Spring 5-15-2022

Comparison of training load between NCAA DIII tennis resistance training, practices, and matches

Lauren Pascadlo
University of Lynchburg, pascadl482@lynchburg.edu

Comparison of training load between NCAA DIII tennis resistance training, practices, and matches

Lauren Pascadlo

Senior Honors Project

Submitted in partial fulfillment of the graduation requirements of the Westover Honors College

Westover Honors College

May 2022

____
Jeffrey Herrick, PhD

____
Sean Collins, PhD

____
Christine Terry, PhD

ABSTRACT

Background: There are 7553 NCAA Division III tennis players, who play with less training coordination than elite players. Most training load research for tennis focuses on elite players, while Division III tennis load research is highly underdeveloped.

Purpose/Hypothesis: The purpose of this study was to describe the training load in Division III tennis players during resistance training, practices, and matches. The hypothesis is that Division III tennis match external and internal loads will be higher than external and internal loads required during practices.

Methods: 6 male and female NCAA Division III tennis players participated in the study. Participants attended 2 regularly scheduled practice, and resistance training sessions along with 1 match. GPS, heart rate (HR), rating of perceived exertion (RPE), and Athlete's Subjective Performance Satisfaction Scale (ASPS) data was obtained.

Results: Match performance duration in minutes (p=0.02), total distance in meters (p=0.04), and walk distance in meters (p=0.04) were significantly longer than practice. No other significant differences were found. Resistance training, practice, and match RPE differences were not significant. ASPS average composite score was 60. RPE was the first most predictive model of ASPS and RPE and 2D load were the second most predictive model.

Discussion/Conclusion: Performance duration and total distance are likely correlated because the longer a player is on the court, the farther the distance they are likely to travel. These two measurements are likely longer for matches than practices, because there is no determined time limit for a tennis match. Walk distance (m) is likely significantly farther for matches because practices are structured differently than matches.

Keywords: Training load, External load, Internal load, Tennis, College athlete

INTRODUCTION

During the 2019-2020 school year, there were 706 men's and women's NCAA Division III tennis teams consisting of 7553 athletes (1). Although Division III athletes play with the mindset of academics before athletics, they are still held to a higher athletic standard than recreational athletes (2). Practice hours are usually split between on-court practice and resistance training. While daily loads will change depending on the institution, an example of a training cycle might be two-hour on-court practice 4-5 days per week and 45-minute resistance training twice a week. Before matches, there is a warm-up period of approximately 45 to 60 minutes. Athletes on the roster can play singles or doubles, both, or neither. In one match, six individual singles matches and three doubles matches are officially played (3). Typically, most of the players in the singles lineup are also in the doubles lineup. At the Division III level, the average roster holds 10 athletes, meaning that 4 would not be playing official matches (1). Those players may have the chance to play non-official exhibition matches.

Training load monitoring measures the physical demand of exercise and consists of both an external and internal training load (4). External load is defined as the work initiated by an athlete that does not account for internal physiological responses and is quantified by distances covered, time spent resting or active, volume load, and movement speed (4, 5). In tennis, external loads can also be measured by counting shots and errors made (4). To obtain this data, different measurements of training load have been used in previous tennis and team sport studies, which includes Global Positioning Systems (GPS), camera use for movement analysis (time-in-motion, stroke count, etc.), and motion tracking analysis (4). Previous research on external load has compared match and tournament demand between players, demand between practice drills, demand between playing type, and demand between court surfaces (4, 6, 7).

Internal load, on the other hand, is defined as the psychological or physiological factors that occur inside the body and are used to indicate levels of fatigue (8). Internal load is an important measure for all athletes because often the external load will be similar across a team, but each individual will be physiologically working at different levels (9). Heart rate (HR) and rate of perceived exertion (RPE) are the most frequently used measures of internal load in tennis research because they represent the physiological and psychological work being performed (4). Heart rate is an important tool because it is broken down into zones that give athletes and coaches a perception of how hard the athlete is working metabolically at any given moment (4). RPE is broken down by method (Borg vs category ratio) and session or instantaneous data (4). All RPE methods have proven useful in tennis research evaluating internal load (4). Previous studies of external and internal training loads looked at mostly elite junior and professional players, with only one article pertaining to collegiate athletes (4, 10). Applying outcomes from elite populations to Division III tennis players may not be comparable, as collegiate athletes' training and competition are tightly controlled by NCAA regulations.

