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EDITORIAL

In this issue ...

CHRIS WHATMAN

Welcome to the first edition of the journal for 2022, an edition which includes selected abstracts from the excellent Sports Medicine NZ conference, held for the first time online in October 2021. The theme of the conference was "The Running Athlete" and we have two excellent commentaries in this issue aligned with this theme. Firstly, Paul Gamble provides an interesting insight into the need for a directed, multi-faceted approach when it comes to managing running related injuries and then Chris Milne follows with a walk down memory lane as he recalls the most significant developments in running over the past six decades – with a distinct kiwi flavour! In the third of our commentaries in this edition Shehnaz Hussain provides timely thoughts on factors that can compromise an athlete's wellbeing.

Our original contributions include two studies involving participants from opposite ends of New Zealand cricket. Sibi Walter and colleagues investigate the prevalence of injuries in senior NZ domestic fast bowlers and Simon Walters and colleagues investigate biological maturation, relative age, and bio-banding in youth cricket. Bio-banding has been a hot topic in English youth football recently and this is possibly the first study to report on the use of bio-banding in cricket. Also in the youth sport space, Rhys Norton and colleagues report on possible links between injury and specialisation in secondary school sport and the potential role of sports academies. Finally, Doug King and colleagues report on their analysis of movement and heart rate data in amateur women's rugby.

As always thanks to all those that have submitted manuscripts to the journal over the last six months and to the reviewers for their expertise during the review process.

Quantifying injuries among New Zealand cricket fast bowlers: A 12-month retrospective injury surveillance

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ABSTRACT

Introduction

Effective sports injury prevention relies on comprehensive injury surveillance. Despite the recognition of cricket's fast bowling position as the most injury-prone, there have been only two injury surveillance studies amongst New Zealand (NZ) cricketers. To help address the lack of research, our study quantified the injury prevalence amongst NZ's domestic fast bowlers.

Methods

For the 2017-2018 year, a 12-month retrospective self-reporting electronic injury surveillance was sent to 62 first-class fast bowlers. The surveillance recorded injury type, onset, description, diagnosis, body area and time-loss.

Results

Fifty six percent (35/62) of the cricketers responded to the injury surveillance, and we found an injury prevalence of 66%, with 25 cricketers recording at least one injury. Forty seven individual injuries were reported, with 32 (68%) defined as acute and 15 (32%) as overuse in origin. Half of all acute injuries (16) occurred during bowling, and the most injury-prone areas were the lower back with 9 (19%) injuries, followed by ankle/feet with 7 (15%) injuries, the thigh also with 7 (15%) injuries and the shoulder with 6 (13%) injuries. Injuries to the lower back (691 days), ankle/feet (358 days) and knees (304 days) accounted for the highest number of time-loss.

Conclusion

Effective injury prevention programmes rely on the accurate identification of the most injury-prone body areas. As over two-thirds of injuries occurred in only four body parts, this highlights the pre-emptive value of targeting the lower back, ankle/feet, thigh and shoulder in any subsequent injury prevention programmes.

Keywords

Cricket injuries, Injury prevention, Injury surveillance

INTRODUCTION

Cricket is predominantly played in most Commonwealth nations.[1] The sport has evolved from multiday matches to shorter formats, including the hugely popular Twenty20 (T20) format. The commercial success of the T20 format has enabled a large number of cricketers to play these matches more frequently in franchise-based competitions at both home and abroad.[39] Effectively, this has transitioned elite cricket from having primarily a summer season to an almost year-long playing season.[2,3] To be considered for selection throughout the year, cricketers must be consistently playing matches and training year-round.[4] The increased physical and physiological demands on modern cricketers have resulted in an increased workload which has been suggested to contribute to increased injury prevalence.[5-7]

Amongst cricketing positions, the fast bowling position has been repeatedly identified as the most injury-prone.[5,37,39] Injury surveillance of Australian first-class cricketers highlighted that before 2006, a playing season contained 10-11 limited over games (40-44 days) evenly spaced throughout a six-month season, whereas current Australian scheduling requires up to 10 limited over matches played within two months.[8] The increased game saturation results in an overall increased workload, especially for fast bowlers because of the changes between game formats which requires fast bowlers to adapt and bowl only four overs in a T20 match to ~30-40 overs in a first-class multiday match.[8] These sudden spikes in workload have been highlighted as the most common predisposing factor for injuries.[9, 10]

Fast bowler's predisposition to injury is likely multifactorial with bowling style, landing biomechanics, increased workload, training mal-adaptations, recurrent injuries and joint anatomy all having been implicated.[11-16] With fast bowlers, the lower back, ankle/foot and thigh have been acknowledged as the most injury-prone body areas, with some studies highlighting the prevalence of shoulder injuries.[10,37] Most cricket-related injuries have been attributed due to overuse. Hence, short-term injury surveillances (tournaments) are less likely to record and report overuse injuries in comparison to the more extended yearly surveillances.

Most commonly, cricket injury prevalence has been calculated based on time-loss injury definitions[7], while the inclusion of non-time loss injuries has appeared only in the past ten years.[14] Despite any injury requiring medical attention and causing match or training loss, being considered worthy of recording. Most cricket-related injuries are of overuse origin [10], and the presentation of pain severe enough to impact bowling might take weeks or even months to develop. Hence, there may be a reluctance for fast bowlers to seek medical attention at an early stage, and fast bowlers will often continue to bowl during this period with some degree of tolerable pain.[10] As most overuse-related conditions are associated with long-term anatomical changes, presentation of pain severe enough to impact bowling might have already undergone mild anatomical changes due to repetitive overuse.[26,38] Subjective collection of pain and/or injury data directly from cricketers regardless of time-loss and/or medical attention sought will provide a valuable information source about bowlers and may aid in better injury prediction and help design injury prevention programmes. Hence, this study aimed to conduct a 12-month self-reporting retrospective injury surveillance on NZ male first-class fast bowlers.

METHODS

Participants

The University of Canterbury's Human ethics committee approved the study (HEC 2016/74/LR-PS). The six cricket player associations in NZ and the New Zealand Cricket (NZC) approved and provided consent for the injury data collection. Participants in the study had to be at least 18 years of age. Participants for the study had to be specialist fast bowlers and should have been contracted to play first-class cricket during the year 2017-2018. Based on the inclusion criteria, the management of the six cricket player associations provided a list of 62 players who were contracted to play as specialist fast bowlers during the 2017-2018 cricket season.

Study Design

A total of 62 fast bowlers were invited to participate in the injury surveillance, and all the participants were informed of the study purpose; only after obtaining the participant's voluntary consent, they were allowed to partake in the injury surveillance. An electronic self-reporting injury surveillance system was created by the research team using Qualtrics, LLC USA, which enabled participants to record their injuries using their smartphones or devices. The injury surveillance design also allowed the participants to record, save and submit multiple injuries. The participants were informed to record their injuries even if medical attention was not sought.

Injury Survey Questions

A total of 35 questions were included in the survey. The survey questioned participants' anthropometry and identified the bowling arm. In the subsequent sections, participants were able to record their injury type, injured body part, injured side, provide an injury description and identify the activity at the onset of injury, the situation of injury and any medical diagnosis. The number of training and match days missed due to injuries was also recorded by the participants.

Injury Definitions

All injuries could be recorded as either an acute, overuse injury or recurrent injury and the participants were informed to record each injury separately based on the following definitions:

Acute injury: *An acute injury is any injury that occurred suddenly or accidentally. It may or may not have interrupted your training session or your match. It may or may not have resulted in a physiotherapist or doctor's care.* [17]
Overuse injury: *Overuse injury is any injury that has caused you pain or is causing you pain during bowling, batting, fielding or anytime during the match, training or during exercise workouts. This injury might not have any noticeable external cause of injury. This injury could have gradually caused worsening pain during or after bowling, in matches, training or exercise. The pain would have become worse when loading is continued or may stop you from exercising completely.* [17]
Recurrent injury: *A recurrent injury is an injury occurring on the same body side, and body part reported as the same injury earlier in the same season but which had recovered.* [17]

Data Analysis

Participants' data were analysed using Microsoft Excel descriptive statistical functions. All injuries were presented as descriptive data. All reported injuries were presented descriptively as injury percentages. The overall injury prevalence was calculated as the sum of injured fast bowlers divided by the sum of all fast bowlers multiplied by 100. Seasonal incidence was calculated as the number of injuries multiplied by 1,500 (for a squad of 25 players over 60 days), divided by the actual number of bowlers' days of exposure.[34]

Injury percentage per body area was calculated as the sum of injuries per body area divided by the total number of injuries multiplied by 100. The percentage of days missed due to injury per body area was calculated as the sum of days missed due to an injured body part divided by the total number of days missed due to all injured body parts multiplied by 100. Injury percentage per activity at the time of an acute injury onset was calculated as acute injuries per activity divided by the sum of all acute injuries multiplied by 100. The percentage of each medical diagnoses for the reported injuries was calculated as the sum of each injury diagnosis divided by the sum of all injury diagnoses by 100.

RESULTS

From the 62 cricketers surveyed, only 56% responded to the injury surveillance invitation. A total of 35 cricketers (weight, 87 ± 9 kgs; height, 1.86 ± 0.06 m; age 26 ± 4 years) took part in the injury surveillance study. There were a total of 29 right-handed and 6 left-handed bowlers. During the 12-month study period, 25 (71%) cricketers reported multiple injuries (giving 47 total injuries). In total, 32 (68%) injuries were identified as acute, with 15 (32%) recorded as overuse injuries. Among the 35 cricketers, 23 (66%) reported one acute injury, while 8 (23%) reported two acute injuries, and one cricketer experienced three acute injuries and we found an injury prevalence of 66%, with 25 cricketers recording at least one injury. Seasonal incidence by body area was calculated as the 47 reported injuries multiplied by 1,500 (for a squad of 25 players over 60 days), divided by the actual number of players days of exposure (1960 days). The overall seasonal injury incidence is shown in Table 1.

Table 1. Seasonal injury incidence by body area

Body area	Injury incidence
Lower back	6.9
Ankle/foot	5.4
Thigh	5.4
Shoulder	4.6
Hand	3.1
Hip	1.5
Knee	1.5
Abdomen	1.5
Side of trunk	1.5
Shin	1.5
Groin	0.8
Calf	0.8
Elbow	0.8
Neck	0.8
Total	35.0

The lower back injury (9) was reported as the most common injury, with 19% of all reported injuries occurring in this region. Injuries to the lower back caused the cricketers to miss a high number of playing days (691 days) during the playing season. Interestingly, the ankle/foot injuries caused cricketers to miss 358 days, a figure 3 times as high as the number of days missed due to thigh injuries (107 days). Despite the shoulder area experiencing the fourth-highest injury percentage of 13% (6 injuries), it only resulted in cricketers missing five playing days (0.2%), as shown in Table 2.

Table 2. Injury percentage and missed days by body area

Body area	Acute injuries n	(%)	Overuse injuries n	(%)	Total injuries n	(%)	Days missed	(%)
Lower back	5	11	4	9	9	19	691	30
Ankle/foot	6	13	1	2	7	15	358	15
Thigh	5	11	2	4	7	15	107	5
Shoulder	4	9	2	4	6	13	5	0.2
Hand	4	9	0	0	4	9	141	6
Hip	2	4	0	0	2	4	130	6
Knee	2	4	0	0	2	4	304	13
Abdomen	1	2	1	2	2	4	240	10
Side of trunk	1	2	1	2	2	4	64	3
Shin	0	0	2	4	2	4	130	6
Groin	1	2	0	0	1	2	21	0.9
Calf	1	2	0	0	1	2	3	0.1
Elbow	0	0	1	2	1	2	0	0
Neck	0	0	1	2	1	2	16	0.9
Total	32	68	15	32	47	100	2330	100

n = number of injuries

Of note, all reported shoulder injuries were on the player's dominant bowling/throwing shoulder. A total of 2330 days were missed by the 25 injured cricketers. Thirteen (41%) of the experienced acute injuries reoccurred in the same body area. Specifically, the lower back and ankle/foot had 3 (23%) reoccurring injuries, while both the shoulder and thigh 2 (15%) recurrent injuries as shown in Table 4. The hip, knee and wrist/hand each experienced one recurrent injury. The most common activity during the onset of an acute injury was bowling (16 injuries) followed by fielding (7 injuries), as shown in Table 3. Fifty-one percent of all acute injuries were experienced during matches, while only 17% were reported to occur during team training sessions. Bowling in matches and fielding during team training sessions jointly accounted for all four acute shoulder injuries.

Table 3. Activity during acute injury onset

Activity	n	(%)
Bowling	16	50
Fielding	7	22
Other activity	5	16
Batting	4	13
Total	32	100

n = number of injuries

Table 4. Recurrent injury incidence during the season

Body area	n	Seasonal injury incidence
Lower back	3	2.2
Ankle & Foot	3	2.2
Shoulder	2	1.5
Thigh	2	1.5
Hip	1	0.7
Knee	1	0.7
Wrist & Hand	1	0.7
Neck	0	0.0
Total	13	9.7

n = number of injuries

The most commonly injured tissues were related to muscle strain/tears/ inflammation, with 15 injuries (32%). This was followed by ten bone fractures (21%) and four ligament sprains/rupture/tears (9%). The five stress fractures of the lower back (11%) accounted for the highest percentage of injury diagnosis by specific body part, and this was equally followed by four hamstring strains (9%) and four rotator cuff pathology (9%), as shown in Table 5.

Table 5. Player reported medical diagnoses for the injuries

Injury diagnoses	n	(%)
Lower back stress fracture	5	11
Hamstring strain	4	9
Rotator cuff inflammation	4	9
Osteitis pubis	3	6
Ankle impingement	3	6
Lumbar disk prolapse	2	4
Metacarpal fracture	2	4
Subacromial impingement	2	4
Anterior cruciate ligament rupture	1	2
Medial collateral ligament injury	1	2
Tennis elbow	1	2
Cervical disc prolapse	1	2
Medial sesamoid ligament tear	1	2
Jones fracture	1	2
Achilles tendon strain	1	2
Quadriceps strain	1	2
Hip flexor strain	1	2
Hernia	1	2
Rib impingement	1	2
Shin stress fracture	1	2
Shin splints	1	2
Calf muscle tear	1	2
Groin muscle tear	1	2
Thigh muscle tear	1	2
Trunk side muscle strain	1	2
Hand web split	1	2
Unknown hand ligament tear	1	2
Unknown ankle fracture	1	2
Unknown lower back muscle soreness	1	2
Unknown lower back pain	1	2

n = number of injuries

DISCUSSION

Although injury surveillance of elite cricketers has been successfully implemented across most international cricketing boards, the last scientifically published injury surveillance report of NZ cricketers was more than a decade ago in 2008.[5] Our current study provides a detailed description of the injuries sustained during 12 months by an elite cohort of cricket fast bowlers in NZ. Despite having a 56% injury surveillance response rate, the obtained data offers a descriptive summary of the most injured body areas, the injury descriptions, injury percentage and diagnoses. That said, while players were encouraged to undertake the injury surveillance even if they had not experienced any injury, the likelihood that players who did experience injuries undertaking the injury surveillance may have been higher, which itself may have influenced the injury patterns observed in these results. In the current study, a high percentage of injuries occurred in the lower limb, lower back and shoulder, with the lower back experiencing the highest percentage of all sustained injuries, this finding is consistent with a recent review which highlights the high prevalence of lumbar spine injuries among fast bowlers.[35] Lower back injuries also caused the fast bowlers in the current study to miss more days in comparison to other body parts which is also reflective of a recent study where it was reported that lumbar injuries cost fast bowlers a mean time loss of 239±120 days per injury.[36] From the several aetiologies proposed for fast bowlers' lower back injuries, repeated lumbar rotation and lateral flexion during the delivery stride has been identified as a high-risk causative factor.[12] In the lower back area, the L4 and L5 vertebrae are susceptible to a higher injury rate, and this may be due to their anatomical proximity to the pelvis. During every bowling delivery, the L4 and L5 vertebrae are subjected to flexion, extension and rotation over the relatively stable pelvis.[13] This repeated lumbar vertebral movement over the pelvic joints may predispose the lumbar soft tissues to overuse injury. Also, during the front foot landing phase, the impact of the bowler's body weight and the high ground reaction forces encountered by the lumbar vertebrae might cause degenerative changes to it. In the current study, 4% of players reported lumbar disk prolapse, and 11% reported lower back stress fracture. Following a lumbar injury, a minimum recovery period of 90-120 days is recommended, with some athletes taking up to a whole year to recover.[18] As these lower back injuries present a chronic condition, taking longer recovery times might explain the high percentage of days missed by the fast bowlers in the current study.

In the current study's 15% of injuries occurred in the ankle/foot and this is similar to previous injury surveillance reports of Australian and NZ first-class cricketers.[5-7] In the current study, the cricketers reported 6% of injuries related to ankle impingement. While the exact impingement condition is not reported, posterior ankle impingement has been identified as a major cause of ankle pain among cricketers due to repeated landing on the back foot during the delivery stride.[19] Sesamoid ligament tear and fractures have also been reported, with ground hardness, repetitive impacts and increased bowling workload all identified as aetiologies for ankle injuries.[20] As fracture and impingement related pain could be easily aggravated due to impact while bowling, the cricketers might have taken more extended recovery periods, this may help to explain the 15% days missed (358 days) due to ankle/foot injuries.

Since 2006, an increase in thigh injuries has been consistently reported amongst international elite cricket cohorts.[15,39] In the current study, 15% of injuries occurred in the thigh and specifically, 9% of injuries were related to the hamstring. Since the year 2006, hamstring injury incidence has been reported to increase, especially after the prominence of T20 cricket.[15] In the current study (Table 4), cricketers experienced a seasonal injury incidence of 1.5 injuries on their thighs, and research reveals that there is a 3.7 times increased risk for thigh injuries among players with a previous history of a thigh injury.[4] Sudden spikes of bowling workloads amongst elite cricketers have been postulated to contribute to thigh injuries.[21] As the current study cohort consisted of elite cricketers, some of whom also played different cricket formats internationally, there is the possibility that injuries may be due to a sudden increase in bowling volume. Most reported thigh injuries are tendon related strains and, these soft-tissue injuries recover faster in comparison to hard tissue injuries leading to an earlier return to play.[22] This might explain the low percentage of days missed due to thigh injuries amongst the current study participants.

