Original Article

# Modelling the relationship between relative load and match outcome in junior tennis players

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**ABSTRACT**

The acute:chronic workload ratio (ACWR) is a metric that can be used to monitor training loads during sport. Over the last decade researchers have investigated how this metric relates to injury, yet little consideration has been given to how this metric interacts with performance. Two prospective longitudinal studies were implemented investigating internal and external ACWRs and match outcome in junior tennis players. Forty-two and 24 players were recruited to participate in the internal and external load studies, respectively. Internal load was measured using session rate of perceive exertion, while external load was defined as total swing counts. The main dependent variable was tennis match performance which was extracted from the universal tennis rating website. The ACWR for internal and external load were the primary independent variables. Acute load was defined as the total load for one week, while a 4-week rolling average represented chronic load. There were no significant associations between internal ($p$-value = .23) or external ($p$-value = .81) ACWR and tennis match performance as assessed by multivariate regressions. The ACWRs in these datasets were close to 1.00, thus a balanced training load was undertaken by these athletes upon entering match play but was not related to match success.

**Keywords:** Match performance; ACWR; Load monitoring.

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## INTRODUCTION

Tennis consists of explosive movements (Fernandez-Fernandez et al., 2009) and physiological demands that require complex lateral movements and repetitive high velocity swings of the racquet (Salonikidis & Zafeiridis, 2008). These adaptations are critical for technical proficiency using the entirety of the kinetic chain to achieve maximal velocity during strokes. The physical attributes and technical abilities contributing to these skills are improved upon with consistent training (Reid et al., 2009). These training sessions are vital to athletic improvement and if not managed appropriately may place the athletes at increased injury risk (Kovacs, 2007). Therefore proper planning of training may be crucial for optimal training and recovery and match performance success (Kovacs, 2007).

The physical capabilities of athletes have been shown to correlate to rankings in youth male tennis players (Kramer et al., 2017). In addition, improved youth rankings are thought to be a prominent factor in subsequent international rankings as an adult (Reid & Morris, 2013). The importance of rankings cannot be understated as 91% of the top 100 ranked male tennis professionals earned an International Tennis Federation (ITF) junior tennis ranking (Reid & Morris, 2013). In order to obtain an elite ranking as a junior competitor, players are consistently working on skill improvement which often requires rigorous training demands. These rigorous training demands require an increased need for improved load and fitness tracking and quantifications.

Tracking load and fitness are important pieces of coaching and have remained an important part of scientific literature since 1970 with the introduction of the fitness-fatigue model from Banister and colleagues (Banister & Calvert, 1980; Calvert et al., 1976). An important piece of this model is that "*the performance of an athlete in response to training can be estimated from the difference between a negative function (fatigue) and a positive function (fitness)*" (Gabbett, 2016). As such, the ability for a coach to implement organized and planned training programming to optimize fitness may result in better performance during competitions (Kovacs, 2007).

Load can be defined as a stimulus that is applied to the human biological system and can be measured via external or internal metrics (Soligard et al., 2016). External loads help to identify the amount of work done by an athlete and can range from distances covered (Duffield et al., 2010; Vickery et al., 2014) to more sport specific variables such as total swing count in tennis(Myers et al., 2019). These measurements are important as they help to quantify the activity of the athlete, and the load being placed on tissues. Internal loads represent the response an athlete has to an external stimulus (Bourdon et al., 2017). Rate of Perceived Exertion (RPE) is a commonly used metric to quantify internal load and has been used in many sports, including tennis (Aughey et al., 2016; Collette et al., 2018; Coutts et al., 2010; McLaren et al., 2017; Mendez-Villanueva et al., 2007; Wallace et al., 2008). An extension of this measure often reported in the literature is session RPE (sRPE). Session RPE (calculated as RPE*session duration) considers not only self-perceived intensity following activity, but the duration of the activity (Coutts et al., 2010).

Within the last decade training load metrics have been used to assess relative load changes to better manage injury risk (Hulin et al., 2014) and potentially performance demands. One method used to evaluate relative load changes is the acute:chonic workload ratio (ACWR)(Blanch & Gabbett, 2016; Hulin et al., 2016). This ratio is most often derived using the most recent week's training workload (acute) compared to the 4-week training load (chronic) (7:28 day comparison). The ACWR is an expansion on Banister's fitness fatigue model (Banister & Calvert, 1980; Calvert et al., 1976). The ACWR allows the performance or health care team to plan training sessions that allow for recovery and adaptation to training. The timeline for an athlete's body to recover and adapt to training may span days at a time and proper planning for this delay may be critical for

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improved performance. While the demands of these training loads using the ACWR are most often investigated in relation to injury risk,(Bowen et al., 2017; Hulin et al., 2014; Timoteo et al., 2018) the effect these loads have on match outcome performance is under investigated (Aughey et al., 2016).