Research cited by Murphy compared individual matches and playing surfaces (4). The study on individual matches looked at singles matches. They used RPE (on a 6-20 scale) for internal load and work-to-rest ratio for external load (4). The average RPE was 12 +/- 2 and the work-to-rest ratio was 1:0.5 (4). The playing surfaces study compared work-to-rest ratio for an internal load measure on hard court and clay court (4). The hard courts had a higher internal load with a work-to-rest ratio of 1:3.7 (4). Another study compared active, passive, and natural playing styles (6). An active playing style was defined as actively trying to win the point by forcing errors and hitting winners, while a passive playing strategy was defined as trying to get as many balls back in play as possible (6). The natural playing style was however the participant usually plays (often a mix of the two styles) (6). It was determined that the passive style was the most demanding. With the passive style having an average total distance of 421 m (external load), a maximum heart rate average of 292 s, and an average CR-100 (RPE scale from 0-100) of 36 (6).

Previous tennis training load studies investigated match and drill intensity or compared loads between different court surfaces or playing strategies. However, this study hopes to compare practice and competition loads, which has not previously been done in tennis research. In a systematic review of female basketball training loads, researchers compared competition and practice loads to better match them in order to improve the performance of athletes during competition (11). In another study of female basketball players, similar training loads in practices and competitions were found to reduce fatigue and injuries and the athletes were also more physically and mentally prepared for competition (12). While basketball is a team sport and tennis is a paired (doubles) or individual (singles) sport, they both have similar movements, like quick changes of direction. Therefore, the results of these studies will be useful for tennis coaches and players to balance the training load in practice and matches to improve performance, and properly prepare athletes for competition. Tennis-specific research studies have independently focused on practice and competition training loads. However, they have not been compared. Also, because Division III practice and match loads will be different from professional and junior elite (where most tennis research is found), tennis college coaches will be able to better structure their practices to match competition loads.

Studies on the demands of competing and training in collegiate tennis, especially NCAA Division III, are non-existent. This study breaches that knowledge gap by describing the training load through external and internal data taken during matches, practices, and resistance training sessions. Therefore, it is hypothesized that Division III tennis match external and internal loads will be higher than external and internal loads required during practices.

METHODS

Study Design

This is an observational cross-sectional study. Anthropometric baseline measurements of height and weight were taken prior to data collection. Data was gathered during two practices, two resistance training sessions, and one away match within the spring NCAA Division III interconference competition season during late March and April 2022.

Participants

Participants were recruited from the University of Lynchburg's men's and women's NCAA Division III varsity tennis teams through convenience sampling. Recruitment emails were sent to their University address and information was given during practice. Participants were both male and female with ages ranging from 18 to 22 years old. Exclusion criteria included not being able to fully participate in practices or matches as defined by the athletic training staff, having COVID 19, or not being able to attend required practices and matches due to scheduling. The protocol was approved by the University of Lynchburg IRB LHS2122065. All participants were made aware of the risks and benefits of this study and signed informed consent.

Procedure

Firstly, after showing interest in the study, participants made an appointment with the researcher in the Walker Human Performance Laboratory. There they reviewed and signed the informed consent and were assigned a random identification number. They were also assigned a GPS (SPT2, Sport Performance Tracker, Victoria, Australia) and HR monitor (Polar H9, Polar Electro Inc, Bethpage, NY) that were linked with their identification number. Then the participants' height and weight were measured using a stadiometer and digital scale. Lastly, resting heart rate was measured.

Next, data collection was split into three different types of sessions: match, practice, and resistance training. Practice and resistance training sessions each occurred twice, while match data was collected once. The resistance training sessions were the only ones that participants did not wear the GPS and HR monitors. Instead, participants filled out a Google Form to report RPE, using the Borg 1-10 scale. Because resistance training sessions occurred during the competition season, participants were in the maintenance phase which consisted of 45 to 60 minute sessions 2 days per week targeting the whole body. Practices occurred at the University of Lynchburg's outdoor hard court tennis facility in Lynchburg, VA. Practice sessions were chosen based on when participants could attend regularly scheduled practice during the week of the match session. Participants wore the GPS and HR monitors (Polar H9, Polar Electro Inc, Bethpage, NY). The HR monitor was strapped around the chest. The GPS was placed in a clear ID badge holder and then clipped to the strap on the participants back. When practice ended, participants took off the HR and GPS monitors and were instructed to fill out a Google Form consisting of an RPE scale and Athlete's Subjective Performance Satisfaction Scale (ASPS). The ASPS is a 6 question measure of how well the participant feels they have performed within the last week and it uses a 1-10 scale (Appendix A) (13). The match session was conducted similarly to practice sessions and participants wore the HR and GPS monitors in the same way. Participants took off the monitors when they were finished playing. After the match, they filled out a Google Form with a question on RPE. The match session was taken during a dual match (male and female teams play at the same place at the same time) against Guilford College on April 2, 2022 on outdoor hard courts.

The GPS monitor measured the total time (min) and distance (m) for each session. Distances were broken down into walk, jog, run, and sprint distances in meters. In addition, the GPS monitor provided top speed (m/s), work rate (m/min), intensity (AU), 2D load (load units), and 3D load (load units) values. Data from the monitors was downloaded into the SPT GPS system website. The HR monitor provided the heart rate data (mean, max, efficiency) during sessions.

