THE EFFECT OF EXTERNAL LOAD ON SELF PERCEIVED SHOULDER AND

ELBOW FUNCTION IN COMPETITIVE JUNIOR TENNIS PLAYERS

by

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DEDICATION

       I dedicate this thesis to my parents, Miguel Sr. and Claudia, my brothers, Juan and Martin, and my late grandmother, Juana Guerrero, who have always been a constant support in my life. They are my source of inspiration and motivation. Their support and encouragement have inspired me to work hard, despite the many obstacles. Without them, none of my success would be possible.

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LIST OF ABBREVIATIONS

Abbreviation	Description
KJOC	Kerlan-Jobe Orthopaedic Clinic
SSTS	Sony Smart Tennis Sensor
STSA	Sony Tennis Sensor Application
UTR	Universal Tennis Rating
ACWR	Acute:chronic Workload Ratio

ABSTRACT

Competitive junior tennis players undergo rigorous practice schedules and
participate in monthly local and sectional tournaments. As a result of this competition,
intense training loads are common. Training loads, such as hitting volume, may be related
to shoulder and elbow function. The Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder
and Elbow Score allows players to rate self-perceived shoulder and elbow function. It is
reasonable to suggest that training loads may affect a player's self-perceived shoulder and
elbow function when measured using the KJOC. Therefore, the purpose of this research
was to determine if absolute and relative training load affects KJOC scores over an 8-
month time period in competitive junior tennis players. Eighteen players, 14 males and 4
females, from one tennis academy, were recruited. Each player completed a KJOC prior
to the start of data collection, at 4 months, and at 8 months. External load was defined as
all training drills and simulation match play taking place between Monday-Friday and is
referred to as hitting volume. Hitting volume was collected using a shot tracking sensor.
Load was quantified as the sum of all shots (forehand swings, backhand swings, and
overhead swings) over the 8-month observational period for each player. In order to
quantify absolute load over the 8-month observational period players were categorized
into two groups (high and low hitting volume). These groups were determined by
calculating the median hitting volume (26,044 shots) for all participants. Players who
recorded greater than 26,044 shots were grouped into the high volume (n=9) group while
players below were considered low volume (n=9). Relative load was analyzed using the

acute:chronic workload ratio (ACWR). Acute workload was determined as the total hitting volume for one week, while a 4-week rolling average hitting represented chronic workload. The acute workload was then divided by the chronic workload to determine the ACWR. Relative load was categorized with 2 groups: group 1 (n=10) acquired an ACWR of greater than 1.5 for more than 20% of the observational period while group 2 (n=10) players acquired an ACWR of less than 1.5 for more than 20% of the observational period. A 2X3 repeated measure ANOVA was used to determine differences in KJOC scores using both absolute and relative load groups. The results of the investigation identified no significant differences between high and low absolute volume groups on KJOC scores ($F(1,16)=.12$, $P=.73$, $\eta p^2=.01$) at baseline, 4 months, or 8 months. Additionally, there were no differences in KJOC scores between high and low absolute volume groups ($F(1,16)=.11$, $P=.74$, $\eta p^2=.01$). Additionally, the analysis identified no significant differences between high and low relative volume groups on KJOC scores at baseline, 4 months, or 8 months ($F(1,16)=.12$, $P=.74$, $\eta p^2=.01$). Additionally, there were no differences in KJOC scores between those who had ACWR greater than 1.5 for more than 20% of the observational period ($F(1,16)=.54$, $P=.47$, $\eta p^2=.03$) and those below 1.5. Our results indicate that hitting volume in these junior tennis players may not affect self-perceived shoulder and elbow function over the 8-month study period. It is likely these two variables are still important to risk of injury but appear independent of each another in the study conditions. While our sample size is small making differences difficult to detect, shoulder and elbow function may be driven by a variety of physiological and

psychological factors beyond external training load. This was the first study, to the author's knowledge, to investigate external training load and player perception of shoulder and elbow function in a tennis population.

I. INTRODUCTION

The sport of tennis involves intense, repetitive, dynamic upper limb movements that often result in injury to the shoulder and elbow. The shoulder and elbow are the most common sites for overuse injuries that may be experienced over the course of a players' career.[1] Overuse injuries are usually defined as an injury that developed gradually and could not be explained by a single trauma.[2] In elite-level tennis players, overuse injuries account for 67% of all injuries, and 80% of upper extremity injuries.[2] As a result, one of the biggest problems facing championship level tennis players is the growing incidence of upper extremity overuse injuries.[2] This is problematic as overuse injuries may lead to modified stroke patterns, reduced playing time or the cessation of playing in order to appropriately recover.[3]

With upper extremity overuse injuries becoming a threat to tennis players, there is currently a focus on maintaining shoulder and elbow health and function. The Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow score is a subjective questionnaire that reliably measures the functional status of the upper extremity, specifically the shoulder and elbow in athletes in sports with repetitive overarm motions.[4] It can correctly stratify overhead athletes by injury category ($P<.0001$) and show how the athlete improves after treatment of the injury.[4] The KJOC consists of demographic and injury history information followed by a 10-item visual analog scale questionnaire.[4] The KJOC has been shown to be a sensitive measurement tool for detecting subtle changes in the upper extremity performance of various overhead sport populations.[4] The current literature pertaining to the KJOC identifies normative values within professional baseball players,[5] collegiate swimmers,[6] and elite-level tennis players.[7] In general, normative KJOC scores

for uninjured athletes are 95±3 in baseball players,[5] 86±13 in swimmers,[6] and 92±10 in tennis players.[7] When investigating athletes with a previous or recent history of injury the following studies found KJOC scores to be substantially lower than 90. Professional baseball players undergoing ulnar collateral ligament reconstruction and who were still competing with arm pain on average 38±21 months following surgery reported scores of 74±14.[8] Overhead athletes one year post-operative superior labral tear anterior to posterior repair and playing with arm pain reported KJOC scores of 66±21.[9] Currently, there is only one study, by Myers et al., investigating normative values in elite tennis players.[7] The study recruited one hundred and sixty-seven players of different skill levels (collegiate and junior) to complete the KJOC questionnaire. Players were continuing to play with arm pain despite reporting a KJOC score of 73±10 while those who continued playing without arm pain reported a score of 92±10.[7] The researchers showed evidence of KJOC scores accurately discriminating between asymptomatic and symptomatic players.[7]

Shoulder and elbow dysfunction are likely a multifactorial problem in tennis players that may be influenced by early sports specialization,[10] improper training load,[11,12] and other variables.[13-15] Elite junior tennis players undergo rigorous practice schedules and participate in monthly local and sectional tournaments. As a result of this heightened competition, intense training loads are common. Training load is defined as the cumulative amount or volume of stress placed on an individual from single or multiple training sessions (competition training, weight training, or practice training) over a period of time.[11] This study uses the following terms "load," "stress," and "workload" to refer the overall training and competition physiological overload, not the standard physics or biomechanical meanings of these terms.[16] Often junior tennis players are

exposed to large tournaments, multiple matches within a single day, and intense weekly training sessions, all leading to rigorous year-round training loads.[1,3,10] An athlete's exposure to training load can be measured, and the potential effect of these factors can be analyzed. The amount of stress placed on an individual during training is defined in two ways: internal or external load. Internal load is the physiological or psychological response to an external stimulus. Examples of internal load are heart rate and rate of perceived exertion.[17] External load is defined as any external stress applied to the athlete that is measured independently of their internal characteristics.[18] External load has been measured in sports through methods such as global positioning systems[19] or inertial measurement units[20] in order to quantify or estimate gross movement to provide a quantity of external load. The present study used hitting volume (stroke counts) to represent external load due to previous research conducted on tennis players using the Sony Smart Tennis Sensor (SSTS).[21]

One outstanding source of stress amongst tennis players is the ever-growing number of matches and tournaments in which players participate. This competitive calendar congestion results in junior players to experience an increased risk of injury rates.[3] To help mitigate calendar congestion it may be important to investigate external loads that can help tennis players train appropriately for these competitive schedules. Thus, researchers have begun to investigate external loads in tennis players using hitting volume,[20-22] similar to the pitch counts studies in baseball.[23] Several tennis studies investigating hitting volume have found wearable technology to be reliable and valid in counting the number of strokes during practice and matches.[20,21] The SSTS has an accuracy of 95% with forehand shots, 98% with backhand shots, and 93% with serves.[21]

While no study has adequately identified if hitting volume is a potential risk factor for injury in tennis players, it is reasonable to suggest that it may affect shoulder and elbow function. This is because the average junior player has been recorded to hit 120 serves and 210 groundstrokes per match.[22]

Training load can also be expressed in absolute and relative load terms. Absolute load refers to the load applied to the biological system from training, competition, and non-sport activities, irrespective of the rate of load application, history of loading, or fitness level.[11] More specifically, absolute load quantifies the total load over one time period. Relative load refers to the load applied to the biological system from training, competition, and non-sport activities, taking into account the rate of load application, history of loading, or fitness level.[11] The literature on overhead sports such as; baseball[23,24] and swimming,[25,26] has shown that rapid and excessive increases in higher absolute loads are associated with greater injury risk. However, relative loads have also been found to be associated with injury risk. Specifically, large week-to-week changes in load have shown to place the athlete at a significantly increased risk of injury.[12] One method that can be used to assess week to week change in load is the ACWR. This ratio assesses relative load and is used to determine appropriate training loads with the hope of reducing long-term training-related injuries.[12] This ratio considers the player's acute training load (the previous week's training load) relative to their chronic load (the average of the previous four weeks of acute load).[11,12]