Shoulder injuries may occur due to acute or overuse causes. Acute shoulder injury onset can be either due to direct impacts with the ground while fielding or while running batting (diving when running between the wickets). While the cause for acute shoulder injury onset is mostly due to direct impact, in contrast, overuse related shoulder injury is more likely to be multifactorial. Overuse related shoulder pain is mostly associated with either repetitive throwing or bowling. Bowling and throwing workload spikes have been repeatedly identified as a risk factor for overuse shoulder injuries. [23]

Repetitive bowling and fielding-throwing might cause tightening of the posterior shoulder joint capsule while stretching its anterior aspect.[25] As glenohumeral rotation is elicited by the rotator cuff muscles, repetitive overload could weaken and strain the muscles. The weakening of the rotator cuff muscles strength could, in turn affect glenohumeral instability.[26] These adaptations can also be associated with humeral head translation, labral pathology and sub-acromial impingement.[27,38] In the current study, some of these overuse conditions were reported by the cricketers with shoulder injuries. The shoulder area injuries involved the rotator cuff muscles and subacromial space, as shown in Table 5. Shoulder injuries among other overhead throwing sports athletes have been associated with factors such as altered shoulder rotation range of motion, muscle strength ratio, posterior shoulder tightness, increased training workload and altered scapular kinematics.[28-30] Repeated internal rotation and shoulder circumduction with low rest periods have been proposed to cause structural adaptations to the shoulder joint.[31,38] Detrimental effects on the rotator cuff tendon and joint capsule due to higher training workload have also been proposed as possible shoulder pain aetiology. [32]

The repetitive glenohumeral rotation and circumduction movement executed by elite bowlers may also cause changes to the shoulder's soft tissues. While it is still unclear whether overuse related structural changes lead to an injury or vice versa, periodic shoulder screening may help associate the anatomical changes to shoulder injury incidence. Hence, regular assessment of shoulder range of motion, internal-external rotator muscle strength ratio, posterior shoulder tightness and scapula-humeral rhythm throughout the playing season will help monitor and potentially help to identify cricketers at risk of a chronic shoulder injury. In the current study although 13% of the injuries were related to the shoulder area only 5 days were missed due to shoulder injuries. Previous studies suggest that cricket-related shoulder pain occurs mainly due to overuse [10], and the presentation of shoulder pain severe enough to impact bowling might take weeks or even months to develop and some fast bowlers will often continue to bowl during this period with some degree of tolerable pain.[10] It might be that the rotation of bowlers and the rest that bowlers get between overs might ease the pain and help them continue the match. Also, as fast bowlers are traditionally placed in deep fielding positions there might be less demand on their shoulders and more time for their recovery between overs.[37]

The results of the current study could be influenced by the data collection method. The retrospective data collection method was implemented to collect data directly from the players with a new injury definition in which any experienced musculoskeletal pain could be reported as an injury and not just injuries that caused matches to be missed. However, we acknowledge that retrospective surveys may not accurately report injury prevalence as it relies on the participant's response and lacks the physician's verification. We acknowledge that retrospective injury surveillance methods could also have recall bias, where some injury information could have been lost due to failure to recall the injury event, and also the tendency to over-report the severity of the past injuries concerning the days missed due to an injury.[33] However, as the participants in the current study were professional cricketers who maintained training logs and have immediate access to their medical support team, they would be able to recall the injuries they experienced in the same season, so we believe the data collected may, therefore, contain a greater degree of accuracy and reliability.

The current study provides insight into the injury patterns of elite NZ cricket fast bowlers and their specific injury diagnoses. The study also highlights the acute and overuse-related injuries that fast bowlers experience and the time-loss due to those injuries. This evidence will be useful for future research aimed at exploring cricketers' injuries.

CONCLUSION

In the current study, we identified the lower back, thigh, ankle and shoulder as the most injury-prone body areas and lower back injuries account for the highest number of days missed due to injuries. Lower back stress fractures, hamstring strain and rotator cuff inflammation are the most commonly reported injury diagnoses among elite fast bowlers in NZ.

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ORIGINAL ARTICLE

Association between sport specialisation and injuries in high school students

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ABSTRACT

Objective

To investigate the associations between single sport specialisation and injury history in a group of high school students and to examine the differences in specialisation level and injury between those in high school sport and those in a performance-based sport academy.

Design

Cross-sectional survey study

Methods

High school students (age 12-16 years) from five NZ high schools and one performance-based academy were invited to complete a questionnaire capturing sport specialisation level (low, moderate, or high), sport participation volume, hours of free-play and injury history. Multiple logistic regression was used to investigate associations between specialisation level, participation volume, free-play, and injury history. Differences in specialisation and sport/free-play variables between the high school and academy groups were compared using Chi-square and Mann-Whitney U tests.

Results

One hundred and ninety-nine participants (136 female) completed the questionnaire. After adjusting for age, sex, hours of weekly sport and hours of free-play, the odds of reporting an injury were not significantly higher for specialised students compared to students categorised as low specialisation (OR = 2.1; CI = 0.7-6.0; p = 0.179). Participating in more hours of sport per week increased the odds of reporting a time-loss injury (OR = 1.1; CI = 1.0-1.2; p = 0.011). There was a significant association between playing one sport for more than eight months of the year and reporting a time-loss injury (OR=3.2; p=0.003). Involvement in a performance-based sport academy (n=33) had no association with specialisation level, however participants in the academy group reported higher total weekly sport volume (school group median = 4.5 hours, academy group median = 8 hours, p = 0.006) and were more likely to exceed a 2:1 ratio of weekly hours of organised sport to weekly hours of recreational free-play (OR = 6.8; CI = 2.9-16.0; p = 0.001).

Conclusion

Single-sport specialisation did not increase the odds of reporting a history of injury in this group of high school students and participation in a sports academy did not increase the chances of being highly specialised. However, increased organised sport participation volume was associated with increased odds of reporting a time-loss injury.

INTRODUCTION

It is well recognised that sport participation during adolescence has many benefits including improved quality of life, self-image, and social relationships.[1] Adolescent sport participants have been shown to be less likely to smoke and more likely to have better attendance and grades in school.[1] There is also evidence that active adolescents are much more likely to remain active into their adult years and exhibit a general decrease in morbidity and mortality, including improvements in bone mineral density, lipid profile, cardiovascular endurance, muscle strength and blood pressure.[1,2,3,4] However, involvement in sport also poses a risk of musculoskeletal injury and it is evident from the literature that acute and overuse injuries are a significant issue in active adolescents.[5,6,7,8] Additionally, twenty percent of adult elite athletes reported injury as a reason for retiring from their sport, and up to eight percent of adolescents dropped out of sport due to injury or fear of injury.[6] Importantly, the incidence of injury in adolescents appears to be increasing. An Australian study involving 5,671 children under 15 showed a 61% increase in sport-related injuries between 2003 and 2012 ([8]) and in Canada a study which involved 27,466 sport-related injuries indicated a 28% increase between 1992 and 2005.[7] In New Zealand, national insurance data from the Accident Compensation Corporation (ACC) showed a 60 percent increase in sports-related injuries in the 10-14 year age-group over the past decade.[9] These increases have been partly attributed to an increase in sport specialisation and the associated increases in training volume and intensity typically seen in adolescents.[6]

Sport specialisation has been commonly defined as year-round intensive training in a single sport at the exclusion of other sports.[10] The current trend toward earlier sports specialisation and year-round training has raised concerns that these factors may be increasing the risk for injury. Although evidence is conflicting there have been several recent studies that have reported increased injuries in more highly specialised youth athletes.[10-19] The potential link between sport specialisation and injury has been examined in young athletes aged 10-13 years in New Zealand.[20] This study found that there was a high degree of specialisation in this age group but demonstrated no significant association between specialisation and injury. The authors suggested that the lack of association may be related to the age of the participants, with the selected age group potentially being too young to exhibit the effects of early specialisation. This research highlighted the need for further research around sport specialisation and injury in NZ adolescents older than 13.

At the time in their lives when adolescents are developing and growing the most rapidly, it is important to have well informed guidelines around sport participation. To optimise injury prevention strategies, it is important to examine sport participation in two key settings. One setting was high school sport, where most active adolescents participate in sport and the other setting was a performance-based sports academy, a more recent phenomenon in adolescent sport and potentially a contributing factor to the high levels of sport specialisation seen in young athletes. Thus, the primary aim of this study was to examine the association between specialisation level and injury history and a secondary aim was to investigate if participation in a performance-based academy was associated with differences in specialisation and/or sport participation.

METHODS

Data was collected from five New Zealand high schools and one school age high-performance sport centre during the 2019 and 2020 school years. Schools were invited to participate based on a previous relationship with the local physiotherapy clinics in each area and all the invited schools agreed to participate in the study. Three of the schools included were privately funded and two were publicly funded. School size based on the number of enrolled students in 2019 ranged from 301 to 1,280 students. All schools were in the high decile range of 8-10 (measure of community socioeconomic status). The high-performance sport centre was based at a community fitness centre and was focused on providing a high-performance programme to developing school age athletes in a range of sports. Following agreement from the schools and sport academy, potential participants were recruited via an anonymous survey either filling in a paper copy or via an online survey system commonly used by the schools, using a weblink to access the survey via SurveyMonkey or Qualtrics. All students were provided with a study information sheet. To be included in the study, students needed to be in years 9-11 (age 12-16) at high school and actively participating in some type of organised sporting activity. Ethical approval was granted for this study by the AUT University Ethics Committee (AUTEC), under application number 19/122. All participants and their guardians provided assent/consent prior to participation.

QUESTIONNAIRE

Information was gathered about the school year level and gender of the participants. A questionnaire with 13 questions was used. This questionnaire was based on previous research by McGowan et al (2020) which examined specialisation and injury associations in NZ youth aged 10-13. Participants were asked to report on all organised sport they had participated in over the last 12 months, including the type of sport, the season in which it was played, and the hours of sport performed each day. Additionally, participants were asked to report on the hours of recreational free play (including unstructured and unsupervised physical activity) they participated in on average per week. Sport specialisation was determined using a previously used three-point scale (Jayanthi et al., 2015). The scale included the following questions: (1) Can you choose one main sport that is more important than the others? (2) Did you train/compete more than 8 months out of the year in one sport? (3) Have you only ever trained/competed in one sport? (4) Have you quit all other sports to focus on one main sport? One point was given to each affirmative answer and specialisation classified as low (score = 0-1), moderate (score = 2), or high (score = 3) (note: it is not possible to score a point for both questions 3 and 4, thus the maximum score is 3). Acceptable reliability of this scoring system (ICC=0.85) has been reported previously ([20]). Participants that were considered highly specialised on the three-point scale but reported participating in only 2 hours of sport or less per week (n=7) were re-allocated to the low specialisation group as the authors felt that participation in two hours of sport did not meet the commonly accepted definition of specialisation which includes intensive training.[10] Finally, participants were asked about their history of injuries over the last 12 months, including details on location and whether they were able to continue to participate in sport or needed time off. Injuries that caused the participant to take time off sport were classified as time-loss injuries.

STATISTICAL ANAYLSIS

Categorical variables including gender, school year, specialisation level and injuries were summarised using frequencies and proportions (%). Continuous variables including sport participation volume and free-play (hours) were summarised using medians and range or means and standard deviations. The main explanatory variables investigated included specialisation category (low, moderate, or high) and sport participation volume measures including hours per week and whether the participant exceeded a 2:1 ratio of weekly organised sport hours to weekly hours of recreational free play (recoded as a categorical variable "yes" or "no"). Additional variables, which were considered potential confounders based on previous studies[10,16,19] included school year and gender. These potential confounding variables were controlled for in the logistic regression. Multiple logistic regression (block entry method) was used to examine the association between specialisation category, sport participation volumes and history of injury, while adjusting for potential confounders. Separate analyses were conducted for the outcome variables time-loss injury and any injury.

Unadjusted and adjusted odds ratios (OR) with 95% confidence intervals (CI) were calculated. A Kruskal-Wallis test was used to compare sport volumes between specialisation levels. Chi-square for independence testing was used to compare categorical variables between the school and academy groups (including specialisation, exceeding a 2:1 ratio of weekly organised sport hours to weekly recreational free-play hours and playing one sport for more than 8 months of the year) whereas Mann-Whitney U testing was used to compare continuous variables such as weekly hours of organised sport and weekly hours of recreational free play.

Statistical significance was set a priori at $p \leq 0.05$. All analyses were performed using the Statistical Programme for Social Sciences (SPSS) (IBM SPSS, Chicago), version 25.

RESULTS

A total of 199 participants (136 female) completed the questionnaire and were included in the study (8% Year 9, 10% Year 10, 31% Year 11 and 52% Year 12). A total of 171 (86%) participants reported sustaining an injury in the past 12 months (time-loss n=139, other n=145). A total of 362 unique injuries were reported, of which 58% were to the lower limb, 25% the upper limb, 12% the torso and 5% the head or face. The most common injury sites included the ankle (n=62), knee (n=58) and hip/thigh (n=48). A total of 35 different sports were recorded across all participants, of which 21 were considered individual sports and 14 were considered team sports. The most popular sports included netball (n=65), football (n=61), tennis (n=49) and hockey (n=46). The number of sports played per participant ranged from one to six.

Using the three-point classification method, 70 (35%) of participants were classified as low specialisation, 94 (47%) moderate specialisation and 35 (18%) high specialisation. Based on univariate logistic regression participants in the high specialisation group were 3.2 times more likely to report a time-loss injury than those in the low specialisation group (p=0.002) (refer to Table 1). However, after adjusting for relevant confounding variables (including gender, school year, exceeding a 2:1 ratio of weekly organised sport hours to weekly recreational free-play hours and hours of weekly sport volume), there was no significant association between specialisation level and reporting a time-loss injury (refer to Table 1) or any injury (refer to Table 2).

The median weekly sport volume across all participants was 5 hours (range

Table 1: Association between specialisation level and history of time-loss injury

Specialisation Category	Unadjusted* OR (95% CI)	*p* Value	Adjusted**OR (95% CI)	*p* value
Low	-	**-**		-
Moderate	1.74 (0.90-3.37)	0.098	1.35 (0.67-2.71)	0.397
High	3.22 (1.19-8.77)	**0.022**	2.08 (0.72-6.03)	0.179

OR, odds ratio. p<0.05 is statistically significant (bold font). *Univariate logistic regression analysis. **Multiple logistic regression models adjusted for gender (categorical), school year level (categorical), exceeding a 2:1 ratio of weekly organised sport hours versus weekly recreational free play hours (categorical) and sport volume (hours per week). The reference group was the low specialisation group.

Table 2: Association between specialisation level and history of any injury

Specialisation Category	Unadjusted OR (95% CI)	*p* Value	Adjusted OR (95% CI)	*p* value
Low	-	-	-	-
Moderate	2.06 (0.88-4.81)	0.096	1.71 (0.70-4.13)	0.237
High	4.50 (0.967-20.93)	0.055	3.19 (0.64-15.89)	0.156

OR, odds ratio. p<0.05 is statistically significant (**bold fon**t). *Univariate logistic regression analysis. **Multiple logistic regression models adjusted for gender (categorical), school year level (categorical), exceeding a 2:1 ratio of weekly organised sport hours versus weekly recreational free play hours (categorical) and sport volume (hours per week). The reference group was the low specialisation group.

Table 3: Comparison of specialisation level and sport participation volumes between the performance-based academy group and the school group

	School group (n=166)	Academy group (n=33)	Odds Ratio (95% CI)	*p* Value
Low Specialisation	37.3%	24.2%	1.35 (1.24-1.46)	0.187
Moderate Specialisation	47.0%	48.5%	1.03 (-0.01-1.06)	0.319
High Specialisation	15.7%	27.3%	1.74 (1.59-1.88)	0.067
Exceeding 2:1 volume ratio	28.1%	72.7%	6.75 (2.92-15.60)	**0.001**
Plays one sport more than 8 months of the year?	64.7%	75.8%	1.68 (0.71-3.96)	0.302

$p<0.05$ is statistically significant (**bold font**).

0.5-29.5 hours), whereas the median weekly recreational free-play volume was 4 hours (range 0-25 hours). The low specialisation group reported significantly lower weekly sport volume than the moderate (difference 2.2 hours, p=0.003), and high (difference 3.8 hours, p=0.001) specialisation groups. The median volume in participants that reported a time-loss injury was 5.8 hours while the median in the non-injured group was 3.8 hours. The proportion of participants that exceeded a ratio of 2:1 weekly organised sport hours to weekly recreational free-play hours was 35.7%, however this individually did not have a significant association with injury (OR=0.8; *p*=0.674). The proportion of participants that exceeded the recommended maximum months (>8) per year in a single sport was 66.5%. There was a significant association between playing one sport for more than eight months of the year and reporting a time-loss injury (aOR=3.2 *p*=0.003). Additional regression analysis demonstrated a significant association between reporting a time-loss injury and weekly hours of sport volume (*p*=0.011). For every hour of additional sport volume, participants were 1.13 (95% CI: 1.03-1.24) times more likely to report a time-loss injury. There was no significant association between weekly hours of sport and reporting a history of any injury (time loss and non-time loss injuries combined) (*p*=0.075).

Although there was no statistically significant association between specialisation level and being involved in a high-performance academy, there was a trend for a higher proportion of highly specialised participants in the academy group (n=33) compared to the school group (n=166) (Table 3). However, participants from the sports academy were 6.8 times more likely to exceed a 2:1 ratio of weekly organised sport hours to weekly recreational free-play hours (*p*=0.001) (Table 3). Sport volume was also significantly higher in the sports academy group (median 8.0 hours) compared to the school group (median 4.5 hours) (*p*=0.006).

DISCUSSION

The primary aim of this research was to examine sport specialisation in high school students and its association with musculoskeletal injury. Being highly specialised in one sport did not significantly increase the likelihood of reporting a history of injury in this group of 12-16-year-old NZ adolescents. These findings are similar to previous research performed in NZ youth aged 10-13.[20] However, the results are contrary to previous research conducted overseas.[10-19] There are several possible explanations for this, one of which is that this study controlled for sport volume where other studies did not.[11,12,15,16,18] It is possible that specialisation pathways in high school sport are driving an increase in weekly sport volume. This increase in weekly hours of sport is often coupled with an increase in intensity, competition/training volume and repetition of similar movement patterns.[12] This combination of factors could in turn be what causes an increase in the risk of injury in adolescents.

This study supports the association between injury and increased sport volume that has been seen in previous research.[20,21] The results of this study indicated that for every hour of additional sport volume, participants were 1.13 times more likely to report a time-loss injury. This result highlights the need for sport volume guidelines in adolescent sport. One commonly used guideline recommends that children do not participate in the same sport for more than 8 months of the year.[10] Around two-thirds of the participants in this study participated in one sport for more than 8 months of the year, which is similar to findings in previous studies.[20,22] In keeping with previous literature, these adolescents had increased odds of reporting a time-loss injury.[10,18,20] Although playing one sport for more than 8 months of the year is a criterion used in the sport specialisation rating scale, it is obvious that many multi-sport athletes are still exposed to this volume based risk. This may be indicative of changing sporting habits of adolescents. Anecdotal evidence would suggest that most adolescents are not playing one sport in the winter season and then ceasing this sport to play another in the summer season. The sporting seasons appear to be longer than in the past, often with some cross-over where the athlete may be playing two or more different sports in the same week.

A second guideline on sport volume commonly reported is that youth should not exceed a 2:1 ratio of organised weekly sport to recreational 'free-play'. Free-play is thought to provide some protective effects by providing variety in movement patterns and reducing the likelihood of gradual onset injuries. Recent research indicates that recreational free-play in NZ youth is declining.[23] This reduction in free play has been suggested to be due to an increase in organised sport causing a lack of free time. However, in this study, exploratory analysis found that there were no significant differences in weekly volume of recreational free-play between any of the specialisation groups. Previous research has found a significant association between exceeding the recommended 2:1 ratio and sustaining a gradual-onset or overuse injury.[10,20] In contrast, although this study found that close to a third of the participants exceeded this threshold, it did not increase the likelihood of them reporting an injury. The results of this study may have varied from previous research as we did not separate injuries into 'acute' or 'gradual-onset'. It is difficult to see a strong rationale for how 'free-play' may have any significant protective effects in reducing acute injuries other than the potential for increased total activity improving physical condition and this being protective.

The second aim of this study was to examine the differences in specialisation level and sport participation volume between high school sport and performance-based academy sport. To our knowledge this is the first study performed in NZ that compares these two groups and the first investigating specialisation and injury in the performance academy environment. The results of this study indicate that although there was no statistically significant association between specialisation level and being involved in a performance-based academy, there was an observed trend for a higher proportion of highly specialised adolescents in the academy group. Furthermore, adolescents involved in an academy were more likely to participate in higher sport volumes and were 6.8 times more likely to exceed the recommended 2:1 ratio of weekly organised sport hours to weekly free-play hours. However, these results may have been affected by a high variation in size of the study groups (33 participants in the academy group versus 167 in the school group). That said, these findings provide preliminary evidence that performance-based academies do alter the sport participation volume of adolescent athletes, and this is worthy of further research.

