Preprints of the 19th World Congress
The International Federation of Automatic Control
Cape Town, South Africa. August 24-29, 2014

Classification Efficiency in Wheelchair Rugby: Strength Analysis

Caitlin J. R. Tromop van Dalen*.
Shayne Gooch*.
Benjamin J. Ingram*. Guy L. Borren*. Andrew Jenkins*.
Jennifer Dunn.**

**University of Canterbury, Christchurch, PO 8031 NZ*
(e-mail: shayne.gooch@canterbury.ac.nz).
*** University of Otago, Dunedin, New Zealand*
(e-mail: jennifer.dunn@otago.ac.nz)

Abstract: This study investigates the arm strength and function of people with tetraplegia, specifically in relation to wheelchair rugby athletes and their in game classification level. Four groups of individuals were assessed; able-bodied participants, individuals with natural triceps function, those with limited or no triceps function, and people who had undergone a deltoid-to-triceps assistive surgery. This research seeks to improve understanding the range of muscle function impairment in people with tetraplegia, and to provide insight into the effects of the deltoid-to-triceps procedure on muscle function. It is hoped that these results will aid in the classification process for wheelchair rugby athletes. 16 athletes were tested, and individual force maps were created demonstrating the magnitude and location of high arm strength areas around the body. Results showed that the able-bodied group reached the highest maximum applied force, followed by natural triceps, no triceps, and then the deltoid-triceps group. The results from the no triceps and deltoid-triceps groups showed areas of overlap, indicating a similar function level. It is recommended that the push test be used to aid athlete assessments along with the wheelchair rugby classification process.

1. INTRODUCTION

1.1 Purpose

Tetraplegia is the partial or complete loss of function of all four limbs and the torso of a person who has suffered a major injury or illness. Each year a significant number of people are affected by tetraplegia. The annual incidence of spinal cord injury in the U.S. is approximately 40 per million population (National Spinal Cord Statistical Centre (2013)). This equates to 12000 new cases per year, with ranging degrees of impairment between each case. Currently each individual is assessed by a specialised physiotherapist who will carry out a physical evaluation of the strength and function of different muscle groups. These assessments can often be subjective, leading to inconsistencies in results.

This research aims to establish a new method of physical assessment of people with tetraplegia. This research is a continuation of the work carried out by Laura Hollingsworth at the University of Canterbury (Hollingsworth, L (2010)). While this tool is valuable for understanding function for everyday activities, there are also important implications for sporting activities, particularly wheelchair rugby.

1.1 Wheelchair Rugby Classification

Wheelchair rugby is played by athletes with a range of physical impairments, including tetraplegia. Each athlete is physically assessed and classified from 0.5 to 3.5 points, depending on functional ability. “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.” (IWRF, 2013). Each of the two teams consisting of four team members may have up to a total of 8.0 points on court at one time.

1.2 Deltoid-Triceps Procedure

People with tetraplegia often undergo assistive surgeries, which manipulate remaining muscle function to recover the performance that was lost as a result of tetraplegia. One such procedure is the deltoid-triceps transfer, which offers triceps-like function for people with tetraplegia who have lost function in their triceps.

While the deltoid-triceps transfer is a well established procedure, there is little quantitative information on the improvement of performance that comes with this operation. This is leading to uncertainty in the classification level of wheelchair rugby athletes who have received the deltoid-triceps transfer, specifically whether such players should have a 0.5 point or a 1.0 point classification. Some athletes

are resisting undergoing the deltoid-triceps procedure, which could greatly benefit them in their everyday life, due to fears of the implications in their sporting career.

As well as providing a new method for assessing physical function of people with tetraplegia, this research also aims to increase the understanding of the change in performance that comes with the deltoid-triceps transfer.

2. TESTING

2.1 Test Groups

Testing of wheelchair rugby athletes was carried out at the Wheelchair Rugby Low Pointers National Tournament in Hamilton, New Zealand in April 2013. Some tests were also carried out at the Spinal Unit at Burwood Hospital in Christchurch, New Zealand. Able-bodied testing took place at the University of Canterbury, Christchurch, New Zealand. 16 participants were tested and classified into each of the four groups in question: able-bodied, natural triceps function, no triceps function, and deltoid-triceps. The definition of these groups is as follows:

- An able-bodied participant has no paralysis in the entire body
- A natural triceps participant has no paralysis to the triceps as concluded by a physical assessment, but will have other areas of paralysis in the upper limbs and body.
- A no triceps participant has some or complete paralysis of the triceps as concluded by a physical assessment.
- A deltoid-triceps participant has undergone the deltoid-to-triceps procedure, and will have other areas of paralysis in the body.