Several studies have reported that when the ACWR exceeds 1.5 there is a significantly higher likelihood of injury.[27,29,30,31] This has been reported in elite rugby players[27] and cricket fast bowlers.[29] Surpassing a 1.5 ACWR would suggest that a player

is overtraining and is therefore at a greater likelihood of injury.[11] It is important to note that this ratio is not a definitive threshold in which every player will experience an injury if exceeded. This inappropriate transition can physically manifest itself as fatigue.[30] An inappropriate transition would be a sporadic transition from low to high training loads without any preparation or prior planning. Some studies have found that there is a latent period of increased injury risk following increases in load.[29,31] The authors of these studies showed evidence that despite an injury not occurring immediately, the likelihood for injury will be increased for the following three to four weeks.[29,31] Overall this research on the ACWR supports the hypothesis that players training at higher loads must transition at smaller training intervals or in a gradual and controlled fashion.[27,30] Currently, most of the evidence pertaining to the ACWR is specific to team sports however, it is crucial to distinguish an appropriate load in which a player can safely transition to competition in individual sports.

Since daily training is common in competitive junior tennis players it is important for coaches and healthcare professionals to maintain the integrity of the shoulder and elbow. Due to rigorous training loads and intense tournament schedules a junior tennis player averages approximately 500 total strokes per training session.[21] Each stroke requires effective function and coordination of the major joints of the upper limb. Therefore, the purpose of this study is twofold: 1) to determine if absolute load affects KJOC scores over an 8-month time period. It is hypothesized that players with large external loads will exhibit greater changes in KJOC scores compared to those with smaller external loads, and 2) to determine if relative load affects KJOC scores over an 8-month time period. It is hypothesized that players exhibiting an ACWR over 1.5 for more

than 20% of the observational period will exhibit greater changes in KJOC scores compared to those with ACWR below 1.5.

Statement of the Problem

The shoulder and elbow are the two most common regions injured within the upper limb in tennis players.[32-35] Consequently, it is important for tennis players to maintain the integrity of shoulder and elbow function, as both joints undergo dynamic movement during tennis play. The KJOC Shoulder and Elbow survey is a questionnaire that was developed specifically for overhead athletes to rate self-perceived shoulder and elbow health and function.[4] Shoulder and elbow dysfunction is likely a multifactorial problem in tennis players that may be caused by early sports specialization,[10] improper training load,[11,12] and other variables, such as biomechanics.[13-15] Competitive junior tennis players undergo rigorous practice schedules and participate in monthly local and sectional tournaments. As a result, intense training loads are common to prepare for high-level competition. Therefore, it is reasonable to suggest that training loads may affect a player's self-perceived shoulder and elbow function when measured using the KJOC.

Operational Definitions

- Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder and Elbow score: A subjective questionnaire that reliably measures the functional status of the upper extremity in the overhead athlete.[4]

- Load: The sport and non-sport burden (single or multiple physiological, psychological, and mechanical stressors) as a stimulus that is applied to a human

biological system (including subcellular elements, a single cell, tissues, one of multiple organ systems, or the individual).[11]

- Training Load: The cumulative amount of stress placed on an individual from a single or multiple training sessions (competition training, weight training, or practice training) over a period of time.[11]

- External Load: Any external stimulus applied to the athlete that is measured independently of their internal characteristics.[18] To quantify external load in this research, the authors measured the total number of tennis balls hit during each individual practice session.

- Internal Load: Load measurable by assessing internal response factors within the biological system, which may be physiological, psychological, or other.[18]

- Hitting Volume: The total number of tennis balls hit during each individual practice session.

- Training Volume: The product of duration and frequency of training.[11]

- Sony Smart Tennis Sensor (SSTS): A motion and vibration sensor that tracks the movement of the racket through three-dimensional space, and the strength and point of impact on the racket head based on vibration characteristics, respectively.[21]

- Absolute Load: Load applied to the biological system from training, competition, and non-sport activities, irrespective of the rate of load application, history of loading, or fitness level.[11]

- Relative load: Load applied to the biological system from training, competition, and non-sport activities, taking into account the rate of load application, history of loading, or fitness level.[11]

- Acute Load: Absolute load that is applied over a shorter period of time (e.g. days). It is recognized that this period may vary, but for the purposes of this study, a standard of one week has been adapted to define acute load, as this is the most commonly used practical measure of acute load as defined in the literature.[12]

- Chronic Load: Load that is applied over a longer period of time (e.g. weeks or months). It is recognized that this period may vary, but for the purposes of this consensus a standard of 4 weeks has been adapted to define chronic load, as this is the most commonly used practical measure of chronic load as defined in the literature.[12]

- Acute:chronic Workload Ratio (ACWR): The acute load divided by the chronic load. If the acute load is high (i.e., training loads have been rapidly increased from one week to another) and the rolling average chronic training load (e.g., over 4 weeks) is low, then the ratio of the acute:chronic load will exceed 1.0 and the athlete is likely to experience increased fatigue.[12]

- Universal Tennis Rating (UTR): A number between 1.00 and 16.50 that provides an accurate measurement of a player's skill level. UTRs are purely result-based and are calculated using a player's last 30 eligible match scores from within the last 12 months. For each eligible match, the algorithm calculates a match rating and a match weight and a player's UTR is the weighted average of all the match ratings.[36]

- Competitive Junior Tennis Players: Tennis players who have a UTR ≥3.00.

Delimitations

- All participants will be junior tennis players recruited from a tennis academy in Austin, Texas.

- All hitting volume was measured using the SSTS.

Limitations

- Only practice hitting volume (training drills and simulation match play taking place between Monday and Friday) will be used to quantify external load.

- Practice schedule variations amongst participants. For example, some practice two times a day while others will only practice once a day.

- The intensity of each practice session will not be documented.

- The KJOC questionnaire will only be completed during 3 different time points: baseline, 4 months, and 8 months.

- Participant recruitment from a single location.

- Participant retention during the 8 months of data collection.

- The fragility of the Sony Smart Tennis Sensor as the device would fall off the racket or turn off during play resulting in missed strokes.

- Not accounting for other tennis play, physical training, and actual tournament competition.

<u>Assumptions</u>

- The participants will provide accurate and truthful information when completing the KJOC questionnaire.
- The researcher assumes that the KJOC can assess a participant's actual or perception of shoulder and elbow function.

<u>Hypothesis</u>

- Aim 1 Hypothesis: It is hypothesized that players with large external loads will exhibit greater changes in KJOC scores compared to those with smaller external loads over an 8-month period.
- Aim 2 Hypothesis: It is hypothesized that players with an ACWR over 1.5 for more than 20% of the observational period will exhibit greater changes in KJOC scores compared to those with ACWR below 1.5.

<u>Dependent Variable</u>

- KJOC score at baseline (prior to recording hitting volume), the 4-month score, and the 8-month score,

<u>Independent Variables</u>

- Absolute practice hitting volume (loads over the entire 8-month observational period).
- Absolute volume groups (players were categorized into two groups: group 1 players (high volume) above 26,044 practice shots while group 2 players (low volume) were below this threshold)

- Relative practice hitting volume using the ACWR.

- Relative volume groups (players were categorized into two groups: group 1 players who acquired an ACWR of 1.5 or greater for more than 20% of the observational period and group 2 players who acquired an ACWR of less than 1.5 for less than 20% of the observation period.)

II. METHODS

<u>Participants</u>

Twenty-four competitive junior tennis players provided written informed consent (or assent with guardian consent, where applicable) to participate in an 8-month prospective longitudinal cohort study, which was approved by Texas State University's Institutional Review Board. Number of participants was dependent on the availability of players wanting to participate in the study and is not a self-imposed participant limit. Junior tennis players were considered eligible: if they participated in tennis for three or more times a week (practice and practice match schedules varied between participants), were between the ages of 9 and 18, competed in sectional, regional, or national tournaments throughout the year, and had a Universal Tennis Rating (UTR) of ≥ 3. Collegiate and recreational players were excluded from this study. The excluded players were due to the focus of the study being on competitive junior players. Initially, the investigation began with 24 players enrolled in the study. Four players failed to consistently participate in practice sessions for three or more times a week. Additionally, two players withdrew from the tennis academy. These players were considered dropouts and were removed from the analysis. The results were calculated from the remaining 18 players. The study comprised of 14 males (14.5 $\pm$ 2.0 years; 171.1 $\pm$ 12.7cm; 59.8 $\pm$ 13.0kg; 5.3 $\pm$ 3.0 years of experience) and 4 females (14.8 $\pm$ 2.5 years; 167.0 $\pm$ 4.3cm; 55.6 $\pm$ 7.5kg; 7.8 $\pm$ 1.3 years of experience). All participants that qualified and gave consent were recruited from one tennis academy in Austin, Texas. Data collection began as participants gave consent in the Fall of 2018. It is important to note that this was during the preseason of the competitive season for junior tennis.

