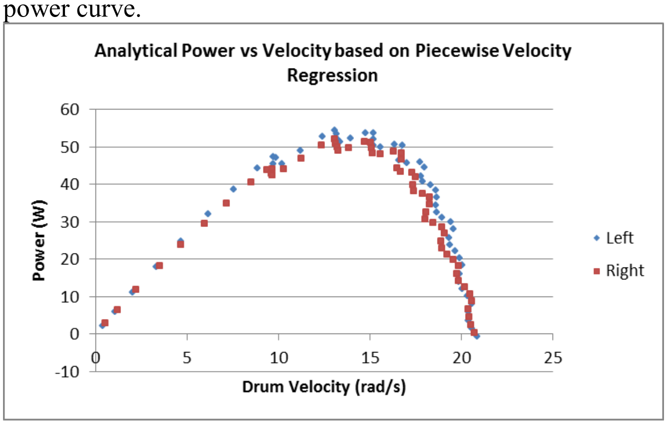

Figure 5: Example of a Participant's Power Curve

From the participant's power curve, Figure 5, the maximum value of the best arm was chosen to represent, as a scalar value, the curve as a whole. This is because it is difficult to quantifiably compare curves in magnitude and all that is desired is a single value for comparison between the different triceps groups.

A diagrammatic representation in Figure 6 below shows, at a glance, the principle behind the data analysis.

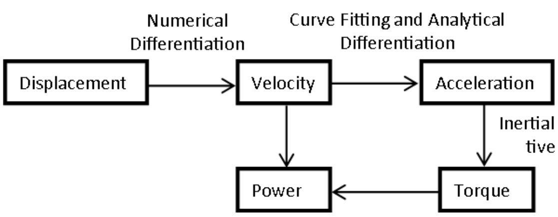

Figure 6: Data Analysis flow chart Summary

5. QUANTITATIVE RESULTS – PEAK POWER

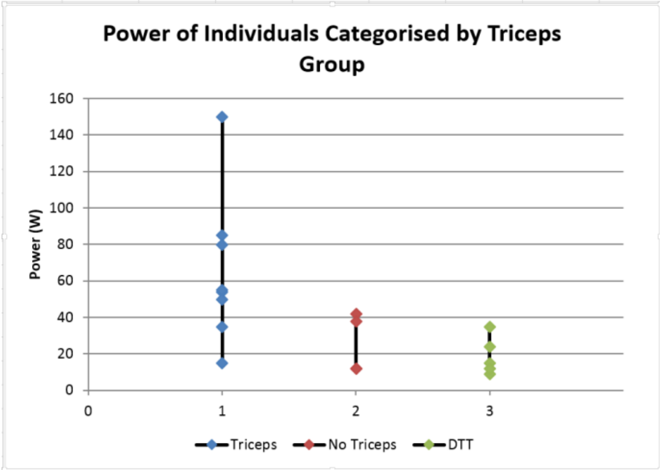

Figure 7: Peak Propulsion Power of each triceps group, showing all individual results as marks and the range as a line.

Table 2: Peak Power Summary by Group

	Triceps (n=8)	No triceps (n=4)	DTT (n=5)
Mean Peak-Power (W)	65.5	26	19
Median Peak-Power (W)	54.5	25	15
Standard Deviation (W)	38.2	14.1	9.44
Lower Bound (W)	15	12	9
Upper Bound (W)	150	42	35

The triceps group demonstrated the most propulsion power compared to both the no triceps and DTT groups (Figure 7). However, this group also had the largest range and standard deviation. The no triceps and DTT groups demonstrated similar mean and median peak power (Table 2). All groups had a similar minimum peak power.

Additionally, as comparison, and for context, one able-bodied person, a 22 year old male not accustomed to wheelchair propulsion, was tested and found to have a peak power of 45W, less than some of those form the triceps group.

