EFFECT OF SEATING CUSHIONS ON PRESSURE DISTRIBUTION IN WHEELCHAIR RACING

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This study investigated the efficacy of pressure mapping technology in quantifying athlete-wheelchair interaction at the seating interface, and the influence of foam inserts on pressure (peak and average), and contact area. An XSENSOR LX100 pressure mat was located at the seating interface of six nationally ranked wheelchair racing athletes, who performed regular propulsion on treadmill. Substantial inter-athlete variation was observed on resulting pressure distribution (area and magnitude) for all athletes. Implementation of a foam insert did not impede recording ability, however did alter seating characteristics, lowering seating pressure (peak and average), and increasing contact area. This increase may enhance athlete-wheelchair interaction, which will likely result in a more powerful technique, and increased probability of winning races.

KEY WORDS: wheelchair racing, contact pressure

INTRODUCTION: There exist multiple classifications of wheelchair racing athletes, based on level of physical impairment (Tweedy & Bourke, 2009). Across all impairments, athletes will have varying levels of sensory and physical function (and correspondingly muscle atrophy) in affected lower extremity limbs. Affected limbs can either have complete or incomplete impairment (Kirshblum et al., 2011), with the latter meaning that function may be present inconsistently throughout each of the lower extremities, with right and left limbs commonly differing in both sensory function, physical function, and mass. As a consequence of the muscle atrophy, the lower extremities of these athletes are considerably smaller than that of able bodied legs, which assists athletes in assuming a more aerodynamic and biomechanically powerful seating position. Through this position, athletes are provided a natural advantage, which can assist athletes in achieving higher speeds of propulsion, ultimately increasing their likelihood of winning a race, however this advantage is more pronounced for some wheelchair racing athletes than others.

Currently, wheelchair racing design is fundamentally performance driven; with suppliers, engineers, and biomechanists challenged to produce a design satisfying athlete specific needs, skills, and capabilities (Lombardi Jr & Dedini, 2009), to optimise performance. Less consideration is placed on comfort however, as sensory function is typically lacking in the lower extremities of these atheltes where pain may be felt. Whilst pain may not be felt, pressure sores and ulcerations resulting from excessive loading or repeated frictional rubbing may prevent athletes from competing, even though their occurance caused the athlete no discomfort. Seating aids to reduce the onset of these issues are commonly observed in clinical applications, which have the sole focus of reducing total seating pressure and hence decreasing the likelihood of developing pressure sore injuries (Linder-Ganz, Yarnitzky, Yizhar, Siev-Ner, & Gefen, 2009) , with no consideration into performance. Similarly, the use of both presure mapping technology and customised seating interfaces have yet to be explored in sporting applications. Although the inclusion of cushioned interfaces may benefit athletes through a reduced risk of injury, it is uncertain whether these cushioning tools may be detrimental to performance. For example, the compressibility of a cushion may absorb applied energy from the lower extremity during propulsion and hence reduce the rate of force transfer to the chair. Similarly, if the seat is compressing, and hence moving underneath the athlete, it is possible that inclusion of these devices may effectively reduce the level of stability an athlete has at the seating interface. This research aims to address the appropriateness of the pressure mat in measuring athlete-wheelchair interaction at the seating interface during propulsion, and assess how this varies when seating cushions are used.

METHODS: Six Australian national age group team members (junior n = 4, senior; n = 2) provided the population sample for this research. Athletes provided signed consent to participate in this research, with ethical approval obtained from the University of Adelaide Human Research Ethics Committee, as well as the Australian Institute of Sport. All athletes completed the testing protocol, in their regular racing wheelchairs, on a treadmill inclined to 1º (Mason, Lenton, Leicht, & Goosey-Tolfrey, 2014). Treadmill speeds were selected based on their individual training speeds, based on whether athletes were either sprinters, or endurance based athletes, to ensure technique was representative, and to minimise effects of fatigue. These speeds ranged from 20km/hr through 38km/hr. Trials were one minute in duration, allowing three periods of 10s data capture at steady state speed. Data were averaged over three separate trials for each athlete. Data processing was performed using MATLAB 2015a (Mathworks, USA). Prior to testing, a period of acclimatization both at steady state (including at speed of testing), and acceleration were provided to all athletes, to provide confidence in the use of the treadmill during the test protocol.

