Influence of different tennis court surfaces on performance in players with lower-limb amputation

by

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Influence of different tennis court surfaces on performance in players with lower-limb amputation

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Para Standing Tennis is a developing form of the sport of tennis for those with physical disabilities who choose to play ambulatory instead of in a wheelchair. The current research on the incidence of injury and gait biomechanics of players on different tennis court surfaces does not include those who use lower limb prostheses on the court. The goal of this study was to investigate the influence of these court surfaces on performance in tennis players with lower limb amputation. The study population consisted of two able bodied tennis players and two players with a below knee amputation. Participants wore inertial measurement units while completing the Comprehensive High-level Activity Mobility Predictor on a hard court and a clay court. The results of the study showed that there were no detectable differences in performance between the two court types, but there was a difference in impact loading patterns. The two able-bodied participants showed higher impact loading on hard courts for both legs, while the two participants with prostheses did not follow this trend. This points to the idea that biomechanically, PST players shift their weight differently while playing. Future research could focus on investigating the effects of different prosthetic componentry within PST players.

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Preface

I am incredibly grateful to my thesis advisor Dr. Fiedler for his invaluable feedback, as well as the other committee members Dr. Brienza and Dr. Proessl for their guidance throughout this project. Additionally, the Department of Rehabilitation Science and Technology generously provided funding for this project.

This study was greatly impacted by the support of Dr. Sions at the University of Delaware who provided me with guidance on the CHAMP protocol and insight on the research process. I was also provided assistance from the University of Pittsburgh Neuromuscular Research Laboratory who graciously loaned me the IMU Step system and instructed me on its use.

I would like to thank Karl Lee and Gabby Hesse at the Junior Tennis Champions Center for collaborating with me throughout this entire project. They were instrumental in connecting me with participants as well as providing tennis courts to use during data collection. Finally, I would like to thank Jeff Bournes who provided personal insight into the sport of Para Standing Tennis as well as overall support and encouragement.

1.0 Introduction

There are over a million people living with limb loss in the United States (Ziegler-Graham, 2008) and that number is expected to reach close to 3.6 million by the year 2050 (Ziegler-Graham, 2008). It is well known that participation in sports or exercise activities is imperative to good physical health; for those with limb loss, getting back into physical activities is not only important for physical wellbeing, but also for mental wellbeing. Those with lower limb amputations (LLA) who participate in sports have shown to have better quality of life and self-esteem compared to those who do not participate in such activities (Bragaru, 2012).

Opportunities for adaptive sports are increasing in availability and popularity. Wheelchair tennis has been around since 1976 and skill levels range from beginner at local clinics to professional at the Paralympics. Para Standing Tennis (PST), also called Adaptive Standing Tennis (AST), is a newer and still developing form of the sport. There are some clinics and tournaments held around the world, but it has yet to be included in the Paralympics. Advocates of the sport, such as Jeff Bournes (a retired PST player) are pushing to make PST more accessible and grow the community around the sport (Bourns, 2024).

PST is classified as a form of tennis where a player with a physical disability chooses to play ambulatory instead of in a wheelchair. This includes anyone with limb loss, neuromuscular conditions, short stature, among other conditions. While this sport is still in the early stages of development, it is slowly becoming more accessible with different leagues and tournaments starting up all over the United States and around the world.

The rules of PST are similar to the standard rules of tennis, with various levels allowing different rules of play. There are different levels of play for PST (USTA Midwest). Para Standing

1 includes players with one upper limb affected due to paralysis, amputation or congenital condition. Para Standing 2 includes players with a below Knee Amputation or very mild cerebral palsy with similar mobility. Para Standing 3 includes players with an above Knee Amputation, bilateral below knee amputations, two limbs affected, or moderate cerebral palsy with two limbs affected or similar. Para Standing 4 includes players of Short Stature, or with three or more limbs affected, or severe cerebral palsy or similar.

