THE INFLUENCE OF BODY POSITION AND USER CHARACTERISTICS ON PEAK SKIN PRESSURE IN ELITE WHEELCHAIR RACERS

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Kinesiology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2017

Urbana, Illinois

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ABSTRACT

The purpose of this mixed methods study was to examine the relationship between body position and user characteristics on peak skin pressures in elite wheelchair racers. Additionally, semi structured interviews were conducted to gain insight into participants' knowledge, history and opinions of pressure-related injuries. 26 individuals with mobility impairments (mean age: 26.81±6.97) who had experience in wheelchair racing participated in the study. Peak pressure on the anterior portion of the lower legs was measured using a Tekscan Conformat pressure mat system while athletes were sitting in their racing chair motionless (static condition) and propelling on a dynamometer at approximately 15 mph**.** During static conditions the mean of the average peak pressure values was 889.06 mmHg (S.D.=318.36) and the mean of the max peak pressure values was 935.20 mmHg (S.D.=315.43). During dynamic conditions the mean of the average peak pressure values was 867.12 mmHg (S.D.=330.28) and the mean of the max peak pressure values was 1015.45 mmHg (S.D. 336.70). The results of the Pearson correlation showed that magnitude of peak pressure was related to kneeling tray incline (r_p =.45, P=.04), duration of disability (r_p=-.48, P=.03) and the use of customized equipment (r_p =.56, P=.01) in the racing wheelchair. The results of the Spearman rank-order correlation revealed that peak pressure was not significantly correlated to level of tactile sensation (r_s=-.33, P=.15). No significant correlations were observed between gender, BMI and stroke count with pressure. Preliminary data indicates that individuals with a longer duration of disability who reduce the incline of their kneeling tray and utilize customized equipment are at a lower risk for developing a pressure ulcer during sport participation. Future research should focus on other vulnerable regions of the body that are susceptible to pressure ulcer development such as the ischial, sacral, and trochanter regions.

ACKNOWLEDGEMENTS

The completion of this project would not have been feasible without the help of many important individuals. I would first like to express my sincere gratitude to both Dr. Laura and Dr. Ian Rice for their valuable advice and endless support during the entire research process. In addition, I would like to thank Adam Bleakney and Michael Groves for their enthusiasm and contribution in the recruitment of the study. I would next like to thank Jonghun Sung, Dennis Minton, Ami Patel, Alex Diab and the entire DPQoL Research Lab team for their help throughout the process. Last, I would like to express gratitude to Dr. Yik-Kuen Jan for allowing me to utilize his pressure mat system for this experiment, as well as the UIUC wheelchair track team for making time to participate in this study. Many of these individuals are world-renown athletes and generously took time out of their active schedules to participate in the study. Without all of your help, this project would not have been possible.

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CHAPTER 1

INTRODUCTION

Adaptive sports are growing at a rapid rate in both numbers and popularity. Adaptive sports can be defined as competitive and recreational sports modified for individuals with disabilities[1]. Athletes recognized by the International Paralympic Committee include those with both mobility and sensory impairments. Adaptive sports often are similar to existing sports for non-disabled athletes, but have modifications in equipment and rules to meet the specific needs of disabled athletes[1]. For example, wheelchair track has the same concepts as the traditional sport except individuals use a sport-specific wheelchair during play.

In 1985, it was estimated that approximately 4,500 individuals with disabilities participated in organized athletic competition within the United States[2]. Now, that number has increased to over 60,000 disabled Americans competing in organized sport[3]. On a world scale, the first Paralympic Games in 1960 had just 400 athletes and has now increased to over 4,000 athletes per Paralympic Games[4].

At the 2012 London Paralympic games, almost one-quarter (N=~1000) of all athletes at the games competed in track and field, the highest percentage of any sport[5]. Along with being an extremely popular adaptive sport, it is very physically demanding. Elite wheelchair racers train most days of the week and total around 20 hours of training per week[2]. Largely due to advancements in the sport-specific wheelchair design and technology, these athletes can reach speeds well over 20 mph[6]. However, these high speeds and the high repetitive forces exerted by the individuals to reach and maintain these speeds puts them at high risk for injury[7]. According to Curtis and Dillon[2], wheelchair track and racing is among the riskiest wheelchair sports. In 2012, track accounted for the most injuries per sport (N=216) at the Paralympics Games[5].

It is now becoming well-accepted that non-disabled and physically disabled athletes have similar injury rates and should receive similar care and attention to their injuries[4]. Still, research surrounding injury prevention in adaptive sports is lacking and incomplete compared to the literature available for athletes not living with a disability.

According to Klenck and Gebke[8], common medical problems seen in athletes with a physical disability include autonomic dysreflexia, thermoregulation, pressure ulcers, and upper extremity injuries. Currently, there is research surrounding autonomic dysreflexia[9, 10], thermoregulation[11, 12], and upper extremity injuries[7, 13] in sport. However, little research has been performed examining pressure in this setting. This is alarming because of the negative consequences linked to pressure ulcers.

The consequence of pressure ulcers can be severe and destructive to one's quality of life. For example, the pain and risk of infection associated with pressure ulcers could take individuals out of their sport for over 2 years[14, 15]. In minor cases, a pressure ulcer may be managed through consistent pressure reliefs and proper hygiene[16]. However, if these skin injuries are not picked up early by the individual, they can progress quickly into a severe pressure injury[17]. If an individual has a medical condition that hinders his or her ability to perceive the development of a wound in a susceptible pressure ulcer location, he or she is at even worst odds to developing a significant injury. Once a pressure ulcer progresses past the point of self-care, it is necessary that a medical provider intervenes. In these severe cases, surgery and full bed rest may be prescribed as treatment[15, 18]. Long durations of bed rest tend to be the most common treatment option for severe skin ulceration. If these steps are not taken and the ulcer keeps progressing in severity, an individual can die from the pressure ulcer. From 1990 to 2001, there were over 100,000 pressure ulcer-related deaths in the United States[19].

Fortunately, it is widely believed that pressure ulcers are preventable. According to the National Pressure Ulcer Advisory Panel (NPUAP), most pressure ulcers are avoidable with only minor exceptions[20]. Currently, there is an abundance of research available in pressure ulcer management in everyday wheelchairs, while little has been done to examine pressure ulcer prevention among adaptive sport wheelchairs. More research directed towards better pressure ulcer prevention could be helpful in preventing the onset of pressure injuries in the adaptive sport population.

In 1985, a study examining common injuries in wheelchair athletes suggested that adequate cushioning, regular skin checks and weight shifts, proper nutrition and hygiene, and water absorbent clothing could help prevent pressure-related injuries[2]. However, these recommendations are generic and outdated, and should be revisited. When a pressure ulcer develops, an individual may be put on bed rest for over a year to treat the ailment[15]. If this happens to an elite athlete, their performance will suffer and possible lifetime achievement goals will have to be delayed. For example, if an athlete develops a severe pressure ulcer leading up to a Paralympic Games, he or she may be forced to withdraw from the event, which could have a detrimental effect not only on their athletic career, but also on athletic sponsorships and funding. The consequences for developing a deep tissue injury in these athletes can be catastrophic. Currently, there are no published studies examining pressure management in wheelchair racing. In addition to the lack of research, it should be noted that conditions within the racing wheelchair are less than ideal. The racing wheelchair is tight fitting and contains little to no padding. Combined with the frequent long durations of time exposed to these conditions, racers may be extremely vulnerable to high levels of pressure on their skin. Due to the popularity of wheelchair racing as an adaptive sport and the hazardous conditions associated with the sport, there may be a wide range of pressure injuries within this diverse population.

The purpose of this study is to identify and better understand various factors related to peak pressures and pressure ulcer development in the sport of the wheelchair racing. This study can also serve as the foundation for the development of sport-specific guidelines promoting skin safety in adaptive sports. First, the researchers will examine the effect of force propulsion on lower leg peak pressure in the racing wheelchair utilizing a thin pressure mat and an indoor roller system designed specifically for racing wheelchairs. Second, the researchers will conduct a semi-structured interview examining the participants' knowledge and potential history of pressure-related injuries. Our goal is to use the information obtained through both quantitative and qualitative data analyses to identify individuals at high risk for pressure ulcers and develop recommendations to reduce peak pressure in the racing wheelchair.