Statistical Analysis

Independent t-tests were used to analyze differences between practices and matches (independent variables) with significance set a priori of $p \leq 0.05$. Sexes were combined due to the low participant number and no difference in match rules. T-tests analyzed the dependent variables for performance duration (min), total distance covered (m), walk distance (m), jog distance (m), run distance (m), sprint distance (m), work rate (m/min), top speed (m/s), intensity (AU), 2D load (load units), 3D load (load units), HR_{mean} (bpm), HR_{max} (bpm), $HR_{efficiency}$ (m/beat), and RPE. An ANOVA was used to analyze differences between practices, matches, and resistance training sessions (independent variables) for RPE (dependent variable) with significance set a priori of $p \leq 0.05$. A stepwise linear regression was used to analyze which dependent variables predicted the ASPS composite score. The dependent variables used were performance duration (min), total distance covered (m), walk distance (m), jog distance (m), run distance (m), sprint distance (m), work rate (m/min), top speed (m/s), intensity (AU), 2D load (load units), 3D load (load units), HR_{mean} (bpm), HR_{max} (bpm), $HR_{efficiency}$ (m/beat), and RPE. Significance for the stepwise linear regression was set at a priori of $p \leq 0.05$. Independent t-tests and the ANOVA were analyzed using JASP 0.16.1 (University of Amsterdam, Netherlands, 2022). The stepwise linear regression was analyzed using SPSS 27 (Chicago, IBM, 2022).

RESULTS

There were 6 participants, 4 female and 2 male. Descriptive statistics can be seen in Table 1. Means, standard deviations, and *p*-values during practices and matches for total distance, walk distance, jog distance, run distance, sprint distance, and hard running are in Table 2. Total distance and walk distance were significantly farther during the match than during practices with a *p*-values of 0.035 and 0.037, respectively (Figures 1 and 2). No other significant differences were found for distance measurements (Table 2). Run and sprint distance (m) averages were almost the exact same for match and practices (Table 2). Jog distance averages between matches and practices had a difference of 445.6 m, where participants jogged farther during matches than practices (Table 2).

Table 1: Means and Standard Deviations of Demographics of Female (n=4) and Male Participants (n=2).

	Females (n=4) Mean +/- SD	**Males** (n=2) Mean +/- SD
Height (m)	171.3 +/- 8.5	177.6 +/- 6.4
Weight (kg)	69.4 +/- 14.9	80.5 +/- 2.8
Resting HR (bpm)	70.0 +/- 18.6	65.5 +/- 9.2
Age (years)	20.8 +/- 2.8	20 +/- 2.8

Table 2: Means, Standard Deviations, and p-values of Distance Measurements during Practices and Matches.

	Practice Mean +/- SD	**Match** Mean +/- SD	***p*-Value**
Total Distance (m)	3154.2 +/- 583.5	4432.2 +/- 1830.0	0.04*
Walk Distance (m)	2355.2 +/- 512.2	3186.9 +/- 1142.4	0.04*
Jog Distance (m)	772.2 +/- 276.3	1217.8 +/- 694.6	0.052
Run Distance (m)	23.6 +/- 12.2	23.8 +/- 25.9	0.50
Sprint Distance (m)	3.2 +/- 2.7	3.8 +/- 5.6	0.39

* indicates statistical significance where $p \leq 0.05$

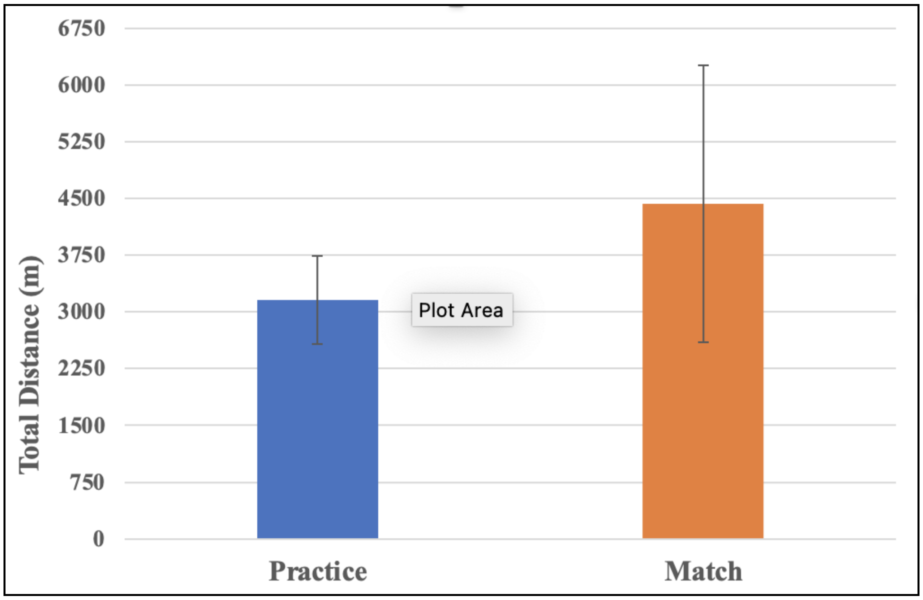

Figure 1: Total Distance (m) Covered during Match and Practice (*p*=0.04).

