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A multi-year injury epidemiology analysis of an elite national junior tennis program

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ABSTRACT

Objectives: To profile multi-year injury incidence and severity trends in elite junior tennis players from a national program.
Design: Prospective cohort.
Methods: Injury data was collated by sex, age and region for all nationally-supported Australian junior players (58m, 43f 13–18y) between 2012–2016. Injury was defined as a physical complaint from training/matchplay interrupting training/matchplay determined by presiding physiotherapists and doctors. Severity represented the days of interrupted training/matchplay per injury. Injury incidence was reported per 1000 exposure hours. Incidence rate change and rate ratios (RR) ±95% confidence intervals were used to assess changes over time.
Results: No difference in male and female injury incidence existed (2.7 ± 0.0 v 2.8 ± 0.0) yet male injuries were more severe (3.6 ± 0.6 v 1.1 ± 0.9 days). The lumbar spine was the most commonly and severely injured region in both sexes (4.3 ± 0.2, 9.9 ± 1.4 d). Shoulder injuries were the second most common in both sexes (3.1 ± 0.2) and with the second highest severity in males (7.3 ± 1.4d). Knee injuries were also common in males (2.3 ± 0.2) yet potentially reduced over time (0.4 ± 0.6 RR) as pelvis/buttock injuries increased (3.4 ± 14.0 RR). Females had high trunk and abdominal injury incidences (2.5 ± 0.3). Independent of sex, the injury incidence increased with age from 2.0 ± 0.1 (13y) to 2.9 ± 0.1 (18y).
Conclusions: Despite no sex-based difference in injury incidence, male injuries resulted in more interrupted days of training/matchplay. The lumbar spine and shoulder were the most commonly injured body regions in both sexes. The number of injuries sustained by players also increased as they aged.

1. Introduction

Injuries in junior tennis players can disrupt their long-term athletic development.[1] Therefore, an understanding of the injury epidemiology in junior tennis is important to assist medical, physiotherapy and strength and conditioning professionals to monitor and manage the musculoskeletal health of young elite tennis players. However, limited evidence describing the injury epidemiology of junior tennis players exists, and that which does is inconsistent in reporting of injury incidence by anatomical region or sex.[2–4] This makes for an incomplete view of tennis injuries in youth tennis and may inadvertently affect the treatment and care of players.

Of the sparse research that is present, a three-year analysis of 16–20 year old players in a national program in the 1980s found that lower limb injuries were the most common in both genders as compared to trunk and upper limb injuries.[5] These findings were reported as absolute values and not relative to training volume or other extrinsic risk factors. Conversely, back injuries were found to be the most common in national junior male tennis players over a six-year period in the 1980s and 1990s.[4] Since then, the sport has observed dramatic changes in equipment and strategy,[7,8] likely influencing the sport's injury profile.[7] More recently, junior male club tennis players aged between 12 and 18 were shown to be more prone to injury than girls over a 2-year period of training and matchplay.[2] However, this contrasts with another study where girls of the same age bracket were reported as more susceptible to injury than boys during higher level national competitions.[3] Although these studies provide some context to the injuries sustained by

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junior tennis players they are limited in their variation of study design, the age and standard of athletes, injury classification, period of data capture and relative exposure measure.[2,4,5] Further, much of the research has focused on the epidemiology of junior injuries in-event rather than in training settings.[3,6] In turn, this highlights the need to better understand whether sex and age-based differences exist in the injury patterns of a homogenous sample of elite junior tennis players.[9]

An understanding of the severity of injury is important for determining the extent to which injuries impede training and potentially athletic development,[1] yet this has also been poorly examined in the tennis injury literature. Particularly, previous studies are limited by definitional differences[2,3] and methodological limitations in quantifying the severity of injury.[2] For example, the severity of injuries in Swedish local junior tennis players was collected over a two-year period via player recall.[2] However, the use of recall to quantify injury time-loss has been criticised for its bias and inaccuracy.[10] Additionally, no tennis injury study has described injury severity by body region which would be a valuable addition to the knowledge base of the sport. The same applies to the lack of investigation into the change in injury profile over time which is especially important among adolescent cohorts where maturation and risk of injury have been linked.[11]

Overall, the relevance of previous attempts to profile injuries in junior tennis has been limited by the timing,[5,6] tournament-only focus,[6] length of data collection[4] and lack of trend analysis.[4,5] Therefore, the aim of this study was to comprehensively examine the injury epidemiology of junior, elite tennis players of both sexes over a five-year time period. Specifically, the incidence, severity and changes over time in injuries of elite tennis players between the ages of 13 and 18 was assessed.