Procedures

The Sony Smart Tennis Sensor (SSTS) was used to track external load in tennis players for a consecutive eight months. External load was defined as all training drills and simulation match play taking place between Monday and Friday and is referred to as practice hitting volume. The SSTS is a reliable and valid measure for assessing hitting volume.[21] 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. An image of the sensor is presented in Illustrations 1 (A & B). The device has a three-axis motion tracking sensor which tracks the racket movement through the three-dimensional space. The SSTS is compatible with a variety of different rackets made by Wilson, Head, Prince, and Yonex. A member of the research team reported to the academy prior to every scheduled practice and handed the SSTS out to everyone enrolled in the study. At the end of practice, each sensor was collected and charged. Practice sessions were competed in as they would normally be without the research teams' involvement. Attendance was taken each day on all players enrolled in the study.

The KJOC questionnaire was completed by all eligible players at three different time points: baseline (1-day prior to measuring practice hitting volume), 4 months, and 8 months. A majority of the players (n=16) completed their baseline during the preseason, however, new recruits (n=2) completed their baseline during the competitive season. Players completed the KJOC questionnaire using the traditional pencil-and-paper method. The KJOC questionnaire is comprised of two sections. Section 1 includes demographic information; questions related to past injury history specific to the arm, level of competition, and current playing status. Playing status was categorized into 1 of 3

categories: playing without arm pain (group 1), playing with arm pain (group 2), or not playing because of arm pain (group 3). Section 2 included 10-questions in which players used a visual analog scale (VAS) to rate their level of perceived function during sport. The questions pertain to shoulder and elbow function, athletic performance, and social relationships related to performance. Players were instructed to mark a 100mm VAS and the location of each mark were measured to the nearest millimeter. The average of the 10 VAS questions was calculated to determine a final KJOC score, with a possible range of 0 to 100 points. Scores closest to 100 represent perfect shoulder and elbow self-perceived function. On average, players completed the KJOC questionnaire in five minutes.

Data Processing

The SSTS has two working modes: Bluetooth and memory mode. Bluetooth mode allows the player to view real-time data via phone or tablet with the use of the Sony Tennis Sensor Application (STSA). Memory mode allows data to be stored on the sensor and uploaded to the STSA later for review and analysis. The SSTSs were used in memory mode during all data collection. After each practice, the data on the SSTS was imported from the sensor into the appropriate player profile located within the STSA on a tablet (Samsung Galaxy Tab A (2016) Android Version 5.1.1). Once the data were imported into the tablet, the data were exported from the STSA and stored in the tablet's memory. The exported file was then transferred to the principal investigators' computer via USB. The data from the STSA were categorized into eight types of swings: serve, smash, volley forehand, volley backhand, topspin forehand, topspin backhand, slice forehand, and slice backhand. The data were then further categorized in an Excel spreadsheet by the principal investigator into three swing types: forehand swings, backhand swings, and

overhead swings. Forehand swings included volley forehand, topspin forehand, and slice forehand. Backhand swings included volley backhand, topspin backhand, and slice backhand. Overhead swings included serve and smash shots. Total practice volume was calculated as the sum of the three swing categories.

Illustration 1 A. Photo of the Sony Smart Tennis Sensor next to tennis racket

Illustration 1 B. Photo of the Sony Smart Tennis Sensor attached to the tennis racket

The present study analyzed absolute load as the sum of all shots over the 8-month observational period for each player. Players were then categorized into groups based off the median practice shot count for all players enrolled in this study. Players were categorized into two groups: group 1 players (high volume) above 26,044 practice shots while group 2 players (low volume) were below this threshold. Relative load was analyzed using the ACWR. The coupled method for ACWR was used.[12] An example of a rolling average ACWR (coupled method) calculation, which was used in the current study, is presented in Illustration 2. Players were categorized into two groups: group 1 players who acquired an ACWR of 1.5 or greater for more than 20% of the observational period and group 2 players who acquired an ACWR of less than 1.5 for less than 20% of the observation period. The acute workload was calculated using the most recent week's load (beginning on Monday and ending on Sunday). This value represented the loads undergone by the athlete over the last seven days. The chronic workload was the rolling average of the most recent four-weeks loads. This value represents the loads undergone by the athlete over the last 28 days. The acute workload was then divided by the chronic workload to determine the ACWR. In order to account for data outliers, any acute training loads below one standard deviation of the chronic load were removed from the chronic load average.[29] Therefore, leading to an adjusted chronic load which was a more accurate portrayal of the player's typical training load.

How to Calculate the Rolling Average
Acute:Chronic Workload (Coupled Method)

Week 1 = 2,000 shots

Week 2 = 1,000 shots

Week 3 = 1,600 shots

Week 4 = 1,400 shots

Acute ÷ Chronic

1,400 ÷ 1,250 = **1.2**

Compare your Results
(>1.5) = increase chance of injury by 2-4x
(0.8-1.3) = decrease chance of injury

Total = 5,000 shots (Average = 1,250 shots/week)

Gabbett. The training—injury prevention paradox: Should athletes be training smarter and harder?

Illustration 2. Rolling Average ACWR (Coupled Method) Calculation

Statistical Analysis

     A 2X3 repeated measure ANOVA was performed to determine if changes in KJOC scores are different in players with varying absolute and relative loads. The 2x3 ANOVA represents 2 independent variables; the first independent variable has two levels: high and low hitting volume, and the second has three time levels: baseline, 4 months, and 8 months. The dependent variable was final KJOC score at each of the 3 timepoints. Descriptive statistics were used to report load and KJOC scores for each participant included in the study. The Shapiro-Wilk test was used to assess the distribution of the data given that previous studies have reported negatively skewed KJOC scores.[4,8] The final KJOC score distribution was negatively skewed (Shapiro-Wilk test, $P < .001$). An assumption for using general linear models is the normality of sampling distribution of means; however, the analysis of variance is not sensitive to

moderate deviations from normality. Simulation studies using a variety of non-normal distributions show that the false-positive rate is not affected much by this violation of the assumption.[67-69] Therefore, the 2X3 repeated measure ANOVA was used. The significant level was set to P<.05. The data were analyzed using IBM SPSS (version 25.0; IBM Corp., Armonk, N.Y., USA).

III. RESULTS

Of the 24 initial participants, 18 competitive junior tennis players completed all aspects of the study. Six players did not complete all aspects of the research project and were removed from the final analysis. Given the small sample size data, each of the 18 players has been individually recorded. Participant characteristics are presented in Table 1. Regardless of group, the 2x3 repeated measures ANOVA identified no significant differences across KJOC scores ($F(1,16)=.12$, $P=.73$, $\eta p^2=.01$) at baseline, 4 months, or 8 months. Additionally, there were no differences in KJOC scores between high and low volume groups ($F(1,16)=.11$, $P=.74$, $\eta p^2=.01$). The absolute load and KJOC score of all participants is presented in Table 2. Changes in KJOC scores between high and low absolute volume groups are shown in Figure 1.

Table 1. All player demographics

Participant	Sex	Age	Height (cm)	Weight (kg)	Years of tennis experience	UTR*
1	Male	14	168	48	5	5.0
2	Male	15	173	64	5	5.6
3	Male	16	175	61	4	4.7
4	Male	15	178	59	5	9.1
5	Male	14	178	57	4	5.0
6	Male	13	170	56	2	5.6
7	Male	15	178	66	3	6.0
8	Male	16	173	68	10	5.5
9	Male	16	170	62	2	5.5
10	Male	17	193	86	10	9.2
11	Female	16	168	55	7	6.0
12	Male	13	168	61	4	6.2
13	Female	16	173	62	10	5.2
14	Male	11	140	35	6	3.4
15	Female	16	165	60	4	7.7
16	Male	11	152	41	5	5.0
17	Male	17	180	74	10	11.3
18	Female	11	163	45	8	6.4
All participants	M=78% F=22%	15±2	170±11	59±12	6±3	6.2±2

*UTR = Universal Tennis Rating

Table 2. Absolute hitting volume from baseline to 8 months of tennis participants for each player categorized into high and low groups