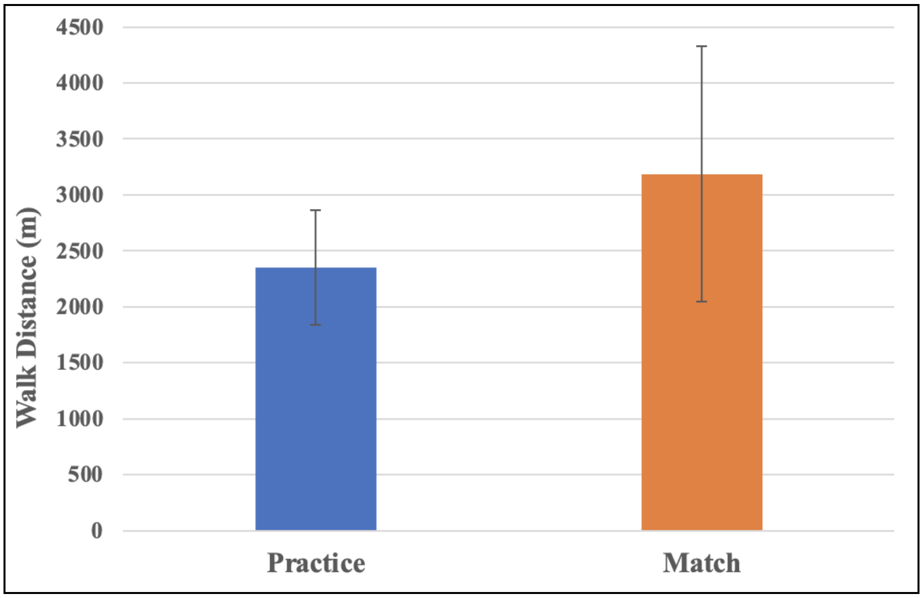

Figure 2: Walk Distance Covered (m) during Match and Practice (p=0.04).

Table 3 displays the means, standard deviations, and *p*-values for HR_{max}, HR_{mean}, $HR_{efficiency}$, work rate, performance duration, top speed, 2D load, 3D load, and intensity during practices and matches. Performance duration was significantly higher during matches than practices with a *p*-value of 0.02 (Figure 3). Figure 4 shows that intensity was significantly higher in matches than in practices with a *p*-value of 0.05. No significant differences were found between practices and matches for any of the HR measurements, work rate, top speed, 2D load, or 3D load (Table 3). Interestingly, HR_{mean} and HR_{max} averages were higher during practices than matches (Table 3). The HR_{mean} averages had a difference of 14 bpm and HR_{max} had a difference of 13.2 bpm. The average difference between match and practice for $HR_{efficiency}$ and top speed (m/s) were too similar to determine any differences (Table 3). Work rate average had a difference of 3.7 m/min between matches and practices with practice data being higher than match data (Table 3). 2D and 3D load averages were higher during matches than practices with average differences of 98.7 load units and 133.6 load units respectively (Table 3). Table 4 displays the mean, standard deviation, and *p*-value for RPE during practice, matches, and resistance training sessions with no significant difference found. Average RPE's ranged from 0.1 to 0.4 away from each other for matches, practice, and resistance training sessions.

Table 3: Means and Standard Deviations of HR Measurements, Top Speed, Work Rate, Performance Duration, 2D Load, 3D Load, and Intensity during Practices and Matches.

	Practice Mean +/- SD	**Match** Mean +/- SD	***p*-Value**
HR_{Mean} (bpm)	132.9 +/- 18.9	118.9 +/- 20.4	0.90
HR_{Max} (bpm)	138.1 +/- 18.6	124.9 +/- 22.4	0.88
$HR_{Efficiency}$ (m/beat)	0.9 +/- 0.4	0.8 +/- 0.4	0.66
Top Speed (m/s)	6.9 +/- 0.8	6.4 +/- 1.5	0.77
Work Rate (m/min)	33.6 +/- 5.7	29.9 +/- 2.1	0.92
Performance Duration (min)	96.3 +/- 21.6	148.8 +/- 62.8	0.02*
2D Load (load units)	282.2 +/- 164.0	380.9 +/- 282.0	0.20
3D Load (load units)	337.7 +/- 177.8	471.3 +/- 320.4	0.16
Intensity (AU)	9.8 +/- 2.1	14.0 +/- 6.7	0.05*