There are various surfaces on which tennis can occur, such as: hard courts (concrete), asphalt, grass, carpet, green clay, and red clay. Players have personal preferences based on their abilities and familiarity with that specific court type. Each surface has its benefits and disadvantages; some clay courts are easier to slide on due to the loose nature of the surface material, which can be beneficial to a player who knows how to slide to reach wide shots. Hard courts offer a much faster paced game as the ball moves quicker and has less bounce. There are also several types of tennis balls to play with: standard duty, heavy duty, high altitude, and junior which are each useful in different circumstances. Heavy duty tennis balls are better for hard courts that will wear down the felt of the tennis ball faster. Junior tennis balls can be green dots, orange dots, or red dots. Starting at red dots and going up to green dots, the tennis balls start larger and have less bounce, and gradually decrease in size and increase in bounce as players learn and eventually progress to a standard tennis ball.

Running is a critical component of the game of tennis; a competitive player must move quickly and efficiently. Court surfaces may play a factor in that ability to move quickly, as some surfaces have more friction than others. Mechanical testing has supported the idea of significant differences in friction between hard court and clay court surfaces (Damm et al., 2013). More friction could make it easier to quickly change directions when playing a match. Higher friction surfaces from hard courts have been associated with higher loading (Damm et al., 2014). This may correlate to the lower injury rates recorded on clay courts compared to hard courts (Bastholt, 2000).

Something that sets a player apart in terms of skill is the ability to slide on a tennis court to reach a wide or short shot from the opponent. However, sliding can be challenging for a player wearing a lower limb prosthesis who lacks proprioception and may have less balance. Since clay courts allow a player to slide easier due to the loose material that makes up the surface, it may be more difficult for a player to remain steady/stable on this type of court. It is already known for able bodied players that higher muscular activity is required when sliding on a hard court compared to regular footwork but was no different compared to clay court sliding (Pavailler, 2015).

Since tennis is a game of quick directional changes and weight shifting, players with prostheses must adapt to the way they play the game. The gait of an able-bodied person is different from that of a person with a LLA and individuals with different levels of amputation will have unique gait patterns amongst themselves. While playing a tennis match, staying in a "ready" position usually includes knees bent, being up on the balls of the foot, and slightly leaning forward. This position allows a player to react quickly to the opponent's return. This is a tough position to achieve if someone lacks an ankle joint and extremely difficult if they lack a knee joint. This is just one example of why PST athletes must adapt to how they play.

Since PST is a developing sport, it was difficult to find literature relevant to this topic. A literature review through Google Scholar found no information regarding how players with LLA perform on tennis courts or the prevalence of injury. One study investigated the performance of able-bodied tennis players on different court surfaces, specifically hard courts and carpet courts, but found no significant differences (Fernandez-Fernandez, 2010).

For this study, the focus was on hard courts and green clay courts, as these are common court types found in local parks and country clubs in the United States. It is not known if PST players perform better or worse on different court surfaces or if their risk of injury is different compared to able-bodied players. The first step is understanding if PST players perform differently compared to able-bodied players; if they do, this can point to the need for LLA athlete specific research.

The purpose of this study was to determine if specific tennis court surfaces are associated with better performance in players with LLA. The first aim was to determine if players with LLA performed better on hard courts or clay courts. It was hypothesized that players would have better performances on hard courts due to higher friction on the surface allowing for more stability. The second aim was to determine if PST players' performance differed from non-amputee players. It was hypothesized that non-amputee players would perform better on clay courts compared to PST players due to easier sliding without a prosthesis.

2.0 Methods

To assess these objectives, a combination of an activity-based performance tool paired with a biomechanical sensor was used. The performance tool was needed to quantify performance, but a verified tool that was designed to include those with amputations was difficult to find. The Comprehensive High-level Activity Mobility Predictor (CHAMP) was chosen as an acceptable outcome measure tool for this study (Jayne, 2013). It involves participants running and quickly changing direction throughout the activities and was specifically designed for individuals with amputations. Aside from measuring performance, it was decided to also investigate the biomechanical loads occurring in the body at the same time to see if increased impact loading was related to overall performance. External inertial measurement units that could measure such loads without interfering with the prosthesis were used. The protocol designed with both the CHAMP and use of IMUs was approved by the University of Pittsburgh Institutional Review Board (IRB).