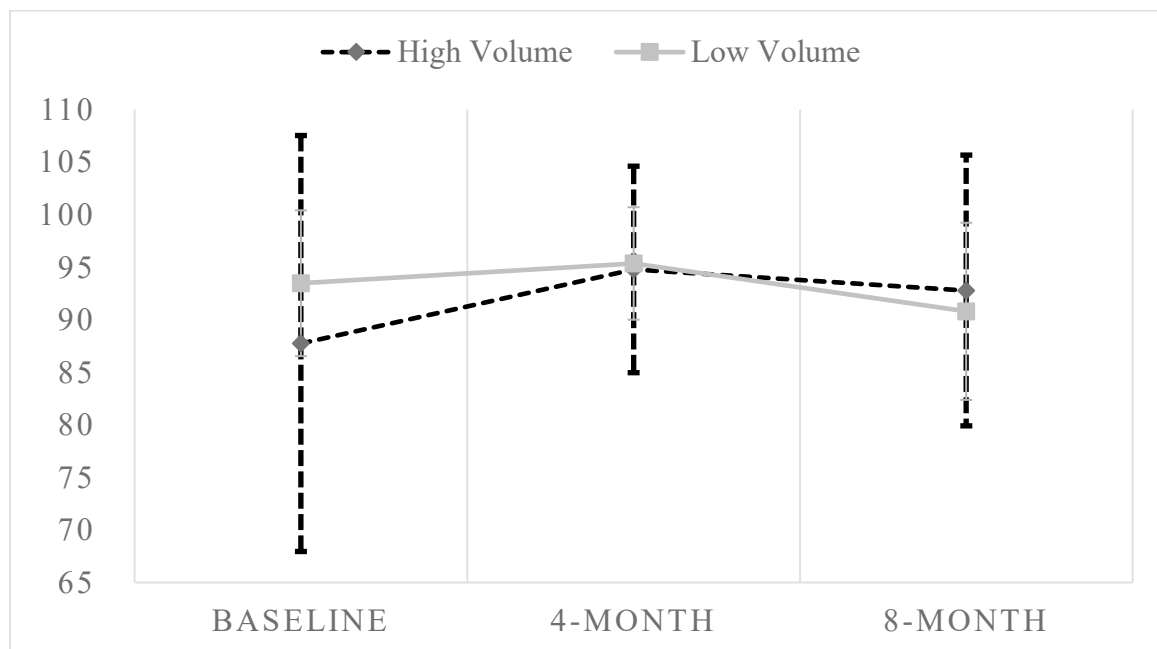| Participant	Hitting Volume	Baseline KJOC Score	4-month KJOC Score	8-month KJOC Score
		High Hitting Volume		
1	30,217	100	100	100
3	40,469	71	69	59
5	35,297	41	98	98
6	34,633	100	100	99
7	51,022	95	98	96
9	53,070	96	95	96
13	33,952	98	96	97
17	27,560	90	98	94
18	27,293	100	100	97
All	37,057±9,447	88±20	95±10	93±13
		Low Hitting Volume		
2	15,713	98	100	100
4	13,187	99	92	92
8	15,626	90	100	83
10	24,156	100	100	98
11	21,410	96	92	95
12	23,595	77	92	74
14	24,018	94	100	97
15	24,795	94	97	92
16	18,556	94	85	86
All	20,117±4,433	93±7	95±5	91±8

Figure 1. Changes in KJOC scores between high and low absolute volume groups

The same participants were used to investigate if relative load effects KJOC scores. Regardless of group, the 2x3 repeated measures ANOVA identified no significant differences across KJOC scores at baseline, 4 months, or 8 months $(F(1,16)=.12, P=.74, \eta p^2=.01)$. Additionally, there were no differences in KJOC scores between those who had ACWR greater than 1.5 for more than 20% of the observational period $(F(1,16)=.54, P=.47, \eta p^2=.03)$ and those below 1.5. Participants who had an ACWR below 1.5 for 20% of the observational period scored on average 94±9 at baseline, 95±10 at 4 months, and 93±13 at 8 months compared to those above 1.5 who scored on average 87±18 at baseline, 95±5 at 4 months, 91±8 at 8 months. Changes in KJOC scores between high (an ACWR above 1.5) and low (an ACWR below 1.5) relative volume groups are shown in Figure 2.
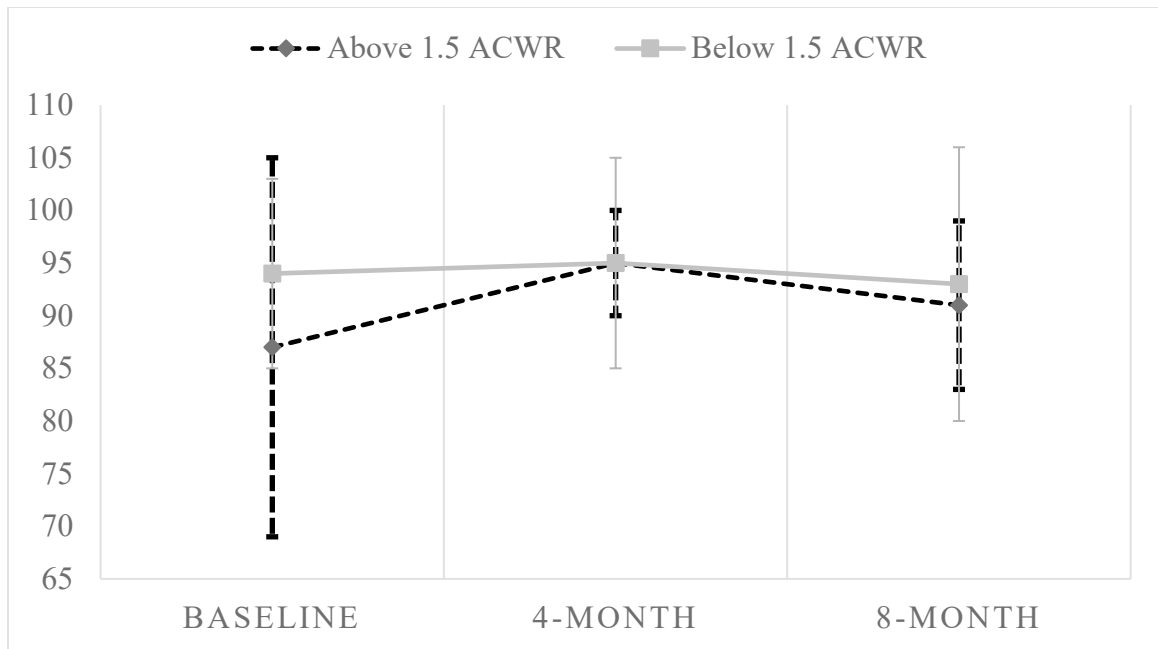
Figure 2. Changes in KJOC scores between high and low relative volume groups

IV. DISCUSSION

To the author's knowledge, this is one of the few studies in junior tennis that has prospectively tracked hitting volume for an extended period of time in competitive tennis players. Furthermore, it is the only study that has investigated the effect that workload metrics have on self-perceived shoulder and elbow function. The initial purpose of this investigation was to determine whether absolute loads may affect a player's self-perceived shoulder and elbow function when measured using the KJOC Shoulder and Elbow questionnaire. The hypothesis was not supported as players with large external loads did not exhibit greater changes or differences in KJOC scores compared to those with smaller external loads. The secondary purpose was to determine whether relative load affects KJOC scores. The hypothesis was not supported as players exhibiting an ACWR over 1.5 for more than 20% of the observational period did not exhibit greater changes or differences in KJOC scores compared to those with an ACWR below 1.5. Regardless of groups (relative or absolute), the mean difference in KJOC score was 4 ± 14 from baseline to 4 months, 1 ± 14 from baseline to 8 months, and 3 ± 6 from 4 months to 8 months. A post-hoc power analysis was conducted to indicate the generalizability of the results given the low sample size. For the absolute load groups, the observed power for $(F(1,16)=.12, P=.73)$ was n=6.3%, while the power for $(F(1,16)=.11, P=.74)$ was n=6.1%. For the relative load groups, the observed power for $(F(1,16)=.12, P=.74)$ was n=6.2%, while the power for $(F(1,16)=.54, P=.47)$ was n=10.6%.

Monitoring a player's workload and self-perceived shoulder and elbow function should be considered as components when training competitive tennis players. In general, appropriate load management protocols may improve performance and will diminish the

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likelihood of injury.[17] Researchers interested in training load have shown absolute and relative load to be associated with pain[23,24] and injury.[27,29] More specifically studies conducted on elite athletes have shown that higher absolute load and rapid and excessive increases in relative load are associated with greater injury risk.[3,19,23] A higher absolute load has been shown to increase the risk of injury and pain in tennis,[3] Australian football,[19] and baseball.[23] A study conducted on junior tennis found that players were at a significant increased risk of withdrawing from a match if they played beyond the fourth match of a tournament.[3] Another study on Australian football found that players that ran a 3-weekly distance between 73 and 86 km were associated with a 5.5 times greater risk of injury when compared to those than ran less than 73 km.[19] Lastly, researchers investigating youth baseball pitchers determined that there was an increased risk of shoulder and elbow pain if players, between the ages of 9 and 14, throw more than 75 pitches a game or 600 pitches a season.[23]

More recently exposed in the literature is the concept of relative load, which are the rapid increases in acute load relative to chronic load. Large week-to-week changes in load have shown to place the athlete at a significantly increased risk of injury.[12] Relative load can be assessed using the ACWR.[12] A study on elite cricket fast bowlers found that an ACWR greater than 1.5 leads to a three to four week delayed increase risk of injury after the initial acute overload.[29] Another study on professional rugby players found when comparing players with a low chronic workload, that those with a higher chronic workload are more resistant to injury with moderate (0.85-1.35) ACWR. Furthermore, players were less resistant to injury when subjected to spikes in acute workload that were over an ACWR of 1.5.[27] Myers et al., identified that internal injured junior tennis players

generally reported an average ACWR 1.5 times greater than their ACWR from the week

prior to injury compared the previous 4 weeks.[71] The results indicated that the majority of

injured players in the study were not prepared for such an increased spike in load.[71]

Nevertheless, while most of the research investigating external training load is not

specific to tennis, the principles of training should remain consistent as similar results are

found across multiple sports.