2. Methods

A total of fifty-eight male and forty-three female Australian junior tennis players were included in the study and had mean peak national rankings of 117 ± 139 and, 57 ± 48 respectively. All players were aged 18 or under at the time of each injury and were full-time scholarship-holders for at least a year between 2012 and 2016 in a national tennis academy governed by Tennis Australia. The number of players in a national academy fluctuated each year resulting in changes in the participant numbers year on year. The number of unique players in each year of the study included 69 (40m, 29f) in 2012, 75 (44m, 31f) in 2013, 64 (39m, 25f) in 2014, 59 (34m, 25f) in 2015 and 56 (30m,26f) in 2016. All players in the study did not participate in other sports. Given the lack of data prior to 2012, this year was used as the base year for ensuing analysis. Data was collected and stored in a secure, Tennis Australia managed data repository (Athlete Management System). This study received human ethics committee approval from Australian Catholic University (reference number 2015-196N) with informed consent obtained from players and player parents if those under the age of 18.

An injury was diagnosed by Tennis Australia's physiotherapists and doctors and defined as a physical complaint from training/matchplay resulting in interrupted training or matchplay.[12] Interrupted training was defined as any restrictions to tennis and off-court training resulting in an athlete unable to take a part in the full session.[12] Injuries were calculated as injury incidence, which describes the number of new injuries within the population over the period of time.[14] Severity was defined as the mean number of days since injury onset to a particular region to the day that the player returned to full training[13] both on and off court. Injury data was classified by region as per the Orchard Sports Injury Classification System (OSICS)[15] with only musculoskeletal injuries included (lacerations/abrasions and bruising/haematomas were omitted). The injury data was entered and stored on the Athlete Management System by the designated Tennis Australia treating physiotherapist ($n = 32$, mean 2.3 ± 1.3 years treating Tennis Australia athletes) and doctors ($n = 14$, mean 3.1 ± 2.0 years). Injury severity was also entered and stored in the repository via athlete self-reporting. Injury data, including OSICS-definedinjury region, year of injury, age and injury severity on the studied population between 2012–2016 were exported for analysis.

Injury incidence was reported per 1000 exposure hours which is consistent with recommendations in the consensus statement on epidemiological studies of medical conditions in tennis.[13] Exposure hours included the durations of both on and off court training and matchplay and were recorded via athlete daily self-reporting. The total exposure hours were the total exposure hours for all athletes in each given year which allowed for a relative comparison year-on-year. All players trained and competed on multiple court surfaces throughout the data collection period however this was not captured due to the epidemiology, not aetiology, focus of the study.

Statistical programming (R Core Team, 2012) was used for all analyses. The 'metafor' package was used to implement the fixed-effects meta-regression analysis of incidence rates ±95% CI with precision weights. Incidence rate changes represent the year-on-year change in injury counts by region and severity, where 2012 was the base year. The magnitude of change over time is inferred by rate ratios (RR) ±95% CI whereby a ratio of greater than 1 is considered to be an increase, and less than 1, a decrease. Results are reported as mean injury incidence ±SD, incidence rate change ±95% CI, and RR ±95% CI. The RR 95% CI values truncate at 0 when lower bound value is larger than the RR. Incidence rate changes ±95% CI are reported to two decimel places due to the size of the values.

3. Results

There were 327 male injuries and 258 female injuries during the time period. The exposure hours equated to a mean ± SD of 648.8 ± 108.6 and 661.8 ± 112.6 training hours per year for male and female players respectively. Injuries were comparable between sexes over the time period with 2.7 ± 0.0 and 2.8 ± 0.0 in female and males per 1000 exposure hours respectively (Table 1).

The lumbar spine, followed by the shoulder, had the highest incidence of injuries by region in both sexes over the observed time period (Table 1). Junior female tennis players experienced an increase in total injuries and particularly the upper limb (shoulder, elbow, wrist), neck, thoracic spine, trunk and abdominal, knee and foot injury incidence over time ($RR \geq 2.1 \pm 5.0$–14.4). There was also a reduction in hip and groin and lower leg injuries over time (0.4 ± 1.0 RR; Table 2). Males experienced an increase in pelvis/buttock injuries (3.4 ± 14.0 RR) over time, with a reduction in thoracic spine, knee, ankle and wrist injuries ($RR \leq 0.4 \pm 0.5$–0.7; Table 1).

Male injury severity was greater than females with 3.6 ± 0.6 days lost (Table 2), compared to a female injury severity of 1.1 ± 0.9 days lost. Male injury severity also increased over time (2.6 ± 2.5 RR). Lumbar spine injury severity was the highest in both sexes ($>4.6 \pm 0.6$ days lost). The shoulder, hip and groin and wrist also had high injury severity in male tennis players, with an increase in pelvis/buttock injury severity (3.4 ± 14.0 RR) and a reduction in trunk and abdominal severity (0.3 ± 0.4 RR) over time. Female tennis players experienced high elbow, ankle and knee injury severity with an increase in neck (2.3 ± 2.8 RR), elbow (2.5 ± 13.4 RR), thoracic spine (6.1 ± 13.4 RR) and foot (7.5 ± 12.8 RR) injury severity over time.