We acknowledge this study had limitations. The first was related to the methodology used in the research where a cross-sectional study design was used and participants were asked to recall retrospective events. This allowed examination of associations between variables, but we were unable to determine causation. With this type of study there was likely an element of recall bias involved. To reduce this, a survey that had been designed for younger participants was used and an information sheet was provided for the participant to read before commencing the survey. Due to ethical considerations, the survey was made completely anonymous, which meant that we were unable to collect potentially useful information such as date of birth to calculate exact chronological age and we were also unable to contact the participant following the survey to verify information given about injuries they sustained over the past 12 months. This meant we were unable to accurately determine if these injuries were acute or gradual-onset. Furthermore, due to ease of access, this research was performed in only two regions in NZ (Hawke's Bay and Kapiti) and the schools that were involved were all high decile, suggesting that these areas tended to be of higher socio-economic status. This, along with the small sample size, means that generalising these findings to the wider population should be done with caution. Furthermore, although we were aware that maturation is a likely factor that has the potential to affect injury risk, we did not measure this during data collection. Prospective, longitudinal studies following adolescents through high school are needed to better understand the risk of injury in adolescents from sport specialisation.

CONCLUSION

In this group of 12-16-year-old NZ high school students there was no significant association between specialisation in a single sport and reporting a history of injury. However, we did find that increased weekly sport volume increased the likelihood of reporting a time-loss injury. In addition, involvement in a performance-based academy was associated with increased sport volumes and decreased recreational free-play. This study provided an exploratory look into the sport engagements of adolescents in a performance-based academy setting and could be used to inform sport guideline for active adolescents. However, larger scale research is needed to better examine this recent phenomenon in the adolescent sport environment.

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ORIGINAL ARTICLE

Match participation and movement demands in amateur domestic women's rugby union in New Zealand

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ABSTRACT

Objective

To describe the movement analysis and heart rate data of amateur domestic women's rugby union match activities.

Design

Prospective cohort study.

Methods

Data were collected from 69 amateur female club level rugby union players over two consecutive seasons, using heart rate and microtechnology devices. Total distance, maximum velocity, Player Load ([PL] accumulated accelerometer-derived load), and individual PL vectors (PL forward [PL_F], PL sideward [PL_S] and PL vertical (PL_V]), speed zones and heart rate variables were examined. Analysis by player position, player group, matches won and lost, and years of competition were conducted.

Results

Inside Backs recorded a significantly higher mean distance (3920.4 ±1,437.3 m) per-match than Front-Row-Forwards ($\chi^2_{(1)}$=12.6; *p*=0.0004 Friedman repeated measures ANOVA on ranks; *z*=-4.1; *p*<0.0001 Wilcoxon signed-rank post-hoc test; *d*=0.55 Cohen's effect size) and Outside-Backs ($\chi^2_{(1)}$=27.3; *p*<0.0001; *z*=-5.3; *p*<0.0001; *d*=0.36). As a result, backs recorded a significantly higher mean distance per-match (3,692.3 ±1,440.5 m) than forwards ($\chi^2_{(1)}$=4.9; *p*=0.0273; *z*=-2.5; *p*=0.0132; *d*=0.36). Players recorded a significantly higher max HR in 2018 per-match (192.6 ±34.7 $b{\cdot}min^{-1}$) compared with 2019 ($\chi^2_{(1)}$=9.1; *p*=0.0025; *z*=-2.6; *p*=0.0087; *d*=0.20).

Conclusions

The results of this study suggest that the physical and physiological profiles of the playing positional groups at the amateur, domestic club level of women's rugby union were similar (but not the mean distance covered) and may be suggestive of generalised, rather than specialised, training regimes that fail to prepare players for higher levels of competition. Amateur women's rugby union may benefit from the incorporation of positional specific training that would provide forward playing positions with the opportunity to develop collision and contact abilities, while concurrently allowing backs a greater opportunity to train their high intensity running capacity.

INTRODUCTION

Rugby union is an intermittent contact invasion game, involving periods of high-intensity activity (i.e. running, collisions, scrummaging) interspersed with lower-intensity activities including periods of rest.[29] The incorporation of microtechnology (Global Positioning System [GPS] and integrated tri-axial accelerometer) devices has enabled researchers and practitioners to quantify the workloads experienced within team sports such as rugby union.[15, 29] Furthermore, the use of microtechnology has been reported to be a reliable indicator of the physical demands of team sports.[15] The knowledge attained from the incorporation of GPS microtechnology enables specialist coaching staff to monitor detailed sport-specific data and positional specific movement profiles.[15, 29] This is deemed to be invaluable[20] to coaching staff assisting with the facilitation of optimal player training programmes and therefore, match-play preparation.[9]

The physiological demands of male rugby union players have been reported at the international,[34] professional[9] and amateur[29] levels of participation. These studies have reported that the total mean distances vary per-match from 3,698 m[28] to 6,130 m[4] and that the majority of the game (83 to 86% of the total distance) is played at low intensity.[9, 28] Total match-play distance is however, dependent upon playing position, with back playing positions (e.g. halfback, stand-off, centres, wings and fullbacks) (7,227 m) covering more distance than forward playing positions (6,680 m).[16] Positional differences are also reported to exist in relation to the intensity of match-play, with back playing positions covering a greater relative distance than forward playing positions (71.9 versus 66.7 $m \cdot min^{-1}$, respectively).[16]

Contradictory literature has, however, been published stating that back playing positions covered slightly less high-speed distances (323 m vs 369 m) compared with the forward playing positions.[9] In addition to playing position, athletic calibre and age have been reported to impact on the distance covered throughout match-play with elite senior,[9] male amateur,[29] and junior[24] rugby union forwards covering 5,850 m, 4,260 m and 3,511 m, respectively.

Despite the ever increasing body of knowledge on male participation in rugby union, there is a paucity of published studies reporting on the physical and physiological demands of women's 15-a-side rugby union.[6, 8, 42, 43] The match demands of women's rugby union have utilised video data collection,[43] and GPS sampling rates at 5 Hz[42] and 10 Hz[6, 8] to obtain the data for respective studies. These studies[6, 8, 42] have reported a mean total distance per-match from 4,982 m[6] to 5,820 m,[42] with forwards covering a mean distance of 5,049 m[6] to 5,616 m[8] per-match, while backs covered a mean distance of 4,908 m[6] to 6,471 m[42] per-match. Of note, the study by Virr et al.[43] had limited numbers, with only four premier division club level players analysed per-match using video analysis and heart-rate monitors. The study by Suárez-Arrones et al.[42] utilised a 5 Hz GPS device on eight players during a single women's national rugby union match which may not be reflective of the demands occurring within the women's game or across a competition season. Only two studies[6, 8] utilised a GPS system at a greater sampling rate (10 Hz) in an effort to increase the validity and reliability of the data obtained.[40]

Although the movement demands of women's rugby union have started to be explained, these studies have been undertaken at either premier[6] or elite[8, 42] level of competitions. More recently, one study[8] reported the running demands of women's rugby union in New Zealand, covering seven matches of a provincial team, over one competition. As such, there is a paucity of studies reporting the physical and physiological demands at the amateur domestic level of women's rugby union. Therefore, the aim of this study was to quantify the match participation movement demands and physiological responses of senior amateur rugby union players by player roles and player positional groups over two consecutive seasons of domestic competition matches within New Zealand.

METHODS

A prospective cohort descriptive study was undertaken to record the movement demands and physiological responses of 69 (age: 26.5 ±7.4 years [range: 17.6 to 48.5 years]; Height: 1.67 m ±0.08m [range 1.50-1.80 m]; mass 87.1 kg ±18.9 [range 50-127 kgs] years playing experience 4.3 ±4.2 years [range 0-18 years]) amateur women 15-a-side rugby union players, in New Zealand, from the same team over two consecutive years participating in a domestic club level competition. A total of 34 players participated in the first season and 35 players competed in the second season. A total of 22 players participated in both competition seasons. All players were considered amateur, as they received no remuneration for participating in rugby union activities and derived their main source of income from other employment activities. Players competed in a single level competition where all teams (the number varied each year) played each other once before the top five were identified for a second-round top five and bottom six competition format. There were a total of 28 matches played under the rules and regulations of New Zealand Rugby, with matches comprising of two 40-minute halves, with a resulting match exposure of 558.6 match exposure hrs. Players were categorised according to their (1) playing group and (2) positional group.[9] These two groups were: (1a) Forwards (loose-head prop, hooker, tight-head prop, left lock, right lock, blind-side flanker, open-side flanker, and number eight) and (1b) Backs (halfback, first-five, left wing, second-five, centre, right wing, and full back); and (2a) Front-Row Forwards (loose-head prop, tight-head prop; left lock, right lock); (2b) Back-Row Forwards (hooker; blind-side flanker, open-side flanker, number eight); (2c) In-Side Backs (halfback; first-five, second-five, centre) and (2d) Out-Side Backs (left wing, right wing, full back). The hooker was included in the Back Row Forward's due to their roving style of play.[18] This would most accurately reflect the positions with similar match demands and enable comparisons to be undertaken. Utilising GPS and HR monitors, the players were measured during competition matches over the 2018 and 2019 competition seasons. Prior to the competition commencing, all players provided written consent to participate in the research and all procedures were approved by the institutional ethics committee prior to data collection.

Equipment and Procedures

Players heart rates (HR) were continuously monitored during match participation using a portable monitor (Team Heart Rate System, Polar, Kempele, Finland). Player movements were monitored using microtechnology devices (OptimEye S5 device; Catapult Innovations, Melbourne, Australia), worn in a custom designed pocket, within a vest supplied by the device manufacturer, between the shoulder blades. The devices produced a 10 Hz GPS sampling rate through the in-built GPS-chip. Additionally, the devices contained a tri-axial accelerometer, gyroscope, and magnetometer sampling at 100 Hz (firmware v.5.27). As such, the device could continuously monitor linear and rotational accelerations, direction, and orientation of the player during match-play. Post-match data were downloaded and trimmed (to include on-field match-play time only) using proprietary software (Openfield, Catapult Innovations, Melbourne, Australia). The use of GPS technology has been utilised for research in several sporting codes including soccer, rugby league, Australian football league[15] and rugby union[29, 34] and has been reported to be acceptable[35] and ecologically[22] valid when assessing contact-based team sports. The OptimEye S5 has been previously reported to have valid and reliable distance and speed measurements, with very high correlation (r=0.94) for distance covered and acceptable within- and between-device reliability for measuring acceleration forces.[2, 3]

Mean and peak HR for each match were calculated for each player. During each match, the following time and GPS-based variables were analysed: match time (min), total distance (m) and maximum velocity (Vel_{Max} in m.s^{-1}). Additionally, accumulated accelerometer-derived loads (arbitrary unit known as PlayerLoad (PL)) were calculated by the sum of accelerations in the mediolateral [x], anteroposterior [y] and vertical [z] directions to provide a measure of the total stress upon an athlete as a result of accelerations, decelerations, changes of direction and impacts.[3] The frequency, duration, and distance of locomotive activities were also obtained in six speed bands, as have been previously reported.[29]

Player Load (PL) is expressed as the square root of the sum of the squared instantaneous rate of change in each of the three vectors. The application of this variable as a marker of training load has been established against both internal[10] and external load[41] measures. PL has been shown to be reliable both between (1.02% Coefficient of Variation (CV)) and within devices (1.05% CV) for dynamic movements.[17] Further, within a team sport circuit, the reliability of PL was reported as having a CV of 4.9%. Additionally, PL demonstrates high inter-unit reliability within Australian Rules Football (1.94% CV).[17] There is a strong relationship between PL and total distance[5] and as such, the vertical vector of the PL equation can be removed, thereby providing a measure of acceleration in the medio-lateral and anterior-posterior planes only (Player Load Two-Dimensional (PL2D)).[27] Such 2D measures have recently been shown [31] to be more sensitive to collision load within contact based team sports such as rugby league. To report only low-speed activities (<2 m·s^{-1}) the PL_{SLOW} was recorded. The PL_{SLOW} is accumulated through accelerations that are recorded in the three vectors of movement and is a proxy measure for the frequency and magnitude of low-speed exertions in rugby union (e.g., rucking and scrummaging)[37] that GPS or video analysis are unable to provide. The PL_{SLOW} is related (r^2=0.62) to collisions that occur during rugby union match-play.[39] The PL and 2DPL were recorded as well as the PL in each of the individual axes i.e. PL forward (PL_F), PL sideward (PL_S) and PL vertical (PL_V). Each PL variable were normalised for all match times (minutes) and reported in arbitrary units (au·min^{-1}).

Statistical Analyses

All data were downloaded onto a Microsoft Excel spreadsheet and analysed with SPSS (IBM SPSS Statistics for Windows, Version 26.0.0 Armonk, NY: IBM Corp). Data were checked for normality and homogeneity of variance using a Shapiro-Wilk's test of normality. If tolerances were not met, equivalent non-parametric tests were utilised. Physical demands (i.e., PL, PL2D, PL_F, PL_S, PL_V, PL_{Slow}, Vel_{Max}) among player positions, and years of competition were compared using a 1-way analysis of variance (ANOVA) with a Tukey post-hoc test to determine the source of differences. Non-parametric data (Match duration, Distance, Relative Distance, HR_{Max} and HR_{Mean}, speed zones) were analysed with a Friedman repeated measures ANOVA on ranks. If notable differences were observed, a Wilcoxon signed-rank post-hoc test was conducted with a Bonferroni correction applied. A t-test was utilised to assess differences in player age. Cohen's effect size (d) were utilised to calculate practically meaningful differences between playing positions and for different levels of participation. Effect sizes of <0.19, 0.20-0.60, 0.61-1.20 and >1.20 were considered trivial, small, moderate, and large, respectively.[26] The level of significance was set at $p \leq 0.05$, and all data are expressed as means and standard deviations.

RESULTS

Players in the 2019 cohort were significantly older than the 2018 cohort (28.9 ±8.0 yr. vs. 24.2 ±6.0; $t_{(17)}$=-2.4; p=0.0289; d=0.66) (see Table 1). Players were involved in a total of 28 matches for an exposure of 558.6 match hrs. Although 2018 recorded a higher mean distance per-match (3,604.2 ±1,365.6 m), compared with 2019 (3,463.1 ±1,273.0 m; $\chi^2_{(1)}$=2.6; p=0.1088; z=-1.2; p=0.2355; d=0.11) this difference was not significant. There was a statistically significant difference that players recorded a higher Vel_{Max} in 2019 when compared with 2018 (5.78 ±1.02 vs. 5.77 ±1.27 m·s^{-1}; $F_{(139,84)}$2.04; p=0.002; d=0.01). Players recorded a significantly higher max HR in 2018 per-match (192.6 ±34.7 beats-per-minute) compared with 2019 (185.6 ±34.4 beats-per-minute; $\chi^2_{(1)}$=9.1; p=0.0025; z=-2.6; p=0.0087; d=0.20). Players recorded a significantly higher mean distance in the 1.2 to 2.5 m·s^{-1} velocity band in 2018 when compared with 2019 ($\chi^2_{(1)}$=4.0; p=0.0450; z=-2.4; p=0.0160; d=0.18).

Table 1: Summary of movement analysis and heart rate data for domestic amateur women's rugby union players in New Zealand by participation year and combined seasons of competition matches reported in distances and arbitrary units by means with standard deviation.

	2018	2019	Total
Players (n=)	34	35	69
Age (yr.)	24.2 ±6.0^{b}	28.9 ±8.0^{a}	26.5 ±7.4
Games (n=)	12	16	28
Match exposure (hr.)	239.4	319.2	558.6
Match time per player (min)	56.1 ±25.8	57.8 ±24.2	56.8 ±25.2
Match demands			
Distance (m)	3,604.2 ±1,365.6	3,463.1 ±1,273.0	3,546.6 ±1,329.2
Distance (m·min^{-1})	91.5 ±73.5	76.5 ±52.9	85.4 ±66.3
PL (au·min^{-1})	3.8 ±1.3	3.9 ±1.4	3.9 ±1.4
PL2D (au·min^{-1})	2.9 ±1.1	2.8 ±1.0	2.9 ±1.1
PL_F (au·min^{-1})	1.8 ±0.7	1.7 ±0.6	1.8 ±0.7
PL_S (au·min^{-1})	1.9 ±0.7	1.9 ±0.7	1.9 ±0.7
PL_V (au·min^{-1})	3.0 ±1.1	2.9 ±1.1	2.9 ±1.1
PLSlow (au·min^{-1})	2.7 ±0.8	2.6 ±0.8	2.6 ±0.8
Vel_{Max} (m.s^{-1})	5.8 ±1.3^{b}	5.8 ±1.0^{a}	5.8 ±1.2
Max HR (b·min^{-1})	192.6 ±34.7^{b}	185.6 ±34.4^{a}	189.5 ±34.8
Mean HR (b·min^{-1})	149.2 ±22.4	147.5 ±26.7	148.5 ±24.4
Running profile			
Band 1: 0.0 to 1.5 (m·s^{-1})	2,004.3 ±635.1	1,924.6 ±595.5	1,971.8 ±620.0
Band 2: 1.5 to 2.5 (m·s^{-1})	711.5 ±320.9^{b}	654.6 ±295.5^{a}	688.3 ±311.8
Band 3: 2.5 to 3.5 (m·s^{-1})	557.1 ±310.7	516.6 ±268.2	540.6 ±294.5
Band 4: 3.5 to 6.0 (m·s^{-1})	323.0 ±273.8	347.6 ±305.3	333.0 ±287.0
Band 5: 6.0 to 7.0 (m·s^{-1})	17.2 ±32.5	17.4 ±32.9	17.3 ±32.7
Band 6: 7.0 to 8.0 (m·s^{-1})	1.5 ±6.9	2.1 ±6.8	1.8 ±6.9

SD = standard deviation; min = minutes; m = metres; au·min^{-1} = arbitrary units per minute; PL = PlayerLoad; PL2D = PlayerLoad 2-dimension (frontal & sagittal); PL_F = player load in frontal plane; PL_S = PlayerLoad in sagittal plane; PL_V = PlayerLoad in transverse plane; PL_{SLOW} = Player Load <2 m·s^{-1} (metres per second); Vel_{Max} (m·s^{-1}) = Maximum Velocity (metres per second); HR = Heart rate; b·min^{-1} = beats-per-minute; Significantly different (p<0.05) than (a) = 2018; (b) = 2019.

Table 2: Summary of movement analysis and heart rate data for domestic amateur women's rugby union players in New Zealand for the 2018, 2019 and combined seasons of competition matches for player groups and player roles reported in distances and arbitrary units by means with standard deviation.