The division of these groups can be seen in **Table 1**. This sample size is statistically small, but is able to provide valuable insight into a small population in New Zealand.

Table 1. Participant Numbers

Triceps Category	Number of Participants
Able-Bodied	4
Natural Triceps	6
No Triceps	3
Deltoid-triceps	3

2.2 Testing Rig

A custom-built test rig was used to directly measure the arm strength of test participants. Participants push on two hemispherical hand supports. The hemispherical hand support (**Figure 1**) transfers the hand force to a load cell.

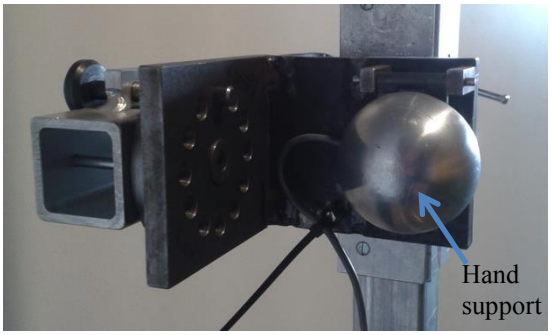

Figure 1. Hemispherical hand support

The hemispherical hand supports are positioned on a frame consisting of two adjustable upright and horizontal members, which can be seen in **Figure 2**. The supports can be moved horizontally and vertically to discrete locations at 100mm intervals on the frame, and secured in place with metal pins.

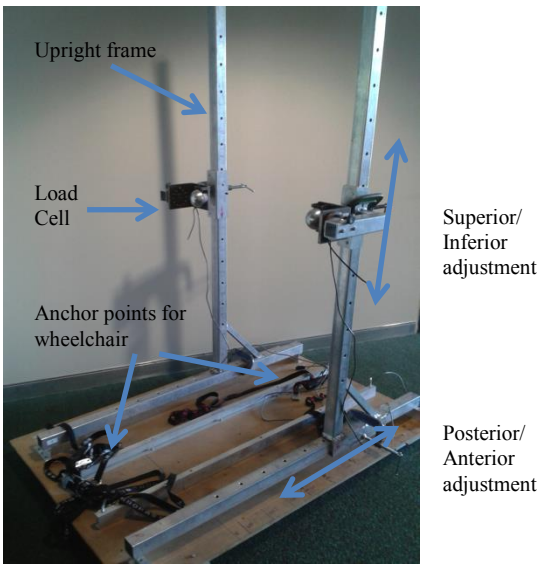

Figure 2. The push test rig

2.3 Testing Procedure

A participant is tested in their day chair, which is secured to the base of the test rig. The axle of the back wheel is located to the datum point on the base of the test rig. The strain gauges are positioned at corresponding locations and the participant is asked to push on these with maximum force for roughly 3 seconds, as shown in **Figure 3**.

Figure 3. A participant pressing on the two strain gauges

The participant is instructed that they must not grip the strain gauge with their fingers, and able-bodied participants are instructed not to use their legs or feet for additional force. Each participant is allowed trial pushes to check comfort in each adjustment. Once a measurement is taken at a location, both strain gauges are moved to the next location. Anterior to posterior adjustments are made between 600mm in front of and 400mm behind the axle of the wheelchair wheel. Superior to inferior adjustments are made from level with the wheel axle up to 1200mm above it. The position of the vertical member is alternated between in front of and behind the participant to allow recovery time for different muscle groups. A complete set of test results includes measurements at 100mm intervals over the two planes in front of each of the participant's arms. The test takes approximately 1 hour to complete so the participant is instructed to push with high force but not so high as to fatigue rapidly. The participant is also offered small breaks from testing to allow recovery from fatigue.

2.4 Ethics

Testing was carried out under existing ethics approval from the University of Otago Ethics Committee (ref 13/042) for classified wheelchair rugby athletes, and additional ethics approval was secured from the University of Canterbury Human Ethics Committee (ref HEC 2013/26/LR) for able-bodied testing at the university. The principle investigators supervised the testing and obtained consent from participants.

3. PROCESSING

The raw data obtained from the push test was uploaded onto a laptop PC using LabVIEW. The data was exported to Matlab where it was then processed to produce force-contour maps using custom Matlab codes. A single contour map was created for each participant by averaging the results from the left and right hands. These force maps indicate the magnitude of forces applied by the arms, and the distribution of strength capability at different points around the body.