1.1 Research question/hypothesis

Question #1: Will individuals that design their chairs to hold their knees in a more vertical position have higher levels of pressure compared to individuals that keep their knees more parallel to the ground in their racing wheelchair?

Hypothesis for research question #1: Individuals who kneel in their racing wheelchair in a more vertical position will have higher levels of peak pressure compared to those with a less inclined shin tray.

Question #2: Will individuals that have been racing and/or have been utilizing some sort of mobility device longer have lower levels of pressure compared to more novel, less experienced wheelchair racers?

Hypothesis for research question #2: Individuals that have utilized a wheelchair longer will have more experience managing pressure, thus have lower levels of peak pressure in their racing wheelchair

Question #3: What is the impact of customized equipment and/or pressure-related chair modifications on peak pressure?

Hypothesis for research question #3: Individuals that have made modifications in their racing wheelchair will have lower levels of peak pressure.

BACKGROUND OF STUDY

1.2 Importance of Adaptive Sports

Initially, sport was introduced to those with physical disabilities as a means to increase their overall quality of life[21]. During World War II, Ludwig Guttman introduced sport to newly disabled veterans as a form of rehabilitation to help improve their function and independence. In individuals with Spinal Cord Injury (SCI), it is widely accepted that regular exercise and adaptive sport can offer both physical and psychological benefits[21]. Individuals living with a SCI, amputation, or neural infection have shown to have decreased psychomotor function[22]. However, when sport was incorporated into daily life, an increase in executive function was observed, thus compensating for the initial executive control impairments observed in this population[23]. In children with CP, Vershuren et al.[24] examined the effects of physical activity on physical and mental health. The researchers assigned children to two groups: an exercise training group and a control group. They observed that the inclusion of physical activity improved outcome measures in aerobic, anaerobic and neuromuscular function, athletic competence, and quality of life[24].

Hutzter and Bar-Eli observed that functional efficiency, perceived self-efficacy, self-esteem, personality disorders, mood, and social acceptance were positively affected by exercise in people with disabilities[25]. Greater physical activity levels have been shown to increase functional status and reduce functional limitations[26], which can be associated with shorter length of stay (LOS) in the hospital and discharge into the community in individuals with traumatic SCI[27]. According to C. Stephens et al, 7 participants who had recently been diagnosed with a SCI felt that getting introduced to sport helped with the transition from a rehabilitation environment back into society, suggesting that rehabilitation units should be promoting the benefits of physical activity to their patients[28]. These perceived benefits of physical activity have led to an increased emphasis on adaptive sport in individuals with disabilities[28-31].

1.3 Racing Wheelchair Design

The positive effects of sports for people with physical impairments have been recorded since the 1940s with wheelchair racing being the initial adaptive sport, as wheelchair racers used their everyday chairs during physical activity[32, 33]. The only difference seen in their everyday wheelchairs would have been a lower seat height or a larger wheel diameter and/or wheel camber. Initially, racing wheelchairs were prohibited from competition if they contained less than 3 wheels, were longer than 48 inches, and contained some sort of steering gear. Now, all of these aspects are present on the current racing chair, making it one of the most engineered and ergonomic human-machines[33]. The current racing wheelchair model contains 3 wheels in a T-frame design with one front wheel and two rear wheels[34].

With less frontal area, the T-frame design is able to reduce drag, is lighter in weight, stable and can allow for many different seating configurations. The frame is usually made out of some sort of metal alloy (e.g. steel, aluminum or titanium) with carbon fiber framed wheels[35]. As technology and popularity for the sport has increased, some of the top automobile companies such as Honda, Toyota, and BMW are now beginning to fully customize the racing chairs using composite materials such as graphite or carbon fiber [36]. These materials tend to be more rigid than metal alloys, while also being lighter in weight and density[37]. The stiffness and lightweight components of a composite material allows the chair to be more easily moved so the athlete not only reduces his or her the risk of upper limb injury, but also moves at faster speeds, ultimately increasing sports performance.

According to Cooper and De Luigi, the sport wheelchair design must optimally fit the athlete, weigh minimally, minimize rolling resistance and optimize performance[34]. All of these aspects are featured in the current racing wheelchair design allowing one's energy to fully transfer to wheels in the form of speed and power. However, athletes are beginning to push the thresholds of these concepts. In the pursuit of both speed and efficiency, athletes are gravitating towards racing chair configurations that are increasingly rigid and tight fitting, similar to the fit of a prosthesis [34]. The athlete is fastened snug to the seat, causing direct contact to occur between the skin and metal frame. In addition, wheelchair racers tend to sit in a kneeling position, placing most of their body weight directly on their lower legs, targeting the area from the tibial tuberosity all the way to the ankle joint. The racing wheelchair is designed keep one's knees higher than the buttocks, which could also have an impact on the amount of pressure located in this area. Due to these reasons, skin over bony prominences is exposed to significantly high loads, increasing the individual's risk of developing pressure ulcers[38]. Deep tissue injuries are a major concern in adaptive sports due to both wheelchair design and the individual's ability to produce high amounts of force during propulsion. Currently there are no guidelines for pressure management in adaptive sports.

1.4 Lower Leg Pressure

According to Cooper and De Luigi, most wheelchair racers use a kneeling position, in which the athlete leans forward in the chair with their knees close to their chest. This puts a majority of the racer's body weight over their lower legs during the force application phase of propulsion [34]. Due to a SCI, many of these individuals have little to no sensation in their lower extremities, allowing them to withstand the racing wheelchair conditions (e.g. tight fit, metal frame, poor padding) that an individual with full somatosensory most likely would be unable to endure [39, 40]. The lack of sensation, vascularity problems, and muscle atrophy associated with a SCI, may put these individuals at an increased risk for pressure ulcers development in the anterior lower leg region during racing activities[41, 42].

A wound on the shin or lower leg area is referred to as a pre-tibial laceration [43]. According to Bradley, several factors can contribute to these skin integrity injuries including pressure, shearing, and friction[44]. These aspects are all associated with wheelchair racing. The problem with these skin injuries is that they can be very difficult to heal. The skin is very thin around the shin area and there is little blood supply. In addition, this area poses a high risk for infection due to the area's sensitivity towards hematoma [44]. It is well known that skin injuries to the lower leg can be very detrimental to one's health. However, little literature exists examining safe levels of pressure in preventing pre-tibial lacerations.

Although there is little information surrounding pressure and pre-tibial lacerations, other areas of research in the health field have determined safe levels of pressure for the lower leg. Much of the information available exists from research dealing with diabetic ulcers, hospital bed sores, and deep vein thrombosis. In the context of lower leg pressure, pressure readings should not exceed 90 mmHg around the shins, 180 mmHg at the ankle, and 47 mmHg around the heel [45, 46]. In addition, if an individual experiences these excessive amounts of pressure for a prolonged period of time, he or she is at an even greater risk.

In wheelchair racing, athletes regularly compete in marathons that last on average about two to three hours. This duration is more than enough time needed to develop a serious pressure ulcer[47]. It is reasonable to assume that wheelchair racers that utilize a kneeling position during propulsion are at a high risk for skin breakdown on the shin area. For this reason, an anterior aspect of the lower leg was selected for examination in this study.

1.5 University of Illinois at Urbana-Champaign

The University of Illinois at Urbana-Champaign is an institution that has led the way in breaking down many barriers for individuals with physical disabilities. Led by Tim Nugent, Marty Morse and other pioneers of the disability and rehabilitation community, the Rehabilitation Education Center (DRES) was built to provide accessibility, recreation, and research to individuals with physical impairments. Due to its rich history and notoriety in Paralympic athletics, DRES was named the United States Wheelchair Track Paralympic Training Center in 2014. It now the central training hub for the top level wheelchair racers in the world, where approximately twenty-five racers, thirteen of which qualified to the 2016 Rio Paralympic games, live and train year-round.