Injury incidence increased with age with 13 through to 18 year-olds incurring 2.0 (±0.1), 2.3 (±0.1), 2.2 (±0.1), 2.9 (±0.1), 3.0 (±0.1)

Table 1
Male and female injury incidence (mean ± SD), incidence rate change (±95% confidence interval (CI)) and rate ratio (RR) (±95% CI), per 1000 exposure hours, by region 2012–2016.

Region	Males			Females		
	Injury incidence	Incidence rate change	RR	Injury incidence	Incidence rate change	RR
Head	0.1 ± 0.0	0.00 ± 0.02	1.2 ± 4.0	0.0 ± 0.0		
Neck	0.5 ± 0.1	0.00 ± 0.02	1.4 ± 2.9	0.5 ± 0.1	0.01 ± 0.03	2.3 ± 6.5
Shoulder	3.6 ± 0.2	−0.02 ± 0.08	0.8 ± 0.8	2.6 ± 0.2	0.07 ± 0.08	3.6 ± 5.8
Upper arm	1.8 ± 0.2	0.01 ± 0.05	1.4 ± 1.9	0.7 ± 0.1	0.00 ± 0.04	0.7 ± 2.0
Elbow	1.8 ± 0.2	24.51 ± 51.66	1.7 ± 2.1	1.7 ± 0.3	0.04 ± 0.06	4.7 ± 14.4
Forearm	0.7 ± 0.1	0.00 ± 0.03	1.3 ± 2.5	0.2 ± 0.1	0.00 ± 0.03	1.3 ± 4.0
Wrist	3.0 ± 0.4	−0.07 ± 0.07	0.3 ± 0.5	2.4 ± 0.2	0.09 ± 0.06	5.8 ± 9.0
Chest	0.0 ± 0.0			0.2 ± 0.1	0.00 ± 0.03	1.3 ± 4.0
Thoracic spine	1.0 ± 0.3	−0.03 ± 0.03	0.1 ± 0.5	1.3 ± 0.2	0.04 ± 0.04	6.1 ± 13.4
Trunk and abdominal	1.2 ± 0.1	0.00 ± 0.05	0.9 ± 1.6	2.5 ± 0.3	0.09 ± 0.06	6.1 ± 9.9
Lumbar spine	4.7 ± 0.2	0.02 ± 0.09	1.2 ± 0.9	3.9 ± 0.2	0.09 ± 0.10	3.0 ± 3.6
Hip and groin	1.9 ± 0.1	0.03 ± 0.06	1.8 ± 2.5	1.4 ± 0.2	−0.03 ± 0.05	0.4 ± 0.7
Pelvis/buttock	0.6 ± 0.1	0.01 ± 0.03	3.4 ± 14.0	0.6 ± 0.1	0.00 ± 0.04	1.2 ± 3.4
Thigh	1.4 ± 0.1	0.00 ± 0.05	1.1 ± 1.5	1.6 ± 0.1	0.01 ± 0.06	1.5 ± 2.5
Knee	2.3 ± 0.2	−0.04 ± 0.07	0.4 ± 0.6	2.0 ± 0.2	0.04 ± 0.05	3.2 ± 5.0
Lower leg	1.0 ± 0.0	0.00 ± 0.05	0.9 ± 1.7	1.2 ± 0.2	−0.02 ± 0.05	0.4 ± 1.3
Ankle	1.4 ± 0.2	−0.03 ± 0.05	0.2 ± 0.7	2.3 ± 0.3	−0.01 ± 0.07	0.8 ± 1.5
Foot	0.7 ± 0.0	0.00 ± 0.04	0.9 ± 2.5	1.9 ± 0.4	0.05 ± 0.05	7.5 ± 10.8
Overall	2.7 ± 0.0	−0.11 ± 0.23	0.9 ± 1.3	2.8 ± 0.0	0.51 ± 0.25	2.1 ± 1.6

Table 2
Male and female mean injury severity (±SD), incidence change (±95% confidence interval (CI)) and rate ratio (RR) (±95% CI), per 1000 exposure hours, by region 2012–2016.