* indicates statistical significance where $p < 0.05$

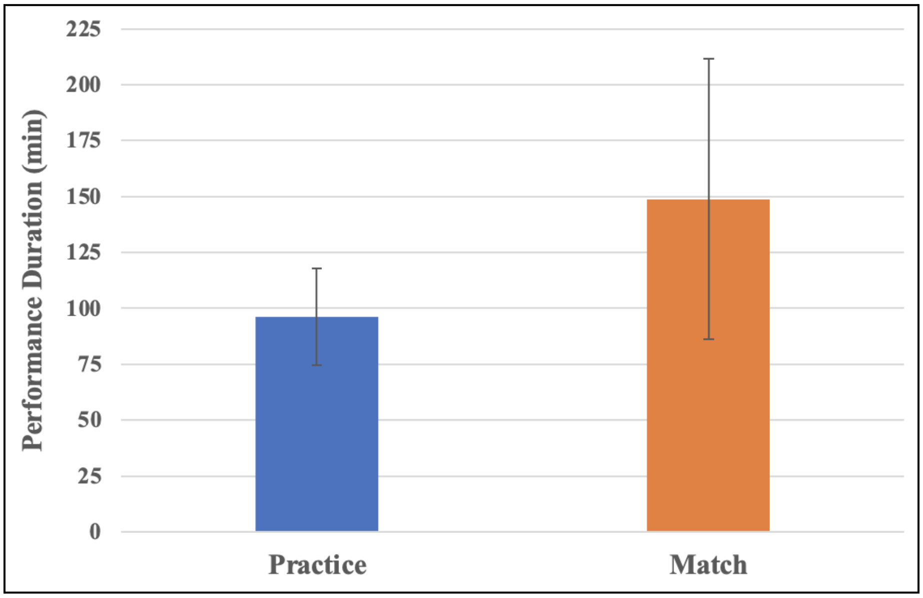

Figure 3: Performance Duration (min) during Match and Practice (p=0.02).

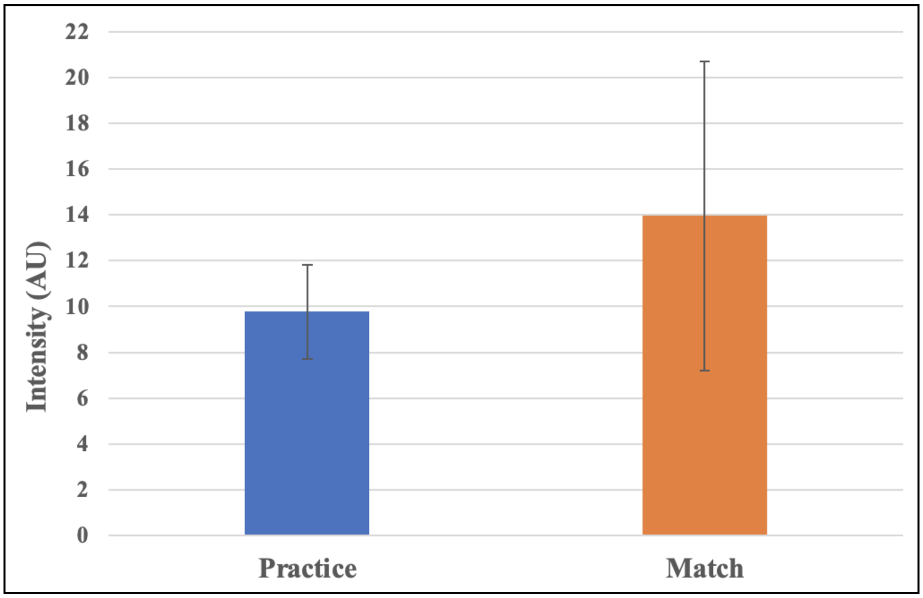

Figure 4: Intensity (AU) during Match and Practice (*p*=0.05).

Table 4: Means, Standard Deviations, and p-Values of RPE for Resistance Training, Practice, and Match Sessions.

	Practice Mean +/- SD	**Match** Mean +/- SD	**Resistance Training** Mean +/- SD	***p*-Value**
RPE	6.2 +/- 1.4	5.5 +/- 3.1	6.1 +/- 1.4	0.76

Lastly, the means of responses to the Athlete Subjective Performance Satisfaction scale (ASPS) ranged from 5.9 to 7.5 and the average composite score was 40 (Table 5). Individual questions were scaled from 1 to 10 meaning that on average participants were satisfied with their performance. Composite score possibility ranged from 6 to 60, so participants' average composite score is 20 away from full satisfaction with performance. Table 6 shows the results of the stepwise linear regression for ASPS and all dependent variables. The most constant predictive model was RPE and the second most predictive model was RPE with 2D load.

.

Table 5: Means and Standard Deviations of Performance based on ASPS.