CHAPTER 2

LITERATURE REVIEW

2.1 Pressure ulcer defined

A pressure ulcer can be defined as a soft tissue injury stemming from unrelieved pressure over a bony prominence that becomes ischemic, dead, and/or necrotic[48]. Extrinsic factors for the development of pressure ulcers include pressure, shear, friction, immobility, moisture, and wheelchair configuration. Many aspects of the everyday wheelchair fit can also have an influence on pressure. For example, increased wheelchair dump has shown to increase the amount of skin pressure exerted on the back by shifting an individual's center of gravity posteriorly and holding the pelvis against the wheelchair's backrest. Wheelchair dump can be defined as angle of the seat along the horizontal axis. An angle of 5^{o} is common, but more than that can increase the load put on the sacral and coccyx region[49]. Backrest angle and height can also have a profound effect on pressure. According to Cooper et al, backrest height should be set as low as possible to not only give stability, but also allow for maximum movement and efficiency. However, another study by the Herman Miller research group shows that a higher back support can better distribute pressure and offload the buttocks [50]. More research needs to delve into the differences backrest height has on skin pressure. In terms of backrest angle, no changes in backrest angle from vertical position of 90^{o} had an increasing effect on pressure on the ischial tuberosity region. However, on the sacrococcygeal region, significant increases in pressure occurred when changing the backrest position from 90^{o} to 100^{o} to 110^{o}[51].

Intrinsic factors for developing a pressure ulcer are based on the condition of the individual with a disability. These include local infection, decreased autonomic control, increased age, anemia, malnutrition, sensory loss, spasticity and more[52]. Fuhrer et al[42] observed that individuals with SCI are the highest risk population for developing pressure ulcers due to a lack of sensation, paralysis and muscle atrophy, and reduced collagen metabolism and blood circulation[53]. In SCI, level of injury and intactness of the lesion also has a profound effect. Individuals that developed a SCI in the cervical region had an increased risk compared to lower level SCIs, and complete lesions had a higher prevalence compared to incomplete lesions [54]. According to Chen et al, pressure ulcers were more common in elderly men, with their risk increasing once they passed 15-year post injury[55]. The prevalence of non-sport pressure ulcers in the SCI population ranges from 25-66%. According to the National Pressure Ulcers Advisory Panel (NPUAP), pressure ulcers are staged into 4 categories, ranging from skin discoloration (Stage I) all the way to full thickness tissue loss with exposed bone, muscle or tendon (Stage IV)[56]. The most susceptible locations on the body for pressure ulcer development are the sacrum, coccyx, ischium and trochanter regions[57].

The buttocks is a very susceptible region for pressure ulcers due to the many bony prominences that exist in the area and the prolonged amount of time individuals living with SCI spend sitting[58]. On average, an individual with a SCI spends 9.2 hours per day sitting in their wheelchair [59]. In addition, individuals living with a SCI tend to have significant muscle atrophy in their lower extremities, leaving the skin as the only means of protection between these bony prominences and pressure. With merely skin as protection, this area is much more sensitive to minor compressions, creating an environment where pressure ulcers can easily develop [58]. Recent research is also suggesting that lower extremity pressure ulcers are becoming a major concern in this specific population. Whittington and Brione found in their 6-year national study of pressure ulcer prevalence that of the 8857 pressure ulcers reported in an acute care setting in 2004, 25% of the pressure ulcers reported occurred around the foot [60]. Another study by Cannon & Cannon also found that 25% of all pressures ulcers occurred on the malleolar, heel, patellar, and pretibial locations[61].

It is believed that pressure ulcers can occur when external pressure exceeds 80 mmHg[47]. Values of 80-120 mmHg should warrant a moderate level of concern and pressure values of 120-200 mmHg should warrant a major level of concern. Values above 120 mmHg can result in serious clinical complications[47]. Although these values are a general rule of thumb surrounding pressure management, some areas of the body cannot even withstand these levels of pressure. According to Ryan and Byrne, pressure scores should not exceed 50 mmHg around the foot [45]. Due to the lack of sufficient padding and the tight fit of the racing wheelchair[38], it can be assumed that pressure values within these sport wheelchairs during force production will exceed what Shapcott & Levy[47] believe to be a "major concern" in pressure readings for non-ambulatory individuals. According to the National Health Services, stage III and IV pressure ulcers can develop in just 1-2 hours[17], showing that it does not take much time to develop a severe pressure injury. Wheelchair athletes tend to be in their sports specific chairs for this duration of time. The combination of high pressure, moisture from sweat, and duration of time in a sport wheelchair put wheelchair athletes at a dangerously high risk for pressure ulcers. Research surrounding pressure management in the sport setting is needed in order to prevent such deep tissue injuries from occurring in wheelchair athletes.

2.2 Pressure ulcer research in adaptive sports

There is little literature available regarding pressure management in adaptive sports. Still, skin and pressure-related injuries have been documented in Paralympic sports since the 1980s. According to a survey on wheelchair athletic injuries in 1985, pressure injuries were the fourth most common injury. Of the 291 athletes observed in this study, approximately 7% of them reported a decubitis ulcer or pressure ulcer as a result of sport participation. Causes for this injury were believed to be from friction, pressure on the buttocks and sacrum, and wheelchair design[2]. However, when this survey was taken, the racing wheelchair design was much different than the design used today. Traditionally, wheelchair racers used an everyday wheelchair with simple modifications such as lowering the seat and/or elevating the knees close to the chest. In this chair configuration, the individual was still sitting on their butt. Now, most individuals utilize a kneeling position. The knees may still be above their butt, but during force propulsion almost all pressure is exerted on their shin area. In a more contemporary study where the latest racing wheelchair configuration could be observed, 14% of pediatric wheelchair track athletes (ages 6-18) at the 1990 Junior National Wheelchair Games reported a developing a pressure ulcer [62]. Derman et al[63] also reported that injury to the skin and subcutaneous system accounted for almost 20% of ailments at the 2012 Paralympic Games. Even though the design of the chair has changed, it is clear that the prevalence of pressure ulcers in adaptive sports is increasing.

To date, only two studies have been performed that directly analyze pressure in adaptive sports. Hirotaka et al. examined deep tissue injury (DTI) prevalence in 20 male athletes on the Japanese national wheelchair basketball team[64]. According to Ankrom et al, deep tissue injuries are the underlying cause of pressure ulcers[65]. Using ultrasonography to detect DTIs, the researchers observed that 45% of the team had some sort of DTI. The majority of these injuries occurred on the sacral region. Given that the basketball wheelchair is set up similar to an everyday wheelchair, it makes sense that the sacral area was most affected during sports participation. In addition, the researchers observed that team members with a SCI, who primarily used a wheelchair for ambulation were at the highest risk for DTIs.

The second study, performed by some of the same researchers, examined the prevalence of deep tissue injuries in female wheelchair athletes. Of the 22 participants, approximately 68% of all athletes on the Japanese national basketball team presented signs of a DTI via ultrasonography. Similar to Hirotaka's initial study[64], individuals living with SCI, who used a wheelchair for ambulation were at the greatest risk for developing a deep tissue injury from sport participation. In the SCI group, sacral DTIs were the most common. However, although skin breakdown was more common on the sacral region, the depth and severity was greater for ischial DTIs. Last, pelvic instability was observed as a risk factor for pressure injuries. This finding was not observed in males. In the able-bodied population, women tend to be more susceptible for pelvic instability than men [66]. In comparing both of these studies side-by-side, women also had a higher rate of pressure related injuries[64, 67]. It could be a possibility that pelvic instability as a function of gender could be an underlying risk factor for pressure ulcers. Moving forward, research needs to further investigate if gender has any effect on the risk for developing a pressure ulcer.

Although these studies served as the initial starting grounds for sport-related pressure ulcer research, they only examined wheelchair basketball and did not give any prevention guidelines or suggestions to reduce the prevalence of pressure ulcers. Moving forward, pressure analysis in other popular adaptive sports, specifically wheelchair racing, is necessary.