	Front-Row Forwards	Back-Row Forwards	Forwards	In-Side Backs	Out-Side Backs	Backs
Players (n=)	24	16	40	20	9	29
Age (yr.)	29.4 ±9.0^{c}	27.5 ±6.5^{c}	28.6 ±8.1^{f}	23.0 ±4.5^{ab}	24.0 ±5.7	23.3 ±4.8^{e}
Games (n=)	28	28	28	28	28	28
Match exposure (hr.)	154.3	154.3	308.6	154.3	115.7	270.0
Match time per player (min)	57.9 ±24.3	57.3 ±25.0	57.6 ±24.6	55.5 ±25.8	56.3 ±25.8	55.9 ±25.8
Match Demands						
Distance (m)	3,189.2 ±1,195.7^{bc}	3,669.2 ±1,161.1^{a}	3,409.7 ±1,201.9^{f}	3,920.4 ±1,437.3^{ad}	3,410.5 ±1,399.5^{c}	3,692.3 ±1,440.5^{e}
Distance (m·min^{-1})	76.2 ±62.1^{c}	88.4 ±66.2	81.8 ±64.1	93.4 ±68.3^{a}	83.9 ±68.4	89.1 ±68.4
PL (au·min^{-1})	3.6 ±1.3^{c}	4.1 ±1.3	3.8 ±1.3	4.2 ±1.5^{a}	3.5 ±1.3	3.9 ±1.4
PL2D (au·min^{-1})	2.7 ±1.0	3.1 ±1.0^{c}	2.9 ±1.0	3.1 ±1.1^{b}	2.5 ±0.9	2.9 ±1.1
PL_F (au·min^{-1})	1.7 ±0.6^{d}	1.9 ±0.7	1.8 ±0.7	1.9 ±0.7	1.6 ±0.6^{a}	1.7 ±0.7
PL_S (au·min^{-1})	1.8 ±0.7	2.1 ±0.6^{c}	1.9 ±0.7	2.1 ±0.8^{b}	1.7 ±0.6	1.9 ±0.7
PL_V (au·min^{-1})	2.7 ±0.9	3.1 ±1.0^{c}	2.9 ±1.0	3.2 ±1.2^{b}	2.7 ±1.0	3.0 ±1.2
PLSlow (au·min^{-1})	2.7 ±0.9^{d}	2.8 ±0.7^{cd}	2.7 ±0.8	2.7 ±0.8^{b}	2.3 ±0.7^{ab}	2.5 ±0.7
Vel_{Max} (m.s^{-1})	5.2 ±0.9	5.5 ±0.8	5.3 ±0.8	6.2 ±1.0	6.3 ±1.6	6.2 ±1.3
Max HR (b·min^{-1})	191.1 ±38.1	190.1 ±29.5	190.6 ±34.3	188.5 ±39.1	188.3 ±29.8	188.4 ±35.3
Mean HR (b·min^{-1})	148.9 ±27.1	151.1 ±22.7	149.9 ±25.1	145.5 ±26.6	148.7 ±18.7	146.9 ±23.5
Running Profile						
Band 1: 0.0 to 1.5 (m·s^{-1})	1,867.4 ±621.4^{c}	2,042.2 ±518.5	1,947.7 ±582.0	2,095.9 ±635.9^{ad}	1,875.8 ±667.3^{c}	1,997.4 ±658.1
Band 2: 1.5 to 2.5 (m·s^{-1})	678.4 ±314.8^{b}	741.2 ±300.3^{a}	707.3 ±309.3	718.7 ±311.5^{d}	605.7 ±306.5^{c}	668.1 ±313.7
Band 3: 2.5 to 3.5 (m·s^{-1})	470.1 ±259.1^{b}	602.6 ±294.7^{ac}	530.9 ±309.3	610.4 ±319.9^{bd}	477.4 ±272.2^{c}	550.9 ±306.2
Band 4: 3.5 to 6.0 (m·s^{-1})	189.2 ±166.9^{bcd}	277.8 ±212.2^{acd}	229.9 ±193.8^{f}	466.2 ±357.7^{abd}	413.6 ±283.4^{abc}	442.7 ±327.0^{e}
Band 5: 6.0 to 7.0 (m·s^{-1})	6.0 ±17.7^{cd}	5.0 ±14.6^{cd}	5.5 ±16.3^{f}	26.6 ±38.9^{ab}	33.7 ±41.7^{ab}	29.8 ±40.3^{e}
Band 6: 7.0 to 8.0 (m·s^{-1})	0.8 ±3.9^{cd}	0.1 ±1.2^{cd}	0.5 ±0.3^{f}	2.3 ±7.7^{ab}	4.2 ±10.8^{ab}	3.1 ±9.2^{e}

SD = standard deviation; min = minutes; m = metres; au·min^{-1} = arbitrary units per minute; PL = PlayerLoad; PL2D = PlayerLoad 2-dimension (frontal & sagittal); PL_F = player load in frontal plane; PL_S = PlayerLoad in sagittal plane; PL_V = PlayerLoad in transverse plane; PL_{SLOW} = Player Load <2 m·s^{-1} (metres per second); Vel_{Max} (ms) = Maximum Velocity (metres per second); HR = Heart rate; b·min^{-1} = beats per minute; Significantly different (p<0.05) than (a) = Front-Row Forwards; (b) = Back-Row Forwards; (c) = Inside Backs; (d) = Outside Backs; (e) = Forwards; (f) = Backs .

Front Row Forwards were significantly older (29.4 ±9.0 yrs.) than Inside Backs (23.0 ±4.5 yrs. $t_{(19)}$=3.2; p=0.0049) (see Table 2). As a result, forwards were significantly older than backs (28.6 ±8.1 vs. 23.3 ±4.5 yrs.; $t_{(29)}$=3.9; p=0.0005). Inside Backs recorded a significantly higher mean distance (3920.4 ±1,437.3 m) per-match than Front Row Forwards (3,189.2 ±1,195.7 m; $\chi^2_{(1)}$=12.6; p=0.0004; z=-4.1; p<0.0001; d=0.55) and Outside Backs (3,410.5 ±1,399.5 m; $\chi^2_{(1)}$=27.3; p<0.0001; z=-5.3; p<0.0001; d=0.36). As a result, Backs recorded a significantly higher mean distance per-match (3,692.3 ±1,440.5 m) than forwards (3,409.7 ±1,201.9 m; $\chi^2_{(1)}$=4.9; p=0.0273; z=-2.5; p=0.0132; d=0.36).

The Outside Backs recorded a significantly lower mean PL_{Slow} (2.3 ±0.7 au.min^{-1}) compared to Front Row Forwards ($F_{(112,6)}$=5.2; p=0.0211; d=0.50) and Back Row Forwards (2.7 ±0.9 au.min^{-}1; $F_{(112,6)}$=8.2; p=0.0064; d=0.71) (see Table 6). The Inside Back's recorded a significantly mean higher distance in the 0.0 to 1.5 m·s^{-1} (2,095.9 ±635.9 m·s^{-1}) than Front Row Forwards (1,867.4 ±621.4 m·s^{-1}; $\chi^2_{(1)}$=5.7; p=0.0168; z=-2.8; p=0.0047; d=0.36) and Outside Backs (1,875.8 ±667.3 m·s^{-1}; $\chi^2_{(1)}$=19.5; p<0.0001; z=-4.7; p<0.0001; d=0.34). Forwards recorded a significantly lower mean distance per-match in the 3.5 to 6.0 m·s^{-1} (229.9 ±193.8 m·s^{-1}) velocity band than Backs (442.7 ±327.0 m·s^{-1}; $\chi^2_{(1)}$=36.1; p<0.0001; z=-7.9; p<0.0001; d=0.72).

DISCUSSION

This prospective study undertook to document the physical demands occurring in an amateur women's club rugby union team during match participation over two consecutive seasons. The results identified the physical and physiological profile of individual positional groups in amateur women's rugby union throughout match participation. Given the paucity of the availability of both GPS- and accelerometer-based variables in amateur women's rugby union, this study highlighted the importance of integrating microtechnology into the routine monitoring of amateur women's sports such as rugby union.

The reporting of total distance covered per-match in the current study revealed differences between the playing groups, but provides little comparison with other sporting studies.[15] However, by reporting the mean relative distance (m·min^{-1}) per-match, this provides a more accurate reflection of the intensity of the workload the player's undertake during the activity.[15] For example, by comparing the total distances in women's football (3,977 m to 9,997 m; mean: 7,797 ±1,976 m), women's hockey (5,541 to 6,154 m; mean: 5,824.5 ±329.5 m)[25] and other studies in women's rugby union (4,982 to 5,820 m, mean: 5,576.5 ±398.5 m),[6, 8, 42] it can be seen that the mean distance per-match in the current study was much lower by 40% (rugby) to 55% (football) of the total distances recorded. However, this does not account for the match duration. When comparing the relative distances in women's football (79.3 to 118.0 m·min^{-1}: mean 101.0 ±11.9 m·min^{-1}), hockey (79.0 to 115.0 m·min^{-1}: mean: 98.5 ±15.6 m·min^{-1})[25] and rugby (54.8 to 68.0 m·min^{-1}; mean: 61.4 ±9.3 m·min^{-1}),[6, 8, 42] the relative distance per-match in the current study was less (38.3 ±13.7 m·min^{-1}) by 38% (rugby) to 62% (football) of the relative distances covered per match. The differences between the current cohort and other studies indicated that the total and relative distances covered at the amateur club level were much lower and may be attributed to a difference in player fitness, playing style, match intensity, and player preparedness at the higher levels of participation.[28] Other aspects that should be considered are characteristics of the different sporting activities, number of physical contacts/impacts, body composition of participants, field size, player numbers, match duration and substitution rules.

Throughout the matches, the back-playing positions travelled greater total distances, including distances above 6.0 m·s^{-1} and accumulated PL and PL_V values, compared with the forward playing positions. This finding was not surprising, given the vertical component of running as this accelerometer-based metric accounts for between 50% to 60% of the overall three-dimensional load.[3] Interestingly, back playing positions accumulated a similar mean PL2D throughout match-play. This finding was highlighted in a previous study where players with a similar PL2D were likely to undertake comparable collisions and tackles.[14] A possible suggestion for this finding is that backs have both short bursts of changes in direction and are more often being tackled in open space. Conversely, the PL and PL_V for forwards is comprised predominantly of collision and tackle events in confined spaces, such as rucks and mauls, at a lower velocity. Although there were some subtle differences for a number of metrics (PL, PL_V and PL2D), the variance between positions was somewhat trivial from a practical perspective, suggesting that minimal differences were apparent in the physical demands of match-play at this level of competition. Further, such findings highlight the importance of incorporating a variety of external load metrics into the routine monitoring of collision-based sports such as women's rugby union, in order to adequately quantify the workload across different playing positions.

Although differences were noted between positional groups in regard to PL_{Slow}, from a practical perspective it appears that both forward and back playing positions accumulate similar loads from low velocity activities, such as physical collisions and tackles. This was contrary to previous work reporting that forwards attained greater PL_{Slow} than their back playing counterparts.[36] Such discrepancies may, however, be attributed to altered physical capacities and game play strategies between the examined cohorts.

The use of heart rate monitors have been previously utilised as an indicator for determining the physiological demands of the players[13] and can be a useful index of the overall physiological strain and quantification of the total work performed during match activities.[13] Although heart rate may be an effective way to measure the intensity of activities,[21] other factors may also influence the heart rate of players, such as the level of fatigue the player is experiencing. The maximum heart rates reported in this study may be an indication of the fatigue the players experienced during match participation and further studies may consider a fatigue monitoring scale to be incorporated into the study parameters.

The results of this study suggested that the physical and physiological profiles of the playing group at the amateur domestic club level of women's rugby union were quite similar and may be suggestive of generalised, rather than specialised, training regimes that fail to prepare players for higher levels of competition. Amateur women's rugby union may benefit from the incorporation of positional specific training that would provide forward playing positions with the opportunity to develop collision and contact abilities, while concurrently allowing backs a greater opportunity to train their high intensity running capacity. Although the use of microtechnology may not be available to the majority of amateur women's rugby union teams, measurements such as heart rate measurement and the use of scales such as the Borg Rating of Perceived Exertion (RPE)[11] may be useful in monitoring player loads. The various RPE scales have been reported[1, 7, 30] to be a valid measure of exercise intensity independent of participant sex[7, 19, 23] and age.[33, 38] These scales may provide the coaching and management team with an alternative means of assessing and monitoring exercise intensity[12, 32] in women's rugby union.

LIMITATIONS

The current study followed a domestic women's rugby union team during two years of competition matches. Therefore, the results reported in this study should be interpreted with caution and may not be transferable to other levels of rugby union participation. Additional information such as the number of tackles, contact events and scrums were not obtained and future studies would benefit from the inclusion of this information to assist with PL assessment.

CONCLUSIONS

The game participation physical demands in an amateur domestic women's rugby union team in New Zealand measured using heart rate and movement analysis indicated there was very little difference between positional groups. It was also apparent that the physiological profiles gathered from using microtechnology were much lower in rugby union when compared with other women's sports. Given the limited availability of microtechnology data at this level of competition, the study highlights the importance of integrating a variety of external load metrics into the routine monitoring of collision-based sports such as rugby union.

Practical Applications

- The findings of this study can be utilised to assist with the training and preparation for specific tactical strategies that are used in match environments for women's rugby union.
- Training for these roles should focus on the development of the aerobic capacity for both attack and defending roles as well as skill development and the development of anaerobic capacities.

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ORIGINAL ARTICLE

Maturity status, relative age and bio-banding in youth cricket

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ABSTRACT

Aims

The aims of this study conducted at a male youth cricket camp were to investigate (i) maturation status and relative age (ii) the relationship between biological maturation and physical performance (iii) the impact of bio-banded games on players' enjoyment and performance and (iv) coach perceptions of bio-banded games.

Study Design

Exploratory multi-method study.

Setting

A 3-day regional under-14 boys' cricket development camp.

Participants

Fifty-seven youth male cricket players (mean age 13.3 ±0.29 yrs).

Method

Biological maturity status, physical performance (strength and jump tests) and cricket performance (batting, bowling, and throwing) were assessed and players engaged in a series of bio-banded games. Focus groups with players and interviews with coaches were conducted to gain deeper insight and to evaluate player and coach experiences during the bio-banded games.

Results

Late maturing players were underrepresented in the age group cricketers investigated in this study, however there was no relative age effect. Bio-banded games were viewed favourably by both coaches and players with the biggest benefits appearing to be to the least mature players. More mature players have advantages in terms of strength that give them certain batting advantages and likely allow them to throw faster and further.

Conclusion

These findings have important implications for selection processes, talent development, player enjoyment and relevance for other sports beyond cricket.

Keywords: Maturation, growth, adolescents, talent identification, skill development, youth sport.

INTRODUCTION

Currently the effectiveness of 'early selection of talent' in youth sport is limited, and frequently this is a consequence of the impact of athletes' biological maturation and/or the relative age effect (RAE).[1] The maturity status of a young athlete is predominantly determined by genetic factors, whereas the RAE is a function of the birth date and selection cut-off dates. Both can create a bias when selecting young players resulting in the over-selection of relatively older and/or more physically mature players ignoring relatively younger or less mature players with potential. A negative consequence is the early exclusion of some players who miss exposure to quality coaching and in the worst-case scenario leads to drop-out; with players perceiving themselves not to be good enough.[2]

The impact of RAE, defined as the overrepresentation of players born early in the sport's selection period, has been evidenced in a wide range of sports across childhood and adolescence with agreement that it is detrimental to the effective selection of future talent.[1-5] In contrast, selection bias due to biological maturation emerges at 11-12 years of age with the bias increasing as children get older.[6] The magnitude of RAE has been suggested to be dependent on a range of factors, including participation numbers, competition for positions in teams, with a greater effect in sports where there is more competition[1-3] and high physiological demands.[7]

Previous research in cricket has suggested evidence to support the RAE concept, with coaches selecting junior representative teams that have a bias towards those born earlier in the 'cricket year'.[1] The rationale for this may be due to a short-term focus on 'winning' rather than a focus on 'developing talent'. Selectors have been more likely to pick older and/or more biologically mature children due to their increased physical size (on average those born earlier or who have reached puberty sooner are likely to be taller and stronger) influencing their ability to bowl faster and hit the ball further. More mature youth male athletes have been reported to be stronger and more powerful than less mature peers.[8] If not recognised, then these differences in maturity may have significant implications for an athlete's opportunity to access future skill development and quality coaching, specifically in terms of selection in representative age group teams. These 'maturity level' effects are most pronounced in roles where greater strength is advantageous to performance outcome (e.g., batting in the middle order in cricket or opening fast bowler). In contrast, other roles in cricket, such as opening the batting, spin bowling or even wicketkeeping, are viewed as requiring less strength and, therefore, being smaller is seen as less of a disadvantage.[1] When selection in junior representative sports teams is significantly biased by the physical characteristics of players rather than skill level of players then early maturers have an advantage. Given that in an average population of boys, 17% are early developers, 66% are 'on-time' and 17% are late developers,[9] selecting players based on physicality is likely to reduce the talent pool, thus limiting the number of possible future 'champions' who may develop with sufficient time and support.

One emergent solution to address this selection bias in youth sport is bio-banding. This is defined as the selecting of young athletes based on their biological maturation rather than their chronological age. Most of the current research is in football (soccer) and has found that incorporating bio-banding in selection has a positive impact on an athletes' skill development, injury prevention and improves psychological factors, especially player confidence.[10,11]

Currently there is a lack of knowledge regarding the presence of a RAE and/or maturation bias in junior cricket selection and any subsequent impact on performance and development. Therefore, there is a need to evaluate the performance of junior players when they participate in bio-banded teams and games. These findings will help inform future development of representative and athlete development pathways in cricket, and potentially in other sports, that could lead to enhanced skill development, increased participation/retention rates and enhanced experiences of all young people playing the sport. This study represents a collaboration between researchers and New Zealand Cricket who co-designed and implemented the study at a regional youth cricket development camp. The aims of this exploratory multi-method study were to investigate; (i) player maturation status and relative age (ii) the relationship between biological maturation and physical performance (iii) the impact of bio-banded games on players' enjoyment and performance and (iv) coach perceptions of bio-banded games.

METHODS

Study Design

This study is part of a wider youth sport project aimed at enhancing youth sporting experiences in New Zealand. This specific study was conducted at the end of 2018 at a regional youth cricket camp and utilises a multi-method design. Multi-method research entails the application of a number of sources of data or research methods to investigate a specific research question or two different, but highly linked research questions.[12] Quantitative and qualitative (interview and focus group) data were collected and analysed separately.

Ethical approval was granted by the primary author's institution research ethics committee AUTEC (approval 19/181).

PARTICIPANTS

Participants were recruited from a three-day regional under-14 boys cricket talent development camp. All players (N=57) who attended the camp were nominated by their club coaches. Although there was no formal selection process, these players were predominantly identified as being the 'better' players for their age in their club with potential to play representative level cricket in the future.

Procedures

Biological maturity status, physical performance (strength and jump tests) and cricket performance (batting, bowling, and throwing) were assessed and players engaged in a series of bio-banded games. Focus groups with players and interviews with coaches were conducted to gain deeper insight and to evaluate player and coach experiences during the bio-banded games.

Biological Maturity Classification

Anthropometric variables of body mass and standing height were collected as was the self-reported height of both parents. Stretched standing height was measured to the nearest 0.1 cm using a stadiometer (Model: WSHRP; Wedderburn, New Zealand). Body mass was measured to the nearest 0.1 kg using a digital scale (Model: TI390150K; Tanita, New Zealand). Maturity classification (timing) was based on percentage predicted adult stature at the time of measurement calculated using the Khamis-Roche method.[13]

Percentage predicted adult stature was then expressed as a z-score relative to age specific means and standard deviations previously reported in a longitudinal study of boys' growth.[14] Based on the z-scores boys were then classified as late/delayed (z-score <-1.0), average/on time (z-score <1.0 and >-1.0) or early/advanced (z-score > 1.0) maturing in line with previous studies of youth athletes.[6,15] Given recent suggestions these z-score bands may not differentiate individuals who still differ substantially in maturity,[4] a secondary classification with a z-score +/- 0.5 defining on time, >0.5 early and <-0.5 late was also undertaken.

Physical Performance Measures

The strength and jump performance of all players was assessed using the isometric mid-thigh pull (IMTP) and the standing broad jump. Jump strength tests are commonly used field tests in bio-banding studies to measure player muscular power.[16] For the IMTP all participants stood with feet shoulder-width apart and gripped a bar connected to a base plate under their feet. Arms were straight and the hips and knees were both at angles of 130-140°. Once ready, participants pulled on the bar as hard and as fast as possible for 3 seconds with the intent to stand straight up. Participants were allowed 3 maximum effort pulls, separated by approximately one minute. The IMTP was performed using a metal straight T-bar with a chain attached to a single-axial load-cell (MT501, Millennium Mechatronics, Auckland, NZ) sampling at 1000 Hz. All participant data was recorded using a custom-designed MATLAB program (MathWorks, Inc., Natick, MA, USA). An expert-user then looked for the sudden onset of force (above the pre-tension level) in the load-cell to determine the start of each lift and exclude any potential system lag. Peak force was calculated for each pull and then normalised against participant body mass. To assess broad jump performance participants were asked to stand with their feet flat on the ground with their toes behind a line marked perpendicular to a measuring tape (0 cm mark). They were then asked to jump as far forward as possible, using arm swing and landing on both feet. The participants were required to 'stick their landing' and stay in the end position until the measurement had been taken. Jump distance was measured from the start line (0 cm mark) to the heel of the back foot upon landing. If participants did not stick the two-foot landing it was considered a "non-jump" and they were required to repeat the jump until three successful jumps were recorded, with 30 seconds rest between trials.