Pressure parameters at the seating interface were calculated using specialised software (ForeSite SS), accompanying a pressure mat (XSENSOR LX100; Calgary, Alberta, Canada) recording at 4Hz. Pressure parameters included; peak pressure (PP) which is the average of the highest pressure values within a 9-10cm^2 area (Davis & Sprigle, 2008), average pressure (AP) which is the average of all non-zero pressure sensing cells, and contact area (CA) which is calculated by the number of pressure sensing cells under load (Davis & Sprigle, 2008). Specific placement of the pressure mat can be visualised in Figure 1, which facilitated the measurement of applied pressures normally (directly below shins), laterally (towards the seating bucket), and in the direction of motion (in front of knees). Settling time was greater than 24 minutes to ensure appropriate calibration and equilibration (accounting for creep demonstrated in sensors, tissues, and cushion material when used), with no visible shear or crinkling of the mat demonstrated within this period. Paired t-tests were used to determine the influence of the seating cushion on resultant seating pressure and contact area. Statistical analysis was performed using SPSS 13.0 (SPSS Inc., Chicago, IL, USA), with a significance set at α = 0.05.

Figure 1: Placement of pressure mat within wheelchair racing chair, with corresponding tablet demonstrating no singularities present from placement method into chair.

RESULTS: Substantial inter-individual variation in both AP and CA was present between athletes, as demonstrated in the left two pressure maps in Figure 2. Variation between PP measurements was not obtained as sensor saturation (when pressure values exceed the measuring capabilities of the sensor) occurred for all athletes. Implementation of a foam insert (rightmost pressure map in Figure 2) demonstrates lower PP (visually represented by the absence of localised dark region), as well as a greater CA CA varied from 220.97cm^2 through 688.71 cm^2 (where laterally applied pressures were present), highlighting an increase of 312% was present between athletes.

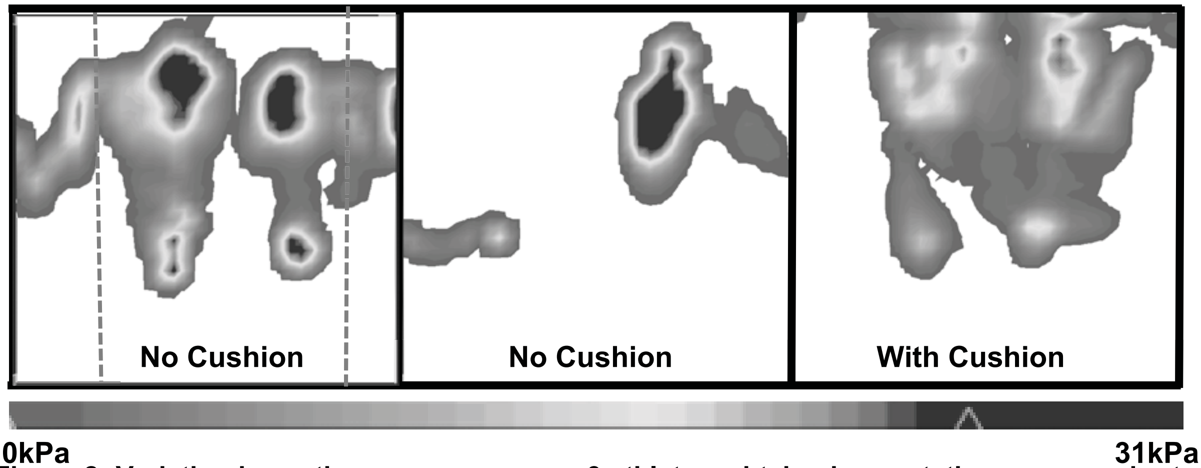

Figure 2: Variation in seating pressure across 3 athletes, obtained as a static measure prior to data collection. Dashed lines are representative of laterally applied pressures.

When foam cushions were used there was a significant decrease in AP and significant incresease in CA (p<0.01) The magnitude of differences shown in Figure 3, for a single, ten second trial. It is clear that foam cushions can effectively reduce PP, such that they are below this threshold of sensor saturation, with data presented as a mean of all athletes who use, or do not use, foam seating cushions. Average pressures were also considered as being more consistent, which suggests an enhanced seated stability when athletes use foam inserts.