CHAPTER 3

METHODOLOGY

3.1 Study Design

This research study is a mixed-method design composed of objective assessments and a semi-structured interview. Wheelchair track athletes at the University of Illinois at Urbana-Champaign (UIUC) were recruited between January 2017 and December 2017 to participate in the study. All individuals utilized a sport-specific racing wheelchair during their sport participation. The Institutional Review Board (IRB) at UIUC approved the study. Before participation, all participants provided verbal and written permission via informed consent form. The study required approximately 45 minutes of the participant's time.

3.2 Participants

Study participants were recruited via posting of flyers and face-to-face interaction with research staff. All interested individuals were invited to participate in the study if they met the following inclusion criteria: 1) 18 – 65 years of age and 2) Experience participating in wheelchair athletics. The individuals were excluded from participation if they met any of the following criteria: 1) Any health condition or injury that prevents safe sport participation and 2) A current student of Dr. Ian Rice, Dr. Laura Rice, or Dr. Yih-Kuen Jan. Participants were asked to complete a demographic survey, a pressure assessment in both their everyday wheelchair (EWC) and racing wheelchair (RWC), and a semi-structured interview.

Overall, twenty-six participants were recruited into this study. For the purposes of the quantitative portion of the study, six participants were left out of analysis because of equipment failure or seating configuration of their racing wheelchair (sitting vs. kneel position). All subjects were treated in accordance with UIUC and IRB standards in terms of treatment of human subjects.

3.3 Study design/protocol

Demographic information was collected via demographic form that included gender, age, type of disability, level of lower extremity tactile sensation, athletic classification, wheelchair usage, wheelchair athletic experience, sport wheelchair manufacturer, chair modifications and history of sport-related pressure ulcers. Level of sensation was broken up into three categories: no sensation, partial sensation, and full sensation. Partial sensation meant that the individual had reduced sense of touch in their lower extremities. The individual was still sensitive to sensory stimulus, but he or she would be unable to feel superficial pain and/or changes in temperature[40, 68]. Demographic characteristics and other background information were examined for their potential role in the occurrence of peak pressures.

Following the demographic survey, pressure assessments were performed in the RWC. Using a flexible, thin, light-weight pressure mat, peak pressure was assessed in an individual's RWC using The CONFORMat® System by Tekscan. With 1.47 cm x 1.47 cm sensors located throughout the mat, the pressure mat could measure an area of 47.1 cm x 47.1 cm. Pressure mat system calibration was performed via the manufacturer's guidelines. The sensor was placed in between the participant's anterior portion of their lower leg and the kneeling tray of their racing wheelchair. Figure 1 shows the pressure mat placed on the kneeling tray along with the total set-up of the pressure mat system during data collection. Pressure was assessed during both static and dynamic conditions. During static conditions, the individuals stayed still in their "ready" stance for 20 seconds. A "ready" stance is the stance an individual holds when he or she is on the start line in preparation for a race to begin. The individual is leaning forward in their racing wheelchair, with their hands close to the hand rims. During dynamic conditions, the individual would propel at approximately 15 mph for 20 seconds. Speed was measured by the dynamometer and displayed on an iPad in real time. Incline of the kneeling tray was measured via inclinometer. After racing chair assessments were obtained, semi-structured interview was conducted.

Figure 1. Pressure mat system measuring pressure skin pressure on the kneeling tray

Qualitative Interview

Conducted by a trained interviewer, the participants would begin a recorded, face-to face, semi-structured interview following the pressure mat assessment. Participants were asked to respond to the following questions:

1. Are you comfortable in your sport wheelchair?
2. Have you ever developed a pressure ulcer as a result of your sport?
3. How long are you in your chair during practice and competition?
4. Do you worry about developing pressure ulcers in your everyday wheelchair and racing wheelchair?

5. Where do you feel that pressure is the highest within your sport wheelchair during propulsion?
6. Are you satisfied with your sport wheelchair fit?
7. Are you willing to overlook pressure management aspects of your sport wheelchair for improved performance?
8. Would an increase in comfort within your sport wheelchair help increase performance?
9. What parts of the sport wheelchair can be improved to reduce pressure spikes?
10. Have you gotten customized equipment to manage large pressure spikes?

Based on the individual's responses, follow-up questions were asked to clarify various aspects of the discussion. Each interview lasted approximately 15 minutes.

3.4 Data Analysis

Quantitative analysis for the demographic survey and pressure mat assessment was performed using SPSS version 24.0 (SPSS Inc., Chicago, IL, USA). To examine the relationship between variables, both Pearson and Spearman rank-order correlation analysis was used. Pearson correlations were calculated to examine associations between dynamic peak pressure scores, kneeling tray incline, the use of customized equipment, duration of disability, gender, BMI and stroke count. Only dynamic conditions were utilized for correlative analysis because dynamic conditions most closely represented the conditions experienced by the wheelchair racers in their sports activity. During wheelchair racing, the athlete is consistently engaged in vigorous force propulsion. In addition, forces should be higher during dynamic conditions, because one's chest is driven onto the leg—which contacts the kneeling tray—with each stroke. Spearman rank-order correlation was calculated to examine the association between level of tactile sensation and peak pressure values. A correlation coefficient of $\leq$.30 was considered weak, between .30 and .60 was considered moderate, and $\geq$.60 was considered strong [69]. Descriptive statistics were calculated for all variables to characterize the sample with significance set *a priori* at $p<0.05$. Correlations were reported for Pearson as r_p and Spearman as r_s.

Thematic analysis was used to analyze the qualitative data. Interviews were audio recorded and transcribed verbatim with notes taken by the interviewers during the interview in case of inaudible dialogue. Once each transcription was complete, two researchers, M.G. and J.P., carefully read and re-read all the interviews, individually coding each interview for common themes found in the qualitative data. After individual coding was complete, M.G. and J.P. met to compare and discuss the key themes and patterns related to the original research questions. Once a consensus was reached, a codebook was created to help with analysis. All the final coded transcripts were reviewed by author L.R. who did not take part in the data collection and initial coding. L.R. examined the final codes for bias, discrepancies and any outstanding data concerns. These discrepancies were discussed, and once a consensus was reached, changes were made in the codebook. Data analysis was performed on an ongoing basis.

<u>3.5 Data Reduction</u>

The CONFORMat® System by Tekscan was used to obtain the peak skin pressures occurring on the anterior portion of the lower leg. In this study, peak pressure scores were collected bilaterally (right side and left side of the pressure mat). The right side and left side of the pressure corresponded to the right lower leg and left lower leg respectively. During analysis, peak pressure was collected at 10 Hz. In essence, the pressure mat system collected the peak pressure value on each side of the body every 10^{th} of a second, meaning that after a 20 second trial, the pressure mat system would have a peak pressure value for each side of the pressure mat for 200 frames. These values were then averaged to provide the average peak pressure on the right side and the left side. "Total" average peak pressure corresponded to the largest average peak pressure value occurring between right and left sides over 200 frames. These 200 peak pressure values were then averaged to give the "total" average peak pressure. Max peak pressure represented the highest value on each side occurring over a 20 second trial. Left max peak pressure referred to the left side, and the right max peak pressure referred to the right side. "Total" max peak pressure, looked at the maximum value of the whole pressure mat system regardless of the location during the 20 second trial. After data was reduced, an individual was given six scores for both static and dynamic conditions: 1) right average peak pressure, 2) left average peak pressure, 3) total average peak pressure, 4) right max peak pressure, 5) left max peak pressure and 6) total max peak pressure. These scores were used in both the descriptive statistics and correlational analysis.