Region	Males			Females		
	Mean severity	Incidence rate change	RR	Mean severity	Incidence rate change	RR
Head	0.4 ± 0.4	0.00 ± 0.02	1.2 ± 4.0	0.0 ± 0.0		
Neck	1.1 ± 0.3	0.00 ± 0.02	1.4 ± 2.9	0.3 ± 0.3	0.01 ± 0.03	2.3 ± 6.5
Shoulder	7.3 ± 1.4	0.11 ± 0.11	2.7 ± 3.1	1.4 ± 0.9	−0.21 ± 0.11	0.2 ± 0.2
Upper arm	4.1 ± 0.0	0.04 ± 0.09	1.5 ± 1.4	0.6 ± 0.2	0.00 ± 0.04	0.7 ± 2.0
Elbow	4.8 ± 0.7	24.51 ± 51.66	1.7 ± 2.1	3.0 ± 2.4	0.13 ± 0.14	2.5 ± 2.8
Forearm	2.5 ± 0.7	0.00 ± 0.04	0.9 ± 1.3	0.5 ± 0.4	0.00 ± 0.03	1.3 ± 4.0
Wrist	5.3 ± 0.6	0.06 ± 0.11	1.9 ± 2.1	1.2 ± 0.7	−0.02 ± 0.10	0.9 ± 0.6
Chest	0.0 ± 0.0			0.2 ± 0.1	0.00 ± 0.03	1.3 ± 4.0
Thoracic spine	1.9 ± 0.4	−0.03 ± 0.03	0.1 ± 0.5	0.5 ± 0.5	0.04 ± 0.04	6.1 ± 13.4
Trunk and abdominal	4.7 ± 0.9	−0.09 ± 0.07	0.3 ± 0.4	1.3 ± 1.0	−0.04 ± 0.09	0.7 ± 0.5
Lumbar spine	15.2 ± 1.4	0.02 ± 0.09	1.2 ± 0.9	4.6 ± 0.6	0.12 ± 0.14	1.9 ± 1.6
Hip and groin	6.2 ± 1.7	0.05 ± 0.08	2.3 ± 3.3	0.8 ± 0.8	−0.08 ± 0.07	0.1 ± 0.4
Pelvis/buttock	1.4 ± 0.2	0.01 ± 0.03	3.4 ± 14.0	1.2 ± 1.2	0.00 ± 0.04	1.2 ± 3.4
Thigh	1.7 ± 0.2	0.03 ± 0.04	2.7 ± 3.5	0.3 ± 0.2	−0.01 ± 0.05	0.7 ± 1.1
Knee	2.7 ± 0.5	−0.07 ± 0.07	0.1 ± 0.5	2.1 ± 1.6	−0.03 ± 0.12	0.8 ± 0.8
Lower leg	3.9 ± 0.9	0.04 ± 0.06	5.4 ± 11.6	1.6 ± 2.0	−0.03 ± 0.09	0.6 ± 1.0
Ankle	1.7 ± 0.2	−0.03 ± 0.05	0.2 ± 0.7	2.4 ± 2.7	0.05 ± 0.13	1.4 ± 1.2
Foot	2.6 ± 0.4	0.00 ± 0.04	0.9 ± 2.5	1.5 ± 0.7	0.05 ± 0.05	7.5 ± 12.8
Overall	3.6 ± 0.6	0.10 ± 0.10	2.6 ± 2.5	1.1 ± 0.9	−0.01 ± 0.12	0.9 ± 1.6

and 2.9 (±0.1) injuries per 1000 exposure hours respectively. The lumbar spine featured as the most common injury region for 14–18 years olds, whereas the shoulder and hip and groin were the most common injury regions for 13 year old players (Table 3). Changes over time highlighted an increase in wrist injuries in the 13th (9.2 ± 12.1 RR) and 18th birth years (3.4 ± 13.1 RR), pelvis/buttock injuries in the 14th (5.2 ± 13.9 RR) and 15th birth year (2.2 ± 9.9 RR), knee injuries in the 16th (3.0 ± 9.9 RR) birth year and shoulder injuries in the 17th (6.0 ± 11.1 RR) birth year (Table 3).

4. Discussion

This study provides a comprehensive longitudinal examination of injury incidence and severity in elite junior tennis players by sex, region and age (injury incidence only). Injury incidence in junior male and female tennis players was comparable when expressed relative to exposure hours. This finding is novel in elite junior tennis, although it is consistent with reports in collegiate tennis.[16] However, when all body regions were considered, male junior players experienced higher injury severity than female juniors. Further, and in line with previous research,[6,17,18] the lumbar spine was the most commonly and severely injured region across both sexes.

In addition to the lumbar spine being the most common and severe injury region in both sexes, it was also the most common and severe across age groups (14–18 year olds). Previous research has identified the mechanical loading of serving, primarily through lateral flexion and extension, as a risk factor for the development of low back pain in adolescent tennis players.[19] The performance of the kick serve is known to be particularly problematic in this regard with coaches generally introducing and then emphasising this type of serve to players between the ages of 12–15.[19] The combination of high joint loads, increased repetition of an unaccustomed skill and physical growth during this time may therefore contribute to the high incidence of lumbar region injuries.[19] Interestingly, the high eccentric-concentric activation of the abdominals during the serve would also appear to be implicated in the high incidence of trunk and abdominal injuries sustained by junior female players.[20] Further research is required to determine why this injury is less common among junior male players. Given trunk injuries are of concern in elite junior tennis players, careful monitoring of serve loads, technique via biomechanical analyses and targetted injury prevention programs may mitigate occurence and severity.

The shoulder was found to be the second most common region of injury in both sexes and the second most severe in junior males.

Table 3
Birth year injury incidence (mean ± SD), incidence rates change (±95% confidence interval (CI)) and rate ratio (RR) (±95% CI), per 1000 exposure hours, by region 2012–2016.