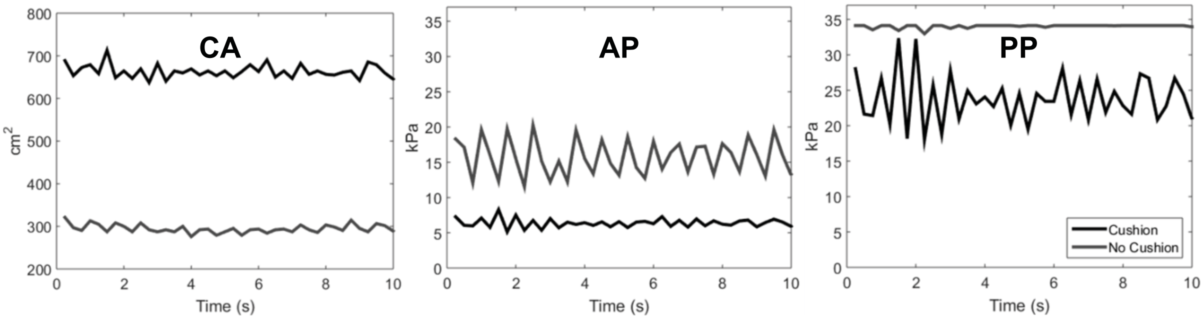

Figure 3: Effect of foam inserts on pressure parameters during propulsion

DISCUSSION: Pressure mapping technologies were investigated for use with wheelchair racing athletes during propulsion, with both the inclusion and exclusion of foam seating cushions. Use of foam seating cushions did not interfere with the capability of the pressure map to record, nor did the pressure mat interfere with athlete motion. Wheelchair racing athletes present largely varying measures of seating CA and AP, which is likely attributable to the kneeling posture adopted by these athletes. Implementation of customised seating cushions effectively increases the CA of athletes, whilst minimising both AP and PP. Aside from the benefits of decreased likelihood of injury, increasing CA, may improve the athlete – wheelchair interface. By having a more stable base of motion, athletes are more likely to be able to more consistently contact the wheel symmetrically, and over an optimal push range; both of these metrics have been established in enhancing athlete performance. Furthermore, these interfaces may promote consistency at the seating interfaces of wheelchair athletes,

which may benefit athletes who have greater physical impairment, and greater muscle atrophy in the lower extremities.
Assessment of the use of pressure mapping technology in a performance capacity is still required, to determine the impact of these reductions in pressure. It can be observed in the leftmost pressure map of Figure 2, athletes sometimes push outwards on the seat. A seating cushion may not be able to cover these surfaces to lower the loading in these regions, however, If athletes have a larger contact area under their legs, they may be less inclined to push outwards, but instead direct their momentum forwards.
One of the limitations identified from this research was the low sampling frequency of the pressure map used. Although the 4Hz recording frequency was sufficient to identify strokes, which can be seen by the peaks for both the PP and AP traces, this frequency cannot quantify within-stroke characteristics or identify when within the contact phase, this pressure is being measured. This low sampling frequency means interstroke performance cannot be obtained for each athlete, particularly during the propulsion phase when athletes are likely to be transferring force to the wheelchair. Pressure mats with recording frequencies of 100Hz would be more preferable, to obtain these between stroke characteristics, as well as allowing better synchronisation with force plates, and high speed cameras. Another limitation with the utlised pressure mat was that sensor saturation occurred at or above 34.13 kPa, as demonstrated through the consistency in the grey dashed line, with the majority of non-cushion trials exceeding this value, limiting the reliability of the average measurements.
Despite these limitations, this research has demonstrated the plausibility and usefulness of pressure mapping at the seating interface, as well as how cushions can effectively reduce peak pressures acting on the lower extremity during wheelchair propulsion.
Due to the small sample size presented in this research, strong correlations cannot be observed as part of this investigation. However, it can be suggested that based on these preliminary results, further investigation of both pressure mapping technology, as well as customised cushions would largely benefit wheelchair racing athletes.

CONCLUSION: Cushions at the seating interface effectively increase total contact area of an athlete, which can hence be correlated with lower peak pressures. As these do not impede regular athlete motion, implementation of seating cushions can be considered as a beneficial tool for the real time assessment of athlete seating performance. Additionally, use of a cushion can decrease peak pressures, reducing risk of obtaining pressure sore related injuries, and promote greater stability at the seating interface.

REFERENCES:

Davis, K., & Sprigle, S. (2008). *The science of interface pressure mapping - updates for application.* Paper presented at the 24th International Seating Symposium, Vancouver.
Kirshblum, S. C., Burns, S. P., Biering-Sorensen, F., Donovan, W., Graves, D. E., Jha, A., . . . Waring, W. (2011). International standards for neurological classification of spinal cord injury (Revised 2011). *Journal of Spinal Cord Medicine, 34*(6), 535-546.
Linder-Ganz, E., Yarnitzky, G., Yizhar, Z., Siev-Ner, I., & Gefen, A. (2009). Real-time finite element monitoring of sub-dermal tissue stresses in individuals with spinal cord injury: toward prevention of pressure ulcers. *Annals of Biomedical Engineering, 37*(2), 387-400. Lombardi Jr, A. d. B., & Dedini, F. G. (2009). Biomechanical model for the determination of forces on upper-extremity members during standard wheelchair propulsion. *Mathematical and Computer Modelling, 49*(7–8), 1288-1294.
Mason, B., Lenton, J., Leicht, C., & Goosey-Tolfrey, V. (2014). A physiological and biomechanical comparison of over-ground, treadmill and ergometer wheelchair propulsion. *Journal of Sports Science, 32*(1), 78-91.
Tweedy, S., & Bourke, J. (2009). IPC Athletics Classification Project for Physical Impairments; Final Report - Stage 1. In I. Athletics (Ed.), (pp. 107). Bonn.

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