CHAPTER 4

RESULTS

4.1 Quantitative Results

All participants in this study were elite level racing wheelchair athletes. Athletes were deemed “elite” if they had competed in a Paralympic Games, >4 years of RWC experience, or currently compete in >5 racers per year. Fourteen (54%) males and twelve females (46%) voluntarily participated in this study. Their mean age was 26.61 years (SD= 6.97) and mean BMI was 22.35 (SD=7.95). The following racing wheelchair brands utilized by the participants were Top End, Eagle, Carbonbike, OX, Nissen. Participant’s diagnoses included Spinal Cord Injury (n=12, 46%), Spina Bifida (n=3, 12%), Transverse Myelitis (n=2, 8%), Cerebral Palsy (n=2, 8%), Amputee (n=2, 8%), Cauda Equina Syndrome (n=1, 4%), Dysthymia Myelia (n=1, 4%), Demyelinating Polyneuropathy (n=1, 4%), Arthrogryposis (n=1, 4%) and Amyotrophic Lateral Sclerosis (n=1, 4%). Participants were also classified based on their Paralympic classification. A description for the athletic classes involved in the study can be found in Appendix I. Twelve (46%) were T-53, ten (38%) were T-54, two (8%) were T-52, and two (8%) were T-34. The mean score for number of years living with a physical disability was 19.16 years (range, 3-29y). 7 (27%) participants explained that they had developed a pressure ulcer as a result of sport participation. This frequency is similar to recent epidemiological research on adaptive sport injury prevalence [5]. Due to equipment malfunction or an individual’s specific seating configuration, pressure data was not used for 6 of the 26 participants, resulting in a final sample of 20 participants (11 males, 9 women). A full list of participants’ demographic characteristics is presented in Table 1.

Table 1: Participants' demographic characteristics

Participant ID	Sex	Age (y)	BMI (kg/m^2)	Disability Type	Duration of Disability	Athletic Classification	Athletic Experience	RWC Make	Customized Equipment?	Level of Sensation
0[#,i]	F	26	15.98	SCI	20	T-54	15	Top End	Yes	None
1[#,i]	F	24	22.13	SCI	14	T-54	8	Top End	Yes	Full
2[#,i]	M	21	17.79	SCI	9	T-53	4	Top End	No	None
3[#,i]	F	20	20.56	CES	16	T-53	7	Top End	No	None
4[i]	F	20	20.07	DP	3	T-54	6	Top End	No	Partial
5[#,i]	F	31	17.97	TM	26	T-53	20	Top End	Yes	Partial
6[#,i]	M	23	21.53	Arth.	23	T-52	18	Top End	No	Full
7[#,i]	M	28	18.37	SCI	28	T-53	28	Carbonbike	Yes	Full
8[i]	F	20	21.29	Amp	20	T-54	20	Top End	Yes	Full
9[#,i]	M	22	24.03	CP	22	T-34	6	Top End	Yes	Full
10[#,i]	M	21	27.60	CP	21	T-34	10	Top End	No	Full
11[#,i]	F	28	19.91	SB	28	T-54	20	OX	Yes	Full
12[#,i]	M	19	20.53	SB	19	T-54	14	Eagle	No	None
13[#,i]	F	33	16.8	ALS	28	T-52	15	OX	Yes	Full
14[i]	F	19	58.53	Amp	19	T-54	3	Eagle	No	Full
15[#,i]	F	23	18.88	SCI	17	T-53	11	Top End	No	None
16[#,i]	M	22	20.83	SB	22	T-54	4	Eagle	No	Full
17[#,i]	M	33	21.48	SCI	29	T-53	23	Top End	No	Partial
18[#,i]	M	42	20.92	SCI	22	T-53	21	Carbonbike	Yes	None
19[i]	M	39	20.45	SCI	13	T-53	7	Top End	No	None
20[#]	M	26	23.71	SCI	4	T-53	2	Top End	No	None
21[#]	M	34	23.67	SCI	16	T-53	4	Top End	Yes	Partial
22[n/a]	M	41	n/a	SCI	n/a	T-54	2	Top End	No	n/a
23[#]	F	28	23.79	DM	28	T-53	10	Top End	Yes	Full
24[n/a]	M	33	20.89	SCI	12	T-54	12	Nissin	No	n/a
25[#]	F	21	21.03	TM	20	T-53	10	Top End	No	Partial

#: Pressure Assessment Performed
i: Interviewed
n/a: Withdrew from study

Each participant was asked if they had customized their current sport wheelchair and their level of sensation. Results can be found in Table 1. The mean incline of the racing wheelchair kneeling tray was 18.86° (S.D.=13.07). During static conditions the mean of the average peak pressure values was 889.06 mmHg (S.D.=318.36) and the mean of the max peak pressure values was 935.20 mmHg (S.D.=315.43). During dynamic conditions the mean of the average peak pressure values was 867.12 mmHg (S.D.=330.28) and the mean of the max peak pressure values was 1015.45 mmHg (S.D. 336.70). The descriptive results for pressure variables can be found in Table 2.

Table 2: Mean values for pressure variables during both static and dynamic conditions

Variable	Value
Left Leg Average Pressure – Static (mmHg)	708.44 ± 392.77
Right Leg Average Pressure – Static (mmHg)	652.34 ± 306.35
Total Average Pressure – Static (mmHg)	889.06 ± 318.36
Left Leg Max Pressure – Static (mmHg)	754.95 ± 387.05
Right Leg Max Pressure – Static (mmHg)	693.15 ± 309.02
Total Max Pressure – Static (mmHg)	935.20 ± 315.43
Left Leg Average Pressure – Dynamic (mmHg)	702.89 ± 386.09
Right Leg Average Pressure – Dynamic (mmHg)	647.10 ± 301.66
Total Average Pressure – Dynamic (mmHg)	867.12 ± 330.28
Left Leg Max Pressure – Dynamic (mmHg)	851.80 ± 385.33
Right Leg Max Pressure – Dynamic (mmHg)	816.25 ± 306.75
Total Max Pressure – Dynamic (mmHg)	1015.45 ± 336.70
Kneeling Tray Incline (degrees)	18.86 ± 13.07
Stroke Count (strokes/20 sec)	26.40 ± 7.44
Note: Values are mean ± SD.	

Pearson correlation was used to analyze the associate between age, sex, BMI, duration of disability, kneeling tray incline, and customized equipment with peak pressure values during the dynamic condition. Age was significantly related to total max peak pressure values (r_p=-.49, P=.03) and right leg max peak pressure values (r_p=-.45, P=.05). Neither sex or BMI were significantly correlated to peak pressure. Duration of disability was significantly correlated to total max peak pressure values (r_p=-.43, P=.05) and right leg max peak pressure values (r_p=-.48, P=.03). Duration of disability displayed a moderate correlation with right leg average peak pressure values, but was not statistically significant (r_p=-.42, P=.06). Kneeling tray incline was significantly correlated to total average (r_p=.45, P=.05) and total max peak pressure values (r_p=-.45, P=.04). Kneeling tray incline displayed a moderate correlation with left leg average peak pressure values (r_p=.38, P=.10) and left leg max peak pressure values (r_p=.41, P=.07), but was not statistically significant. No significant correlations were observed between stroke count and pressure scores. Whether an individual used customized equipment in their racing wheelchair or not had a significant correlation with right leg average peak pressure values (r_p=.56, P=.01) and right leg max peak pressure values (r_p=.55, P=.01). Spearman rank-order correlation was used to analyze the association between sensation level and peak pressure values during the dynamic condition. No significant correlations were observed between sensation and pressure scores. A full list of the correlative results can be found in Table 3. In addition, duration of disability was significantly correlated to athletic experience (r_p=.55; P=.006). Level of sensation was not significantly correlated to customized equipment (r_s=-.28; P=.19). Age was significantly correlated to the development of a sport-related pressure ulcer (r_p=-.44, P=.03).