2.1 Participants

2.1.1 Study Population

The population consisted of two groups: Group A included able-bodied tennis players who fit the inclusion criteria. While Group B included those with below the knee amputations who wore well-fitting prostheses and fit the inclusion criteria.

2.1.2 Inclusion & Exclusion Criteria

The United States Tennis Association (USTA) has a rating system for all adult tennis players known as the National Tennis Rating Program (NTRP). They have a chart that describes what skills a player must possess to classify for a certain level. The rankings start at a 1.0 which is a beginner and go up to 7.0 which is considered a world class professional. Players are allowed to play up a level but are not permitted to play down. For this study specifically, the focus was on players between the levels of 3.5 and 4.0, as these are considered intermediate skill players who have a strong understanding of movement on the court and can play competitively.

Eligibility for this study required to possess a USTA NTRP of 3.5 or higher. Participants must be over the age of 18 and have at least one year of experience playing tennis. Participants would be ineligible if they possess any conditions that affected balance or coordination, aside from amputation for group B. Participants in group B had to be cleared for play by a Certified Prosthetist (CP) or Certified Prosthetist Orthotist (CPO) before enrollment.

2.1.3 Sample Size

A power analysis using G*Power determined the sample size necessary for this study to be considered significant (Faul, 2007). To find the appropriate sample size given effect size, error probability, and chosen power, a priori t-test was used (Kang, 2021). A study using the CHAMP to determine the reliability of the tool was used to determine the effect size of 2.44 (Gailey, 2013). The error probability was set at 0.05 and the power was set to 95%. The determined sample size for significance was 6 participants per group, with 12 participants in total for a total power of 96.6%.

2.1.4 Recruitment

A tennis facility that hosted a weekly PST clinic was chosen as the best location to recruit participants. Individuals with different abilities and skill levels attended these clinics, including players with amputations. After a discussion about the aims of this study and review of the study protocol, the coach agreed to distribute recruitment flyers to those who may be eligible and to provide the necessary facilities and equipment for data collection. This included a hard court and a clay court, both located inside their indoor domes, and cones/markers for the performance tool. Any player who expressed interest in the study was contacted by phone to verify eligibility before enrollment in the study.

Two players with LLA were identified as eligible for group B. Two eligible able-bodied players were then enrolled into group A as the control. All participants were male, with USTA NTRPs between 3.5 and 4.0, and had been playing tennis a minimum of two years. The ages of eligible participants could range from 18 to 80.

Participant 1B presented with a right leg symes amputation and reported left hand dominance. Their socket used a silicone suspension sleeve, with an ankle unit, and an Otto bock Challenger foot. He also wore a shoe with his prosthesis while playing tennis.

Participant 2B presented with a right leg transtibial amputation and reported right hand dominance. Their socket used a lock and pin suspension system with a Fillauer Obsidian blade posteriorly mounted for the foot.

2.1.5 Informed Consent

Participants were sent a consent form that detailed all information regarding the study, risks, and benefits. Signed consent forms were received from all participants before any data collection was conducted.

2.2 Outcome Measures

2.2.1 Comprehensive High-level Activity Mobility Predictor

The CHAMP is a performance outcome measurement tool used for high functioning amputees (Armitage, 2021). It is divided into 4 tests: the Single Limb Stance, the Edgren Sidestep Test, the T-test, and the Illinois Agility Test. Each of the four tests are scored in either seconds or points. Each test's raw data is converted to a CHAMP score based on a 10-point scale, totaling a high score of 40 points (Appendix A). A score of 33 is the threshold for a non-amputee active-duty service member. This tool was used in the study to quantify performance on the two court types.

2.2.1.1 Single Limb Stance Test

The single limb stance test (SLS) involves the participant standing on one foot with the other raised 15 cm above a cone while their arms are crossed over their chest. They are instructed to hold this position for a maximum of 30 seconds without losing contact with the ground, moving their raised foot away from the cone, or falling. If the participant can reach the 30 second marker, that leg is completed, otherwise the time they reached is recorded and they are given two more attempts. This is done for both legs. The best time for the left and right legs are added together for a total score out of 60 seconds, which is then converted to a CHAMP score rated out a 10.