Monitoring load in sport has become easier over the last decades due to the increase in technology. Quantifying loads in team sports is becoming common practice; however, tennis has lagged as minimal longitudinal studies are available on training load and how load impacts performance. Therefore, the primary purpose of this study was to determine the relationship between internal and external load and match outcome in tennis athletes. It is hypothesized that internal and external ACRWs (acute < chronic) would be related to better match outcomes in junior tennis players.

## MATERIALS AND METHODS

### *Participants*

Junior tennis players were recruited from one tennis training facility in Austin, Texas and provided written informed consent (or assent with guardian consent, where applicable) to participate in this study, which was approved by Texas State University's Institutional Review Board. Both internal and external load were prospectively collected at two different time points. Both internal and external load data were an extension of injury monitoring studies (Myers, Aguilar, et al., 2020; Myers, Farnsworth, et al., 2020). Internal load data were collected between May 2018 and December 2018 for a consecutive 31 weeks. Forty-two junior tennis players were recruited to participate in the internal load study. Twenty-nine tennis players (19 males and 10 females; average age 14 ± 2) successfully completed all aspects of the study. External load data were collected between September 2018 and April 2019 for a consecutive 34 weeks. Twenty- four junior tennis players were recruited to participate in the external load study. Twenty-one athletes (16 males and 5 females; average age 14 ± 2) successfully completed all aspects of the study. Players were included in the studies if: (1) participated in tennis at least three times a week during the fall, winter, or spring months; (2) ranged in age between 9 and 18 years old; (3) participated in sectional, regional, or national tournaments; and (4) had no injuries that influenced tennis participating at the time of enrolment. Players were excluded from the internal load study if they did not have access to a tablet or smartphone (used to record load variable) and from the external load study if the racket was not compatible with the Sony Smart Tennis Sensor (SSTS).

### *Quantifying internal load*

Internal load was measured using sRPE. Players were asked to provide a subjective rating of RPE using a 0-10 point scale as an estimate of training intensity and to document the length of each training/competition session (Foster et al., 2001). Ratings of perceived exertion and duration were documented within 30 minutes after every training or match session Monday through Sunday. Internal load was calculated by multiplying the training/match session RPE by the session duration in minutes to calculate sRPE (Hulin et al., 2014). Rate of perceived exertion and training/match duration were recorded using AthleteMonitoring Software (FITSTATS Technologies) after every tennis session. The software is accompanied with the AthleteMonitoring Application which can be used on any smartphone or tablet. Each player was given a username and password and asked to document daily RPE and duration of training or match time. Players received daily notifications from the software alerting them to document internal training data.

### *Quantifying external load*

External load was defined as total swings that took place during training practices and simulated match play taking place between Monday and Friday. Total swing counts were defined as the combination of forehand swings, backhand swings, and overhead swings. There were options for two training practice sessions each day for each week during the data collection period. These training practices were group led by multiple coaches from one tennis academy. Training practices usually had between 4-6 players to a court. Once a week, players had the option to partake in simulated match play. Individual training sessions, tennis played outside of this tennis academy (example high school tennis), and scheduled match play were not included in external load data collection.

Total swings were collected for each participant using the SSTS which has been previously validated (Myers et al., 2019). The SSTS attaches to the end of the racket handle and weighs 0.28 ounces with a height of 17.6 mm and a diameter of 31.3 mm. The device has a three-axis motion tracking sensor which tracks the racket movement through the three-dimensional space. The sensor is able to record shot type (e.g., forehand, backhand, serve, smash, forehand volley, and backhand) and volley hitting volume. The sensor is compatible with a variety of different rackets made by Wilson Head, Prince, and Yonex.

### *Performance measures*

Performance was tracked via match outcome. Match outcomes were extracted from the universal tennis rating website (Oracle, 2018). Over the length of the data collection periods one member of the research team extracted each participant's win/loss singles match data. In most tournaments players competed in multiple matches and the results of these matches were recorded as a win or loss. Winning percentages were calculated from total wins during each tournament for all participants in both the internal and external load data sets. Winning percentage was the main dependent variable in this study. It is important to note that no one player partook in the same number of matches during these longitudinal studies. Continuation of competition in a tennis tournament is a direct result of the players ability to win a match. In addition, as stated previously, these data were an extension of injury monitoring studies; therefore, if a player was injured, we no longer required the player to record internal and external load and the research team would no longer collect performance data on that particular participant.