Athlete's Subjective Performance Satisfaction Scale	**ASPS** Mean +/- SD
Satisfaction with Own Performance	6.4 +/- 1.3
Contribution to Success of Team	7.1 +/- 2.1
Extent of Own Capabilities Reflected	5.9 +/- 1.3
Contribution to Improving Team Members Performance	7.5 +/- 1.3
Satisfaction with Performance When Challenged	6.4 +/- 1.6
Extent of Coach's Satisfaction with Your Performance	6.9 +/- 1.4
Composite Score	40 +/- 6.7

Table 6: Predictive Models of the Stepwise Linear Regression on the Prediction of ASPS by all Dependent Variables.

Predictive Models	**R**	**R^2**	**Adjusted R^2**	**SEE**	**F-value**	**p-value**
RPE	0.650	0.422 (42.2%)	.370	5.853	8.04	0.016
RPE and 2D Load	0.791	0.625 (62.5%)	0.550	4.94	8.342	0.007
Most constant predictive model: RPE 2nd most constant predictive model: RPE & 2D Load						

DISCUSSION

Overall, this study described differences between practices and matches for Division III tennis players. External load measures of performance duration (min), total distance (m), walk distance (m), and intensity (AU) were significantly longer during matches than during practices. External load measures of jog distance (m), run distance (m), sprint distance (m), work rate (m/min), top speed (m/s), 2D (load units) and 3D load (load units) were not significant. The internal load measurements of HR_{mean}, HR_{max}, and $HR_{efficiency}$ were statistically significant within practices and matches. Also, RPE was not significant across practices, matches, or resistance training sessions. The most constant predictive model for ASPS was RPE and the second most constant predictive model was RPE and 2D Load. Therefore, my hypothesis is partially supported. External loads were higher during matches than practices but internal loads were not.

Performance duration is expected to be significantly longer during matches because the match duration is not limited by time. Instead, each player plays for as long as their match requires to determine a victor, whereas practices are capped in duration due to NCAA regulations. One set lasts approximately an hour (14). Because many Division III tennis players play doubles (8-game pro-set) and singles (best 2 out of 3, 6 game sets), they could be on the court for more than 4 hours (4 sets at 1 hour each). As the University of Lynchburg's practices range from 1.5-2 hours in length, matches should be longer. With that, if athletes are on the court for longer during matches than practices, it would suggest that they also travel a farther distance. Thus, total distance would be significantly farther in matches than in practices, which is consistent with our data. Total distance may also be significantly farther during matches than practices because of the significantly higher walk distance. If players walked farther during matches then they're total distance would be farther too.

A significantly higher walk distance during matches may also be explained by the style of play during practice and matches. During matches, there is time in play and time between play (15). Time in play involves the time from when the ball is served to when the point ends and time between play includes everything else that happens while players are still in the match and on the court (15). While practices are not matches, they often incorporate shortened versions of matches (especially during the season). These shortened practice matches typically do not involve change overs or set breaks. Change overs are when the players switch ends of the court on odd numbered games and set breaks are breaks between sets (at the end of the first set in singles). NCAA rules govern that change overs are no more than 90 seconds and that set breaks are no more than 2 minutes in length (3). This time will be spent mostly walking. Without these in practice, the walking distance will be less. In addition, during a tennis match, each court is given one can of tennis balls (3 balls are in each can). Because a player has 2 serve chances to start the point, they must have at least 2 balls on their person to serve. This means that time will be spent chasing balls prior to serving by both the returner and server. Players often walk while chasing balls. In contrast, during practice a whole cart of balls (anywhere from 50-200 balls) is available for the players to pick from. This means that more than 3 balls will be on any given court at a time and thus less time will be spent chasing balls. Less time chasing balls translates into less distance walked during practice. Therefore, a lack of changeovers and set breaks during practice matches along with the availability of tennis balls during practice leads to more distance walked during matches.

Intensity is also expected to be higher during matches than practices. Matches tend to be higher in intensity even if the loads are the same because match play adds more pressure to the player. If the player is already feeling anxious about the match, then the level of intensity will increase. Also, players tend to give all the effort possible in a match because it is a win or lose situation. However, they may not do the same during practices, leading to increased intensity during match play. As previously mentioned, in season practices at Lynchburg often incorporate practice matches. One research study on field hockey practice and competitions found that practices incorporating match play have a significantly longer time spent in a low intensity than other practices (16). They claimed that this lower intensity did not align with match intensity and that match intensity exceeded practice intensity in this scenario (16). This was consistent with our data because practice intensity was significantly lower than match intensity.