2.2.1.2 Edgren Sidestep Test

The Edgren sidestep test (ESS) involves the player side stepping as fast as possible, without legs crossing, between two cones four meters apart for 10 seconds. The participant is instructed to move as quickly and safely as possible between the two cones, making sure to break the plane of the farthest two cones each time. Each meter is marked with a cone and the participant receives one point for each meter passed during the 10 seconds. The best score out of three trials is recorded and converted into a CHAMP score rated out of 10.

2.2.1.3 T-Test

The T-Test (TT) involves the participant running as fast as possible through a “T” shaped course, with the best time of three trials being recorded. The participant starts at baseline cone 1 and on the count “go” runs forward 10 meters to cone 2, sidesteps 5 meters right to cone 3, sidesteps 10 meters left past cone 2 to cone 4, sidesteps 5 meters right to cone 2, and then returns 10 meters to baseline cone 1. The time is recorded in seconds and the fastest performance is converted to a CHAMP score rated out of 10.

2.2.1.4 Illinois Agility Test

The Illinois Agility Test (IAT) involves the participant following an “M” shaped path with the best time of three trials being recorded. Participants begin lying prone on the starting line beside cone 1. On the mark “go” they will get up and run as fast as possible forward 10 meters to cone 2.

They will then turn around and run 10 meters to cone 3. Then they weave between four cones up 10 meters to cone 4 and weave back 10 meters to cone 3 again. Then they run forward 10 meters to cone 5, turn around, and run 10 meters to cone 6 at the finish line. The time is recorded in seconds and the fastest performance is converted to a CHAMP score rated out of 10.

2.2.2 IMU Step

During this study, participants wore inertial measurement units (IMUs) from Vicon's IMU Step system. The specific sensors were Blue Trident IMUs. These are capable of measuring step count, impact load, bone stimulus, and the number of low, medium, and high intensity steps taken throughout a given period. These are designed to be used in a real-world setting compared to in a gait lab (Armitage, 2021). IMUs are used for sports science research as they are an effective way to measure biomechanical loads without the costs or restrictions of force plates and motion capture.

2.2.2.1 Placement of IMUs

Accurate placement of the IMU sensors on the limb is necessary for valid results. For the participants in group A, the IMUs were placed just superior to the medial malleolus via silicon bands with Velcro closures that housed the sensors. The "head" of the logo pointed to the anterior aspect of the leg as per the instructions and can be seen in Figure 1.

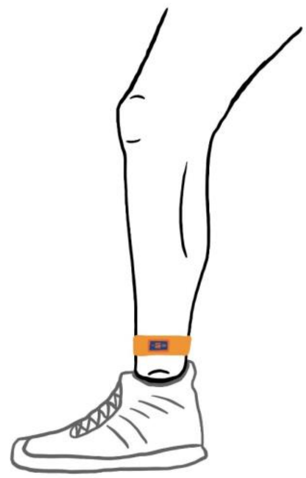

Figure 1 Sound Limb IMU Placement

For the participants in group B, the sensor on the sound limb was placed in the same manner. However, a different method was required for the prosthetic limb placement.

2.2.2.1.1 IMU Placement for a Symes Prostheses

For participant 1B with a Symes amputation, the IMU was attached via self-adhesive Velcro around the ankle unit of the prosthesis as it aligned with the placement of the IMU on the sound limb. Just as with the sound limb, the sensor was placed on the medial aspect of the limb, with the "head" of the logo pointing to the anterior aspect of the device, as seen in Figure 2 below.

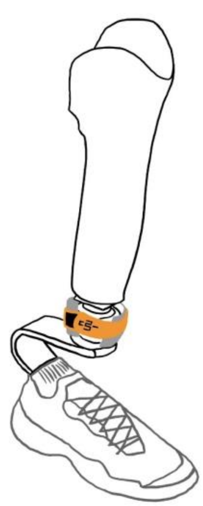

Figure 2 Symes IMU Placement

2.2.2.1.2 IMU Placement on Transtibial Prostheses

For the participant 2B with a transtibial amputation, there lacked a connection point below the socket, similar to what was present on participant 1B, due to the posteriorly mounted blade. Therefore, the locking unit at the base of the socket was determined to be the best point of placement. This location was chosen because of the proximity to the anatomical ankle and natural progression of the leg compared to placing it on the blade. The IMU was attached to the locking unit via self-adhesive Velcro that had been wrapped around the lock at the base of the socket. Similar to the sound limb placement, the sensor was placed on the medial aspect of the limb, with the "head" of the logo pointing to the anterior aspect of the device, as seen in Figure 3 below. Since this placement meant it was located higher on the limb than what is instructed, the sensor on the sound limb was raised slightly higher to match the prosthetic side. This was done in an attempt to make the data consistent.