Table 3: Correlations during dynamic conditions

Peak Pressure Variable (mmHg)	Age (y)^{rp}	Sex^{rp}	BMI (kg/m^2)^{rp}	Duration of Disability (y)^{rp}	Kneeling Tray Incline (°)^{rp}	Stroke Count (strokes/20s)^{rp}	Customized Equipment^{rp}	Sensation level^{rs}
Left Average	-.09 (.73)	.10 (.68)	.11 (.66)	-.16 (.50)	.38 (.10)^{å,M}	-.02 (.95)	-.22 (.35)	.02 (.94)
Right Average	-.29 (.21)	-.26 (.27)	-.11 (.65)	-.42 (.06)^{å,M}	.23 (.33)	.22 (.38)	.56 (.01)^{*,M}	-.33(.15)^{M}
Total Average	-.34 (.14)^{M}	-.02 (.92)	.09 (71)	-.34 (.14)^{M}	.45 (.05)^{*,M}	.05 (.83)	.27 (.26)	-.12 (.61)
Left Max	-.23 (.34)	.13 (.60)	.12 (.62)	-.23 (.34)	.41 (.07)^{å,M}	-.03 (.90)	-.19 (.42)	-.002 (.99)
Right Max	-.45 (.05)^{*,M}	-.23 (.33)	-.07 (.77)	-.48 (.03)^{*,M}	.29 (.21)	.22 (.36)	.55 (.01)^{*,M}	-.33 (.15)^{M}
Total Max	-.49 (.03)^{*,M}	-.03 (.91)	.10 (.68)	-.43 (.05)^{*,M}	.45 (.04)^{*,M}	.06 (.80)	.29 (.21)	-.22 (.35)

Note: Data are reported as r_p or r_s (*P value*).

*: Significant at P<.05.

å: Approaching Significance at .1>P>.05

M: Moderate Correlation

S: Strong Correlation

4.2 Qualitative Analysis

Sport Chair Design

In the context of pressure, participants were asked to talk about the design of their racing wheelchair. During analysis, two main categories were developed: (1) High areas of pressure and (2) customized equipment.

a. High areas of pressure

Our analysis of high areas of pressure in the racing wheelchair revealed that many body parts experience a high level of pressure during sport participation. The majority of individuals reported high levels of pressure on their shins. Perceived pressure also occurred on the hips, buttocks, rib cage, ankle, thigh, foot and heel.

"Well, I can't feel my legs, but just ***seeing where the red spots are, it's usually under my knees, and then my ankles because the bone touches [racing wheelchair]****. (Participant #15)"*

b. Customized Equipment

Study participants were asked if they have ever received customized equipment for their wheelchair. The majority of participants stated that they would not get customized equipment for their sport wheelchair to manage pressure. Participants were then asked to describe why or why they did not customize their sport chair. Of the participants who did not customize their chair, some stated that chair customization was too expensive, while others discussed the lack of available resources. In addition, two individuals felt they were not in the chair long enough to get customized equipment. One participant had never developed a pressure ulcer so he did not see the use for customized equipment. Several individuals did not customize their racing wheelchairs simply due to a lack of desire to change their current set up. They did not believe they would experience any pressure relief from chair customization.

"It's expensive and I don't really know where the resources are*. Also it's just [extra] effort and my chair is good now and* ***I don't feel the need to change it****. (Participant #4)"*

Sports Pressure Ulcer Attribution

According to the participants, there were many attributing factors related to pressure ulcer development. The most common cause perceived by the interviewees was an insufficient amount of cushioning within their racing chairs. Half of the individuals that developed a sport-related pressure ulcer believed a better cushion would have prevented the ulcer.

"…all the time in the chair caused it [pressure ulcer]. ***I didn't have a Roho foam cushion. I just had a regular cushion****. (Participant #0)"*

With inadequate levels of cushioning in the racing chair, the skin can get exposed to the metal wheelchair frame. A few participants talked about their pressure ulcer resulting from excessive exposure to metal on their skin combined with the excessive time in their chair. Athletes seemed to be equally susceptible whether they were performing in practice or competition. Last, moisture and poor hygiene served as a major contributing factor.

"The last one [pressure ulcer], ***I was out at the OTC [Olympic Training Center] training and had some stuff to do before I had showered, and I was sweating and any bit of chaffing, and moving around took that skin right off…It's always been moisture and movement with me*** *that causes them [pressure ulcers]. (Participant #12)"*

Many of the study participants are professional athletes. Three of these individuals were forced to withdraw from major competitions, such as an international race, World Championships, Paralympic Trials, and/or Paralympic Games due to the pressure ulcer.

"Actually, the ulcer occurred in 2008. ***It caused me to miss Beijing Trials****. (Participant #0)"*

Pressure management in the sport of wheelchair racing

Participants were asked *"What do you think could be done to reduce pressure?"* The athletes explained many ways to reduce pressure within their racing wheelchair. A majority of the participants believed modifying the foam within the racing wheelchair could foster skin safety. In addition, alterations in seating position were another popular idea. According to the athletes, adjustments to the seating position mainly dealt with changes in the steepness of incline of the kneeling tray. According to these participants, positioning themselves more parallel to the ground would more evenly disperse pressure.

*"****For me, I race with my butt up so there is little pressure. So if other racers changed their position to butt up, it could help reduce pressure. But it is a change in position so I see why not everyone does that****. (Participant #3)"*

In this statement the individual talks about having her "butt up", meaning the knees are lower than the butt. If the knees are lower than the butt, then the kneeling tray incline must be less steep and more parallel to the ground. Next, some athletes desired a more solid seat or rigid frame. Sport wheelchair size was also brought up in the interviews. These individuals wanted a smaller, tighter fitting chair. One athlete discussed making the metal sideguards on his racing chair wider because skin kept rubbing up against the metal causing discomfort and injury. Outside of directly adjusting the racing wheelchair, participants also stressed the need for regular sports chair maintenance, education programs, and an increase in pressure ulcer prevention research.

In addition, coaches were asked to give their perspective of pressure ulcer risk and sport. The two wheelchair track coaches were asked "Which athletes do you believe are at the most risk to developing a pressure ulcer?" and "What situations do you believe pose the biggest threat to them developing pressure ulcers?". Following analysis of the coaches' perspectives, two categories emerged: (1) Sport characteristics and (2) athlete characteristics.

a. Sport characteristics

There are many characteristics involved with wheelchair racing that pose a threat to the athlete and skin safety. According to the coaches, excessive time in the sport chair was a major reoccurring theme regarding the inherent dangers of wheelchair athletics. Being in the chair for excessive periods of time occurs during both practice sessions and competitions. The training involved in preparing for a marathon is both long and strenuous; competing in a major competition is no different. In addition, traveling and long pre-race wait times accompany major competitions, creating even more worry for coaches. In the context of the racing chair, one coach highlighted the slope of the kneeling tray as a potential risk factor.

*"**The larger the incline, the more pressure is placed on the shins during force propulsion. If the incline is more horizontal to the ground, the less energy will be transferred onto the shin tray during pushing.** (Participant #18)"*

b. Athlete characteristics

Following the interviews with the coaches, many characteristics of the athlete were discussed as potential risk factors. A lack of tactile sensation, increased perspiration, pressure ulcer history, and congenital disabilities were at the highest risk for a pressure ulcer. In terms of a protective factor, one coach described how athletic experience could lend to better pressure distribution in the racing wheelchair.

"*I wanted to get my shoulder in an optimal position for performance and when I first started getting into the sport I played around with different seating position trying to find the best fit. After years of trial and error, I moved into this current position and it happened to help out my comfort and skin safety as a bonus to my performance… (Participant #18)"*

Both coaches also explained that athletes who choose performance over comfort were at an elevated risk.

"*[In response to 'Do you think racers overlook comfort for increased performance?']* ***Yes…any athlete would probably do that. A lot of people take their cushion out because it is extra weight. Or they want to be tighter in their chair so they make it tight****. (Participant #19)"*

CHAPTER 5

DISCUSSION

This study examined risk factors for peak pressure values observed in the sport of wheelchair racing and sought to understand the perception of athletes and coaches towards the occurrence of pressure in their sport through in-depth interview. It was hypothesized that a steeper kneeling tray incline would lead to higher levels of peak pressure. In addition, duration of disability and customized equipment was hypothesized to have a protective effect against pressure.