Region	13th birth year			14th birth year			15th birth year			16th birth year			17th birth year			18th birth year		
	Injury incidence	Incidence rate change	RR	Injury incidence	Incidence rate change	RR	Injury incidence	Incidence rate change	RR	Injury incidence	Incidence rate change	RR	Injury incidence	Incidence rate change	RR	Injury incidence	Incidence rate change	RR
Shoulder	0.3 ± 0.1	0.05 ± 0.27	2.6 ± 11.2	0.3 ± 0.1	−0.01 ± 0.18	0.8 ± 3.0	0.2 ± 0.1	−0.05 ± 0.11	0.0 ± 1.1	0.3 ± 0.1	0.03 ± 0.10	1.6 ± 3.2	0.3 ± 0.1	0.06 ± 0.14	6.0 ± 11.1	0.3 ± 0.1	−0.02 ± 0.17	0.7 ± 1.6
Neck				0.1 ± 0.0	0.03 ± 0.10	2.9 ± 10.1	0.1 ± 0.0	0.00 ± 0.10	0.9 ± 3.3	0.1 ± 0.0	−0.02 ± 0.08	0.5 ± 1.7	0.1 ± 0.0	−0.02 ± 0.08	0.5 ± 1.7			
Head																0.1 ± 0.1	−0.03 ± 0.11	0.4 1.3
Upper Arm	0.2 ± 0.0	0.09 ± 0.23	5.7 ± 12.3	0.1 ± 0.0	0.04 ± 0.13	2.9 ± 8.7	0.1 ± 0.0	0.00 ± 0.09	1.0 ± 2.8	0.1 ± 0.0	0.00 ± 0.08	0.9 ± 3.0	0.2 ± 0.0	0.04 ± 0.14	3.4 ± 12.2	0.2 ± 0.1	−0.09 ± 0.14	0.2 ± 0.5
Elbow	0.2 ± 0.0	0.04 ± 0.25	1.9 ± 5.8	0.1 ± 0.0	−0.02 ± 0.13	0.5 ± 2.7	0.1 ± 0.0	−0.02 ± 0.11	0.5 ± 2.5	0.2 ± 0.0	0.03 ± 0.11	2.4 ± 7.4	0.2 ± 0.0	0.04 ± 0.11	2.4 ± 6.7	0.2 ± 0.0	0.03 ± 0.14	1.7 ± 5.0
Forearm				0.1 ± 0.0	0.01 ± 0.11	1.6 ± 7.2	0.1 ± 0.0	0.01 ± 0.08	1.4 ± 5.6				0.1 ± 0.0	−0.02 ± 0.08	0.5 ± 1.7			
Wrist	0.1 ± 0.0	0.12 ± 0.20	9.2 ± 12.1	0.2 ± 0.1	−0.10 ± 0.16	−0.1 ± 1.0	0.3 ± 0.1	−0.06 ± 0.12	0.2 ± 1.1	0.3 ± 0.1	−0.06 ± 0.11	0.4 ± 0.7	0.2 ± 0.0	0.01 ± 0.12	1.3 ± 2.8	0.3 ± 0.1	0.07 ± 0.17	3.4 ± 13.1
Chest							0.1 ± 0.0	0.01 ± 0.08	1.4 ± 5.6	0.1 ± 0.0	0.00 ± 0.08	1.3 ± 4.5						
Thoracic spine	0.1 ± 0.0	0.05 ± 0.20	3.1 ± 13.2	0.1 ± 0.0	0.03 ± 0.10	2.9 ± 10.1	0.1 ± 0.0	0.00 ± 0.08	1.2 ± 4.6	0.2 ± 0.1	−0.04 ± 0.12	0.3 ± 1.2	0.1 ± 0.0	−0.03 ± 0.09	0.4 ± 0.9	0.1 ± 0.0	−0.03 ± 0.11	0.4 ± 1.3