Jog distance, 2D load, and 3D load had average differences that were higher during matches than practices. While these differences were not significant, each difference should be higher in matches than practices. Jog distance, much like walk distance, should be higher because of the style of play. Players will often chase after balls while jogging. Also, if performance duration and total distance is longer for matches than practices, then there must be differences within the distance zones too. This study found those distance differences within walk and jog speeds. 2D load is created by acceleration and deceleration going in a 2D plane (forwards, backwards, and side-to-side). Because matches are more intense and they take longer (performance duration) it would follow that 2D load would also be higher. If players are on the court for longer, they have more time to accelerate and decelerate on the 2D plane. Also, these decelerations and accelerations may be harsher than during practice because of the higher intensity. 3D load is the load on the body from jumping and landing (up and down movement) on the 3D plane. Because players will likely be serving more during matches because of the longer duration they will also be jumping more.

Contrastingly, practice HR_{mean}, HR_{max}, and work rate average differences were higher than match. While these differences were not significant, it is interesting that practices were higher than matches. HR_{mean} and HR_{max} are two of the internal load measurements. Another internal load measurement was RPE. Interestingly, RPE also had a higher average difference during practices than matches. Therefore, participants had higher HRs and felt like they were also working harder during matches than practices. Because less breaks are taken during practices, it is possible that HR levels were more sustained and thus also reached higher levels during practices. Because of the higher HR participants may have felt like they were working harder because their HR was higher. Work rate was a measure of how far participants went within a minute. Because of the increased walk time during matches, it is likely that participants traveled farther per minute of practice because they were moving faster. Although no significant difference was found for top speed.

Run distance, sprint distance, $HR_{efficiency}$, and top speed were so similar across practices and matches that differences could not be discerned. One goal of this study was to determine if practice and match internal and external loads were similar. The goal of these similar loads was to prepare athletes for matches properly (12). Lynchburg coaches did a good job of creating a practice that incorporated similar run distance, sprint distance, $HR_{efficiency}$, and top speeds between practices and matches.

While there were no significant differences between practices, matches, and resistance training sessions for RPE, participants reported higher RPEs for practices and resistance training sessions than matches. These differences suggest that the athletes feel like they are training hard. It is important that athletes feel like they are training hard because then they will be more prepared for competition. If they feel more prepared, then they will perform better during matches (12). ASPS was our determinant for participant performance. With an average composite score of 40, only 20 away from the maximum of 60, participants felt like they were performing well. This link between RPE and ASPS was further supported by the stepwise linear regression results. RPE was the most constant predictive model for ASPS. This means that when participants felt like they worked hard (reported a higher RPE), they also felt like they performed better (reported a higher composite ASPS). The second most predictive model added 2D load to RPE to increase in ASPS. Therefore, the more athletes moved in a 2D plane and the higher their RPE, the higher their reported ASPS composite score. The addition of 2D plane results as a part of the predictive model could be explained by participants' natural movement on a tennis court. Players typically play along the baseline or back and forth between the net and baseline. If a player has moved well, then they will have mostly moved within the 2D plane. Therefore, when participants' 2D load was higher, then they may have felt like they were moving well. If they are moving well then they are often performing well too.

Some limitations of my study include unsupported GPS accuracy for tennis, lack of hydration and nutrition control, and a small sample size. Firstly, the SPT GPS device used in this study is marketed for Australian football, American football, soccer, rugby, hockey, and lacrosse (17). These sports use a large field with players moving across all of it. A tennis court is much smaller than any of these fields and play is restricted to one half of the court at a time. In addition, GPS accuracy for tennis was tested by Duffield, Reid, Baker, and Spratford using 10 repetitions of four different drills that replicate movement during tennis play (18). They determined that GPS units had an inter-unit coefficient of variation ranging from 4% to 30% depending on the speed of the individual (18). They also claimed that distance measurements were underestimated at higher speeds and with repeated movements in a confined space (18).

Lastly, top speeds were underestimated by anywhere from 10% to 30% (18). Therefore, GPS data in tennis is not accurate and not supported. Hydration and nutrition information were neither reported nor controlled within this study. Daily hydration and nutrition levels can affect internal load measurements like HR (8). Therefore, hydration and nutrition could be important factors. With only 6 participants across the men's and women's University of Lynchburg tennis teams, the sample size was small. Also, only University of Lynchburg players were tested, lowering the generalizability. There is significant variability in practice methodology between different teams and divisions, which may lead to differences in training load.

Because of these limitations, future research should use data collection methods with greater sensitivity to assess the nuances of tennis play movements, such as cinematography and notational techniques (4). In addition, future research should incorporate multiple teams across different NCAA Divisions. This will allow for data to be relatable for all NCAA tennis players and take into consideration the variability of practice styles among different teams. Furthermore, testing multiple teams will increase the sample size and add diversity of individual play and practice. Hydration and nutrition should also be recorded and or controlled by researchers. In addition, researchers could include comparisons between sexes to adjust practice prescriptions so they are sex specific. Lastly, tennis research using ASPS in the future should conduct a stepwise linear regression with all dependent variables to determine any trends across data. These trends could potentially lead to the creation of a formula that would predict the ASPS of tennis players before they report it.