Our results demonstrated a moderate positive correlation between the steepness of incline and peak pressure during dynamic conditions. These results suggest a moderate, positive association between steeper incline and increased peak pressure. This finding is consistent with the evidence from *Wheelchair Sport Technology and Biomechanics*, which describes that a more vertical seat angle may lead to pressure ulcers [49]. As the incline increases, pressure on the supporting limbs should increase too. Notably, the influence of seat angle on peak pressure was also supported by the qualitative data. A handful of participants believed that reducing the incline of the kneeling tray would help reduce pressure. One of the coaches stated that chair incline elevated pressure because the vertical seating configuration allowed for more extension and flexion of the torso. He described how a more horizontal kneeling position would restrict excessive trunk movement since the momentum created during force propulsion would be less able to drive the chest into the thighs. This is important because if more pressure is placed on the thighs, more pressure should transfer onto the anterior portion of the lower legs during wheelchair racing. Unfortunately, out of all the athletes that developed a pressure ulcer, none addressed the kneeling tray incline as a contributing factor towards the development of their racing-specific pressure ulcer. Moving forward, more athletes need to be aware of the negative effects that a vertical kneeling position has on peak pressure.

Our hypothesis that duration of disability has a protective effect on peak pressure was also supported. Duration of disability was negatively correlated to dynamic peak pressure, indicating the association of diminished peak pressures based on time living with disability. Experience may be an explanation for the observed phenomenon. During Participant #18's interview, he explained years of practice offered him the opportunity to explore several seating configurations in search of the perfect kneeling position. However, the literature supports as age increases, so does one's chance of developing a pressure ulcer [55]. Accordingly, our results showed a moderate positive correlation between age and pressure ulcer development. It is encouraging that as wheelchair athletes age, they have the ability to utilize preventative strategies to lower their risks of PU development.

Last, customized equipment showed to have a protective effect against peak pressure values, supporting our third hypothesis. Answering "No" was moderately associated with higher pressure values. According to the data, the majority of participants did not customize their racing wheelchairs. When asked why they did not seek customization, many simply expressed their lack of desire to change. Moving forward, more emphasis needs to be placed on skin benefits associated with equipment customization.

Qualitative analysis was used in the current study to complement the correlative analysis, creating a more complete picture of the principle problem. Being a novel study, it was important that the researchers understood the range of perceptions existing around pressure ulcers in adaptive sports. The advantages of doing this allowed us to answer multiple research questions, while also providing greater validity via triangulation [70-72]. By using a mixed-method approach, we were able to explain and illustrate the quantitative findings[72]. For example, we were able to determine if our observed correlations were supported by the participants' perceptions. Many of the participants believed that sensation offered a protective effect against pressure ulcers, which is consistent with Fuhrer *et al's* evidence that a loss of somatosensory function increases one's risk for pressure ulcers [42]. However, our quantitative findings did not support this claim as level of sensation did not significantly correlate to peak pressure.

Both quantitative and qualitative data points to high levels of peak pressure on the anterior portion of a wheelchair racer's lower legs. During the interviews, the participants perceived pressure to be highest around the shins and pressure mat testing found peak pressure values on the lower leg to exceed Shapcott and Levy's "safe" values of approximately 80-120 mmHg by over eight fold [47]. Time spent in the racing chair should also warrant a high level of concern. Athletes are in their racing chairs for at least 1-2 hours each day. Prolonged periods of high pressure exerted onto a bony prominence are proven to cause pressure ulcers [45]. Unfortunately, the time spent in a racing wheelchair is unlikely to change. Even if practice times were significantly reduced and individuals were performing pressure reliefs and proper hygiene during practice, these measures may be impractical during a competition. Thus, athletes and coaches must examine other methods to prevent pressure ulcer development.

When asked to discuss the mentality of wheelchair athletes, both coaches in this study expressed their beliefs that wheelchair athletes tend to favor performance over safety. In the context of performance, some athletes remove pressure relieving foam from their racing chairs to shed ounces. Although this may give them a slight edge, if a pressure ulcer should occur, this individual will be no longer be able to compete. One individual explained how she was forced to miss the 2008 Paralympic Trials due to developing a pressure ulcer that occurred prior to trials. The common sport notion of "toughing it out" or "no pain, no gain" could prevent an individual from seeking help due to the fear that he or she will be seen as weak or the possibly of being removed from sport participation. Many athletes play through pain at their own peril putting them at a higher risk for developing and managing pressure ulcers [73]. Given that death can result from a severe pressure ulcer, coaches should correct these performance-driven behaviors early on in the careers of wheelchair athletes. Coaches should prioritize reminding their athletes of the negative consequences associated with pressure ulcers and the negative effects the skin injury can have on their athletic career. Discussions on the benefits of using cushions or other pressure relieving devices should also be discussed. As reported by study participants, a pressure ulcer can take an athlete out of the biggest competitions (e.g. Paralympic Games), preventing an individual from reaching his or her full athletic potential. Individual performance will ultimately suffer and possible lifetime achievement goals will have to be delayed, if not entirely lost.

Given that the duration of time in a racing wheelchair will not change, various aspects of the chair need to be modified to decrease the prevalence of pressure ulcers in wheelchair racing. Therefore, it makes sense to investigate the influence of changing the incline of the kneeling tray, and examine its effect on both pressure readings and propulsion biomechanics. Moving forward, sport-specific pressure ulcer research should look into the potential effects of light-weight cushions on pressure. Light-weight foam could offer some protection against high levels of pressure without adding bulk and extra weight to an athlete's chair. Research should also delve deeper into the effects of incline on both performance and efficiency. Last, peak pressure needs to be investigated around the buttocks where pressure ulcers are most common in the wheelchair population.

5.1 Implications/Clinical Applications

This study has contributed to the advancement of literature examining sport-related injuries specific to adaptive sport athletes. In terms of rehabilitation, sport participation can help reintegrate an individual with a physical disability back into society following a traumatic occurrence. If an individual starts wheelchair racing during their time at a rehabilitation institute, recreation therapists should be aware of the potential dangers associated with the sport, making the necessary modifications to ensure skin safety. The same efforts should be made by adaptive sport coaches when working with novice athletes. In addition, racing wheelchair manufacturers should be aware of these findings and promote the use of foam to their buyers. They should create cautionary labels on the racing wheelchairs about the dangers of direct skin contact with the metal frames. Most importantly, the results from this study may help spark future research in this new field of sport-related pressure research.

5.2 Limitations of study

Although our findings are promising, they should be taken with caution due to the small sample size and homogenous sample population. This study is a cross-sectional design based on correlative analysis. Therefore, it is not possible to claim the causal effects on peak pressure. The testing speed of 15 mph may have been too high for a novice wheelchair racer or a wheelchair racer with a lower functional level. The population utilized in this study were elite wheelchair athletes that train year-round at the United States Wheelchair Paralympic Track Training Center. These athletes may not be representative of the entire racing wheelchair population. Another possible limitation of this study is self-reported level of injury due to recall bias and the researcher's inability to verify the actual diagnosis of the participants. Next, research participants may have misinterpreted the survey and/or interview questions. For example, "ulcer" can refer to a multitude of different meanings. Small sample size significantly limited the power of the findings. Ideally, this study would have quantitatively assessed 30-40 wheelchair racers. Additional recruitment would have forced the study to extend into future semesters, which would not have been possible for the researchers. Still, with the little literature surrounding peak skin pressure in adaptive sports, this study serves as important pilot data to help inform future, larger studies.

CHAPTER 6

CONCLUSION

This study examined the modifiable factors associated with the high levels of pressure observed on the anterior portion of the lower leg during force propulsion in elite wheelchair racers. In this study population, pressure exerted on the lower leg is extremely high. Steeper kneeling tray incline was associated with higher dynamic peak pressure scores. Simultaneously, customized equipment and a longer duration of disability were associated with lower dynamic peak pressure scores. Gender, BMI, and stroke count showed no significant association with dynamic peak pressure scores. Research should continue to examine lower leg pressure, as well as the pressure exerted on other anatomical landmarks, including but not limited to the buttocks. Furthermore, research should begin looking into how different types of foams and cushions can affect peak pressure values. In summary, healthcare providers, coaches, athletes, and racing wheelchair manufacturers should understand the cautions of a vertical kneeling position and make changes to better distribute pressure over the anterior portion of the lower legs. In addition, customized equipment for pressure management should be considered.