The principles of training load are meant to improve performance and control the

fitness resources to mediate the risk of injury. Two common principles reviewed in the

literature are periodization and load monitoring using the ACWR.[54-56] Periodization is a

strength and conditioning program design strategy intended to optimize training

specificity, intensity, and volume.[54] The program is designed according to the desired

training cycle: Macrocycle, Mesocycle, and Microcycle. These cycles are simply training

blocks that help to target the athlete's training goals. A Macrocycle is a group of

Microcycles with the same training direction which can greatly vary in length, a

Mesocycle covers typically a month, and lastly, a Microcycle is typically a week-long

training block.[54] An athlete who undergoes periodization is training at planned loads

which are designed for peak performance at key competitions, usually higher preparing

for competition and lower immediately approaching competition.[55,56] Periodization

models should be monitored over time so athletes can see progress, and are aware of the

training that has been done compared to what is currently being done. The ACWR is one

method that can help coaches and health care professionals monitor periodization training

in order to not only reduce the risk of injury but to also best optimize physiological

adaptations.

While both absolute and relative loads have been correlated with injury risk, the authors acknowledge that the main outcome in this study was self-perceived shoulder and elbow function. It is imperative that researchers consider shoulder and elbow function in a tennis population as the loads placed upon these two joints during tennis activity cause large levels of stress.[16] In fact, tennis players are commonly playing with arm pain and do not always meet standard injury definitions of time loss.[7] Players reporting to play with arm pain during tennis report a KJOC score of 73±10 while those playing without arm pain report a score of 92±10.[7] As suggested by the findings of this study, it is reasonable to suggest that other factors besides load monitoring may play a role in maintaining a player's shoulder and elbow health. Factors, such as, biomechanics, musculoskeletal adaptations, nutrition, and psychological health.

The shoulder and elbow undergo stress due to repetitive motion and improper biomechanics during strokes.[13,14,45] One of the most energy-demanding tennis motions is the serve, which comprises about 45-60% of all strokes performed in a tennis match.[64] The tennis serve comprises of five phases of motion; (1) wind-up, (2) early cocking, (3) late cocking, (4) acceleration, and (5) follow through.[64] Each motion requires specific and dynamic upper extremity arrangement, which accounts for large amounts of speed at impact and lengthening for optimal height.[64] Tennis researchers have demonstrated that faulty mechanics during the serve are associated with increased risk of injury specifically in the shoulder and elbow.[13,14,45] Investigators have found that injured players display delayed trunk rotation timing compared to non-injured players resulting in increased upper limb joint loads.[14] In addition, increased upper extremity loads were present in injured tennis players as these players remained in horizontal abduction during maximal

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shoulder cocking for an extended period compared to non-injured players, certainly a mechanism for increased shoulder dysfunction.[14] Other researchers investigating improper temporal mechanics[14] and improper energy flow from proximal to distal segments during the serve,[15] found that they can lead to an increase of overuse injury in the upper extremity.

Other potential contributing factors to shoulder and elbow dysfunction in tennis players are musculoskeletal adaptations, nutrition, and psychological health. The rigorous demands the tennis strokes place on the shoulder result in musculoskeletal adaptations. When there is a repeated stress place upon a joint, often times that joints normal range of motion will change due to a cycle of microtrauma that results in tighter muscles.[75,76] One particular study that investigated 86 junior elite tennis players found areas of musculoskeletal tightness identified in the shoulder.[72] These researchers suggested that decreased flexibility at the shoulder put this joint at risk for future injury due to the lack of mobility.

The next factor to consider is a player's nutrition and dietary intake. Nutrition, in combination with proper training, is considered to be an essential factor of success in sports, especially in adolescent athletes.[77,78] This is partly due to the increased training demands competitive youth players undergo and the nutritional demands generated by the body for growth due to puberty.[77,78] A study conducted on adolescent tennis players found players had an insufficient intake of essential nutrients: fiber, calcium, and potassium. Such deficits can lead to deficiencies and harmful consequences, especially for age groups undergoing growth spurt.[73] More specifically, a diminished platform for essential nutrition can lead to improperly developed muscles and physical attributes,

which can make them more susceptible to injury due to muscle imbalance.[77] Last, one must consider the psychological health of players which is greatly affected in this particular population through stress. In junior athletes, stress illness is often displayed through physical ailments such as headaches and muscle strains.[79] A study addressing competitive stress in junior tennis players, found through the assessment of health needs, identified stress illness as a major mental health problem in this population. As a result, stress is a cause of injury that must be considered by players and coaches.[74] Consequently, there are numerous factors that could contribute to shoulder and elbow dysfunction and or injury in junior tennis players.

This study is not without its limitations. Primarily limited recruitment, as the study was only able to recruit from a single location. Additionally, participant retention, as retaining participants for 8 months was challenging due to either players failing to attend practices due to either personal issues or schedule conflictions. Also, only the practice hitting volume was used to quantify external load which underestimates the player's actual load when considering private lessons, matches, or tournament play. The players enrolled in this study all participated in tennis at least three times a week, but practice and practice match schedules varied between participants. Future research should incorporate Monday-Sunday volume tracking of both practice and matches. In addition, the intensity of practice sessions was not considered, which has been previously shown to be a factor in injury susceptibility in the current population.[71] Furthermore, KJOC surveys were distributed at 3 different time points throughout the observational period; while the repeated assessment of elbow and shoulder health is warranted in this population, the timeframe of distribution was too long. Future research should investigate

more frequent time periods for KJOC distribution. Lastly, the sensor does come with some technological flaws. More specifically there were a few cases in which the sensor disconnected from the end of the racket handle, resulting in lost data.

V. CONCLUSION

In conclusion, the viewpoint of junior tennis epidemiology on injuries is that while lower extremity injuries are common, upper extremity injuries are chronic in nature and oftentimes affect the shoulder and elbow. Competitive junior tennis players undergo rigorous practice schedules and participate in monthly local and sectional tournaments. As a result, intense training loads are common to prepare for high-level competition. Consequently, it is important for tennis players to maintain the integrity of shoulder and elbow function, as both joints undergo dynamic movement during tennis play. As such, the study aimed to determine if training load affected shoulder and elbow dysfunction. The results of the current study were not able to find significant differences between absolute or relative load and KJOC scores. Despite this study not finding significant results, it does not mean shoulder and elbow dysfunction and load are not important. The results of this study suggest that self-perceived shoulder and elbow function and hitting volume are independent factors and should potentially be managed separately when treating tennis players. While both of these variables are more than likely important on their own, it is necessary to reiterate that both can be easily tracked with questionnaires and wearable technology.

APPENDIX SECTION

APPENDIX A. Review of Literature

The shoulder and elbow are the two most common regions injured within the upper limb in tennis players.[32-35] Consequently, it is important for tennis players to maintain the integrity of shoulder and elbow function, as both joints undergo dynamic movement during tennis play. The KJOC Shoulder and Elbow questionnaire is a questionnaire that was developed specifically for athletes in sports with repetitive overarm movement to rate self-perceived shoulder and elbow health and function.[4] Shoulder and elbow dysfunction is likely a multifactorial problem in tennis players caused by early sports specialization,[10] improper training load,[11,12] and other variables.[13-15] Elite junior tennis players undergo rigorous practice schedules and participate in monthly local and sectional tournaments. As a result, intense training loads are common in the preparation for this high-level of competition. Therefore, the purpose of this literature review is to 1) investigate the epidemiology of shoulder and elbow injuries in tennis players, 2) identify common risk factors in tennis players 3) describe how training workloads are often assessed in sports, and 4) present data relative to the KJOC assessment in overhead sports.

Epidemiology of Tennis Injuries

Tennis is a sport that involves rigorous training and repetitive, high-speed stroke production in order to compete at a competitive or advanced level. As a result, it is not uncommon for injuries to occur. Injuries often accumulate over the course of a player's career and can lead to either taking time off to recover or needing to adapt a particular stroke pattern. As the sport becomes more physically demanding and players are

specializing in tennis at a young age,[10] chronic overuse upper extremity injury is becoming a growing concern for a player's long-term development.[1,2] While chronic overuse injuries to the upper limb are common in tennis players, lower extremity injuries constitute the higher prevalence of injuries in the sport. Researchers determined that injuries to the lower limbs were 1.3 times more likely than injuries to the upper limbs (23.00 vs 17.68 per 1,000 match exposure) amongst professional tennis players.[37] The higher rate of lower extremity injury as compared to upper extremity is consistent with injury epidemiology research on professional tennis players.[38] The epidemiological literature has established that lower limb injuries occur suddenly and more often than upper limb injuries. Chronic-onset injuries in the lower extremity occurred at a rate of 9.3 per 1,000 match exposure while the rate for upper extremity was 8.2 per 1,000 match exposure.[37] Lastly, the epidemiological literature indicated that while acute lower extremity injuries do directly impact performance for a single match or tournament, chronic upper extremity injuries can lead to greater long-term negative effects on a young player's career and development than lower extremity injuries.[32,38]

The research on epidemiology and elite junior tennis players has reported varying levels of lower and upper limb injuries. A prospective cohort study[1] found that the incidence of lower extremity injuries nearly doubled that of upper extremity injuries in elite junior tennis players (lower extremity: 4.9/100 athletes, upper extremity: 2.6/100 athletes).[33] Additionally, another study found a considerable difference in overall acute injuries with lower extremity injuries making up 64% of all injuries while upper extremity injuries only made up 20%.[1] The same study also found similar results in that chronic lower extremity injuries made up 43.2% of all injuries while chronic upper

extremity injuries made up 33%.[1] The studies do not only establish that lower limb injuries occur more frequently than in upper limb but that acute injuries occur at a higher rate in elite junior tennis players than in professional adult players. Therefore, the concentration should be on how the accumulation of these acute injuries along with repetitive motions can lead to an overuse injury.