Trunk and abdominal	0.1 ± 0.0	0.04 ± 0.19	2.6 ± 11.4	0.2 ± 0.0	−0.02 ± 0.14	0.6 ± 2.3	0.1 ± 0.0	0.01 ± 0.08	1.9 ± 6.4	0.2 ± 0.0	0.01 ± 0.10	1.3 ± 3.1	0.3 ± 0.1	0.06 ± 0.14	4.0 ± 7.5	0.1 ± 0.0	0.00 ± 0.13	0.9 ± 2.9
Lumbar spine	0.2 ± 0.0	0.08 ± 0.23	5.3 ± 11.5	0.4 ± 0.1	0.06 ± 0.20	1.9 ± 3.9	0.5 ± 0.1	−0.08 ± 0.20	0.2 ± 1.3	0.4 ± 0.1	0.08 ± 0.12	2.7 ± 4.5	0.5 ± 0.1	0.02 ± 0.16	1.2 ± 1.8	0.4 ± 0.1	−0.11 ± 0.17	0.3 ± 0.6
Hip and groin	0.3 ± 0.1	0.15 ± 0.24	6.5 ± 18.2	0.1 ± 0.0	27.81 ± 83.20	4.1 ± 4.1	0.3 ± 0.1	−0.03 ± 0.13	0.5 ± 1.6	0.1 ± 0.0	0.02 ± 0.09	2.2 ± 8.0	0.2 ± 0.1	−0.02 ± 0.14	0.7 ± 1.9	0.1 ± 0.0	−0.01 ± 0.12	0.9 ± 2.3
Pelvis/buttock	0.1 ± 0.0	0.08 ± 0.18	6.1 ± 11.6	0.1 ± 0.0	0.04 ± 0.11	5.2 ± 13.9	0.1 ± 0.0	0.01 ± 0.08	2.2 ± 9.9	0.1 ± 0.0	0.01 ± 0.09	1.6 ± 5.2	0.1 ± 0.0	0.00 ± 0.09	1.0 ± 3.4	0.1 ± 0.0	0.01 ± 0.12	1.2 ± 4.0
Thigh	0.2 ± 0.0	0.07 ± 0.22	4.6 ± 18.7	0.1 ± 0.0	0.02 ± 0.15	1.9 ± 9.0	0.1 ± 0.0	0.01 ± 0.08	1.5 ± 4.4	0.1 ± 0.0	0.00 ± 0.07	0.8 ± 2.9	0.2 ± 0.1	−0.03 ± 0.14	0.6 ± 1.6	0.2 ± 0.0	−0.03 ± 0.14	0.6 ± 1.6
Knee	0.2 ± 0.0	0.04 ± 0.25	1.9 ± 5.8	0.1 ± 0.0	0.00 ± 0.11	1.1 ± 3.8	0.2 ± 0.1	−0.02 ± 0.09	0.7 ± 1.8	0.2 ± 0.0	0.05 ± 0.13	3.0 ± 9.9	0.1 ± 0.0	0.01 ± 0.11	1.1 ± 3.3	0.2 ± 0.1	−0.08 ± 0.13	0.2 ± 0.6
Lower leg	0.1 ± 0.0	0.04 ± 0.19	2.6 ± 11.4	0.1 ± 0.0	0.01 ± 0.14	1.3 ± 6.5	0.1 ± 0.0	−0.02 ± 0.09	0.5 ± 2.3	0.2 ± 0.1	−0.02 ± 0.12	0.7 ± 1.7	0.1 ± 0.0	−0.01 ± 0.10	0.7 ± 2.0	0.1 ± 0.0	0.00 ± 0.13	0.9 ± 2.9
Ankle	0.2 ± 0.0	0.06 ± 0.20	3.1 ± 10.5	0.2 ± 0.1	−0.02 ± 0.14	0.4 ± 3.2	0.1 ± 0.0	−0.02 ± 0.11	0.5 ± 2.0	0.1 ± 0.0	0.01 ± 0.10	1.4 ± 5.4	0.2 ± 0.0	0.01 ± 0.11	1.2 ± 3.5	0.4 ± 0.1	0.01 ± 0.19	1.1 ± 2.3
Foot				0.2 ± 0.0	0.02 ± 0.12	1.7 ± 4.8				0.1 ± 0.0	0.00 ± 0.08	1.2 ± 3.7	0.2 ± 0.0	0.05 ± 0.13	4.3 ± 12.7	0.3 ± 0.1	0.06 ± 0.17	2.5 ± 7.3
Overall	2.0 ± 0.1	0.38 ± 0.67	2.0 ± 6.1	2.3 ± 0.1	−0.39 ± 0.48	0.4 ± 1.6	2.2 ± 0.1	−0.46 ± 0.37	0.3 ± 1.4	2.9 ± 0.1	0.2 ± 0.39	1.3 ± 4.2	3.0 ± 0.1	0.31 ± 0.46	1.6 ± 5.0	2.9 ± 0.1	−0.15 ± 0.54	0.8 ± 2.9