An averaged force map was also generated for each of the four sample groups in question. It was hoped that individual force maps could be compared to these generic force maps to aid the wheelchair rugby classification process.

4. RESULTS

Figure 4 shows the wheelchair rugby classification and the maximum force pushed by each participant. Results showed that there were differences between an individuals left and right hand results including size and locations of maximum forces. Both sets of results were averaged to give an overall representation of a participant's strength and function. The maximum force seen in **Figure 4** is the force averaged between both hands.

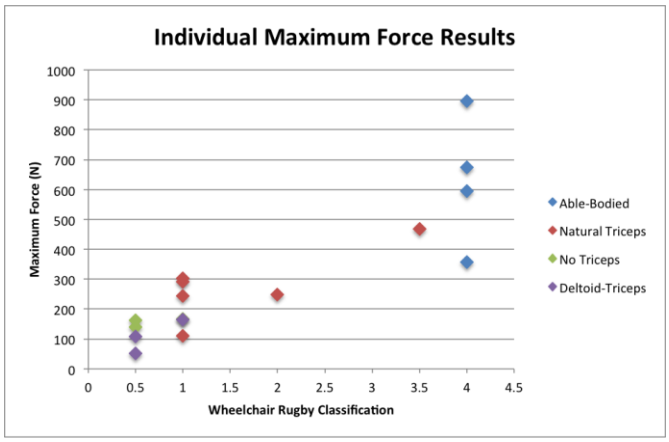

Figure 4. Maximum forces reached by participants

There is a visible correlation between wheelchair rugby classification and the maximum applied force from an individual where a higher wheelchair rugby classification typically corresponds to a higher maximum applied force. Able-bodied participants demonstrated an ability to reach the highest maximum force out of all groups tested, followed by natural triceps, no triceps, and deltoid-triceps participants. The range of forces achievable by groups appeared to overlap into other test group ranges, indicating that individuals with less muscle function were able perform better than the class above.

The results from the no triceps and the deltoid-triceps groups can be seen in **Table 2**. All maximum force results can be seen in Table 3 in Appendix A.

Table 2. Classification and maximum push force results

Identification Number	Test Group	Rugby Classification	Max. Force (N)
5	No Triceps	1	166
21	No Triceps	0.5	139
22	No Triceps	0.5	163
3	Deltoid-Triceps	1	164
13	Deltoid-Triceps	0.5	52
19	Deltoid-Triceps	0.5	109

Representative force map from one of the participants in each group are shown in Figures 5 to 8. It is important to note the different scaling used on each figure due to the differences in maximum applied force between individuals.