### *Data reduction*

#### *Internal load*

The sRPE 7:28 day ACWR was the primary independent variable within the internal load study. Data was categorized into weekly blocks running from Monday to Sunday. One-week data in conjunctions with 4-week rolling average sRPE data, were calculated using the traditional coupled method for ACWR (Windt & Gabbett, 2018). The one-week data represented sRPE acute load, whereas the 4-week rolling average data represented the sRPE chronic load. The sRPE was left blank for players who participated in tennis training/match but forgot to record RPE and duration data. Missing data is likely inevitable in longitudinal studies and there is no consensus on what constitutes a large amount of missing data (El-Masri & Fox-Wasylyshyn, 2005). Players included in the final analysis had a > 84% compliance rate throughout the study.

#### *External load*

The total swings 5:28 day ACWR was the primary independent variable within the external load study. While the 7:28 day model is commonly reported it was removed from this analysis and replaced with a 5:28 day model as swing count was only collected Monday-Friday during this study. Five-day data in conjunction with 4-week rolling average data (28 days) were calculated using the traditional coupled method for the ACWR. In this study, missing data accounted for 17% of the data; enough data that the authors of the research decided to incorporate a strategy for accounting for the missing data. Thus, missing swing counts were estimated using a player's mean weekly value (Brink et al., 2010; Kang et al., 2009). For both internal and external load metrics, weekly loads that were below 1 standard deviation of the player's chronic load were


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removed from the analysis. These methods were in accordance with Hulin et al so the final analysis would not consider small absolute increases of acute load at low chronic loads (Hulin et al., 2014).

### *Statistical analysis*

Descriptive data were calculated for the main outcome measure and the main independent variables (ACWR). Two complex samples multivariate regressions were used to identify if either internal or external training loads are associated with match outcome as measured by weekly win percentage in junior tennis players. All analyses were conducted in SPSS 26.0 (IBM, Armonk, New York). One model incorporated internal load (sRPE) while another model incorporated external load (swing counts). The two loads were not considered in the same model as data collection for these two independent variables took place at different time points and used data from different participants. Both internal and external load regression models included sex, age, years of experience, previous injury history (dichotomous), and the ACWR from the previous week of match play as additional explanatory variables. Assessment for normality of the independent variables was completed with the Anderson-Darling test. To control for the increase in type I error associated with multiple analyses a Bonferroni adjusted alpha (0.05/2) was used to determine significance of predictors within each regression model.

## RESULTS

### *Internal load*

There were 13 players removed from the original 42 recruited players and considered dropouts. Thirteen athletes were noncompliant with data collection. The average number of matches of all participants in the internal load model was 20 ± 13 matches. Participants in the internal load group won on average 54% of the singles matches played over the observational period. The average 7-day and 28-day sRPE were 3,959 ± 1,546 arbitrary units (AU) and 3,802 ± 1,093 AU, respectively. The average ACWR from the previous week of match play was 0.98 ± 0.20. The ACWR quartile ranges of 25%, 50%, and 75% were 0.84, 1.00, and 1.11, respectively. Results of the multivariate regression model analysis indicated that none of the explanatory variables: sex (Wald F = 2.05; *p*-value = .16), age (Wald F = 1.08; *p*-value = .31), years of experience (Wald F = 0.03; *p*-value = .95), previous injury history (Wald F = 0.58; *p*-value = .45), and 7:28 day ACWR (Wald F = 1.05; *p*-value = .23) were associated with win percentage.

### *External load*

There were 3 players removed from the original 24 recruited players and considered dropouts. Three athletes were noncompliant with data collection. The average number of matches of all participants in the external load model was 40 ± 21. Participants in the external load group won on average 44% of the singles matches played over the observational period. The average 5-day and 28-day swing counts were 858 ± 363 swings and 956 ± 394 swings, respectively. The average ACWR from the previous week of match play was 1.11 ± 0.26. The ACWR quartile ranges of 25%, 50%, and 75% were 0.97, 1.12, and 1.26, respectively. Results of the multivariate regression model analysis indicated that none of the explanatory variables: sex (Wald F = 2.81; *p*-value = .10), age (Wald F = 0.39; *p*-value = .59), years of experience (Wald F = 0.01; *p*-value = .91), previous injury history (Wald F = 0.14; *p*-value = .70), and ACWR (Wald F = 0.05; *p*-value = .81) were associated with win percentage.