6. QUALITATIVE RESULTS

Looking specifically at the discrete velocity data can reveal details about the propulsion that are lost in just a value of maximum power. Three examples of individuals of each group were selected, to be representative, based on proximity of their peak power to that of their group mean to demonstrate why there are differences between the triceps groups in power output.

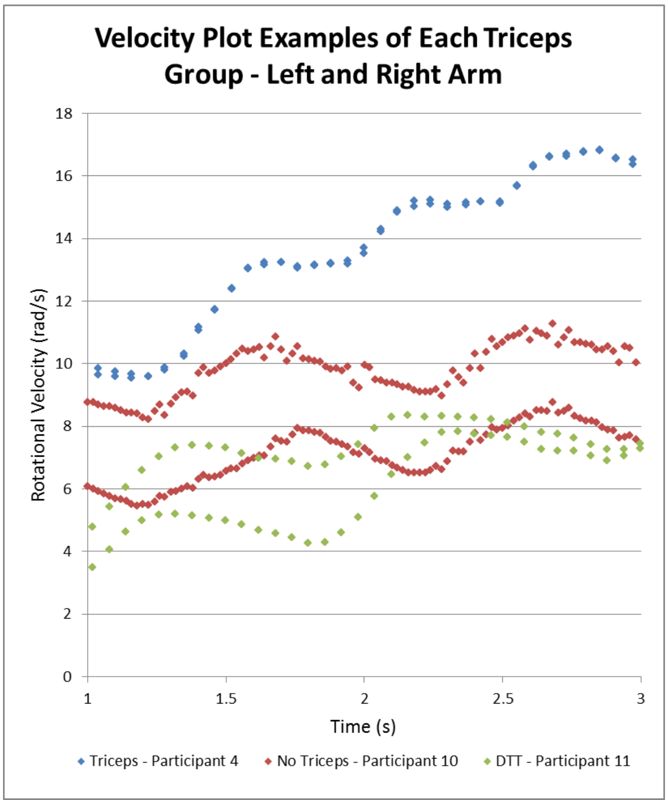

Figure 8: Example of Velocity-Time Plots of three typical participants, each of one of the Triceps, no triceps or DTT groups. Peak Power outputs of these individuals are 55W, 38W and 15W respectively. Note: The triceps group (in blue) has two lines for each arm, as the others do, but they are overlaid.

In Figure 8, by the time one second has elapsed, the triceps group participant has already increased their velocity to 10rad/s, an equivalent wheelchair speed of 1.3m/s (or 4.5km/h). Within three seconds, the Triceps participant completed three propulsion cycles, while the participants in the no triceps and DTT group performed two. The change in velocity per stroke is similar between all three but it is the speed of the stroke, and thus higher force and power output in that shortened period of time, which allows the person with triceps to attain greater speed and acceleration.

7. DISCUSSION

7.1 Expected Results

7.1.1 Group 1, Triceps

It is expected that this group will measure the highest of the three groups' with tetraplegia in regard to propulsion power output. This is because of their natural triceps capability and digit mobility allowing increased grip and push power over the push phase of the propulsion stroke.

7.1.2 Group 2, No triceps

It is expected that this group will measure lowest in the propulsion power output. This is due to this group's extent of paralysis of key upper limb muscle groups. This means they will have poor power output in the push phase of propulsion and may well rely on pulling of the wheel's rim from behind them. In addition, while the group is defined by having no triceps function, in reality this is usually combined with a more severe degree of paralysis that will include reduced finger and wrist motion, thus impairing their ability to grip the wheelchair rim.

7.1.3 Group 3, DTT

It is expected this group's performance will sit between that of group 1 and 2. This is due to their capabilities being similar to the no triceps group in all muscle groups, including finger function, except for the elbow extension function due to their DTT procedure. The degree to which improved elbow extension assists rugby wheelchair propulsion is somewhat unknown. It is possible that the push phase of the propulsion could be improved and overall propulsion power greater than the no triceps function group.