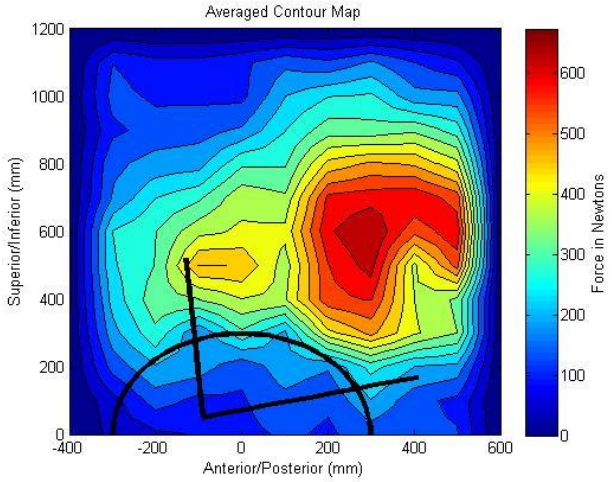

Figure 5. Able-Bodied sample force map

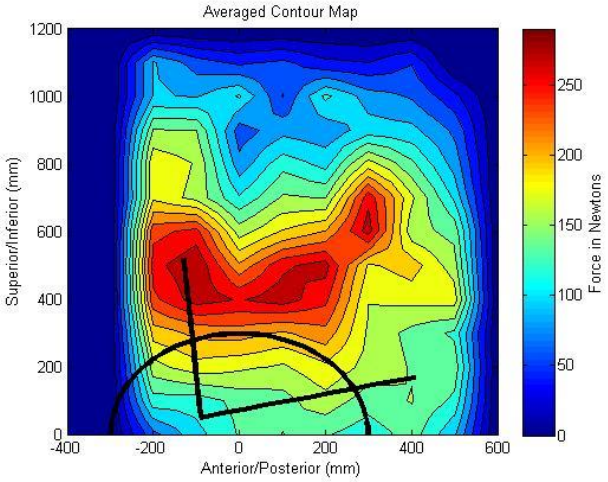

Figure 6. Natural Triceps sample force map

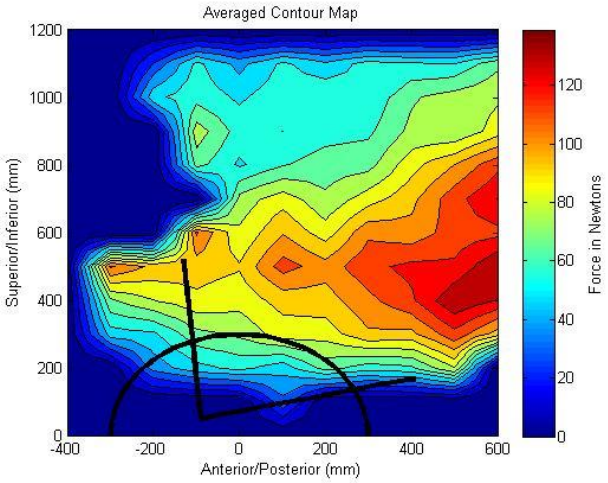

Figure 7. No Triceps sample force map

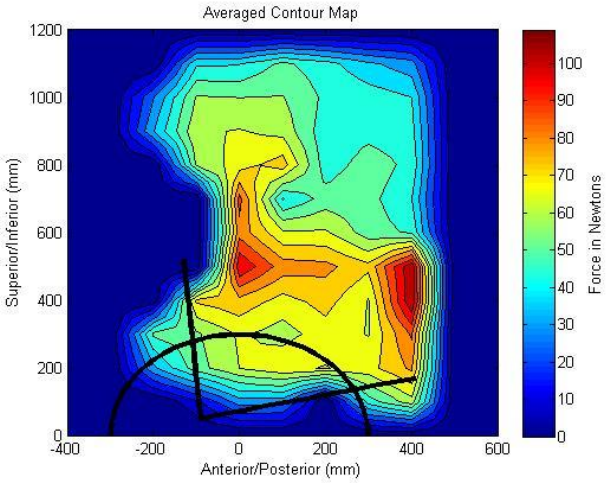

Figure 8. Deltoid-Triceps sample force map

Able-bodied maps showed a common trend where one maximum force was located in a region in front of the chest. The natural triceps, no triceps, and deltoid-triceps groups had maps varying greatly from the able-bodied map. Maximum forces from these groups tended to be much lower than those achieved by able-bodied participants, and these forces were located at varying locations around the body. Some participants presented multiple locations of high applied forces. The location and maximum applied force of all tested individuals is shown in Figure 9. The magnitude of the force applied is indicated by the size of the circle on the chart.

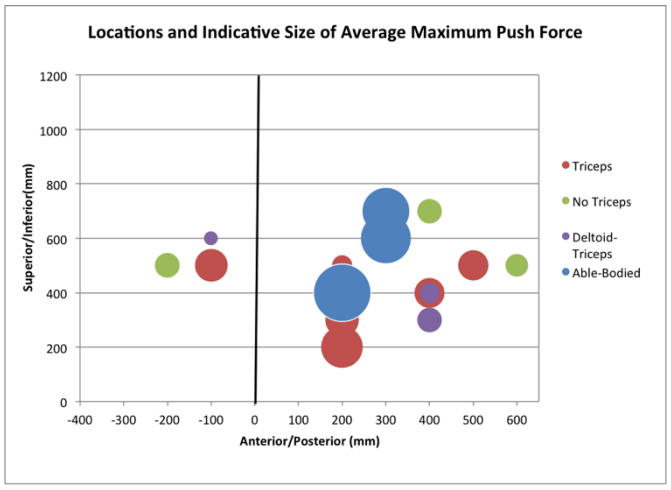

Figure 9. Locations and Indicative Magnitude of Individual Average Maximum Push Force

5. DISCUSSION

5.1 Key Results

On average the natural triceps group reached higher maximum applied pushing force than the no triceps and deltoid-triceps groups. The no triceps group also performed better than the deltoid-triceps participants on average, although it is important to note the range in the results for each group. Some individual participants in the deltoid-triceps group performed equal to individuals in the no triceps group, but never to a higher level than the no triceps group. This indicates a high level of individual variation, and also provides insight into the effects of the deltoid-triceps procedure on arm push strength.

In reference to **Table 2**, participants 5, 22 and 3 received different wheelchair rugby classifications despite very similar maximum applied forces. The two no triceps participants are classified at 1 point and 0.5 points, while the deltoid-triceps participant in question is classified at 1 point. This indicates the importance of factors other than arm strength when assessing classification levels. The push test provides valuable insight into an individual's muscle function and is an appropriate tool for aiding the wheelchair rugby classification assessment, but it should not be used as the sole criteria for wheelchair rugby classification.