Cricket Performance Measures

Bowling. Bowling velocity was assessed for two different weighted balls (142g and 156g) and two different pitch lengths (18m and 20m). All bowling velocities were measured indoors using a radar gun (Stalker ATS II, Texas, USA). The radar gun had a sampling rate of 47Hz and was positioned 1m behind the stumps on a tripod set at 1m above the ground. Following an appropriate warm-up all players delivered six total balls with 3 bowling opportunities at 18m with the 142g ball, and 3 opportunities at 20m with the 156g ball. To simulate a game situation stumps were set up for players to aim at. Each player was instructed to target their bowling at leg, middle, then off stump as if they were bowling to a right-handed batter. Peak horizontal ball velocity was measured for each bowl using Stalker ATS System™ software radar gun (version 5.0.2.1, Applied Concepts, Inc., Texas, USA). Due to technical issues readings were only obtained for 3 of the 8 groups (n=21).

Fielding. Throwing velocity and distance of the throws were assessed using two different weighted balls (142g and 156g) performed outdoors on a grass school field. The cricketers performed each throw within a longest throw competition where each throw was recorded for distance and speed. Peak horizontal ball velocity was measured for each throw using Stalker ATS System™ software radar gun (version 5.0.2.1, Applied Concepts, Inc., Texas, USA). The distance of each throw was recorded (m) from the front of the throwing box. Each player received a rolling ball to mimic the game movement of 'collect and throw' which they fielded (picked up) before throwing. Each player performed 3 consecutive maximum distance overhead throws with both a 142gram cricket ball and a 156gram cricket ball.

Bio-banded Games
To allow players to practice and play games against teams of similar maturational classification, players were grouped into eight bio-banded teams at the end of day one. To create teams players were ranked from most mature to least mature based on percentage of predicted adult stature and then allocated to teams in groups of seven (e.g., team 1 = seven most mature players). This resulted in seven teams of seven players and one team of eight players (team 8 = eight least mature players). Teams were then organised into two leagues (league one = four most mature teams and league two = four least mature teams). The four teams in each league played against each other in a 10-over per side game, round robin competition over two days. Each batter was instructed to retire if they made 25 runs. Boundaries were set as per junior game formats for this age group (40 m). Each player in the bowling team was required to bowl at least one over (except for the wicketkeeper). To ensure equal opportunity the batting order was continued into subsequent games, ensuring that a player who was next to bat (i.e., had not had a turn batting yet) would start the innings in the following game. Games were scored by using CricHQ (www.cricHQ.com) with every ball recorded. This produced all relevant batting data for each innings. Total runs scored off the bat; percentage boundaries; run rate per 100 balls; balls scored off per 100 balls and percentage boundaries scored 'in the V' were all recorded. The 'V' was operationally defined as hitting the ball over an imaginary straight line which ran through the bowler's end stumps from the off-side to the leg side boundary. Due to technical issues, only 10 of 12 innings were recorded for league one and only five of 12 innings for league two.

Focus Groups with Players
Short focus group interviews were conducted on day three of the camp with five teams (one, three, five, six, seven) involving a total of 15 boys. Through consultation with the regional cricket body responsible for the camp, focus group interviews were kept short (approximately fifteen minutes) so as not to interfere with the boys' enjoyment of the camp. Interview formats were semi-structured with guiding questions being designed to establish their: enjoyment of cricket, their enjoyment of the camp, and their feelings about being bio-banded.

Interviews with Coaches
Individual semi-structured interviews were conducted with three male coaches. Interview lengths again were kept short so as not to interfere too much with the camp experience and were approximately fifteen minutes. All were experienced coaches and qualified to coach to at least district level for senior teams. One coach was a long-time coach (NZ Cricket Level 3), another coach (England and Wales Cricket Board Level 2) had completed a Master's sport science degree, and the third was a coach (NZ Cricket Level 2). Guiding questions were designed to establish their: perspective of the camp and the format adopted, their perception of children's experiences of the camp, and their feelings about bio-banding.

Data Processing and Analysis
To assess for RAE player month of birth was used to group players into quartiles relative to the selection cut-off dates for each age group (e.g., 1st quartile included all players born in the first 3 months of the selection period).

To assess for differences in performance outcomes players were separated into four groups with each group comprising players from two bio-banded teams (i.e., most mature group = Teams 1 and 2, least mature group = Teams 7 and 8). Descriptive statistics are presented for all performance variables for each of these four groups. An independent samples t-test was used to investigate the mean difference in performance between the most mature and the least mature group. Statistical significance was set at $p<0.05$.

A six-step inductive thematic analysis was conducted following guidelines by Braun and Clarke.[17] (1) Familiarisation with data occurred through audio-recorded interview transcription and initial note taking; (2) closer reading of transcripts followed by generation of initial codes; (3) research team meetings discussed and named potential themes; (4) themes were reviewed and agreed upon; (5) final themes were defined; and (6) preliminary findings were written. To account for individual bias and to account for rigour and trustworthiness, regular qualitative data analysis meetings were held between three authors to discuss and triangulate themes as they were identified.[18]

RESULTS

Participants
Fifty-seven youth male cricket players (mean age 13.3 ±0.29 yrs; height 162.1 ±9.2cm; weight 49.8 ±12.5kg) volunteered to participate in this study.

Maturation and Relative Age
Based on maturity classification 42% of participants were early maturers (n=24), 56% were on-time (n=32) and 2% were late maturers (n=1). However secondary analysis using z-score cut-off of +/- 0.5 suggested 65% (n=37) could be considered early, 30% (n=17) on-time and 5% (n=3) late maturing. Distribution of birthdates was similar across birth quartiles, with slightly more players born in quarter 1 and quarter 2 (both 29%) than quarter 3 (19%) and quarter 4 (22%). Descriptive statistics, mean percentage of adult stature and maturity classification of team members, for each of the eight bio-banded teams are shown in Table 1. League One (Teams 1-4) were mostly (82%) early maturers while League Two (Teams 5-8) were mostly (93%) on time.

Physical Performance
There was a statistically significant difference in absolute strength between the early mature group (Teams 1 and 2)

Table 1: Characteristics of each of the eight bio-banded teams

Team	Height (cm)	Weight (kg)	% Predicted Adult Stature	Maturational Classification (n)
1	169.4 ±7.4	59.2 ±11.4	90.32 ±0.42	Early (7)
2	169.1 ±7.1	57.4 ±13.9	88.97 ±0.29	Early (7)
3	168.4 ±8.1	57.7 ±15.5	88.05 ±0.32	Early (4)/On-time (3)
4	166.8 ±5.7	49.7 ±8.3	86.95 ±0.39	Early (5)/On-time (2)
5	162.0 ±8.7	48.6 ±8.7	85.80 ±0.50	Early (1)/ On-time (6)
6	156.7 ±12.2	47.8 ±12.2	84.95 ±0.28	On-time (7)
7	155.7 ±3.5	40.6 ±3.5	84.05 ±0.17	On-time (7)
8	150.8 ±6.8	38.6 ±6.8	80.66 ±1.00	On-time (7)/Late (1)

data = mean ±standard deviation

Table 2: Differences in Strength and Broad Jump Performance between Groups based on Maturity (Group 1 = early mature, Group 4 = on-time mature)

IMTP	Group 1 (Team 1,2)	Group 2 (Team 3,4)	Group 3 (Team 5,6)	Group 4 (Team 7,8)
Absolute (N)	860 ±219*	774 ±167	691 ±198	605 ±120
Relative (N/kg)	15 ±3	15 ±3	15 ±4	15 ±3
Broad Jump				
Absolute (cm)	182 ±26	176 ±20	177 ±20	166 ±18
Relative (cm/cm)	1.1 ±0.1	1.1 ±0.1	1.1 ±0.1	1.1 ±0.1

data presented as mean ±SD; *significantly different (p<0.05) to group 4; IMTP = isometric mid-thigh pull

Table 3: Differences in Bowling and Throwing Performance between Groups based on Maturity (Group 1 = early mature, Group 4 = on-time mature)

Pitch (20m); Ball (156g)	Group 1 (Team 1,2)	Group 2 (Team 3,4)	Group 3 (Team 5,6)	Group 4 (Team 7,8)
Bowling velocity (km/h)	75.0 ±14.6	76.4 ±11.4	72.9 ±9.7	66.6 ±12.8
Throwing distance (m)	43.5 ±4.9*	43.4 ±6.2	40.4 ±8.3	38.3 ±6.2
Throwing velocity (km/h)	75.0 ±4.5*	73.8 ±5.9	71.6 ±9.0	69.2 ±6.7
Pitch (18m); Ball (142g)				
Bowling velocity (km/h)	71.7 ±13.1	77.8 ±10.0	77.0 ±8.4	68.1 ±13.3
Throwing distance (m)	44.0 ±4.1*	43.6 ±4.4	41.3 ±7.4	38.9 ±5.6
Throwing velocity (km/h)	76.4 ±4.2*	76.0 ±3.8	73.6 ±8.4	71.3 ±6.1

data presented as mean ±SD; *significantly different (p<0.05) to group 4

Table 4: Batting Data by Team (Team 1 = early mature, Team 8 = on-time mature)

Team	Innings	Runs (mean) *	Percentage Boundaries (mean)	Run Rate/ 100 balls	Balls Scored off (%)	Sixes in V (%)	Sixes Outside V (%)	Fours in V (%)	Fours Outside V (%)
Team 1	2	84	63	141	62	50	50	65	35
Team 2	3	130	63	145	62	100	0	64	36
Team 3	2	109	60	136	68	0	100	33	67
Team 4	3	85	67	144	57	75	25	52	48
Team 5	1	89	63	148	75	50	50	64	36
Team 6	2	69	64	115	75	0	0	39	61
Team 7	3	78	55	130	77	0	100	45	55
Team 8	1	77	55	128	63	0	0	12.5	88

*Other than for teams 5 and 8 (who only had one innings recorded)

and the on time mature group (Teams 7 and 8) (mean diff = 255N; p=0.001) (Table 2). Although the difference in broad jump was substantial, it was not statistically significant (mean diff = 16cm; p=0.06). There was no statistically significant difference in relative strength or relative jump performance between the early mature and on-time mature groups (Table 2).

Cricket Performance

The early mature group threw the ball significantly further than the on-time mature group with both the 142g ball (mean diff = 5.1m; p=0.01) and 156g ball (mean diff = 5.2m; p=0.02) (Table 3). They also threw the ball with significantly greater throwing velocity (142g ball mean diff = 5.1 km/h; p=0.02, 156g ball mean diff = 5.8 km/hr; p=0.01) than the on-time mature group (Table 3).

Table 4 presents the batting data for each bio-banded team. The teams are listed in order of maturation with the team containing the early mature players numbered first. The descriptive data indicated a trend of increased performance with early maturity. The teams containing a greater number of early maturing players generally scored more runs, had a higher percentage via boundaries, had a higher run rate and scored more boundaries 'in the V' than those teams containing the on-time maturing players. The teams containing the greater number of on-time maturing players generally scored off a higher percentage of balls faced.

Table 5: Boys' focus group themes

Theme	Indicative quotes
Learning	"The technique batting was quite helpful, making sure you are getting on top of the ball and just like keep it out and learning how to play that in the future and I transferred those to the games." "[The best part of the week] was playing T20, playing the games, and doing the activities and learning new stuff". "I learnt how to change the action of my bowling when we were over doing the spin bowling, to adjust my leg to come round quicker and my arm to point straight."
Challenge	"I really liked attacking the spin bowlers – that was a good challenge." "When they are smaller [bowling] the ball doesn't come at you as high and such and it's definitely a bigger challenge when you have another big guy coming at you. It's definitely more challenging this week and it's a good challenge."
Playing without fear	"It's a lot of fun because we get to learn a lot of stuff like playing with people the same size as us. Because when you play with the bigger people like you get intimidated, so when you play with your own size you don't feel like that and you just play naturally."

Table 6: Coach interview themes

Theme	Indicative quotes
Coach curiosity	"I mean I was very keen to coach on it for, to learn about, do some constraints coaching and also that stuff like all this would be quite interesting to get my head around as well so it's exciting." "I'd like to see this at grassroots level, as here, everyone's got talent, which sustains them, but then when you go down to grass roots level, actually that's when the big kids really, really dominate, because you've not just small kids but you've also got small kids who are low ability as well, whereas everyone's high ability here, so, that's where I think it'd be really interesting to see."
Player enjoyment	"I've been in a lot of, over the years, coaching clinics and holiday programs, and I said to [other coach] this morning, when they're all mucking around, they're laughing, carrying on, I thought that's a good sign that they actually want to be here." "This is very important research to dwell on a little bit more because I think this is definitely one of the reasons why some of the kids enjoy cricket more than others and some are a little bit scared of facing taller boys but they are all in the same age group, so I think it's definitely a very key development going forward."
Benefits of biobanding to skill development	"I think this sort of cricket definitely rewards better technique [. . .], you haven't seen the smaller kids trying to keep up with the bigger kids, just go out there and hit it as far as they can. They're actually just playing proper shots and also because on the other team there isn't two or three bigger kids who have just scored 20 off 4 balls, the little kids don't have to go in and do the same thing. So because the scores are relative to their ability to hit fours and sixes, actually, it doesn't force them into playing rash or shots with bad technique, actually they maintain their technique because they don't have to go quite so hard." "[These] match ups that sort of give you like big to big, I think that's, where you see a big improvement in the involvement of the kids, and their skill and confidence levels." "I think it [biobanding] makes it a much more level playing field, which I think you often can't get at this age level." "Look it's exciting, and I think in the coaching world we need to be quite open to what else could be available to enhance a sporting experience, you know, and developing skills not just for cricket, for other sports as well, you know?"

Focus Groups with Children

All 15 players enjoyed the camp. The dominant themes identified related to learning, challenge and playing without fear. (See Table 5).

The boys liked being exposed to new skills or refining existing skills in the morning in game-based skill development sessions, and then having the opportunity to put those skills into practice in actual matches in the afternoon sessions.

Comments were consistent from all boys interviewed, they enjoyed playing with people the same size as them, either for the challenge or for the opportunity to be more involved and not feel intimidated.

Coach Interviews

Themes identified included coach curiosity, player enjoyment of the camp, and benefits of biobanding to skill development that could potentially be applied across other sports. (See Table 6)

DISCUSSION

This study investigated the influence of biological maturity and relative age in a group of youth male cricket players attending a talent development camp. This is an area of growing interest in youth sport,[4] however, to our knowledge this is the first study to explore the influence of maturation in youth cricket.

Maturation and Relative Age

First, it is important to note that there is no evidence of a RAE in the current study with a relatively even distribution of birth dates relative to the selection cut-off date. This contrasts with the recent study of Connor et al.[1] in junior cricket in Australia and other studies in youth football where a clear RAE has been reported, with an over representation of players born in the first quarter of the selection period.[4] This may be because players in the current study, although identified as potentially talented, had not been formally selected as a team or squad of players and thus the RAE selection bias was less evident. For example, 57 players attended the camp rather than squads of 13-16 generally common when selecting junior representative cricket teams.

A clear bias toward early maturing players was only evident when a stricter criterion (z-score ±0.5) was used. Based on the more common criterion (z-score ±1.0) there was no obvious over representation of early maturing players, however, there was an under representation of late maturing players. This contrasts with findings from youth football where a bias toward selection of early maturing players has been reported.[6,19] A recent study in youth football has however highlighted that maturation selection bias varied across age groups and was only clearly evident when the stricter criterion (z-score ±0.5) was used.[4] This was also the case in the current group of youth cricketers where a bias toward early maturing players was clearly evident using this stricter criterion. It should be noted that while the stricter criterion has potential for better detecting maturation selection bias, it also likely increases the error rate in maturational classification. Any selection bias that disadvantages late maturing players in cricket is a concern as similar to other sports it is possible these players if retained in the game may ultimately possess better technical and tactical skills.[11] If deselected they potentially drop out of the game.

Physical Performance

A selection bias toward more mature players is likely due to physical advantages (mainly in strength, associated with earlier gains in lean mass) that aid performance.[20] In our group of young cricketers, the most mature players were stronger, performed better on tests of throwing distance and speed and tended to jump further (although this finding just failed to reach statistical significance). This is similar to previous reports in youth soccer players that indicated more mature players perform better in functional tests of strength and power.[21] As expected, there were no differences in our group when strength and jump measures were expressed relative to body weight. Interestingly, additional exploratory analysis showed that the height of players in the current study was more closely associated with strength (r=0.68) than was the maturity classification based on percent of predicted adult height (r=0.51). Given differences in strength are considered the most likely cause of physical performance differences, it raises the possibility of bio-banded teams based on standing height rather than maturity classification. The advantage of this for community sport with relatively few resources is that height is simpler to collect.

Cricket Performance

A key aim of the bio-banded games was to compare the batting performance based on maturation. These preliminary findings (with limited data from some teams) suggest teams in League 1, who were largely early maturers, scored more runs per innings, scored at a faster rate, and hit more sixes than teams in league 2. This provides tentative support for the notion that early maturers (physically more capable players) have advantages when batting, although this needs confirming with a larger data collection. The trend for early maturing teams to score more boundaries 'in the V' (vertical bat shots) may be due to their strength and other potential biomechanical advantages when batting. The on-time maturers tended to score more runs using their 'whole body' via cross bat shots.

To consider how stage of maturation impacted the way that players scored their runs we also looked at the percentage of balls scored off and run rate. Interestingly, on-time maturing teams 5-7 scored off a higher number of balls than the early maturing League 1 teams. A tentative explanation is that because league 2 players were not as mature they were not strong enough to score as many runs in boundaries ('in the V') and therefore adapted their batting to score more singles and twos. This finding is supported by the work of Renshaw and Holder,[22] who demonstrated that younger (less powerful) players could not hit as far. The younger players technique was not too different from adults, but their difference in size did not afford them the same shot selection as stronger adults, and so they just could not hit as far.[22] However, at this stage, further analysis is needed to explore this idea. Nevertheless, these preliminary findings, supported by coach observations, do suggest cricket performance and player strategies are impacted by player maturation level and associated differences in physical capabilities. These findings have potential implications for bio-banding and talent development in cricket. Cricket performance may be impacted by stage of maturation as players attempt to achieve their goals based on their current physical capabilities. An advantage of playing with similarly bio-banded players may be the development of a wider range of scoring strategies. Similarly, the throwing data indicated that many later maturers would not be physically capable of fielding on the boundaries and they would also tend to be spin bowlers. This raises issues relating to the scalability of the sporting environment to match the physical capabilities of children. In a review of the scaling sport literature, although a complex area for organisations to consider, Buszard et al.[23] noted that "it seems reasonable to think that scaled environments in junior sport will heighten children's perception of their own ability, which will then lead to more participation in the sport, improved actual motor competence, and a greater likelihood of sustained participation". Increasing opportunities for bio-banded experiences would enable players to play in different positions and to feel competent in other aspects of the game (such as fielding) ultimately enhancing their experience. For early maturers, biobanding creates challenge and the environment that would encourage them to develop additional technique as opposed to relying upon their superior strength. This final point is supported by similar research with bio-banding in football.[20]

Insights from Players and Coaches

Research with children both in New Zealand and internationally has consistently shown that key aspects of what they enjoy about sport relate to the experience being enjoyable and learning new skills.[24] A key consideration for the cricket organisation and researchers was that the three days should be an enjoyable experience supporting learning and skill development. Both the players and coaches liked the format of the development camp, with comments coming from both about the value of the structure of the camp for skill development. The boys talked about their enjoyment of learning skills in the morning, then having the ability to put this into practice in the games in the afternoon, whilst the coaches discussed possibilities of further enhancing this learning by adding constraints around games to encourage the use of the skills learnt. What the late maturers enjoyed about the camp was that they did not "feel intimidated" and were able to focus on developing their technique and skills. Early maturers found that having to play and practice with other early maturers was more challenging for them and they found that aspect of the experience enjoyable, supporting previous research findings in a football academy setting.[25] A considerable body of sporting research has shown that coaches are key in creating environments that can nurture, or thwart, intrinsic motivation [for example see,[26] which has been defined as one's innate inclination to "seek out novelty and challenges, to extend and exercise one's capacities, to explore, and to learn".[27 p70] The environment created in this camp clearly supported these boys' needs for challenge and opportunities for learning.