Consistently, the shoulder has been highlighted to be the most common upper limb injury region in tennis irrespective of age and standard.[9,18,21] Shoulder injuries in tennis are generally reported to be overuse injuries as opposed to acute.[21] As the joint is utilized in all strokes in tennis, it is likely the repetitive strain on the shoulder results in the large injury incidence often observed.[21] As context, profiling of junior tennis matchplay suggests that players hit 2.5–3 strokes per point[22] and in excess of 90 serves per tennis match.[23] When extrapolated to include the potential multiple singles and doubles matches completed in a day[24] and then on repeated days,[18] the escalation in shoulder joint loading from hitting volumes and intensity may be cause for concern.[21] Similarly, these playing demands expose the wrist to large forces which may explain the high incidence and severity of wrist injuries in both sexes in this study. In turn, these ballistic and repetitive movements are performed with equipment that is selected with little systematic regard to the loading implications for the upper limb.[7] The adverse effects of the inappropriate selection of equipment are likely to be magnified by biomechanical limitations that may also be associated with injury.[25] Consequently, when these factors are coupled with high or increasing hitting volumes and intensities, the high incidence of wrist and global upper limb injuries among juniors is explicable.

Junior males had a high incidence of knee and ankle injuries, yet both trended downwards and were highly variable (large CI bounds) over time. Nevertheless, with these injuries to the lower limb in mind, the court surface upon which players train may be worth considering. Australian tennis players have naturally trained on hard rather than clay tennis courts, yet almost the same amount of international junior tournaments are offered on clay as compared to hard.[26] As a result, Australian junior tennis players have recently increased their clay-court training leading to some of the juniors sampled in the current study spending up to 5 times more time training on clay over the time period than previous cohorts in this National program. The increase in time spent training on clay, as compared to hard, may play a role in the reduction in knee and ankle injuries over time, as clay courts transmit less force through the body and allows players to slide more freely.[27] However, the potential rise in pelvis/buttock injuries over the time period may have been a byproduct of this increased clay-based hitting, as the movement and sliding actions on clay courts result in greater strain on the gluteus muscles.[28] In comparison, a reduction in pelvis/buttock injuries over time was found at the Australian Open which is competed on hard court.[18] Court surface may impact on junior tennis injuries and should be considered by both athletes and performance staff during junior athetic development.

The age-based analysis of injury incidence in this study provides a novel insight into the increasing injury occurrence in a developing junior population. Peak height velocity is generally experienced between the ages of 13–15 years,[11] whereby soon after, the risk of injury is suggested to be greatest.[11] In addition to physical growth, training and matchplay volume and intensity rise as junior tennis players begin to specialise in the sport and compete more often. This increase in load has been linked to a rise in injury risk,[23] The finding that lumbar spine injuries were the most common injury region for players aged 14–18 is consistent with what was observed with the cohort overall. Shoulder, hip and groin injuries were the most common in 13 year-olds. The age analysis of injuries over time highlights an upward trend, albeit subject to large RR CIs, in upper limb injuries in early and late teen players (13, 17 and 18 year-olds) and lower limb and trunk injuries in mid teen players. Changes in technique, tactical approach, physicality of the players and matchplay, as well as equipment selection may all contribute to the variations in anatomical injury incidence by age over time.[7,8,20,22]

It is important to recognise the large size of the RR 95% CIs as a limitation, interpreted as the lower bounds extending beyond the null value (<1.0). A primary explanation is the small and variable injury numbers from year-to-year in the dataset, which then limits the strength of our conclusions. Future research should explore changes in injury rates over time with a larger and less variable dataset to provide some more meaningful insights. Additionally, although reporting tennis injuries per 1000 exposure hours has been recommended as the best exposure measure,[13] recent findings suggest that training/match duration may not be the optimal denominator for reporting injuries.[29] However, a more precise measure of training and matchplay, such as hitting volume and distance covered, was not available in the dataset. The court surface of each training session and match was not recorded, which may have added to the understanding of changes in injury incidence. Also, no gender and severity analysis by age was undertaken due to limitations with sample size dilution.[30] Furthermore, there was a lack of control in the injury prevention and interventions implemented during the time period. This may have impacted injury incidence by region, gender and age over time.

5. Conclusion

The profile of junior injuries in the Australian national tennis program revealed that there was no sex difference in injury incidence, yet male injuries were more severe. The lumbar spine presented as the most frequent region of injury resulting in the most time-loss. Junior males experienced high shoulder, wrist and knee injury incidence and severity yet knee incidence shifted downwards over time. Junior females also experienced a high incidence of shoulder as well as trunk and abdominal injuries which trended up over time. The incidence of injuries also increased with age. Collectively, these findings describe common injury trends in elite junior tennis via assessment of injury incidence, severity, age and changes over time, whilst utilising a recommended exposure measure. In practice, this insight can inform injury prevention and training programs, equipment selection as well as tournament scheduling for elite junior tennis players.

Practical implications

- No sex-based differences in injury incidence relative to exposure hours, and greater junior male injury severity compared to females, provides insight for sex-specific injury prevention and treatment programs.
- There is a need for enhanced lumbar spine injury prevention strategies in both sexes and all junior ages.
- The awareness of the increase with injury incidence with age from 13 through to 18 year old national, junior tennis players may assist with load monitoring, tournament scheduling, equipment selection and training programs to mitigate the injury risk.

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Ethics

This study received human ethics committee approval from Australian Catholic University. Reference number 2015-196N.