Figure 3 Transtibial IMU Placement

2.2.2.2 Data Processing

The IMU Step sensors recorded impact on each leg throughout the entire CHAMP protocol. Data recording started at the beginning of the SLS test and ended at the end of the IAT. The participants are given a 30 second rest period between SLS Test trials, and 60 second rest periods between ESS Test, T-Test, and IAT trials. The sensors were removed between the testing on the clay courts and hard courts as the participants had an hour break in between. All participants completed the CHAMP on the clay courts first and the hard courts second due to the availability of the courts at the data collection site. There is a chance for potential learning leading to the participants doing better on the second court type, however this was unavoidable due to the facility limitations.

The data from the sensors was exported to the IMU Step Dashboard where total impact load was calculated, for each individual leg or combined, for the entire session. This system calculates impact load by multiplying the number of steps taken at a certain impact level (ex. 1g) by the impact amount and then adding all impacts together. Meaning if someone took 4 steps at 5 grams and 4 steps at 8 grams, the total impact load would be 52 grams. This means that total impact load will increase for an activity if a participant is taking higher intensity steps or has a higher frequency of steps. Total Impact Load is a cumulative metric that allows for an overall understanding of the impact the lower limbs are experiencing throughout a given activity.

It is important to note that the sensors took continuous data collection throughout the entire CHAMP protocol, which included any trials that were disqualified due to a fall. This could have some impact on the accuracy of the overall impact load. Ideally, there would have been to data collectors present: one to record the times of the CHAMP and one to start and stop the IMUs after each trial for each test. However, since only the PI was present, it was decided that for the sake of efficiency, the IMUs would collect data the entire protocol.

2.3 Analysis

Due to the number of participants in this study, there was a limited amount of statistical analysis that could be done. Because of this, the raw data was converted into the respective CHAMP Scores and conclusions were drawn from there. The data from the IMUs was exported from the sensors into the IMU Step Dashboard where total impact load from each session could be pulled.

To investigate if PST players with LLA perform better on clay vs hard courts, the CHAMP scores for each court type were compared and the IMU data was used to gain a potential understanding of why they may have performed better.

To investigate if PST players with LLA perform differently than able-bodied tennis players, the overall CHAMP scores were compared on both court types. To get a better understanding of what may be going on biomechanically during the CHAMP, the IMU data was used to see if there were loading differences between participant groups.

3.0 Results

3.1 CHAMP Results

The CHAMP is broken down into SLS, ESS, TT, and IAT, with both the raw score and converted CHAMP score, displayed for each participant on the two surface types in Table 1. The measured performance is shown as the total combined CHAMP score on the far right of the table.

Table 1 CHAMP Results

	CHAMP Results								
	SLS		ESS		TT		IAT		Total
	Raw	CHAMP	Raw	CHAMP	Raw	CHAMP	Raw	CHAMP	CHAMP
Participant 1A Hard Court	60	10	30	9	9.15	10	14.87	10	39
Participant 1A Clay Court	60	10	29	9	9.59	10	16.32	9	38
Participant 2A Hard Court	60	10	20	6	14.78	9	25.66	8	33
Participant 2A Clay Court	60	10	17	5	18.31	8	28.31	7	30
Participant 1B Hard Court	42.68	6.5	25	7	8.37	10	19.35	9	32.5
Participant 1B Clay Court	34.72	5.5	21	6	9.78	10	20.57	9	30.5
Participant 2B Hard Court	32.82	5	26	7	9.31	10	17.84	9	31
Participant 2B Clay Court	32.65	5	27	8	9.17	10	19.13	9	32

3.2 IMU Results

3.2.1 Total Impact Load

To compare the impact through each leg on the two court types, the clay court data is on the left and the hard court data on the right for each participant.