Overuse injuries are often induced by repetitive actions and cannot be linked to a clearly identifiable event.[39] Accordingly, this injury type also has a gradual onset that is often overlooked using standard sports medicine methodology due to these injuries not causing an absence from training or competition.[1] Tennis injury epidemiology studies on junior tennis report that overuse injuries due to hours played contribute the most to injury[1] with the rate of incidence ranging between 1.2 injuries per 1,000 hours[40] to 21.5 injuries per 1,000 athletic exposures.[33] The large variation between these two statistics is due to the difference in how the studies defined injury and expressed injury exposure. The study that expressed injury per units of time did so because of their method of data collection involved parents of the participants recording daily activities in a weekly diary format.[40] In reporting activities, parents also included exact locations, time spent, description of the activity, and type of play. They also defined injury as any incident for which first aid treatment was given with aggravation of previous injuries excluded.[40] The other study that expressed injury rate per athletic exposure, did so because their data collection consisted of using previous injury reports to determine the incidence and prevalence of areas of injury.[33] They also classified injuries as either recurrent or new and defined incidence as the number of new injuries at the tournament.[33]

The next concern when observing a rise in acute injuries is how a culmination of these injuries over a long span of time may affect the athlete. One study discovered that overuse injuries amount for 67% (28 out of 42 injured players) of all injuries recorded, with 38% (16 out of 42 injured players) of all injuries being upper extremity overuse injuries.[2] The study determined that the biggest problem facing championship level junior tennis players is the growing incidence of upper extremity overuse injuries.[2] Another factor to consider is how the player's sex could possibly affect the location and types of injuries sustained.

The incidence of tennis injuries differs between sexes.[2,32] While mechanisms of injury are likely multifactorial, it is likely that sex-based physical,[41] technical and tactical differences[41,42] are contributors as well. The epidemiology on sex differences found that adult professional male players sustained more injuries overall (0.66 injuries/season), which was significantly more than the rate of female injuries (0.2 injuries/season).[2] The same study also investigated hours of tennis played and found males sustained 2.7 injuries/1,000 hours of tennis, which was considerably more than the females 1.1 injuries/1,000 hours of tennis.[2] But these findings were contradicted as a six-year epidemiology study found that adult professional female players had more injuries than male players (201.7 vs 148.6 per 10,000 game exposures, respectively).[32] Additionally, another study that accounted for injuries per 10,000 game exposures found higher injury rates being reported among female professional players than male players.[32] This is consistent with the higher incidence of injury in female professionals previously reported at Wimbledon, which used a set exposure injury rate to account for differences in sex set requirements.[43]

Focusing on the region of injuries, it was reported that male players sustained 40% of injuries in their lower extremity and 47.5% in their upper extremity.[2] In female players, 33% of injuries were evenly distributed between the lower and upper extremity.[2] This is supported by the evidence found in a six-year epidemiology that concluded that both upper and lower extremity injuries affected females while lower limb injuries were more prominent in males.[32] However, over a five-year period, researchers noticed upper limb injury doubled (2.4 times) in both males and females, thus affirming a concern for upper extremity injuries in professional tennis players.[32]

A six-year study on junior boys' tennis found that one of the most common anatomic sites of injury in the upper body was the shoulder.[33] The literature on shoulder pain in tennis players has shown that it can be attributed to a variety of different pathologies.[35] Shoulder injuries were reported in 36 out of 120 athletes, 13 of which were newly diagnosed (incidence = 0.9 per 100 athletes, prevalence = 2.5 per 100 athletes).[33] Another study found that the shoulder was the most commonly injured region (4.8±1.1 injuries per year) amongst female professional players compared to males (2.2±0.8 injuries per year).[32] Other studies have determined that the shoulder was the second most prevalent location of overall injury by junior tennis players, with the first being back injuries.[44] Shoulder injuries do occur frequently (17%; 8 out of 46 players), whereas tennis elbows represented 10% (5 out of 46) of all injuries.[2] However, the next hurdle to overcome in tennis epidemiology is that this crucial information is difficult for researchers to condense and even more challenging for parents and coaches to understand due to the variation in injury reporting. The differences in terminology and methodology

in tennis epidemiology studies creates a barrier between those wanting to make sure the data is seen by the public and those trying to understand it.

The reported incidence and injury rates in tennis studies vary noticeably between investigators. These variations are mainly caused by differing terminology, injury definitions, and methodologies used in tennis epidemiological literature.[38] Tennis injury surveillance studies have relied on team-based consensus statements and methodology, which are not appropriate for studying individual sports. There are three major issues with tennis-related epidemiological literature.[38] The issues are: 1) there is a perception of tennis players being more susceptible to chronic injuries than are normally reported in contact team sports, 2) most tennis players do not have a dedicated healthcare professional especially when it comes to long-term rehabilitation from injury; therefore, making it difficult to track a player's progress or condition, 3) lastly, the responsibility for decisions related to return to training or competition solely rests on the individual player and their support network rather than a team of medical or healthcare professionals.[38] To combat some of these issues researchers are striving to standardize and maintain consistent definitions and methodologies which will hopefully lead to the information to be more accessible for not only other researchers but for the general population.

<center>Identify Common Risk Factors in Tennis</center>

As with any other sport, tennis is not without injurious risk factors. There are many risk factors that can accumulate and are shown to increase a player's likelihood of injury. Tennis risk factors are likely multifactorial and may be attributed to poor biomechanics,[14,15] competitive calendar congestion,[11] sports specialization,[10] sex,[41,42] and improper training loads.[11,12]

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Tennis Biomechanics

Tennis requires players to produce high ball speeds in strokes by transferring forces up the body to the racket.[14] This is especially true when it comes to the key elements of a successful player's game, the tennis serve.[14,15] All tennis strokes and, particularly, the serve involves a whole-body motion that starts from lower limb actions followed by the rotation of the trunk and upper limb.[45] As a result, injuries can occur due to a biomechanical issue, e.g. muscle weakness and imbalance or excessive joint loading.[46] An upper extremity injury can result in adaptation of upper extremity motion and affect the quality of energy flow through the upper limb during the final phases of the serve thus decreasing ball speed and, potentially influence the risk of overuse injuries.[15] One compromised movement is improper timing in both sagittal (94.9±1.9) or transverse (89.2±2.3) rotation of the trunk and in between horizontal adduction and external rotation (4.4±8.8) of the shoulder. This causes the player to reach significantly lower ball velocities, and demonstrate higher upper limb joint kinetics.[14] Furthermore, the shoulder, elbow, and wrist of injured players absorb significantly higher rates of energy than the joints of non-injured players which can further impair the already injured limb.[15] For those reasons, biomechanical issues are a risk factor of tennis that can hinder a junior player's growth and development.

Competitive Calendar Congestion

The number of elite junior tennis players increasing over the years naturally means a higher level of competition. As a result, most junior tennis players stay competitive year-round.[10] This often leads to the players being exposed to not only higher training loads but also to an increasingly saturated schedule of matches and tournaments

or as it is commonly known as, calendar congestion.[11] Competitive calendar congestion (CCC) refers to the accumulation of matches and events over a shorter period of time than usual, which may represent an exacerbated rapid increase in acute load imposed on the athlete.[11] This increase in acute load has been found to lead to increased injury rates in junior tennis.[3] One study investigated medical withdrawal rates in USTA junior national tennis tournaments and found a statistically higher rate of medical withdrawal after the fourth match in a single tournament, which included doubles and consolation matches.[3] Despite the limited data, much of the available data on competition frequency seems to indicate that CCC is associated with an increased risk of competition injury.[11] Therefore, with the trend of CCC in junior tennis expected to continue rising, one can also expect the number of tennis injuries to follow suit.[2]

<u>Sports Specialization</u>

Sports specialization (SS) is defined as intense, year-round training in a single sport with the exclusion of other sports.[47] The rate of sports specialization is becoming more common in elite junior tennis, as the average age for specializing was calculated to be 10.4 years old.[10] Players who specialize only in tennis, especially at an early age, are 1.5 times more likely to report an injury.[10] Early childhood sports specialization is a highly debated concern, as to whether specialization benefits the player. The conclusion from one study found that while some degree of sports specialization is necessary to attain elite-level skill, that for most sports, specialization should be delayed until late adolescence or from the ages of 18-24 years old.[47] This allows the player to optimize success while minimizing risk for injury.[47] Sports specialization before adolescence or the age of 13 years old, may be doing more harm to a young athlete's progress then

benefit.[47] Another study found that for most sports, including tennis, achieving elite status is not precipitated by early sports specialization before puberty.[47] Furthermore, it was found that early sports specialization increased risks of injury, psychological stress, and can lead to a higher rate of burnout or quitting sports.[47] The risk of injury from intense training and specialization may be affected by age, competitive level, growth rate, and pubertal maturation stage.[47]

<u>Sex</u>

The epidemiology literature is inconsistent on which sex maintains higher injury rates. The inconsistency is likely due to sex-based physical, technical, and tactical differences.[41,42] For example, professional female tennis players have been reported as having slower movement speeds[41] and weaker shoulder internal rotation strength[48] compared to their male counterpart. Therefore, female players may have less time to generate the necessary force to perform an optimal serve, which can result in compromised joint positioning.[42] The culmination of these sex-based differences could explain female players having a higher prevalence of injuries across both extremities. Additionally, professional male tennis players could be relatively more likely to sustain lower limb injuries as a result of the heightened absolute movement demands of their playstyle.[41] Indeed, the higher incidence of lower limb injury when compared with upper limb injury in male Australian Open players is consistent with the earlier Wimbledon and US Open Grand Slam injury epidemiology research.[38] However, it is also important to monitor the training load of an athlete regardless of their sex, as training load plays a role in injury prevention.