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APPENDIX A

T-34, T-52, T-53, T-54 PARALYMPIC CLASSIFICATION SYSTEM

Wheelchair Track Classification System	
T-34 – Coordination impairments (hypertonia, ataxia, and athetosis)	Athletes are generally affected in all four limbs but more in the lower limbs than the upper limbs. The arms and trunk demonstrate fair to good functional strength and near to able-bodied grasp, release and relatively symmetrical wheelchair propulsion.
T-52 – Limb deficiency, leg length difference, impaired muscle power or impaired range of movement	Athletes use their shoulder, elbow, and wrist muscles for wheelchair propulsion. There is poor to full muscle power in the fingers with wasting of intrinsic muscles of the hands. Muscle power in the trunk is typically absent.
T-53 – Limb deficiency, leg length difference, impaired muscle power or impaired range of movement	Athletes typically have full function of the arms but no abdominal or lower spinal muscle activity (grade 0)
T-54 – Limb deficiency, leg length difference, impaired muscle power or impaired range of movement	Athletes have full upper muscle power in the arms and some to full muscle power in the trunk. Athletes may have some function in the legs.

Information provided by World Para Athletics[74]

APPENDIX B

INFORMED CONSENT

UNIVERSITY OF ILLINOIS

AT URBANA-CHAMPAIGN

Department of Kinesiology
and Community Health

Louise Freer Hall

906 South Goodwin Avenue

Urbana, IL 61801-3895

217 333-1807 *office*

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Adult Informed Consent Agreement

Project Title: Assessment of Peak Pressure Forces Among Wheelchair Athletes

Principal Investigator: Ian Rice, Kinesiology and Community Health

Co-Investigators: Laura Rice, Yih-Kuen Jan, Joseph Peters, Kinesiology and Community Health

What is the purpose of this study?

The purpose of the present research study is to examine high pressure areas within a wheelchair athlete's sport-specific wheelchair during stationary and dynamic conditions. Wheelchair athletes fit their body's tight within their sport-specific wheelchairs putting them at a high risk for developing pressure sores. The knowledge generated from this study will enhance our ability to detect areas of high risk for pressure sores and/or skin breakdown. Furthermore, these results may lead to the development of guidelines for seating recommendations and various ways to alleviate areas of high pressure. This research is conducted under the guidance of Assistant Professor Ian Rice of the Kinesiology and Community Health Department at the University of Illinois at Urbana-Champaign.

What is the purpose of this form?

This consent form will give the information you will need to decide whether to participate in the study. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else about the research or this form that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

What will happen during the study and how long will it take?

You will be asked to attend one data collection session. The experimental session will last 2-3 hours.

First, you will be asked to complete a short questionnaire. The purpose of the questionnaire is to gather general demographic information and background on your disability and wheelchair athletic history.

Next, we will place a pressure sensing mat on top of the seating surface in your everyday wheelchair. We will then record how much pressure you experience. The mat is very thin and flexible so it will not alter the comfort or position you normally assume. Then, we will place a pressure sensing mat on top of the seating surface in your sport chair and ask you to transfer in. We will again record how much pressure you experience. With the mat still in your chair, we will ask you to perform propulsion activities in your chair. All propulsion activities will be performed on the dynamometer you use for training. We will ask you to propel yourself for approximately 30 seconds at a comfortable speed. Any other areas where levels of high pressure may exist will also be examined at both stationary and dynamic conditions. This portion of the study will require approximately 10-15 minutes of your time. Researchers will stand by if you need any assistance with transferring. If you feel uncomfortable at any time you can stop and rest as needed.

Last, we will conduct a semi-structured interview to examine the participant's knowledge and perception of pressure sores. Questions asked will relate to the participant's chair comfortability, history of pressures sores, and ways to possibly improve the sport wheelchair. All interviews will be recorded via a voice recording device and participants will have to give specific consent to being recorded.

Do I have a choice to be in the study?

If you decide to take part in the study, it should be because you really want to volunteer. You may choose not to take part at all. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering. There will be no penalty for declining to participate in the study or withdrawing from the study at any time. Your decision to participate, decline, or withdraw from participation will have no effect on your grade, status, or future relations with the University of Illinois.

Compensation and payment structure

There will be no compensation for participation in this study.

What are the risks of this study?

The risks of this study are not greater than the risks normally associated with indoor wheelchair training. To monitor your safety, at least one study investigator will present at all times. The measuring devices used in this study are non-invasive and do not have any side-effects. You may experience tiredness and/or muscle soreness following the study, but this will likely go away within one to three days.

The University of Illinois does not provide medical or hospitalization insurance coverage for participants in this research study nor will the University of Illinois provide compensation for any injury sustained as a result of participation in this research study, except as required by law.

What are the benefits of this study?

The results from this study may allow us to provide recommendations about your seating position. For example, pressure under your buttocks can be observed immediately and we can notify you if we observe any extreme levels of high pressures. This study may also lead to the development of guidelines for seating recommendations and various ways to alleviate areas of high pressure in sport wheelchairs.

Who will see the information I give?

The information you provide during this research study will be kept confidential to the extent permitted by law. To help protect your confidentiality, we will identify you on data collection forms and on our computers with a code number. Your name is to remain confidential in the analysis of any information regarding this study. All information, including this informed consent document and study results will be securely stored and accessible only to the primary investigator, co-investigators, and research assistants. At your request, a copy of your results will be given to you. It is expected that the results of this research will be presented at professional meetings and published in scientific journals. In those cases, your identity will not be made public.

In general, we will not tell anyone any information about you. When this research is discussed or published, no one will know that you were in the study. However, laws and university rules might require us to disclose information about you. For example, if required by laws or University Policy, study information which identifies you and the consent form signed by you may be seen or copied by the following people or groups: The university committee and office that reviews and approves research studies, the Institutional Review Board (IRB) and Office for Protection of Research Subjects; University and state auditors, and Departments of the university responsible for oversight of research

What if I have questions?

If you have questions about this research project, please contact: Dr. Ian Rice at 217-333-1807, email: ianrice@illinois.edu

In the event of a research-related injury, please contact Dr. Rice

If you feel you have not been treated according to the descriptions in this form, or if you have any questions about your rights as a research subject, including questions, concerns, complaints, or to offer input, you may call the Office for the Protection of Research Subjects (OPRS) at 217-333-2670 or e-mail OPRS at irb@illinois.edu

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I am 18 years of age or older. I have read and understand the above consent form and voluntarily agree to participate in this study.

Consent to being recorded during interviewer: Yes No

Name of Participant (printed): ____

______________________________________ ________________________________

(Signature of Participant) (Date)

You will receive a copy of this form.

APPENDIX C

DEMOGRAPHIC SURVEY

Please complete the following information about yourself.

1. Gender (circle one): Male Female

2. Date of Birth: ________________________

3. Race (circle one):
    a. American Indian
    b. Asian
    c. African American
    d. Caucasian
    e. Native Hawaiian or Pacific Islander
    f. Other (please specify): ________________________________

4. Height: ____________ inches

5. Weight: ____________ pounds

6. What type of disability do you have? ____

7. Please provide details of your disability (i.e. level of injury, site of amputation, etc)?

____

8. What is the level of sensation in your lower extremities (circle one)?

    None Partial Full

9. What is your athletic classification? ____

10. What year were you diagnosed with your disability? ____________________

11. What year did you start to use any type of wheeled mobility device? ________________

12. Are you a full time wheelchair user (circle one)? Yes No

13. What type of cushion do you use in your everyday chair? _________________________

14. What is your wheelchair athletic experience? ____________________

15. Please indicate the type of sport you participate in. _____________________

16. What is the make and model of your sport chair? Please include year.

____

17. Have you owned pervious sport chairs (circle one)? Yes No

18. Please describe any modifications that have been made to your sport chair to reduce pressure.

19. Have you ever developed a pressure sore as a result of sport participation (circle one)?

Yes No