Acknowledgments

Thank you to my thesis committee, Dr. Jeffrey Herrick, Dr. Sean Collins, and Dr. Christine Terry, for all your guidance, encouragement, and edits. Thank you to the University of

Lynchburg Tennis coaches, Chris Johnson, Reagan Coon, and Randall Carter, for allowing me to work with the team and being flexible. Thank you to the University of Lynchburg Strength and Conditioning coaches, Ed Smith and Margo Lee, for prescribing the resistance training program. Thank you to my subjects for participating and being flexible.

APPENDIX A

Athlete's Subjective Performance Satisfaction Scale (ASPS) Questions

All questions were answered via Google Form and were on a scale from 1 to 10 with 1 being "not at all satisfied" and 10 being "fully satisfied." A composite score for each participant was added together after the form was completed. Composite scores ranged from 6-60.

1. To what extent are you satisfied with your sporting performance this week?
2. To what extent did you contribute to the success of your team this week?
3. To what extent were your capabilities truly reflected this week?
4. To what extent did you contribute to improving the performance of the players around you this week?
5. To what extent are you satisfied with your functioning during the challenging moments this week?
6. To what extent do you think the coach was satisfied with your performance this week?

REFERENCES

1. Tennis Scholarships & Chances of Playing in College | Scholarship Stats.com2020; [cited 2021 Aug 30] Available from: https://scholarshipstats.com/tennis.
2. Parham A. What You Need to Know About DIII Athletics. *Natl Scout Rep*. 2020; [cited 2022 May 4] Available from: https://www.nsr-inc.com/scouting-news/what-you-need-to-know-about-diii-athletics/.
3. ITA_Rulebook_2019_20_FINAL_r3_SINGLE_PAGES.pdf*Google Docs*. [date unknown]; [cited 2022 May 2] Available from: https://drive.google.com/file/d/15pZwnmt_59BU2WFLMHKJRHwaxEPKCQD8/view?usp=embed_facebook.
4. Murphy AP. Methods of External and Internal Training Load Monitoring in Elite Tennis Environments. *J Aust Strength Cond*. 2013;21(3):74–80.
5. Wallace LK, Slattery KM, Coutts AJ. The Ecological Validity and Application of the Session-Rpe Method for Quantifying Training Loads in Swimming. *J Strength Cond Res*. 2009;23(1):33–8.
6. Hoppe MW, Hotfiel T, Stückradt A, et al. Effects of passive, active, and mixed playing strategies on external and internal loads in female tennis players. *PLoS ONE* [Internet]. 2020 [cited 2021 May 15];15(9) Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7508371/. doi:10.1371/journal.pone.0239463.
7. Reid M, Duffield R, Dawson B, Baker J, Crespo M. Quantification of the physiological and performance characteristics of on-court tennis drills. *Br J Sports Med*. 2008;42(2):146.
8. Halson SL. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Med Auckl*

Nz. 2014;44(Suppl 2):139–47.

9. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-Based Training Load in Soccer. [Miscellaneous Article]. *Med Sci Sports Exerc*. 2004;36(6):1042–7.

10. Kraemer WJ, Ratamess N, Fry AC, et al. Influence of Resistance Training Volume and Periodization on Physiological and Performance Adaptations in Collegiate Women Tennis Players. *Am J Sports Med*. 2000;28(5):626–33.

11. Reina M, García-Rubio J, Ibáñez SJ. Training and Competition Load in Female Basketball: A Systematic Review. *Int J Environ Res Public Health*. 2020;17(8):2639.

12. Reina Román M, García-Rubio J, Feu S, Ibáñez SJ. Training and Competition Load Monitoring and Analysis of Women's Amateur Basketball by Playing Position: Approach Study. *Front Psychol*. 2019;9:2689.

13. Nahum O, Ben-Ami M, Cohen, D., Shivek, A. Athlete's Subjective Performance Scale (ASPS). *ASPS*. 2016; [cited 2022 May 12] Available from: https://sportperformance.wordpress.com/.

14. Gescheit DT, Cormack SJ, Duffield R, et al. Injury epidemiology of tennis players at the 2011-2016 Australian Open Grand Slam. *Br J Sports Med*. 2017;51(17):1289.

15. Kovalchik SA, Ingram M. Estimating the duration of professional tennis matches for varying formats. *J Quant Anal Sports*. 2018;14(1):13–23.

16. Gabbett TJ. GPS Analysis of Elite Women's Field Hockey Training and Competition. *J Strength Cond Res*. 2010;24(5):1321–4.

17. Sports Performance Tracking | GPS Tracking for Contact Sports | SPT*SportsPerformanceTracking*. [date unknown]; [cited 2022 May 2] Available from:

https://sportsperformancetracking.com/.

18. Duffield R, Reid M, Baker J, Spratford W. Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *J Sci Med Sport*. 2010;13(5):523–5.