Describe Training Loads in Sports

The two primary focuses coaches should have when it comes to training elite junior players, are preparing players for competition and keeping them healthy and injury-free. Ideally, preparation for elite-level competition training loads are established in order to make sure the player is constantly improving at a safe rate. Training load is defined as the cumulative amount of stress placed on an individual from a single or multiple training sessions (competition training, weight training, or practice training) over a period of time.[11] The amount of stress experienced by the athlete plays a role in injury. Therefore, it is important that tennis training is complemented with a resistance training program, in order to have the athlete's body adapt to competitive stress over time rather than acutely during a tournament.

Strength & Conditioning Programs and Periodization

To reduce a player's rate of injury, a common suggestion is to have players perform a workout program alongside their training and match seasons. A recent injury prevention program on adolescent baseball players showed that appropriate strengthening and stretching exercises resulted in a reduction of medial elbow injuries by nearly 50%.[49] Some of the overall benefits of a properly designed strength and conditioning program include better sports biomechanics, improvements in bone health, and decreased injury.[50] Additionally, with how common early sports specialization is in this population, a well-designed program also offers protective benefits to sports drop out and psychological burnout.[51,52] These strength and conditioning programs for elite junior tennis players should be periodized, sets and repetitions should be balanced and purposeful, and include

full-body resistance training with throwing-specific exercises, as well as a properly designed plyometric program.[53]

Periodization is defined, "a program design strategy to utilize systematic variations in training specificity, intensity, and volume to promote long-term training and performance improvements and minimize the risk of injuries and other symptoms associated with overtraining."[54] Periodization is designed according to the training cycle desired, there are Macrocycle, Mesocycle, and Microcycle. These cycles are simply training blocks that are specifically targeting the athlete's goal. However, there are some obstacles to implementing programs for tennis players, there is the unique tennis calendar schedule as well as the individual player's physical development, goals, and needs to consider.[55] The unique calendar schedule poses an issue due to most junior tennis players not having an official off-season like many other sports.[56] Additionally, there is not a set number of sets or tournaments for the entire season, instead, the amount of tournaments a player gets to participate in depends on their ranking and skill level.[56] There are also other factors to consider like if the player loses the first round of a tournament or makes it to the final along with longevity of matches. The environment in which the tournament is held must also be considered, for example did the player have to travel long distance for the tournament, and the type of court surface the tournament is played on.[56]

Growth and development are especially important when referring to developing programs for young tennis players. A program should develop certain physical and motor skills as well as adjust intensity and volume in accordance with the player's stage of development.[55] It is also important for tennis coaches and trainers to consider the player's long-term development. A common perception among sports training personal is that

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higher training loads are greatly associated with higher injury rates in athletes.[57] Although this perception is true, there is evidence that training may have a protective effect and that undertraining increases injury risk.[17]

Training-Injury Prevention Paradox

The "Training-Injury Prevention Paradox" model is the phenomenon in which athletes that are accustomed to chronic high training loads have fewer injuries than athletes training at lower loads with large, acute spikes in load.[12] There is evidence that indicates that non-contact injuries are not caused by training but instead are more likely caused by an inappropriate training program. Excessive and rapid increases in training loads are likely responsible for a large proportion of non-contact, soft-tissue injuries.[12] When high training loads are appropriately prescribed, it can not only improve a players' fitness but it may also protect against injury.[12] This can ultimately lead to greater physical outputs and resilience in competition and a greater proportion of the players being healthy and available for selection each week.[12] However, to further investigate load one needs to examine its components.

External and Internal Load

Load is often categorized as either external or internal load in the sports science literature. External load is defined as any external stimulus applied to the athlete that is measured independently of their internal characteristics.[18] External load has been measured in research through global positioning systems or inertial measurement units in order to quantify or estimate gross movement to provide a quantity of external load.[20] Monitoring external training load is critical to training prescription and return-to-play

programs in elite tennis. In tennis where hitting load is more associated with lower back and shoulder injuries than gross movement loads, hitting load would be valuable for determining a more specific quantity of external load.[20] Internal load is the athlete's physical and psychological responses to the external load.[17] Internal loads that can be monitored consist of heart rate response, heart rate to rate of perceived exertion ratio, heart rate recovery, etc.[18] However, any appropriate measurement of internal load needs to have an exposure component of the activity and of the athlete's response to that activity.[17]

<u>Absolute and Relative Workloads</u>

Training loads can be primarily analyzed in two ways, absolute or relative loads. Absolute training loads are the sum of all training sessions, or a particular domain of training, over a given period such as a day or week.[17] Absolute workloads are defined in the present study as the load applied to the biological system from training, competition, and non-sport activities, irrespective of the rate of load application, history of loading, or fitness level.[11] Relative training loads express the change in workload relative to a predetermined time period as a percentage or ratio.[17] Relative workloads are defined in the present study as the load applied to the biological system from training, competition, and non-sport activities, taking into account the rate of load application, history of loading, or fitness level.[11] Absolute and relative workloads have been examined to see if they have any correlation to injuries.[70] Absolute workloads have been shown to be related to injury occurrence in elite Australian Football,[19] rugby union,[58] and baseball.[23,24] Relative workloads were introduced by Banister and colleagues[59] to account for the workload that an athlete had achieved in the acute "fatigue" period of training in

comparison to the workload achieved in the chronic "fitness" period, thus allowing athletes of differing training levels to be compared with respect to performance and physiological outcomes. Training load varies between individuals as optimal training loads are dependent on an athlete's previous training loads, previous injury history, physicality, and years of experience.[11] The most optimal way to increase training load is to apply load in a moderate and progressive way in which the athlete remains comfortable.[11]

<u>Acute:chronic Workload Ratio</u>

The ACWR is a method to help quality relative load and to understand that the rate of change towards high weekly loads can cause an increase in injury risk than simply performing higher loads. The size of the acute load in relation to the chronic load provides a ratio score or ACWR.[30] This ratio can be used to monitor training load as it calculates the load that the athlete is prepared for. In general, activities performed by athletes can be viewed as stress, for example, external loads like running distances or the number of accelerations/decelerations performed as well as, internal loads like heart rate or blood lactate. The first study to investigate the relationship between acute and chronic workloads and injury risk studied the relationship in elite cricket fast bowlers.[29] Researchers concluded that high acute workloads greater than an ACWR of 1.5 may lead to a delayed increased risk of injury up to three to four weeks after the acute overload. Other studies elaborated on those findings in different sport populations like elite rugby players and found similar results.[27] They found that the players were less resistant to injury when subjected to spikes in acute workload that caused the ACWR to surpass 1.5.[27] These studies into ACWR led investigators to develop a guide to interpreting and

applying ACWR.[12,30] This guide highlighted and illustrated the ACWR where injury risk is low and where it is high. The data and information on ACWR can greatly help protect athletes against injuries through monitoring training load and developing the best training approach for long-term reduction of training-related injuries.[12] When it comes to implementing the ACWR, it is crucial to consider the method of monitoring an athlete's workload. This monitoring can come in the form of internal (session-rate of perceive exertion) or external (hitting volume) measures of training and competition load. Still, while there are limitations (variable sensitivity, ability to monitor every playing session, etc.) to monitoring workloads, practitioners will still need to consider understanding players' individual needs. Therefore, allowing athletes an opportunity to self-report any dysfunction in their performance is another important aspect of preventing sports-related injuries.

<div align="center">The Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score</div>

The KJOC Shoulder and Elbow score is a validated sport-specific patient-reported outcome measure (PROMs) used to define functional and performance measures of the upper extremity in overhead athletes.[4] PROMs are a helpful way for individuals to report on their health status or condition without having the response interpreted by a clinician or within a research setting.[60] The KJOC was developed due to a lack of validated upper extremity instruments designed to specifically measure the performance and function of overhead athletes.[4] Alberta et al. created a cross-sectional study to investigate the validity, reliability, and responsiveness of scoring systems in the evaluation of overhead athletes.[4] Alberta's study had 282 intercollegiate and professional overhead athletes complete the KJOC and were self-assigned into injury categories: 1) playing without

pain, 2) playing with pain, and 3) not playing due to pain. Correlations between the scores and differences between injury categories were measured. Through their investigation, the KJOC was observed to be more sensitive and accurate than the previous leading instrument for player evaluation, the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire, when determining athletes playing without pain and athletes not playing because of pain.[8] With the KJOC being a valid and responsive patient-reported instrument in the evaluation of overhead athletes, the next focus should be on establishing baseline scores.