## DISCUSSION

The aim of this study was to investigate the relationship between internal and external load metrics and weekly match win percentage. The hypothesis for this study was not supported as neither internal nor external

ACRWs were not associated with win percentage. This was the first study to investigate the influence of ACWRs on match outcomes in competitive junior tennis players. Quantification of load using the ACWR has taken hold in a wide variety of different sports to quantify injury risk; (Colby et al., 2017; Hulin et al., 2016; Malone et al., 2017; Warren et al., 2018) yet, performance outcomes implementing ACWRs is a largely unexplored area of research. The metrics used to quantify the ACWR in this study seem to be independent of match success.

The fitness-fatigue model has been used as a framework to identify differences between fatigue and fitness levels (Banister & Calvert, 1980; Calvert et al., 1976). The model predicts that as fatigue is reduced, performance should increase. As such the need to monitor weekly training loads has become common practice in various sports. This allows for coaches to use periodization modelling to peak for certain events and times of the competitive year as high levels of fatigue entering these times have be linked to poor outcomes (Aughey et al., 2016). A positive training balance has been seen to have a small association with increased wins in Australian Footballers (Aughey et al., 2016). These authors defined a positive training balance as a weekly training load (acute) that was lower than the preceding fourth month's load (chronic). These findings are not supported by our data as there were no associations seen between ACWRs and match outcome in either the internal or external models. Thus, there is conflicting evidence to suggest that an acute load that is less than the chronic load provides a greater likelihood of performance success.

The relationships between absolute training load and athletic performance has been investigated in the literature. A study conducted on marathon runners found increases in training load are linked to improved performance (Foster et al., 1977). While this is the first relative training load and performance study conducted on tennis players the authors felt it was important to investigate as competitive players undergo rigorous training loads. In fact, tennis athletes with more competitions and training sessions have been seen to have improved rankings as shown in previous research (Fett et al., 2017). More specifically, elite German youth tennis players practice technical (e.g. ball velocity) and tactical prowess (e.g. decision-making and anticipation) skills more than 15 hours per week (Fett et al., 2017). If an athlete accustomed to less training volumes attempts to practice with higher volumes the subsequent performance may not improve due to compounding fatigue. As such, these high demands placed upon the athlete may be more than that athlete can recover and adapt to. Banister's model describes the possibility of overtraining, when fatigue exceeds a point the body can no longer positively adapt to but is able to recover from (Banister & Calvert, 1980). Future research should investigate the individual responses to training loads in youth tennis athletes to better understand the inter-athlete variability in adaptation to training for optimal performance.

While this study tracked sRPE and swing count, it is possible other metrics are more closely associated with tennis performance. For example, in youth male tennis players upper body power was a significant predictor of U13 ranking (Kramer et al., 2017). Total number of swings only accounts for a portion of training, disregarding other conditioning drills and strength training activities that take place as part of training loads. In addition, technical and tactical skills have been seen to be very important for improving ranking of an athlete (Kolman et al., 2019). If the time spent practicing is not spent honing these skills in a productive manner, there may be no change to skill regardless of how difficult the practice feels. The breakdown of time spent on various aspects of tennis or an assessment on the productivity of a practice may be an important avenue for future research. In previous research that assessed only tactical skills there is strong evidence that performance can be largely differentiated by the level of technical and tactical skills, such as anticipation and search strategies, that athletes possess (Kolman et al., 2019).

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This study has limitations that should be considered in interpreting the results. First, each athlete had a different number of matches over the course of each group's data collection period, however z-score calculations confirmed there were no outliers within our datasets. Second, sRPE and swing counts were not collected during the same time periods, and therefore were assessed using two different models. Third, different ACWR time windows were used: sRPE = 7:28 day model while swing count = 5:28 day model. In the sRPE model the authors did not account for missing data. Thus, weeks with missing data points specific to missed sRPE reporting are minimized. Missing data are likely inevitable in longitudinal studies and there is no consensus on what constitutes a large amount of missing data (El-Masri & Fox-Wasylyshyn, 2005).

## CONCLUSION

Our study suggests that there is no relationship between sRPE ACWR and swing count ACWR and win-percentage in young competitive tennis players. The ACWRs in these datasets were close to 1.00, thus a balanced training load was undertaken by these athletes upon entering match play but was not related to match success. It may be necessary to progressively build upon the loads to improve match outcome, but to also concentrate on other avenues of tennis such as technical and tactical prowess, and physical and psychological demands. Future studies should monitor multiple variables during one observational period with similar ACWR time windows to see how these variables relate to tennis specific performance variables.

## AUTHOR CONTRIBUTIONS

NM and RM were involved in all aspects of the data collection process. All authors contributed to data organization, management, and analyses along with the writing of the final manuscript.


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## DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.


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