All of the force maps of able-bodied participants included one peak force located in front of the chest, while the remaining groups demonstrated multiple locations of high applied force. These locations changed for each participant, but there are no obvious trends within the tested groups. Further research should be carried out in order to determine the relationship between the peak force locations and loss of muscle function specific to an individual.

Averaged group force maps were created for each of the test groups, but were found to be an inappropriate method for determining general function of different degrees triceps impairment. The individual force maps did not show adequate correlations to the averaged group force maps due to personal variation between each individual. The individual force maps should be used as an additional tool to inform the classification criteria rather than for individual assessment by comparing to an averaged map.

5.2 Controls

Restrictions on test participants exist due to the small population of wheelchair rugby athletes in New Zealand. The limited range of potential participants meant there was little opportunity for selection control to allow for variation in gender, age, ethnicity, and levels of fitness. Participants tended to be between 20 and 40 year old males of both Maori and Pakeha descent. Generally the levels of fitness were comparatively high as the participants were wheelchair rugby athletes, but this fitness did vary depending on level of involvement in the sport.

5.3 Fatigue

Participant fatigue was a major concern during testing, as approximately one hour was required for a complete test. Each force application was of a very short duration and was followed by a rest period. Participants were instructed to apply a force representative of their maximum without over exerting themselves. Much of the testing was carried out during the wheelchair rugby tournament so athletes were often fatigued to different degrees even before starting the test.

Altering the test rig to allow a much faster testing process would reduce the inconvenience of carrying out an entire one hour test as well as reducing the impact of fatigue on the results. Such alterations could include larger spacing between measurement points so that the number of measurements is reduced. The metal pins that secure the strain gauge to the metal frame would often get stuck, so an alternative to this fastener would also speed up testing.

5.4 Participants

Although the population of people with tetraplegia in New Zealand is limited, the number of people tested for this research did not exhaust this resource. More participants should be tested to support the trends that are currently

visible. Participants should also be tested before and after undergoing the deltoid-triceps procedure so that direct comparisons can be made without considering individual variation.

6. CONCLUSIONS

The push test is a viable method for assessing and visualising the push force capabilities of people with tetraplegia, including those having undergone the deltoid-triceps procedure. Force maps offer insight into the strength and range of motion of individuals. More research should be carried out into the patterns that are currently visible in the force maps, and how these trends relate to the physically assessed muscle function and different areas of paralysis.

The testing of a limited range of wheelchair rugby athletes in New Zealand shows a good correlation between an individual's current classification and their maximum applied force. Able-bodied participants performed best on average out of all the groups, followed by natural triceps, no triceps, and then deltoid-triceps participants. Large amounts of individual variation are visible in the results, and some participant at lower classifications performed better than those at higher classifications. Further sampling and testing should be undertaken to determine the representativeness of the measured results.

The test rig can be adapted to simplify the adjustment procedure, which will result in faster test times and reduce fatigue in the participants. Improved portability would allow it to be used more easily in more locations to assess player classifications. This would help improve the sample size and develop a reliable data basis for the classifications.

The push test provides a quantitative measure of applied force and also shows the locations of these forces in a force map. It has the potential to reduce uncertainty in the classification process of wheelchair rugby players although it is not intended to be the sole criteria for this assessment.

7. REFERENCES

National Spinal Cord Statistical Centre (2013). *Spinal Cord Injury Facts and Figures at a Glance.* Birmingham, Alabama

Hollingsworth, L (2010). *Understanding and Modelling Manual Wheelchair Propulsion and Strength Characteristics in People with C5-C7 Tetraplegia*. Christchurch, New Zealand

Appendix A: All Participants Maximum Force Results

Table 3. Classification and maximum push force results

Identification Number	Rugby Classification	Triceps Function	Max. Force (N)
23	4	Able-Bodied	358
24	4	Able-Bodied	895
25	4	Able-Bodied	594
26	4	Able-Bodied	674
1	3.5	Triceps	469
4	1	Triceps	243
16	1	Triceps	291
17	1	Triceps	110
18	2	Triceps	248
20	1	Triceps	303
5	1	No Triceps	166
21	0.5	No Triceps	139
22	0.5	No Triceps	163
3	1	Deltoid-Triceps	164
13	0.5	Deltoid-Triceps	52
19	0.5	Deltoid-Triceps	109