The following studies aimed to establish normative KJOC values within overhead populations. The results from Wymore and Fronek aimed to establish a KJOC baseline score in collegiate swimmers.[6] The investigators administered the KJOC to 99 swimmers and calculated a mean score as well as determine the differences between sexes, years swimming, and self-reported injury status. The study concluded swimmers had an average KJOC score of 86 (85.9 ± 12.8).[6] When compared to other sports; the scores were lower for active swimmers than for athletes in other overhead sports. Kraeutler and colleagues found that healthy professional baseball pitchers had a mean KJOC score of 94.82 (95% confidence interval, 92.94-96.70).[61] However, the scores were not based on league level or professional playing experience. Thus, team physicians should not assess a pitcher's KJOC score based on these specifications. In addition, although scores are generally high for professional pitchers, some healthy pitchers will still record lower scores.[61] Kraeutler discovered that the most effective way of assessing a pitcher's injury or general soreness may be to look at differences between the individual's "healthy" score and their score after injury.[61] However, further study would be required to

determine a correlation between KJOC scores and a professional baseball pitcher's health status.

The following studies investigated how the KJOC would be used in symptomatic populations. The results from Domb[8] and his fellow colleagues' study support the use of the KJOC score as an outcomes assessment tool for ulnar collateral ligament reconstructions in high-level overhead athletes. Their results suggest that the KJOC score may have advantages in measurement of subtle performance changes in this high-demand patient population and will be a useful adjunct to existing outcomes measures in evaluating the results of this important surgery. The method used for their study included recruiting fifty-five professional baseball players who underwent ulnar collateral ligament reconstruction and having them complete the KJOC score, the Disabilities of the Arm, Shoulder, and Hand (DASH) score, and the DASH sports module. Players were separated into 3 categories; (1) playing without pain, (2) playing with pain, and (3) not playing because of pain and compared with one hundred twenty-three asymptomatic throwers. Pearson (parametric) and Spearman rank (nonparametric) correlations among the three systems were conducted to validate the KJOC score. Means across categories were compared using a Wilcoxon rank-sum test, and a threshold score separating categories 1 and 3 was determined using receiver operator characteristic discrimination analysis. The results from Franz[5] and his fellow colleagues' study help to further define the utility of the KJOC score in the functional assessment of professional baseball players. Players without a history of upper extremity injury or surgery who reported playing without pain (n = 122) averaged 96.9 on the KJOC score. Age of a player and time of administration of the KJOC questionnaire did not significantly affect the outcome

of the KJOC score. The KJOC score reliably differentiated between players based on their history of injury and history of surgery. The strongest predictor of a lower KJOC score was missed time because of injury in the previous year. They also found that major league players averaged significantly higher scores than minor league players. Overall, Franz and his colleagues believe that their study provides a foundation to assist in future outcomes research involving the highly specialized professional baseball player population.

KJOC Shoulder and Elbow Questionnaire

Name _____

University/College _____

Age_____   Sex _____

Date _____   Years Played _____

Dominant Hand (R) _____   (L) _____   Ambidextrous _____

Please answer the following questions related to your history of injuries to **YOUR ARM ONLY**:

	Yes	No
1. Is your arm currently injured?		
2. Are you currently active in your sport?		
3. Have you missed game or practice time in the last year due to an injury to your shoulder or elbow?		
4. Have you been diagnosed with an injury to your shoulder or elbow other than a strain or sprain? If yes, what was the diagnosis? (circle all that apply) **Labral Pathology Instability Bursitis** **Rotator Cuff Pathology Thoracic Outlet Syndrome** **Other _____**		
5. Have you received treatment for an injury to your shoulder or elbow? If yes, what was the treatment (circle all that apply) **Rest Therapy Surgery_____**		
Please describe your level of competition in your current sport:		
6. What is your highest level of competition you've participated at? **Collegiate tennis Professional tennis Junior Elite** **Other _____** If yes to collegiate tennis, what was your division? (circle all that apply) **NCAA: Division 1 Division 2 Division 3**		
7. What is your current level of competition? **Collegiate tennis Professional tennis Junior Elite** **Other _____**		
8. What is your current Universal Tennis Rating? _____		
9. If your current level of competition is not the same as your highest level, due you feel it is due to an injury to your arm?		

Please circle the **ONE category only** that best describes your current playing status:

Playing without any arm trouble

Playing, but with arm trouble

Not playing due to arm trouble

Instructions to athletes:

The following questions concern your physical functioning during game and practice conditions. Unless otherwise specified, all questions relate to your *Shoulder or Elbow*. Please answer with an "**X**" along the horizontal line that corresponds to your current level.

1. How difficult is it for you to get loose or warm prior to competition or practice?

Never feel loose during games or practice   Normal warm-up

2. How much pain do you experience in your shoulder or elbow?

Pain at rest   No pain with competition

3. How much weakness and/or fatigue (i.e. loss of strength) do you experience in your shoulder or elbow?

Weakness or fatigue preventing any competition   No weakness, normal competition fatigue

4. How unstable does your shoulder or elbow feel during competition?

"Popping out" routinely   No instability

5. How much have arm problems affected your relationship with your coaches, management, and agents?

Left team, traded or waived, lost contract or scholarship   Not at all
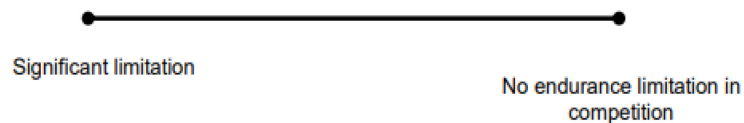
6. How much have you had to change your throwing motion, serve, stroke, etc. due to your arm?
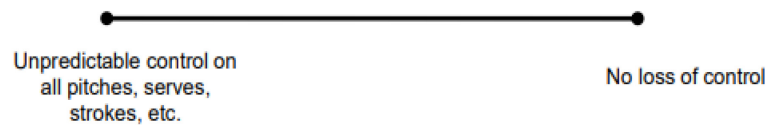
Completely changed,
don't perform motion
anymore

No change in motion

7. How much has your velocity and/or power suffered due to your arm?

Lost all power,
became finesse or
distance athlete

No change in
velocity/power

8. What limitation do you have in endurance in competition due to your arm?

Significant limitation

No endurance limitation in
competition

9. How much has your control suffered due to your arm?

Unpredictable control on
all pitches, serves,
strokes, etc.

No loss of control

10. How much do you feel your arm affects your current level of competition in your sport (i.e. is your arm holding you back from being at your full potential)?

Cannot compete, had
to switch sports

Desired level of competition

TEXAS ★ STATE
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The rising STAR of Texas

In future correspondence please refer to 2018354 or 5429

January 30, 2019

Natalie Myers, Ph.D.
Texas State University
601 University Drive.
San Marcos, TX 78666

Dear Dr. Myers:

Your renewal application titled, "The Acute:Chronic Workload Ratio in Relation to Injury Risk in Adolescent Tennis Players" was reviewed by the Texas State University IRB and it has been determined there are: (1) no changes to the protocol (2) there are no adverse events (3) additional time is needed to collect data (4) risks to subjects are minimized and reasonable; and that (5) research procedures are consistent with a sound research design and do not expose the subjects to unnecessary risk. The IRB determined that: (1) benefits to subjects are considered along with the importance of the topic and that outcomes are reasonable; (2) selection of subjects is equitable; and (3) the purposes of the research and the research setting is amenable to subjects' welfare and producing desired outcomes; that indications of coercion or prejudice are absent, and that participation is clearly voluntary.

1. In addition, the IRB found that you need to orient participants as follows: (1) signed informed consent is required; (2) Provision is made for collecting, using and storing data in a manner that protects the safety and privacy of the subjects and the confidentiality of the data; (3) Appropriate safeguards are included to protect the rights and welfare of the subjects.

This project is therefore approved at the Expedited Review Level until December 31, 2019

2. Please note that the institution is not responsible for any actions regarding this protocol before approval and there is a lapse of approval. If you expand the project at a later date to use other instruments, please re-apply. Copies of your request for human subjects review, your application, and this approval, are maintained in the Office of Research Integrity and Compliance.

Report any changes to this approved protocol to this office. A Continuing Review protocol will be sent to you in the future to determine the status of the project as a courtesy. Notify the IRB of any unanticipated events, serious adverse events, and breach of confidentiality within 3 days.

Sincerely,

Monica Gonzales
IRB Regulatory Manager
Office of Research Integrity and Compliance
Texas State University

CC: Dr. Duane Knudson

OFFICE OF THE ASSOCIATE VICE PRESIDENT FOR RESEARCH
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This letter is an electronic communication from Texas State University-San Marcos, a member of The Texas State University System.

DECLARATION OF CONFLICTING INTERESTS

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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