7.2 Key Result

A total of 17 athletes were tested for wheelchair propulsion from three different groups; triceps, no triceps and DTT. Their results were processed using numerical differentiation and modelling to derive maximum power, a performance indicator of their propulsion ability.

The project successfully determined that the triceps group performed better than no triceps and DTT groups, achieving 252% and 345% of each respectively, by median results. The no triceps group performed better than the DTT group averaging 137% of the DTT mean peak-power.

The performance of the able-bodied person; being less than some wheelchair rugby players was surprising. This along with the variation within the groups indicates that while disability can limit a participant's maximum potential power output, a significant contributor to performance is developed strength and proficiency through training. With this in mind, it seems unwise to categorise an individual player based purely, or even partially, on their propulsion power as it takes away from some of the aspects of natural ability and improvement through training.

Measuring propulsion power across various different groups and then using this information about a group as a whole to aid classification criteria has potential. It would require further testing to increase sample size and information about a group, but not the testing of every player seeking classification.

7.3 Validity

7.3.1 Controls

Given the very small population size, a large sample size cannot be tested. This study took all WCR classified people who were available. There is no control of gender proportions, age, level of fitness, or general health. Additionally, testing has to be conducted around the convenience of the participant, often in between matches at a tournament, so even level of exertion immediately prior to the test can vary greatly. This is simply a consequence of conducting research on people in a population that is very small and geographically difficult to access combined with the difficulty of setting up a large testing apparatus.

7.3.2 Apparatus

A particular issue, especially early in testing was anchoring the participant's wheelchair onto the rig. The force applied must be large enough to keep the wheelchair stationery once testing begins. However, the anchoring force must not be so large that it adds a significant amount of contact force between the roller and wheel, increasing rolling resistance. It was also difficult to secure the wheelchair to the testing apparatus to ensure even resistance between both sides.

Participants commented that it was more difficult propelling themselves on the rig than on the ground. Given the knowledge that the inertia added was appropriate and the above mentioned issues it would seem there was more rolling resistance in the system than participants would experience on level ground. This can be attributed to increased localised pressure on the tyre due to the curved surface of the roller and increased force from the ties, and losses through the rollers' bearings.

While this resistance is accounted for in data analysis and does not affect results, it does limit the rig from achieving desirable ground-like conditions.

7.3.3 Method

Having to convert from discrete series data to an analytical model involves approximation and loss of detail and information. This is not significant as the analysis still shows differences between the groups that are large. Recommendations for future tests would be to use encoders which are more sensitive to displacement or velocity sensors.

7.3.4 Sample Size

The sample size is too small to achieve statistical significance but we are able to determine trends within and between the groups. Larger sample sizes would allow for statistical testing.

7.3.5 Human Input

Testing with people is always inconsistent. They can perform differently on the day to their average performance. If a method like this were to be eventually used to help classification, multiple testing at would be required to ensure all factors were accounted for.

7.3.6 DTT Procedure

Results suggest the no triceps group equals or outperforms the DTT group with regard to power output in their rugby wheelchair. Though this is surprising it does not mean the surgery is not effective. This project did not test participants before or after surgery, additionally this project only tested wheelchair propulsion and does not account for other advantages DTT provides.

8. CONCLUSION

The triceps group outperformed the no triceps and DTT groups by a significant margin in propulsion power. This does not speak for all aspects of the game, but at least suggests that as far as mobility on the court is concerned triceps groups have an advantage, on average. It is worth noting there are some participants with triceps who performed only as well as no triceps and DTT groups did, but not better. This shows that variation in performance, especially within this group is large.

This study indicates that there is little difference in wheelchair propulsion ability between no triceps and DTT groups.

This experiment was reliable and valid in analysing wheelchair propulsion ability; however, a larger sample group should be analysed in order to gain greater certainty in the outcomes. This study also shows that you can quantitatively define wheelchair propulsion ability which is helpful in informing classification but not in its direct use.

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