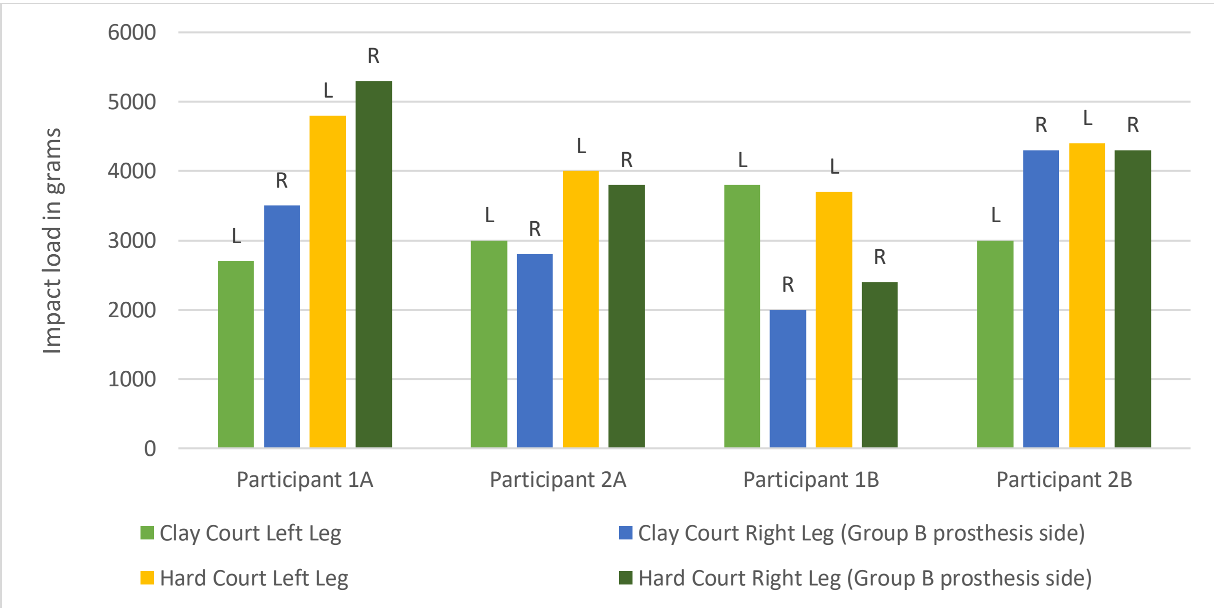

Figure 4 Total Impact Load Per Leg on Both Court Types

4.0 Discussion

It was hypothesized that participants would score better on the CHAMP on hard courts compared to clay courts. The reasoning being that changing directions may be easier with higher friction surfaces, such as concrete. Figure 5 depicts the interaction between court type and total CHAMP Score. The distance between the endpoints on the left of the graph indicates that there may be an interaction between the court type and total CHAMP Score for Group A. However, the endpoints on the right side for group B are much closer together, indicating that the court surfaces have a minimal effect on the total CHAMP score. According to a study on the reliability of the CHAMP, the minimal detectable change (MDC) for total CHAMP Score was 3.74 (Gailey, 2013). None of the participants in this study had over a 3.0 change in total CHAMP score, meaning that there is no detectable difference in performance between the two court types for either groups.