Contributorship

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References

1. Bylak J, Hutchinson MR. Common sports injuries in young tennis players. *Sports Med* 1998; 26(2):119–132.
2. Hjelm N, Werner S, Renstrom P. Injury profile in junior tennis players: a prospective two year study. *Knee Surg Sports Traumatol Arthrosc* 2010; 18(6):845–850.
3. Silva R, Takahashi R, Berra B et al. Medical assistance at the Brazilian juniors tennis circuit—a one-year prospective study. *J Sci Med Sport* 2003; 6(1):14–18.
4. Pluim BM, Loefen FGJ, Clarsen B et al. A one-season prospective study of injuries and illness in elite junior tennis. *Scand J Med Sci Sports* 2016; 26:564–571.
5. Reece LA, Fricker PA, Maguire KF. Injuries of elite young tennis players at the Australian Institute of Sport. *Aust J Sci Med Sport* 1986; 18(4):11––15.
6. Hutchinson MR, Laprade RF, Burnett QM et al. Injury surveillance at the USTA boys' tennis championships: a 6-yr study. *Med Sci Sports Exerc* 1995; 27(6):826–831.
7. Miller S. Modern tennis rackets, balls, and surfaces. *Br J Sports Med* 2006; 40(5):401–405.
8. Reid M, Morgan S, Whiteside D. Matchplay characteristics of Grand Slam tennis: implications for training and conditioning. *J Sports Sci* 2016; 19:1791––1798.
9. McCurdie I, Smith S, Bell PH et al. Tennis injury data from The Championships, Wimbledon, from 2003 to 2012. *Br J Sports Med* 2017; 51(7):607–611.
10. Gabbe BJ, Finch CF, Bennell KL et al. How valid is a self reported 12 month sports injury history? *Br J Sports Med* 2003; 37(6):545–547.
11. Van der Sluis A, Elferink-Gemser MT, Brink MS et al. Importance of peak height velocity timing in terms of injuries in talented soccer players. *Int J Sports Med* 2015; 36(04):327–332.
12. Fuller CW, Ekstrand J, Junge A et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scand J Med Sci Sports* 2006; 16(2):83–92.
13. Pluim BM, Fuller CW, Batt ME et al. Consensus statement on epidemiological studies of medical conditions in tennis, April 2009. *Br J Sports Med* 2009; 43(12):893–897.
14. Hennekens CH, Buring JE, Mayrent SL. *Epidemiology in Medicine*, Boston, Little Brown and Company, 1987.
15. Orchard J. Orchard sports injury classification system (OSICS), in *Science and Medicine in Sport*, 2nd ed., Bloomfield J, Fricker P, Fitch K, editors, Melbourne, Blackwell, 1995, p. 674––681. Current version available at: http://www.injuryupdate.com.au/research/OSICS.htm.
16. Lynall RC, Kerr ZY, Djoko E et al. Epidemiology of National Collegiate Athletic Association men's and women's tennis injuries. *Br J Sports Med* 2015; 0(1–6).
17. Okholm Kryger K, Dor F, Guilluime M et al. Medical reasons behind player departures from male and female professional tennis competitions. *Am J Sports Med* 2015; 43(1):34–41.
18. Gescheit DT, Cormack SJ, Duffield R et al. Injury epidemiology of tennis players at the 2011–2016 Australian Open Grand Slam. *Br J Sports Med* 2017; 51(17):1289–1294.
19. Campbell A, Straker L, O'Sullivan P et al. Lumbar loading in the elite adolescent tennis serve: link to low back pain. *Med Sci Sports Exerc* 2013; 45(8):1562–1568.
20. Ellenbecker TS, Roetert EP. An isokinetic profile of trunk rotation strength in elite tennis players. *Med Sci Sports Exerc* 2004; 36(11):1959–1963.
21. Van der Hoeven H, Kibler WB. Shoulder injuries in tennis players. *Br J Sports Med* 2006; 40(5):435–440.
22. Fernandez-Fernandez J, Sanz-Rivas D, Fernandez-Garcia B et al. Match activity and physiological load during a clay-court tennis tournament in elite female players. *J Sport Sci* 2008; 26(14):1589–1595.
23. Myers NL, Sciascia AD, Kibler WB et al. Volume-based interval training program for elite tennis players. *Sports Health* 2016; 8(6):536–540.
24. Maraga N, Duffield R, Gescheit D et al. Playing not once, not twice but three times in a day: the effect of fatigue on performance in junior tennis players. *Int J Perform Anal Sport* 2018;(1):104–114.
25. Campbell A, Straker L, Whiteside D et al. Lumbar mechanics in tennis groundstrokes: differences in elite adolescent players with and without low back pain. *J Appl Biomech* 2016; 32(1):32–39.
26. International Tennis Federation. *Juniors Tournament Calendar*, 2017. Available from: http://www.itftennis.com/juniors/tournaments/calendar.aspx. Cited 1 September 2017.
27. Pieper S, Exler T, Weber K. Running speed loads on clay and hard courts in world class tennis. *Med Sci Tennis* 2007; 12(2):14–17.
28. Girard O, Eicher F, Fourchet F et al. Effects of the playing surface on plantar pressures and potential injuries in tennis. *Br J Sports Med* 2007; 41(11):733–738.
29. Reid M, Cormack SJ, Duffield R et al. Improving the reporting of tennis injuries: the use of workload data as a denominator? *Br J Sports Med* 2018. In Press.
30. Tomczak M, Tomczak E, Kleka P et al. Using power analysis to estimate appropriate sample size. *Trends in Sport Sci* 2014; 21(4):195–206.