Recently in New Zealand, concerns over the costs of an over-emphasis on winning and the trend towards early specialisation led to the government agency Sport New Zealand, signing a statement of intent with five major sports (cricket, football, rugby union, netball and hockey) to bring back the fun and development focus into young people's sport.[28] This camp was part of a move by NZ Cricket to examine their youth sport structures and to introduce a more developmental approach. However, it was interesting to note that several boys said they had already specialised into a position and saw no benefit in learning other cricket skills which did not relate to their specific position: For example, "I didn't really need to learn about pace bowling, 'cos I'm a spin bowler". The majority of boys in the later maturing banded teams identified as spin bowlers. The implications of this are that by either being pushed into specialising in a position or doing so by self-selecting, players even by the age of 13, are being exposed to very position-specific skill development opportunities.

Through their participation in the camp, all coaches talked about how they found the biobanding concept "interesting" and "it made them think" about what they had for so long taken for granted (competition structures). Coaches also spoke about how the experience made them reflect for the first time on their own experiences, with one coach stating that he had been an "early maturer, who used his size and pace to bowl fast" but he had not really focused on developing his technique as he had not had to. Now he played first class cricket but was a batsman and the camp experience made him realise why he had not developed his bowling technique and skill further as a youth.

STUDY LIMITATIONS

This study had limitations which readers should consider when interpreting the findings. The main limitation is the relatively small sample and a lack of female participants. Concerns from NZ Cricket that led to this study emanated from their perception that representative selection processes were favouring early maturers based on physical attributes as opposed to cricket potential. Although the development camp that was the site for this study replaced a representative tournament for this age group, participants were 'shoulder tapped' for the camp by club coaches. It is likely that these participants were perceived by their coaches to be the most 'talented' of their age group and as such would explain the predominant representation of early maturing boys in our sample. More research is needed at a club level to identify the maturation status of all boys (and girls) who participate in cricket. Additionally, the batting data from some teams was very limited due to technical software issues at the camp outside the research team's control.

CONCLUSION

Late maturing players are under-represented in the age group cricketers investigated in this report, however there is no relative age effect. Bio-banded games were viewed favourably by both coaches and players with the biggest benefits appearing to be to the least mature players. More mature players have advantages in terms of strength that give them certain batting advantages and likely allow them to throw faster and further. This has implications for selection processes and for pitch length, boundary length and ball weight.

The current talent selection methods in junior cricket (and other sports in New Zealand) fail to consider the relative maturation of junior players and this highlights the need for new approaches to be explored. This study is the first in the world (to our knowledge) that explores the promising use of bio-banding in junior cricket. Findings provide tentative, yet promising support for the adoption of bio-banding in junior cricketers. Future work should explore the interaction between batting and bowling performance of junior players across matched bio-bands as well as in situations where early maturers play against late maturers.

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COMMENTARY

Taha hinengaro (mental wellbeing) in our athletes

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ABSTRACT

This commentary is a discussion on athletes' taha hinengaro (mental health) and the unique risk factors that can compromise an athlete's wellbeing. It explores the international research that exists surrounding this topic and provides suggestions on how we may begin to reduce barriers for our athletes, so that they can better access the care they require.

Following the 2020 Tokyo Olympics, we have seen more athletes than ever before, such as Olympic gymnast Simone Biles and tennis player Naomi Osaka, openly discuss their mental health needs and the importance of wellbeing in sport. We cannot also ignore the tragic deaths that result from the mental health struggles of such athletes, which have been headlining news in more recent times.[1,2] Such topics have become increasingly discussed in the sporting community. However, the stigma of mental health troubles, especially in a population that is perceived to inherently possess 'mental toughness', can act as a significant barrier to accessing the help they need.[3] This opens discussion on our role as health professionals for these athletes, in raising awareness, and screening for and preventing the dire consequences associated with poor mental health.

Elite athletes suffer from psychological distress and disorders at rates equivalent to or higher than the general population.[4]

In New Zealand, over a third of individuals were aware they suffered from mental stress, with the highest prevalence among Māori and young adults, aged between 18-24 years old[5]. The career peak for most athletes also falls within this age range,[6] and has been identified as the period during which athletes are exposed to the highest risk to their mental health.[4]

Health is a complex, multifaceted concept. Health professionals whose role is focused on the physical health of athletes, such as sports and exercise physicians, physiotherapists and podiatrists, often compartmentalise the physical and mental manifestations of health, when in reality, they are intertwined. The Māori model of health, Te Whare Tapa Whā,[7] can be adapted to help guide health professionals to address all aspects of health in their care of athletes. While the focus in athletes is often on the taha tinana, or physical manifestations of health, we must also address the taha hinengaro (mental health) and wairua (spiritual health) and include taha whānau, the impact of the family, support network, culture and team that exists around each athlete. This holistic model aligns well with the World Health Organization definition of health as *'complete physical, mental and social well-being'*.[8]

Taha hinengaro, or mental health, is not merely the absence of mental illness, as more orthodox definitions may suggest. If this was true, athletes without diagnosed or clinical mental health issues would be considered mentally well.[9] This black and white approach does not account for the continuum that is mental well-being. Mental health is the ability of an individual to adapt, cope and change with adversity, and perform productively within their capabilities,[9,10] as well as feeling at ease or in control of their emotions. Lardon and Fitzgerald have proposed a continuum which is illustrated in figure 1. At one end of the continuum, athletes whose psychological states do not interfere with their daily activities are considered high-functioning individuals.[10,11] At the other end of the continuum, athlete's whose psychological states severely affect their daily tasks are considered low-functioning individuals,[11]

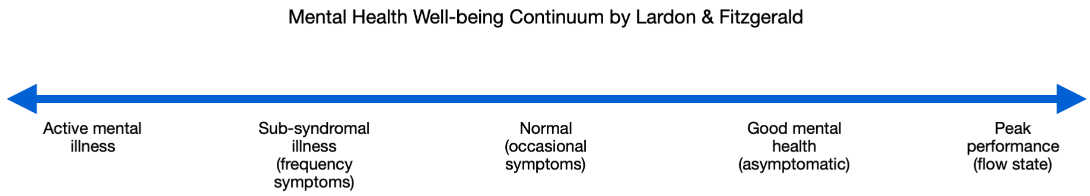

Figure 1

and this is considered mental illness. This continuum is good in identifying that there is a spectrum to mental well-being and that athletes can move up and down the continuum, however it cannot be so rigidly applied to all athletes. Sporting performance does not always correlate with mental well-being, since there are athletes who often perform very well in their sport, whilst also struggling with a diagnosed mental illness.[9] Thus, it can be difficult to decipher which athletes under your care are battling with mental health issues, as athletes may not exhibit the same signs as individuals in the general population.

Furthermore, the traditionally narrow focus on primarily physical health can cloud signs of mental health issues, especially if we fail to consider this in our differentials. For example, an elite athlete presenting with a three month history of fatigue, decreased motivation in training, the development of minor injuries and normal laboratory results, would firstly be considered as overtrained.[3] However, if the same individual was not an elite athlete, the first diagnosis would likely be a form of depressive disorder. This difference in diagnoses may be attributed to a narrow focus on musculoskeletal issues in the case of the athlete. There is pressure on the physician to not miss physiological causes to an athlete's presentation, which often means that psychological issues are not in the forefront of a physician's differentials. It is therefore important to broaden our reasoning by incorporating biopsychosocial models in our approach to health care.[3,10]

An individual's psychological well-being will endure the dynamics of the lived human experience. Additionally, athletes will experience what is known as the 'athlete condition'; the positive and negative experiences that are consequences of their athletic pursuits.[9] There are many factors associated with the athletic condition that can put athletes at a higher risk of experiencing psychological distress.

Firstly, athletes are in a unique environment, in that day in and day out they must push their physical and mental limits, which is rare in most other careers. Physical activity has been widely promoted to improve mental health, however too much of it in conjunction with inadequate recovery can compound to create an overtrained athlete. It has been suggested multiple times throughout the literature that the neuroendocrine changes seen in major depressive disorders are remarkably similar to those seen during over-training.[3,12,13] This includes elevated and unsuppressed cortisol levels, decreased beta-endorphin levels and imbalanced levels of serotonin in both conditions.[3,12]

Secondly, athletes who reach elite level often possess traits of perfectionism.[9,14] This trait, which is advantageous in sport, can come with its equal and opposite disadvantages to mental well-being, resulting in higher levels of avoidant coping mechanisms such as disordered eating, alcohol abuse and doping use,[10] and eventually leading to athlete burnout.[14] This perfectionistic mindset can also mean they are less likely to seek help for deteriorating mental health, as this can be perceived by themselves and their immediate network as a sign of weakness.[4,10] In society, sports culture and media, mental toughness and mental health of athletes appear to be contradictory concepts.[15] This perception creates stigma that prevents athletes from seeking help, or coaches, physiotherapists and doctors from inquiring about mental health.

Thirdly, the recent generation of athletes have had to face more public scrutiny than their predecessors, with the rise of social media and therefore increased exposure to cyberbullying.[4] Athletes are often criticised if their physicality does not match societal standards of 'athleticism' and therefore athletes can feel increased pressure to maintain a particular appearance, especially when magnified by their own perfectionistic traits. This unique ecosphere can trigger eating disorders, which already disproportionately affects elite athletes.[4] Additionally, since sport is inherently competitive, obsessional comparison between one's self and competitors can ensue, which can be to the further detriment of an athlete's mental health.

Furthermore, physical injury, performance failure and retirement (especially if involuntary) can put athletes at an increased risk of mental illness.[4,16] These events can create a sense of loss of identity,[16] which can be especially difficult since the majority of elite athletes have prioritised all of their time and effort into the sport, and often placed their broader life on hold to do so. Additional factors such as relocation from home, sexual harassment, bullying, delayed or cancelled competitions due to COVID-19, and being part of a marginalised community (LGBTQI+, Māori, people of colour, refugees, people with disabilities etc), are all risk factors for poor mental health.

So, what can we, as health professionals and support staff, do for our athletes? If we are going to raise awareness on mental health issues in athletes, it will only be effective if the systems in place are ready to respond to the athlete's needs.[17] Firstly, the system needs to reduce barriers to access for appropriate mental health care for athletes. One known barrier is that the support staff around athletes do not inquire about the taha hinengaro (mental health). If we do not inquire and show curiosity and interest into our athlete's mental health, then they will not feel comfortable coming forward with these issues and will be more likely to suppress thoughts and feelings until it is too late. One way that this can be overcome, is by having targeted mental health screening. The Baron Depression Screener for Athletes[18] or the Athlete Psychological Strain Questionnaire[19] are standardised tools which could be used at regular intervals along with physical health checks, such as every 3-6 months. Regular monthly screening for at least 6 months could be used at specific high risk periods such as when transitioning into or out of a sport or team, after injuries, concussions or performance failures, leading up to and after high-stake competitions or selection periods, and transition into retirement.[4,17] This can allow for earlier detection of changes in mental well-being or behaviour in athletes.

Secondly, the support network of athletes, and especially their whānau, could also be educated on risk factors, signs to looks out for and when and from whom to seek help. This could be achieved through mental health literacy programmes hosted by the sporting organisation. Involving whānau in the care of our athletes, especially for Māori athletes, is an important pillar that can often be forgotten.

Thirdly, having an allocated 'mental health officer',[9] as suggested by Henriksen et al, as an in-house support staff member who's responsibility is being the first port of call for athletes in regards to mental health should be considered. They ideally should have some training in athlete mental health, but do not have to be professional psychologists. Having an allocated mental health officer reduces barriers to care as it provides an easily accessible and known resource for athletes. Mental health officers can then further refer athletes to appropriate services if necessary.

The focus on mental health in our athletes in recent times has been improving, however we are only in our infancy in eliciting change. With regular mental health screening, improved health literacy among whānau members and an allocated mental health officer in sporting organisations, we can help protect our athletes and allow them to flourish inside and outside their sport.

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Resolving running related injury: The need for directed and multi-faceted solutions

PAUL GAMBLE

"There is always a well-known solution to every human problem–neat, plausible, and wrong"
H L Mencken

Running-related injuries have proven to be an intractable problem, despite considerable attention in the sports medicine literature and specialists in the field over the past two decades especially. Essentially on a long enough timeline it seems as though a runner can expect to suffer some sort of injury. The situation is particularly grim for the millions of recreational runners, for whom running-related injury seems like as much a certainty as death and taxes.
Rather than bemoan the recalcitrant nature of these injuries, it is perhaps time for us to acknowledge that this is a feature rather than a bug. By their nature, running-related injuries are multidimensional and complex, which goes a long way to explaining why they defy simplistic unidimensional solutions. Moreover, these injuries often give rise to secondary issues which further compound the problem and add a further layer of complexity. Logically it would follow that complex problems demand multifaceted solutions. By changing how we view and approach these injuries we might yet find a route towards effective interventions in a way that meaningfully improves the situation for runners.

There is also an apparent need to be more directed in how we tackle the problem of running injuries, rather than relying on generic solutions. *Running-related injury* is an umbrella term that encompasses a host of different types of injury commonly experienced by runners, each of which have their own unique characteristics. Given that each of the common running injuries presents different problems to solve it follows that we need to differentiate. Moreover, no two cases of the same type of injury presents or responds in an identical way, so a bespoke approach to fit the individual and the injury presentation is also warranted.

THE NEED TO EVOLVE OUR APPROACH

In addition to the need to be more directed in our approach, there is also an apparent need to be more direct in how we approach running injuries. To put it more succinctly, we need to go to the source of the issue. Acknowledging that running-related injuries can be broadly categorised as biomechanical overload syndromes, and by definition running is the activity that led to their onset, so logically our intervention should address running biomechanics. What is striking is how rates of running-related injury differ by population, such that recreational runners suffer disproportionately higher incidence of injury compared to elite runners (despite performing a fraction of the weekly mileage).[1] This strongly suggests that running proficiency is a major factor. Happily there is growing consensus on this point: much of the recent literature concludes that running gait retraining is the foundation of effective intervention.[2]

That said, there arguably remains a need to address mechanics in a more direct manner. A continuing impediment to effective intervention is that field-based gait retraining interventions described in the literature are generally limited to only a few generic solutions. The options given are typically restricted to switching foot strike, increasing cadence or wearing different running shoes. Whilst each of these interventions have the potential to ameliorate issues for some runners in certain circumstances, the rationale for their universal application is highly debatable. For instance, insisting that a particular foot strike option is uniformly superior irrespective of conditions ignores that what constitutes the appropriate foot strike strategy in fact depends on what velocity we are travelling at[3] (*nota bene*: it is not good advice to forefoot strike when running at jogging pace).

These generic interventions are essentially blunt tools that rely on their indirect effects on critical elements of running technique. Manipulating cadence is an example of providing specific constraints to indirectly encourage favourable changes in running gait. For instance, exposing novice recreational runners to a higher cadence condition (i.e. imposing a step rate that is 10 steps per minute faster than usual) can prompt them to adopt more favourable running mechanics – notably reducing the tendency to over-stride, such that they touch down closer to their centre of mass [4].

However, the universal application of cadence manipulation as our 'go to' gait retraining intervention implies that habitual running cadence differs between injured and healthy runners, despite the fact that no such association has been found.[5] A large investigation of experienced runners failed to find any association between participants' step rates and incidence of running-related injury.[6] This approach also implies that a universal optimal cadence exists and the rationale for intervention relies on the assumption that the habitual cadence (step rate) adopted by the majority of runners is suboptimal. In general, this seems a highly questionable assumption and the contention becomes even less plausible when we consider more proficient runners. Data from experienced runners reveal that step rates vary widely between runners. Individual runners demonstrate that they vary step rates with running speed and also show the ability to switch between step rates when running.[6] As such it becomes debatable whether the standard cadence intervention (increasing step frequency by 10 steps per minute) will be appropriate for more experienced runners and naturally this will reduce the odds that the cadence intervention will ultimately prove effective in resolving the injury. Once again, all of this points to a need to be more direct and directed in our approach in order to cater to the range of needs and characteristics of the runners we might encounter.

We also need to consider the potential negative second-order effects of a generic intervention, such as recommending a switch in foot strike strategy.[7] Switching from rearfoot strike to forefoot strike might reduce mechanical work at the knee but it does so at the cost of displacing it to the ankle and foot.[8] In itself this would seem to rule out the forefoot strike intervention as a universal gait retraining strategy, especially noting that many of the common running-related injuries concern the lower leg. The effects of the intervention itself should also be considered with the final generic intervention commonly advocated in the literature – that is, to switch to minimalist shoes. As with cadence manipulation this is based on the rationale that this will indirectly prompt favourable changes in running gait. However, during the early weeks of the switch to minimalist shoes we may actually see an increase in mechanical stresses, especially at the foot and ankle, which means that the intervention itself is prone to causing secondary problems for runners who are not accustomed or conditioned to the additional demands imposed.[9]

Beyond the need to more directly tackle relevant aspects of running technique, the salient aspects of running mechanics differ according to the type of running-related injury concerned, which in turn serves to determine what specific changes are called for. Each of the common running-related injury has its own somewhat unique set of biomechanical factors that are associated with it. There is no 'one-size fits all' when it comes to running gait retraining. A particular technique intervention that might be helpful for one type of running-related injury might have deleterious effects on another.

A FRAMEWORK FOR EFFECTIVE INTERVENTION ASSESSMENT

Correctly diagnosing the problem is the first step towards devising a solution. As we noted in the opening, the common running injuries differ from each other in important ways, so we need to match our approach to the specific injury. In some cases an accurate diagnosis can take some work to pin down and with bone stress injuries in particular imaging can be important to grade severity and in turn guide the approach.[10] With persisting or recurring running injuries especially, the presentation can also be complicated, such that there is a need to separate primary causes from the cascade of secondary effects that tend to develop over time (albeit we will ultimately need to address both aspects). Establishing the type and grade of injury is an important first step as this will guide and inform our general approach, but there is nevertheless a need to establish the best way to proceed in each case. The assessment serves to inform and shape our initial approach for a given individual and this will necessarily include examining the runner's gait mechanics given that this is the source of the issue. Clearly we need to elucidate what needs to be fixed in order to go about fixing it. Without directly assessing the individual's running gait we are forced to rely upon faulty assumptions. Whilst few practitioners are fortunate to have access to a running gait lab, the availability of various tools (notably smartphones) has now made it possible to reliably capture many of the most critical elements of running gait mechanics in a clinic or field setting.[11] High quality two-dimensional motion capture using a smartphone or similar device can provide a great deal of rich information, assuming the person using it has a decent eye for movement and an adequate understanding of running mechanics to provide the necessary frame of reference.

ANALYSIS AND INTERPRETATION

Whatever tools or facilities are employed to conduct the assessment, the insight we derive from the process largely depends upon our level of understanding of running mechanics. Simply, we need to have some appreciation of what it is we are looking at in order for there to be any meaningful analysis. The level of interpretation required does however tend to increase with the degree of sophistication of the tools employed and the range and quantity of data amassed from the assessment. It is crucial to integrate each of the sources of information and interpret the data properly in order to derive real insights and avoid being led to mistaken conclusions.

It is also important to understand and respect the limitations of what is possible to infer from the tools employed. Whilst ground reaction force data provides useful information it is unsafe to extrapolate mechanical loads further up the chain. Ironically, the most advanced three-dimensional biomechanical assessment in a gait mechanics lab tends to reduce the runner to a stick figure, which can serve to reduce the richness of the information provided.

(RE-)BUILDING CAPACITY AND CAPABILITY

It is important the we understand the likely root causes for what we observe during the initial assessment. Something we need to consider is the extent to which what we are seeing when we evaluate the runner's gait mechanics is a reflection of underlying limitations or impaired function. The movement strategy and running style adopted by the individual may be shaped by a need to compensate for deficits in capacity or capability. For instance, longer contact times may be indicative of deficits in strength capacities, notably at the foot and ankle.