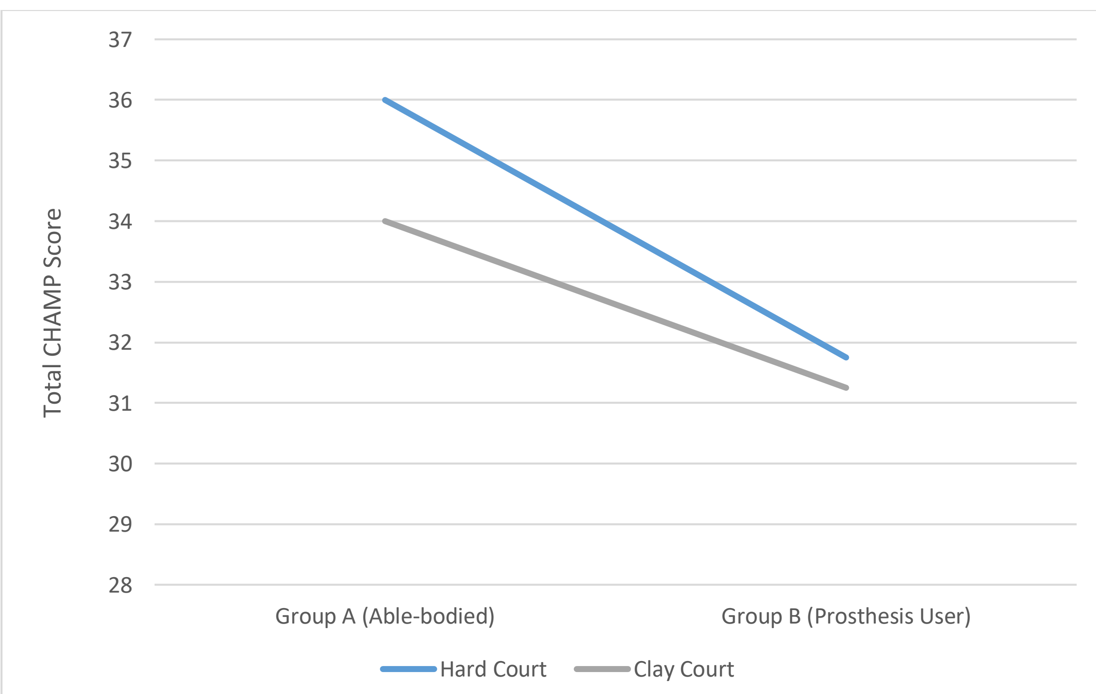

Figure 5 Interaction Plot of Total CHAMP Score and Court Types

The IMU Step sensors were able to record the total impact on each leg throughout the CHAMP protocol for both court surfaces, which is shown in Figure 4. For the participants in group A, there was higher impact on both limbs on the hard courts compared to the clay courts, which was expected. The participants in group B do not follow this trend and it is important to consider which side is dominant and where the prosthesis is located.

It was assumed that participants in group B would favor their sound side on the courts. Since both participants in group B wore prostheses on their right limb, it was expected that there would be higher recorded impact on the left limb on both court types. For participant 1B, this was true and there is a distinct difference in impact between the right and left legs, the left being higher. But this player is also left side dominant, meaning it is unclear whether he is favoring his left leg because it is his sound limb or because it is his dominant side.

Participant 2B may clear this up, since their sound limb is their left side, but they are right side dominant. For this participant, the right leg impact was the same for both court types, but the left leg impact was lower on the clay court. It is important to note that there are many variables that separate these two participants: different levels of amputation, different prosthetic feet, shoe vs no shoe, and sensor placement. Because of these variables, it is difficult to determine exactly why participant 2B had different results compared to participant 1B.

4.1 Impact

While there was no statistical difference in how the PST athletes performed on the two court surfaces, the data does show that PST players may perform differently within group. This could be due to a multitude of reasons: amputation level, socket design, type of prosthetic foot, etc. When compared to the non-amputee athletes, both for overall performance and on the different court surfaces, it points to the idea that PST athletes perform differently.

It may be that overall performance on a court surface comes down to familiarity and confidence on that specific surface type. However, previous studies have shown that experience on clay courts did not influence players' perceptions but did show a reduced risk of injury (Starbuck, 2016). The IMU data showed that biomechanically the PST players did not follow the same trend as the two able-bodied players, meaning they cannot be generalized with all tennis players when it comes to studies regarding injury prevalence.

There are many variables when it comes to those with limb loss, a major difference being the level of amputation someone has. A person with a symes amputation that has weight bearing capabilities may find it easier to maneuver on a clay court compared to a person with an above knee amputation. The socket design and suspension system may both play a hand in how well a person can ambulate. There are multiple distinct types of knees, feet, and activity specific componentry for athletes with amputations. With so many variables, it is hard to know the best combination to achieve top performance.

4.2 Outcome Instruments

While this study lacked a statistically significant result, an important take away is the use of the chosen outcome instruments in this type of study. The CHAMP was originally designed as a way to assess progress towards high-level activity in service members with LLA (Jayne, 2013).

For future research involving PST players, a more specialized instrument involving game play may provide more accurate results. An example could be a two-part protocol, with part one including controlled tennis exercises, similar to the CHAMP, but involving the use of a tennis racquet while returning tennis balls. The use of a ball machine to maintain consistent power and distance could keep it controlled while also allowing for the normal weight-shifting that occurs when returning a tennis ball. Part two could be less controlled and simulate real game play with a ball machine across the net. Not knowing where the next ball will be directed forces the player to quickly change directions and is more representative of what a player might experience in a match, as matches are not controlled settings. However, there still needs to be some parameters set in place to keep some consistency, which is why a ball machine would be ideal. For this study, the facilities ball machines were prohibited for use on the clay courts and there was not an option to purchase one for the study.

4.3 Limitations

With the limited time frame and budget, there were limitations that contributed to the outcomes of this study.

4.3.1 Sample Size

The sample size for this study was smaller than what was calculated for it to be considered significant according to the power analysis done at the start of the project. A post-hoc analysis to compute achieved power was done after completion of the study and a power of 12.71% was achieved. It is also difficult to say that these athletes were representative of the population since all participants were male and only two levels of amputation were studied. This was primarily due to the newness of this sport and the lack of clinics and tournaments throughout the year. The clinic at JTCC that was used for recruitment had a limited number of players with LLA. Other locations were not eligible due to the lack of both court types or travel distance.

4.3.2 IMU Accuracy

Ideally, a load cell would have been incorporated into the prosthesis for an accurate measure of impacts, similar to (Fiedler, 2014). However, the principal investigator conducting the data collection was not certified to manipulate a player's prosthesis and it was not practical to have a CPO present to add a load cell into the device for testing.

The IMU Step System was designed to be used on sound limbs, not on a prosthetic device. There is no evidence to support that the way they were attached to the prosthetic limb would provide accurate data compared to the able-bodied participants. It should be noted that the IMU Step support team was reached out to and it was discussed how to best proceed with placement. It was determined that keeping the sensors parallel to each other was more critical than being close to the anatomically correct location.

4.3.3 Lack of Tennis Specific Outcome Measure

The CHAMP is a reliable and verified tool for quantifying performance of highly active people with amputations. It is not specifically designed for the game of tennis or related activities. A study protocol designed for tennis specific exercises may provide more accurate results as players are not simply running on the court during a match but are actively returning a ball to their opponent. This includes taking multiple short and quick steps in preparation for a stroke, shifting their weight as they contact the ball, and staying in a “ready” position. For the sake of time and validity, the CHAMP was used in place of a new or unverified protocol. This is hopefully something a future study could address.

5.0 Conclusion

The aim of this study was to determine the influence of different tennis court surfaces on performance in PST players with LLA. The data showed that PST players were LLA did perform differently on the court surfaces compared to the able-bodied players. However, there were many variables that could have affected the impact loading of the two participants with LLA, including amputation level, prosthesis type, and foot type.

Determining the best types of prosthetic componentry for different court surfaces could be informative for both player performance as well as injury prevention. If this sport is incorporated into the Paralympics, further research may be beneficial.

Appendix A

Table 2 CHAMP Conversion Chart

	SLS (sec)	ESS (m)	T-Test	IAT
Test Score	Time Range	Point Range	Time Range	Time Range
0	0	< 5	> 124	> 65.4
0.5	0.1 – 3.3			
1	3.4 – 6.6	5 – 7	50.7 – 123.9	60 – 65.4
1.5	6.7 - 10			
2	10.1 – 13.3	8 – 10	45.7 – 50.6	54.5 – 59.9
8.5	53 - 56.2			
9	56.3 – 59.5	29 – 31	11.6 – 16.4	15.9 – 21.4
10	60	> 31	< 11.6	< 15.9

CHAMP Score Conversion Table, modified from CHAMP Scoring System Copyright ©2009 Advanced Rehabilitation Therapy, Inc. Miami, Florida

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