Just as conducting a forensic analysis to elucidate root causes is helpful to inform our intervention, we also need to account for the cascade of secondary effects that are common with running injuries.[12] Once again, this will necessitate remedial strength and neuromuscular training intervention to address adverse changes and restore strength and function.[13] Practically this is likely to encompass a range of neuromuscular training intervention to develop postural control in single-leg support, lumbopelvic stability, dynamic stabilisation and lower limb dexterity.
It is important for injured runners to remain active and avoid losing fitness via the use of cross training and modified running activity. Finding ways to continue to train is crucial for body and mind, yet injured runners often need prompting to do so.[14] Retaining fitness is important, and maintaining regular metabolic conditioning is also key to avoid adverse changes in body composition – i.e., maintaining lean mass and avoiding unproductive weight gain, given that running is a weight-bearing activity. Beyond maintaining body composition, remaining active is important to avoid adverse changes in tissue capacity that otherwise tend to occur with disuse. Supplemental conditioning work likewise serves an import role in maintaining and developing fitness and the capacity to work under fatigue. The importance of reconditioning during the rehabilitation and return to run also extends to rebuilding tolerance of mechanical loading, notably at the foot and ankle. Dedicated training to develop these crucial links facilitates and complements the adaptation that occurs with graduated exposure to running activity.

DIRECT AND DIRECTED GAIT-RETRAINING INTERVENTION

There is a general need for gait retraining employed in the field to actually address salient aspects of running technique in a more direct and directed manner. The specific foci for the gait retraining intervention should be informed by the individual assessment. This will also depend on what is appropriate to the injury, and consideration should be given to any second order effects that might have negative implications.
In general, gait retraining should seek to develop neuromuscular control and coordination elements in the context of running. Practically, this will involve the use of drills and modified running activity to develop feel for the ground, motor control, precision, coupling between limbs, timing and rhythm.
In addition to addressing key elements of technique, drills and technical running workouts can also confer favourable adaptations in the locomotor muscles, weight-bearing structures and connective tissues involved (notably tendon). For instance, faster running sessions, plyometric exercises and running drills offer a potent and highly specific stimulus once tolerated. With selective use of drills and different terrains such as hills and stairs we can similarly direct the training stimulus towards particular links in the kinetic chain (e.g., hip and ankle).

COACHING DELIVERY

The need for a bespoke approach extends to the delivery of coaching intervention. Coaching instruction and the process taken should be tailored to the individual runner. By definition running gait retraining intervention involves relearning and refining motor patterns that are firmly ingrained and this presents a challenge. Individuals differ in their level of body awareness and how easily they acquire new or different motor skills. Moreover, individuals also differ in their bandwidth for coaching instruction and what cues resonate. We can inadvertently tie the injured runner in knots, especially if we bombard them with too much information and too many things to attend to at once. In general, the more sparing we are with our instruction the better, but all the same runners often perceive that the modified running technique demands greater effort in the short term, despite the fact that objectively measured energy cost is not actually higher [15]. Naturally this can be a struggle and it may be a frustrating experience at times. On that basis, the runner will need to keep the faith and persevere.
All of this places a great deal of onus on our effectiveness and skill in coaching. At the very least we need to be capable of demonstrating drills and modelling technique with a high degree of proficiency. Acquiring the necessary technical proficiency and coaching skill requires a considerable investment on the part of the practitioner. In the meantime, best serving the interests of the injured runner demands a readiness to enlist the services of a skilled coach to deliver the intervention in a collaborative manner.

CUSTOMISED PROGRESSION

Volumes of running training during the return to run process should be determined by what the runner is able to maintain with good form, rather than arbitrary guidelines for progressions in weekly mileage. To make this approach viable, we typically need to supplement training volume with cross training and modified running training (such as weight-assisted and deep-water running) to ensure the necessary conditioning stimulus to build aerobic fitness. This is something that will likely need to be directed as injured runners often do not spontaneously choose to engage in other forms of conditioning to compensate during periods when they are unable to run due to injury.[14] Nevertheless, it is unlikely that the injured runner will comply for any length of time if they feel they are falling further behind from a fitness perspective so it is necessary to prescribe and encourage cross training and modified conditioning.

MENTAL AND EMOTIONAL ASPECTS

There is a need to account for both body and mind in how we approach and deliver rehabilitation, gait retraining intervention and the return to run process. There is a considerable psychosocial aspect to running injuries. Injury deprives the runner of an activity that is important not only to their physical health but also their mental wellbeing. Beyond being a fitness activity, running is a cherished activity for many, providing mental refreshment, improving mood and serving as an important outlet to deal with problems at work and life stress. In addition to being deprived of something positive, symptoms of pain and discomfort from often spillover to daily activities, such that these injuries can be a constant nagging presence, which inevitably takes a psychological toll.[16]

There is a considerable mental component to the return to run process. Being injured is no joke and the distress of being injured is then compounded by having to relearn how to run! This can be a difficult journey psychologically and emotionally. The runner persona is an important part of a person's identity, which can make it all the more crushing to be told that the reason they are injured is running technique. We can mitigate the impact by avoiding telling them that it is all their fault and making them feel inadequate! An important aspect of the coaching intervention and the return to run process will be instilling confidence and restoring their sense of self-efficacy.[16]

STRATEGIES TO MARSHALL RESOURCES AND MANAGE LIFESTYLE FACTORS

Contrary to the default assumption that running injuries stem from 'training errors', some in the field have started to recognise that injuries can arise because the runner's ability to tolerate their customary running training was compromised by non-training factors during the preceding period.[17] In such cases the injury stems from other external factors in the life of the individual that impair their ability to regenerate and recover as normal. Nutrition and sleep are critical pillars that support training and these will accordingly be key areas to address. More broadly we can highlight the need to develop strategies to manage work and life stress. In the context of their running training, we can help the runner by making them more aware of the impact of non-training stressors and helping them to become better able to adjust and self-regulate their running training during periods of stress, disrupted sleep, etc.

CONSOLIDATION

Whilst there is naturally considerable temptation to rush to return to their normal running routine, there is a great deal of benefit to providing a consolidation period to enable motor patterns to be fine-tuned and become better established. This is also a good opportunity to develop technical capability for faster running workouts and in particular the ability to regulate and modify foot strike strategy as appropriate for a range of running speeds. Likewise, the consolidation period provides an opportunity to expose the runner to various terrains so that they have an opportunity to learn how to adapt running coordination and devise strategies when running uphill, downhill and on different surfaces. Using quality as the criterion for weekly progression and providing a consolidation period also serve to progressively develop the runner's capability to maintain form under fatigue.

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Snell to sub two hour marathon: A kiwi commentary on sixty years of running

CHRIS MILNE

(Presented at the 2021 Sports Medicine New Zealand Annual Conference - The Running Athlete)

This article is based on a talk I gave in November 2021 at the Sports Medicine New Zealand Annual Conference with the theme, 'The Running Athlete'. It is a general overview of what I believe to be the most significant developments in running over the past six decades and I have emphasised that it is a personal view only. Also, it has unashamedly got a New Zealand bias, given that I am a staunch Kiwi from the Waikato and a proud supporter of the black singlet.

I would like to dedicate this article to a man I very much admired from afar as a young boy and was fortunate enough to collaborate with in later life. This was John Davies, who was what you could call a renaissance man. He was a top level middle distance runner winning the silver medal in the one mile at the Empire Games in Perth in 1962 and a bronze medal at the Tokyo Olympics in 1964. He then had troublesome Achilles tendons and retired from running to go cycling for a while and became a very successful coach of Dick Quax, Anne Audain and many others. Subsequently he became a sports administrator as a senior official within the New Zealand Amateur Athletic Association, as it was called, and a President of the New Zealand Olympic Committee. He was also on the board of the Auckland Commonwealth Games Company heading up to 1990. With his good friend and fellow athlete Dick Quax, he was a promoter of televised athletics meetings in the 1970's plus he wrote articles for the Metro magazine health column. I was fortunate enough to be asked to provide some assistance with those columns, which were invariably models of clarity and good advice. He was a benefactor setting up the Lovelock Davies Athletics Foundation. Probably what I will remember him most from though is his living of the Olympic ideals, and Pierre de Coubertin would have been proud of him I am sure.

You might ask what my credentials are for giving this lecture, so I will spell these out now. I have been an active distance runner since 1969 when my Year 8 intermediate school metalwork teacher introduced me to the sport. I grew up in Tokoroa with a population of under 20,000 and we produced bronze medalists in both the 1964 and 1968 Olympics. Then when I went to medical school in the 1970's, the University Club in Auckland was the strongest in New Zealand. Later in life I managed to run 2h 30m for a marathon and also 3m 58s for a downhill mile in Queen Street Auckland on the same day that Mike Boit ran 3m 28s, so you can see that I was well short of international class. However, being a busy physician, I have stuck with the strategy of maximum gain for minimal training load, which has meant that I have minimal arthritis at the age of 65.

So I am going to cover the history before moving on to trends and training regimes and then advances in running tracks. I will touch on advances in shoe technology before moving on to injury management and medical issues, although I will only cover these briefly. Then I will briefly discuss the role of running in popular culture and then give my own top ten memorable running moments before finishing with a bit of philosophy regarding what I love about running.

The history in the 1960's was dominated by Lydiard trained athletes with Halberg, Snell and McGee all winning medals at the Rome Olympics. Lydiard managed to instill a self-belief in his athletes that was second to none. Sir Murray Halberg, who was a senior runner at the time, tells a wonderful anecdote of himself and Snell sitting in the back of a car on their way to the finals at the Rome Olympics. Lydiard was in the back seat beside them. Lydiard talked to Halberg and said, 'You know you are going to win a gold medal in the 5000m this afternoon'. And then he turns to young Snell who was only 21 at the time and said, 'But you are going to beat him to it and get a gold medal in the 800m beforehand'. And so it proved to be. Snell went on to be the dominant runner of his age, and TV footage from his 1964 Olympic 1500m race, run on a cinder track shows what power he could generate. There were great clouds of cinders coming up behind as he powered away from the field to win by 10m. It is worth a look on YouTube. Also let's not forget Marise Chamberlain who won the Olympic bronze medal in the 800m for women. This is the longest event that women were deemed capable of at the time by the rather reactionary administrators of the sport. Then in 1968 at the Mexico Olympics at an altitude of 2240m, Mike Ryan a hard headed, gutsy Scottish immigrant ran himself into history with a bronze medal in the marathon. Many of the great non-African athletes failed miserably on that day.

We go onto the 1970's where Rod Dixon emerges to take bronze in the 1500m behind Pekka Vasala the Finn and the great Kip Keino. In 1974 New Zealand hosted the Commonwealth Games in Christchurch with a couple of memorable races. Firstly, Dick Tayler inspired a nation on the opening day of competition by winning the 10,000m and beating David Bedford the current world record holder in the process. Then on the last day of the games, in the 1500m, rising star John Walker just about caught the front running Filbert Bayi in one of the more exciting races you would ever see. We go forward to 1976 where a Walker/Bayi clash was expected again but the African nations boycotted these games. Walker had just won the 1500m in a pretty slow time and when asked about his emotion he described it as one of relief for 'not losing'. In the 5000m New Zealand had two world class athletes with Dick Quax and Rod Dixon but the race was won by Lasse Viren who took four gold medals in total winning the 5000m and 10,000m in 1972 and 1976. His ability to peak at the Olympics was legendary and people wondered about blood doping but he always claimed it was the reindeer milk. From my point of view, the reason that the New Zealand runners did well was that they were both converted mile runners so that when it came to the last lap of the 5000m they had more tactical options as they had a better sprint. I often wonder if Dick Quax who was about 5m off the pace at the beginning of the bell lap had been up where Rod Dixon was, whether he would have beaten Viren. He told me he didn't think so. He didn't think anybody would have beaten Viren that day. He would know.

We go forward to the 1980's and because of the Russian invasion of Afghanistan, America and a lot of its allies boycotted the Moscow games. A bit of familiar history with Afghanistan there. New Zealand runners were absent and against most people's expectations, the British runner Steve Ovett won the 800m and his compatriot Sebastian Coe, who was expected to win the 800m, went on and won the 1500m. Then in 1982 the Commonwealth Games came back close to home again to Brisbane. We saw the rise of New Zealand women's distance running with Anne Audain, Lorraine Moller and Diane Rodger featuring in first, third and fourth places in the 3000m and repeating the placings five days later in the 1500m. Then we pan forward to 1984 at the LA Olympics where women were finally allowed to run the marathon. Joan Benoit triumphed, so the Americans were very happy. Unfortunately, the event will be remembered mainly for the staggering attempt to finish by Gabriela Andersen-Schiess, who was clearly suffering heat exhaustion. The rules of competition forbade any assistance to her if she wanted to be registered as a finisher. In 1988 Ben Johnson from Canada ran himself into history and ignominy by winning the 100m and then being disqualified for doping a few days later. The Canadians were highly embarrassed and as an ethical country, set up the Dubin Inquiry to look into various aspects of doping. Also, in 1988 New Zealand hosted the World Cross Country Championships at Ellerslie Racecourse. My good friend, Tony Edwards, was charged with organising medical cover for the event so fellows like myself got a bit of a front row seat. We hosted one of my Welsh medical colleagues Roger Hackney, prior to the event and my wife's cooking may have helped him finish in the top ten. Certainly, it was the fittest I have ever been, hanging off his coattails.

A new decade in the 1990's and the Commonwealth Games come back to New Zealand being staged in Auckland. It was a swan song for John Walker with Peter Snell being given the honour of carrying the flame on the last part of its journey. In 1992 at the Barcelona Olympics we have the memorable feat of Lorraine Moller claiming bronze in the women's marathon. Then in 1996 at the Atlanta Olympics we recall the upright figure of Michael Johnson with his unique running style winning the men's 200m in world record time.

Into the new millennium and Nick Willis is the name to remember from this era, carrying on in the tradition of Lovelock, Snell and Walker in the 1500m, winning medals in both Commonwealth and Olympic games over a ten year span.

I am going to change tact now and talk about some running doctors. You can go right back to the 1924 Olympics in Paris where Sir Arthur Porritt, a New Zealand surgeon, finished third in the 100m and he later went on to a distinguished career as the Queen's surgeon, chef de mission of the New Zealand Olympic team and a seat in the House of Lords. Jack Lovelock won the 1500m in the 1936 Olympics in Berlin with some masterful tactics, and an oak tree given to him was planted at his old school Timaru Boys' High. Then we have Jack Sinclair, the inaugural Professor of Physiology at Auckland Medical School who got to the Auckland Empire Games in 1950 running 4m 13s for the mile off one training day per week. Things had moved on by the 1960's when Dave Gerrard's compatriot Peter Welsh, now an orthopaedic surgeon, won the 3000m steeplechase at the 1966 Commonwealth Games in Jamaica. Dave was making his mark in the pool also winning a gold medal in the butterfly. Another hard man from Otago, Chip Dunckley, was a legend around the running circuits in New Zealand and worked as a GP in North Otago. In more recent years, we've had John Hellemans, better known as a triathlete and coach who has made a great contribution to our athlete preparation as well as medical care.

Overseas, it is hard to look past the achievements of Sir Roger Bannister, who was the first man to break four minutes for the mile and later went on to edit Brains Clinical Neurology. Has there ever been a better name for a medical textbook? Then in the 1970's, we will remember Dr George Sheehan, who did much to popularise running in the US and came and spoke at our conference many years ago. More recent memories are of Professor Tim Noakes, who wrote the bible on running called 'The Lore of Running' and also gave generously of his time at our conference in 1999. In recent years we have had Dr Anthony Fauci who is still incredibly active professionally at age 80. Fortunately his science has outlasted the buffoon who was president of the USA who tried to undermine Dr Fauci, who I will not bother to name.

So moving on to the trends and training regime. The 1950's were dominated by interval training from the Swedish coaches and that of Franz Stampfl. Then in the 1960's we started the Lydiard era. Lydiard conducted a one man experiment on himself during the 1950's and came up with the magical figure of 100 miles per week to spend in training. What this did was build more capillarisation in the skeletal muscles and thereby enable greater endurance. Lydiard worked out that there were plenty of club runners who could run a 400m in under sixty seconds but very few of these who could string four of those together. When he put his ideas into practice with talented athletes, the results were dramatic as we have seen. Halberg, Snell, Davies and Barry Magee were some of his more prominent protégés. The Lydiard dictum prevailed until the 1980's when Bill Bowerman from the US and Peter Coe from England worked on refined periodisation with good effect, particularly with Peter's son Sebastian. Then we go forward to this millennium and it really is a story of the Kenyans and the Ethiopians dominating distance running. As I heard from one of the Kenyan coaches, the best preparation to be an Olympic champion distance runner is to be conceived, born, live and train at altitude and then come down to sea level and beat the pants off anybody else! That is what they have pretty much proceeded to do.

This leads nicely into a summary of the anatomy and physiology of the distance runner and the best term I have heard for this is 'pneumopod', which is a term I think I first heard at a Sports Medicine NZ conference more years ago than I care to remember. It literally means lungs on legs with a supporting circulatory system.

We also need to consider the advances in running tracks. When Roger Bannister first ran under four minutes for the mile it was on the Iffley Road Track in Oxford and you can see the plaque if you go there. Bannister was a medical student at St Mary's Hospital Paddington at the time. He was pretty diligent carrying out his ward round on the Saturday morning and then travelling up by train to Oxford. In the afternoon he became the first man to run a mile in under four minutes and set a world record. As you do.

The first synthetic tracks come along in the mid to late 60's and anybody who ran on a GrassTex track as we initially had at Porritt Stadium will recall that they were rock hard in winter and sticky in summer. Therefore there was a major advance when Tartan tracks came along in the 1970's and the current Mondo track is basically a refinement of the Tartan track. When you consider that Peter Snell was able to run 1m 44.3s for 800m on a grass track in the 1960's and that modern tracks are at least one second per lap quicker, it shows how impressive his achievements were.

Along with advances in running tracks, we have had advances in running shoe technology. In the 1960's we had some rock hard shoes made in New Zealand under the name Road King and there were a few imports from Adidas and Puma. Old fellows like me still remember the import licensing that was in place in New Zealand. To get running shoes in Auckland even in the mid 1970's, you had to rely on word of mouth that a shipment was in at Stenberg's or Stones in Auckland and dive in there before the bikie gang members got hold of the Adidas SL72 or SL76 which were the shoes of the day. John Walker got married to Helen Stenberg, so was probably well looked after in the shoe department!

Then in the 1970's Nike emerged from the shadow of Asics with their innovative waffle designs. If you want a good engrossing read about these times I recommend Phil Knight, the founder of Nike, and his book entitled 'Shoe Dog'. Nike stayed ahead of the game putting air sacs within the midsole to provide more cushioning. There was a further refinement from the Japanese firm Asics with the addition of gel as an impact shock absorber in place of the air. Fast forward to the present day and the benchmark competition shoe is once again made by Nike. It goes under the moniker Vaporfly (that is the American spelling).

We have also got to consider the role of podiatry. As well as shock absorption, running shoes should provide some motion control. The exact degree of this remains controversial but with medial tibial stress syndrome being an occupational hazard of many runners, jacking up the medial side of the foot has definite advantages.

I won't spend much time on injury management because these issues have been well covered in previous conferences. Suffice to say that the commonest problem would probably be patellofemoral knee pain which goes under the pseudonym, runner's knee, which shows how common an affliction it is. The Achilles tendons are another vulnerable area and the term Achilles Heel has become part of the lexicon indicating a point of weakness. Stress fractures of the lower limb and pelvis have a complex etiology, but it usually revolves around suboptimal biomechanics combined with an excess training load and suboptimal bone health. Once again, these issues were very fully canvassed by other speakers, particularly Dr Sarah Beable.

Medical issues should not be overlooked I will touch on a few of these. The advice regarding hydration during events has evolved from when the British marathon runner Jim Peters staggered around the track in the Vancouver Empire Games in

1954, having been told not to drink at all during the event. Naturally enough the pendulum then swung the other way and American commercialism came to the fore, as it often does. Sports drinks companies aggressively promoted a strategy of over hydration and the American College of Sports Medicine actively endorsed this with position statements. It took some people from the old commonwealth, such as Tim Noakes and our own Ben Speedy to question this perceived wisdom, and the current dogma is now to start the event well hydrated and to drink to thirst during the event. This is a much more rational approach.

Fatigue and over training is a huge topic which has again been well covered and the female athlete triad is now renamed Relative Energy Deficiency in Sport. This is the subject of a Master Class by our own Sarah Beable. I will touch briefly on the cardiac issue because in the 1960's heart attack patients were routinely put to bed for several weeks. This is despite Jerry Morris' study from the London bus driver's versus conductors in 1953 showing that more active ticket taking conductors going up and down the stairs in London buses had a lower incidence of coronary disease. Then Bernard Lown in the US and Bengt Saltin in Europe showed the benefit of exercise post myocardial infarct. In New Zealand the Greenlane cardiologists got together with Maurie Rendle from the Auckland YMCA and Colin Kay, local body politician, and promoted the idea. However, not all exercise is benign and with cardiac remodeling some athletes develop atrial fibrillation in later life. Fortunately we have modern strategies such as ablation therapy (or spot welding of the aberrant conduction system) to deal with that. Acute myocarditis is a much feared condition but is actually quite rare. It has recently come into prominence as it is a known complication of COVID-19 infection. Fortunately the COVID vaccine is very effective at minimising the sequelae of COVID infection.

Running has been a feature of human history ever since men had to go out and hunt lunch and dinner. In the 1960's the jogging revolution pioneered by Arthur Lydiard really took off and in the 1970's Jim Fixx's 'Complete Book of Running' added to that. The general populace began to be involved in major fun runs in the big cities, and big city marathons also took off. We should also note the growth in Master's sport. The World Masters' Games in Auckland in 2017 attracted some 28,000 athletes of whom a fair few were runners.

These runners, however, are often weekend warriors that are poorly conditioned and may have concurrent medical problems. It was Martin Schwellnus, the spiritual successor to Tim Noakes from South Africa, who first alerted us to these important issues and the challenges they provide for event medical staff.

I will conclude with some memorable running events and these are my top ten in relative chronological order.

1. 1964, Snell and Davies winning the gold and bronze in the Tokyo Olympics 1500m
2. 1976 Walker winning the Montreal Olympics 1500m
3. 1976 Quax and Dixon coming 2nd and 4th in the Montreal Olympics 5000m
4. 1981 and 1983 Allison Roe and Rod Dixon winning the Women's and Men's sections of the New Your Marathon
5. 1988 Ben Johnson winning the Seoul Olympics 100m before being disqualified for doping
6. 1992 Lorraine Muller winning the bronze medal in the marathon at Barcelona Olympics
7. At the Sydney Olympics, Haile Gebreselassie and Paul Tergat fought out a memorable 10,000m and Kathy Freeman won the 400m in epic fashion wearing a full length running suit
8. Beijing Olympics, Nick Willis, winning a bronze medal in the 1500m subsequently upgraded to silver
9. At the 2012 London Olympics, watching David Rudisha win the 800m in world record time in front of his idol, Sebastian Coe who helped bring the Olympic Games to London, was a special treat
10. At the Rio Olympics watching Usain Bolt sign off his career with wins in the 100m and 200m was also pretty special

I will give you a few thoughts on what I love about running. Firstly it is a basic primeval activity, i.e. an expression of our bipedalism. For the runner, it is an efficient activity both time and equipment-wise compared with activities such as going sailing or rowing or skiing where the time taken to get to the activity and set up the equipment often exceeds the time spent in training. It also has health benefits allowing for a little more dietary indiscretion, although as one wise person once said, 'You cannot outrun a bad diet'. Most importantly for me, is the opportunity to free associate, look at things objectively and do a little strategic thinking. And let's not forget the people you meet and the places you can experience close up. I have run across the Sydney Harbour Bridge and halfway up Table Mountain in Capetown plus over the hills in San Francisco and around Diamond Head in Honolulu. In our own country, running up the side of Mt Kaukau in Wellington with Roger Robinson and the Victoria University club mates of his remains a special memory. It really has been a wonderful sport to be involved in.

So now we come to the finish line and it shouldn't surprise you that the first sub two hour marathon was run by a Kenyan. From the runner's point of view we need to note that this was a paced event so was not regarded as a proper race. One thing I can attest to is the spring in your step that you get from the Nike Vaporfly shoes. As a runner now approaching 80kg, I feel at least 10kg lighter running in these shoes. Hopefully they will enable these aging joints to put up with a few more years of running as there is still plenty I want to get out of this wonderful sport.

Presented at the 2021 Sports Medicine New Zealand Annual Conference "The Running Athlete", held on-line 29/30 October

(In Order of Presentation)

LOW ENERGY AVAILABILITY IN ELITE FEMALE ROWERS IMPROVES WITH AWARENESS, EDUCATION AND NUTRITIONAL COACHING

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Low energy availability is common in sport and is part of the well recognised syndrome relative energy deficiency in sport (RED-S) that results in an impairment of athlete's health and performance.[1,2] Rowing New Zealand (RNZ) elite athletes have an increased risk of LEA considering their large training loads and high energy requirements in a culture that strives for a perceived optimal body composition to improve performance.

In 2018 we assessed the energy availability (EA) of elite female summer squad rowers and its association with bone health and examined the validity of the low energy availability in female (LEAF)[3] and brief eating disorder in athletes (BEDA)[4] screening questionnaires in the elite rowing population. This project was repeated in 2020 to assess the effect of group education, discussion and individualised nutrition coaching.

All 25 elite female rowers (19-31 years) of the NZ summer squad participated in the study in 2018 and 21 of these athletes were still involved in the elite program and followed up in 2020. EA was calculated by means of a 4-day food diary and analysis of training logs during an intense training block and athletes were identified as LEA when EA <30 kCal * kg^{-1} * FFM^{-1} * day^{-1}. Body composition scan (DEXA) was performed to assess fat free mass (FFM) and bone mineral density (BMD). LEA risk and disordered eating habits were assessed by completion of the LEAF- (2018 and 2020) and BEDA-questionnaires (2018).

Although prevalence of LEA in elite female rowers was high in 2018 (64%), bone health was 1.6 standard deviations higher than their age-group peers. Athletes with LEA had a significantly higher BEDA-Q score (mean 5.4 ± SD 3.1, 1.4 ± 1.8, $p < 0.05$), whereas the LEAF-Q score showed no correlation (mean 10.4 ± SD 4.6, 8.2 ± 4.5, $p = 0.29$). The EA of the 2020 female summer squad had greatly improved since 2018 to a LEA prevalence of only 10% (mean EA 22.9 12.7 to 40.2 12.1 kCal * kg^{-1} * FFM^{-1} * day^{-1}, $p < 0.001$), as well as their LEAF-Q gastrointestinal symptom score (2.6 1.6 to 1.5 1.5, $p < 0.05$). With an increase in EA, the mean body fat percentage reduced, and lean mass increased from 54.7 3.4 to 56.3 3.4 kg ($p < 0.001$).

Increasing athlete awareness of LEA and its effect on health and performance, providing education and discussion groups to explore barriers to change and individualised nutritional consultations improved the overall EA of Rowing New Zealand's female athletes and their subjective symptom scores and potentially contributed to the success at the Tokyo Olympic Games. This provides a template for other sporting organisations to analyse and improve the energy availability of their female athletes.

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USING A WEARABLE SENSOR TO MEASURE GROUND CONTACT PARAMETERS TO DETERMINE RUNNING EFFICIENCY

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This study investigates a novel running efficiency (RE) measurement solution in two runner environments. We developed an RE algorithm combining key running metrics, measured by wearable sensor technology, which enables real-time feedback in a non-clinical setting, for improved runner efficiency and performance.

Factors known to influence running efficiency include ground reaction force components, vertical leg spring stiffness, stride length, ground contact time and centre of mass velocity variance. Runner efficiency is dependent on the ability to "carry" the peak velocity attained during the flight phase of gait through the ground contact phase with as minimal additional energy expenditure as possible.

We propose that these factors may be combined to determine running efficiency. This RE metric combines, ground reaction force collisional angles, ground contact time and peak velocity of the centre of mass.

A sensor pod was designed to test the proposed RE algorithm. This consists of a Nordic Semiconductor NRF52832 Bluetooth LE system with High and Low G triaxial accelerometers and a triaxial gyroscope running embedded code developed in C++. The electronics were contained in a 3D printed sensor module housing and included a flexible strap system for attachment to the test subject's distal tibia.

Two participant studies were undertaken. The first analysed the consistency and reliability of the sensor data output in ten participants, treadmill running in a lab setting, over two separate time/speed conditions wearing the same Asics Dynaflyte3 running shoe model. The second study analysed a single subject, running on the road, under controlled condition parameters. We compared the resultant data gathered from two different models of Asics shoes, Dynaflyte3 and Evoride.

Results of the comparison study demonstrated that our implementation of the algorithm produced results that matched expected values across all runners. Captured step by step values were consistent in the context of speed and technique and raw data variance between runners was clearly identified.

In the single subject study, the results demonstrated variance in the RE between footwear conditions. The ASICS EVORIDE returned a lower value for both downhill (11.08% RE gain) and level running (17.68% RE gain). Across the total study period EVORIDE recorded a 10.84% gain in RE. In real terms this this was reflected in an average 28 second time improvement for the 10Km run with less energy expenditure.

This study provides a view that a RE figure for an athlete can be determined by a metric which looks at the relationship between runner velocity, ground contact times and ground contact collision forces.

Typically, running efficiency is not measurable outside of a laboratory setting due to the requirement for VO2, ground reaction and video gait measurement systems. While many strategies for gait retraining have been identified to improve RE, there has been no reliable way to determine if technique modification improves RE outside of the lab. The RE metric and associated sensor technology studied provides a potential means of addressing RE in the real-world setting.

UTILITY OF MRI VIBE SEQUENCES AND BONE MARROW OEDEMA (BMO) IN THE PREVENTION, DIAGNOSIS AND MANAGEMENT OF LUMBAR STRESS FRACTURES.

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Our understanding of the utility of MRI for the surveillance, diagnosis and management of lumbar stress fractures has advanced recently.

In particular, use of the MRI VIBE sequence and the implications of bone marrow oedema (BMO) on STIR sequences continues to be studied.

BMO has been shown to precede lumbar stress injury diagnosis in junior elite cricket fast bowlers (1) making it a potential reliable radiological marker of early bone stress while players are asymptomatic. Thus the potential ability to prevent season ending injuries before they o ccur exists. Understanding the sensivity and specificity of this radiological marker is required before this potential is realised.

Published studies have also confirmed the diagnostic accuracy of MRI VIBE compared with CT in pars stress fractures (2). This provides an option to not only diagnose but also monitor fracture healing free of ionizing radiation. Using a combination of BMO and MRI VIBE may provide a more individualised way of monitoring a players progress through rehabilitation and help return to play decisions.

This presentation aims to update and promote discussion by pre senting the current opinion of an Orthopaedic spine surgeon working in collaboration with New Zealand Cricket and Cricket Australia.

1 MRI bone marrow oedema precedes lumbar bone stress injury diagnosis in junior elite cricket fast bowlers. A Kountouris et al. Br J Sport Med 2018

2 Diagnostic accuracy of 3-T magnetic resonance imaging with 3D T1 VIBE versus computer tomography in pars stress fracture of the lumbar spine. E. C. Ang et al. Skeletal Radiology, November 2016, Vol. 45 (11), pp 1533-1540

SURGICAL REPAIR OF RECURRENT LUMBAR STRESS FRACTURES: INDICATIONS, TECHNIQUES AND OUTCOMES (IN PROFESSIONAL CRICKETERS)

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The physical demands on athletes are well recognised to result in high rates of lumbar stress injuries, particularly in cricket fast bowlers. While the vast majority are successfully managed conservatively, a minority develop recurrent acute or chronic symptomatic pars defects. Whether these scenarios are appropriate for surgical intervention, in order to achieve more robust and durable healing, is often considered.

The results of surgical repair of lumbar stress fractures in a cohort of professional multinational cricketers will be presented. This will provide a reference to discuss appropriate surgical indications, techniques available and the outcomes expected following repair of lumbar stress fractures in athletes.

Methods
Between 2004 and 2019 a consecutive series of male professional fast bowlers with lumbar stress fractures who had repeatedly failed conservative treatment and received surgical repair were reviewed. Analysis comprised of ambispective outcome and radiological data collection and a survey at final follow-up.

Results
The cohort included 13 elite (state and international) cricket fast bowlers from three countries (NZ, Australia and India) with an average age of 26 years. All returned to play professional cricket at a median time of 8 months (IQR, 7-11 months), 12 performing at the same level or better than prior to surgery. All ten players surveyed at final follow-up rated their bowling performance post-surgery as the same or better than prior and reported durability post-surgery with no subsequent periods sidelined by significant spinal injuries or further surgical intervention necessary.

Conclusion

Our results demonstrated favorable return to play rates and career longevity following surgical repair of spondylolysis in professional cricketers. To our knowledge it is the largest published surgical series of spondylolysis repair in cricketers. Published results from other sporting cohorts will be compared and surgical indications for lumbar stress fractures in athletes discussed.

References:

Surgical repair of lumbar stress fractures in professional cricketers. Rowan Schouten, Dayle Shackel, Grahame Inglis. J Spine Surg. 2021.

PRACTICAL LEARNINGS FROM VIDEO ANALAYSIS OF ANTERIOR CRUCIATE LIGAMENT INJURIES IN NETBALL

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Introduction

Anterior Cruciate Ligament (ACL) injuries are common in team sports, particularly amongst females. Analysing video footage of ACL injuries as they occur during televised games, offers an insight into the behaviours and mechanism that lead to injury. These insights then offer practical learnings for coaches, sports professionals, and players alike on how to reduce the future risk of injury.

Design and Method

A systematic video analysis of 21 anterior cruciate ligament (ACL) injuries sustained by elite-level netball players during televised games. The study describes the situation, movement pattern and player behaviour surrounding the injury. A group of experts including two physiotherapists, one orthopaedic surgeon, one retired international player/high-level netball coach and one strength and conditioning coach met and viewed all videos.

Findings

Seventeen (81%) of the ACL injuries occurred from jump-landing actions and only two (10%) from cutting manoeuvres. A common scenario was identified for 10 players (See **figure 1**). In this scenario players were decelerating rapidly after jumping to receive a high pass, utilising a double-footed landing with a wide base of support (WBOS). Deceleration appeared to be applied predominantly via the injured leg with the knee extended and foot planted. Often the players were unbalanced on landing with their centre of mass (COM) posterior to their base of support. ACL injury risk was likely further exacerbated by a counter action-reaction torque, with the head being turned away from the injured limb. Commonly, a pass was received high and then brought low (below pelvic level), likely placing further compression and/or sheer forces through the injured limb.

Implications

1) Players may benefit from landing technique training programmes that encourage shoulder-width foot landings, with ≥30° knee flexion, a small amount of plantar-flexion and their COM over their toes. 2) Incorporating challenges to players balance and ability to cope with perturbation, may also be beneficial. 3) Training programmes should include instruction on securing the ball in a safe neutral chest position after receiving a pass and bringing their whole body around during landing into the direction of their next pass, rather than simply turning their head to look.

Keywords: Sports injury, Netball, Knee, female athletes, Motion-analysis

Figure 1. Common scenario for ACL injury mechanism

Fig 1. (a): Running at medium/high intensity to receive pass. (b): Player performs a jump reaching high to receive the pass. (c): Player is bringing the ball down, their COM is too posterior, preparing for rapid deceleration and turning their head 45-90° away from their injured limb, looking towards their teammate for the next pass. (d): Player has landed with a WBOS, with their COM too posterior, their injured right knee is the second to touch-down and has been used as the predominate breaking force, with an extended knee and their foot planted flat. They have kept their head rotated 45-90° away from the injured side, bringing the ball low over their injured knee.

KNOWLEDGE AND ATTITUDES TO THE MENSTRUAL CYCLE IN THE SPORTS MEDICINE ENVIRONMENT: A QUALITATIVE STUDY EXPLORING THE PERCEPTIONS OF ORTHOPAEDIC SURGEONS, PHYSIOTHERAPISTS, FEMALE ATHLETES, AND ACL PATIENTS IN AOTEAROA

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Objective

To explore key members of the sports medicine community's knowledge of the menstrual cycle, comfort discussing the menstrual cycle, and cultural beliefs or practices in female elite athletes.

Methods

Qualitative study. Semi-structured focus group sessions with orthopaedic surgeons, sports physiotherapists, ACL patients, and athletes (n=18). Focus groups were transcribed verbatim and analysed using six- phase reflexive thematic analysis.

Results

The menstrual cycle was noted to be previously perceived as a taboo subject. Health professionals, patients, and athletes report a lack of structured education regarding the menstrual cycle. Menstrual cycle tracking is commonplace at an individual level by patients, athletes, and female physiotherapists. However, utilisation of this information is seen as "the icing on the cake" or for areas with more resources, such as a high-performance sport environment. Most health professionals, patients, and athletes reported feeling generally comfortable discussing the menstrual cycle. However, many individual factors such as age, gender, and culture of the clinician and the patient were identified as barriers to discussing the menstrual cycle in the sports medicine clinic. Surgeons and physiotherapists reported using pre-screening tools and questionnaires to commence the conversation. Furthermore, developing trust before initiating the conversation was identified as a facilitator to an open conversation regarding the menstrual cycle. Patients' culture was perceived as an additional consideration to consider by surgeons and physiotherapists when discussing the menstrual cycle.

Conclusion

Participants revealed they sometimes feel uncomfortable discussing the menstrual cycle in a clinical setting. Participants identified a need and want for further education regarding the menstrual cycle. Screening tools and questions were identified as facilitators to open and frank discussions regarding the menstrual cycle. Athletes and patients do not usually see the menstrual cycle as a topic associated with sports medicine and musculoskeletal injuries. Researchers and clinicians should be cognisant of a person's cultural perspective and background when discussing the menstrual cycle.

ORAL IRON SUPPLEMENTATION: IS IT TIME TO REVIEW OUR MANAGEMENT OF ENDURANCE ATHLETES WITH IRON-DEFICIENCY NON-ANAEMIA?

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The role of maintaining iron status in exercise performance has long been topical, and particularly challenging in the endurance athlete population. Whilst it is well established that severe iron deficiency and anaemia are detrimental to an athlete's health and performance outcomes, the discussion remains surrounding the role and benefit of iron supplementation in athlete populations who are iron deficient, but are not anaemic (i.e. iron-deficiency non anaemia (IDNA).

This talk aims to present the salient findings of a research review conducted on the role of oral iron supplementation in influencing performance outcomes in the IDNA endurance athlete population. In particular, exploring the role of supplementation in the maintenance of serum ferritin levels in training and competition, summarising key dosing strategies, and novel methods for enhancing iron absorption and uptake. Methods for mitigating enteric side effects, natural bioavailable equivalents, and routine recommendations for iron blood screening will also be covered.

Key conclusions:

- Routine monitoring of iron and haemoglobin status is important for maintaining an athlete's health and improving performance. Screening frequency should be based upon an athlete's medical history and risk factors for iron deficiency anaemia.
- Iron supplementation should be considered for prolonged competition phases, and prior to altitude exposure for the prevention of deficiencies, and improving performance gains.[2,5]
- Consider alternate day dosing for the mitigation of gastrointestinal side effects.[3]
- Concurrent consumption of iron absorbing enhancers such as ascorbic acid and probiotics.[1] may increase serum iron uptake.
- Morning dosing prior to exercise may increase uptake response and attenuate the effects of the hepcidin response.[4]
- No concrete evidence suggests that IDNA impairs oxidative capacity, however supplementation may offer returns in improving cognitive and immune function, and mitigate perceptions of lethargy and offer benefits through these means in performance gains.

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