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Use of Heart Rate Monitoring to Manage Training Loads and Assess Injury Risk in Male University Soccer Players

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Abstract

Introduction: *Injuries are a common occurrence in team sports and have negative consequences on team success. As sudden increases and decreases in training loads increase injury likelihood, monitoring training loads is essential. The acute:chronic workload ratio has been established as a useful tool for identifying periods of increased injury likelihood. Markers such as the session Rating of Perceived Exertion (sRPE) and GPS-based indices are commonly used variables when calculating acute:chronic workload ratios. To date no work has been presented involving heart rate-based measurements. The goal of this research project was to investigate the use of heart rate monitoring to manage training loads and assess injury likelihood in university soccer players.*

Methods: Training load measures from fourteen university male soccer players were collected over a period of seven weeks. Three heart-rate based measurements were monitored including Bannister's TRIMP, Morton's TRIMP and Stagno TRIMP. sRPEs were also measured and acute:chronic workload ratios were calculated for each monitored variable. A total of 256 individual training observations were collected from 22 training sessions with a mean duration of 85 minutes.

Results: Results demonstrated that using the acute:chronic workload ratio for heart rate-based training loads such as Bannister's Training Impulse accurately explained variation in injury likelihood (R^2=0.86-0.89).

Conclusion: The results of this study suggest that monitoring of acute:chronic workload ratios using HR indices such as Bannister's TRIMP or Stagno TRIMP appears to be a practical method to assess injury likelihood in male university soccer players.

Keywords: *football, sRPE, Bannister's TRIMP, morton's TRIMP, stagno TRIMP*

Background

Soccer is a high intensity intermittent team sport that comprised of both anaerobic and aerobic components which requires players to be physically skilled, technically proficient and tactical to succeed [1]. The purpose of practice sessions in soccer is to provide a stimulus, which is quantified as a training load, adequately preparing a team for optimal performance during competition [2]. Training loads have been defined as the product of volume and intensity training [3] and are categorized into internal loads (psychological, physiological stress) and external loads (physical stimuli) [1]. When a load is applied onto players, they will experience a certain amount of metabolic, neuromuscular or mental fatigue, temporarily reducing performance and increasing their injury risk [4]. It has been shown that the inappropriate management of these training loads is one of the main risk factors in non-contact injuries [2]. Therefore, it is a crucial aspect of coaches' and sports scientists' duties to find a balance between insufficient and excessive training loads in order to maximize positive performance factors. Modern training methods require the use of a periodization strategy guiding the timing, sequencing and prescription of training in an effort to achieve targeted performance levels at a given point in time.

Central to this task is the accurate quantification of training loads [3]. Recently, research has focused on several methods to assess training loads (internal and external) in field sports; the most common ones involve using objective measurements such as GPS devices [4] or heart rate (HR) monitors [6], as well as subjective measurements such as the session rating of perceived exertion (sRPE) [6]. HR monitoring is favored in endurance sports as it is an objective measure of the relative exercise intensity during continuous and submaximal work [3]. Despite the intermittent nature of soccer [7], heart rate-based training impulses (TRIMP) like Banister's TRIMP [8], Morton's TRIMP [9] and Stagno's TRIMP [10] have previously been used to quantify the load accumulated by soccer players [11].

For the use of professional teams, training load monitoring has therefore been expanded as a means to model the relationship between training load and injury risk [12]. The acute:chronic workload ratio has increasingly been used to assess an athlete's injury risk and readiness levels [13]. It is defined as the ratio of an athlete's current workload (ie, acute; rolling 7-day average workload) to the mean of the workload that an athlete has been prepared for (ie, chronic, rolling 28-day average workload). Based on early research by Banister et al [11], the acute:chronic workload ratio is likened to the popular fitness-fatigue model, where the chronic load is analogous to a state of 'fitness' and the acute load is analogous to a state of 'fatigue'. To date, numerous studies have investigated the acute:chronic workload ratio using GPS-derived training load variables and the sRPE variable [7]. However, the relationships between different acute:chronic workload ratio time windows are yet to be explored using HR-derived training load variables.

Objectives

The aim of this study was to identify which combination of workload variable and acute:chronic workload ratio time window (chronic, varying from rolling 14-day workload to rolling 28-day workload) best explained the variation in injury likelihood in competitive soccer players.

Materials and Methods

Participants

Fourteen (14) male university soccer players (age 20.5 ± 1.34 years; height 177.62 ± 5.32 cm; body mass: 75.62 ± 7.15 Kg) from the Réseau du Sport Étudiant du Québec University League in Canada took part in the study. The 14 players consisted of 3 defenders, 8 midfielders and 3 forwards. All participants were given a full written and verbal explanation of the study and were required to complete a written informed consent form, in accordance with the Declaration of Helsinki. This study was approved by Concordia University's Ethics Committee.

Training sessions and competitive matches

A total of 256 individual observations were collected from 22 training sessions with a mean duration of 85 minutes. The team would usually play their competitive fixtures on Fridays and Sundays and practice on Tuesdays, Wednesdays and Thursdays. The players had rest days on Mondays and Saturdays. The team played 12 league matches over the 7-week period. (Figure 1) details the timeline of the research project.

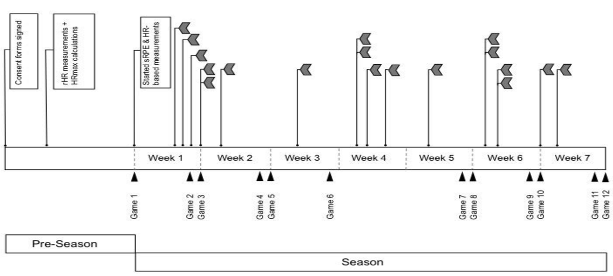


Figure 1: *Study timeline including grey flags account for injury occurrence.*

Heart rate

Prior to the start of the training period, players performed a laboratory test to determine resting heart rate. They were instructed to wear tablePolar H7 heart rate monitors (Polar Indoor Team System, Polar Electro Oy, Kempele, Finland) and lie supine for 15 minutes in the morning. The lowest 5-second heart rate measured was used as resting HR. HRmax was then calculated for each athlete using the Nikolaidis et al. equation [14]. During all practice sessions, HR was recorded via a short-range telemetry system with a Polar H7 heart rate monitor. Each player wore the same monitoring devices each time they were assessed.

$\Delta HR\ ratio = (HRex - HRrest)/\ (HRmax - HRrest)$
HRex is average heart rate of the exercise session. HRrest indicates resting heart rate HRmax is maximal heart rate.

Training Impulse (TRIMP)

Three HR-based measurements were analyzed including Bannister's TRIMP [8], Morton's TRIMP [9] and Stagno TRIMP [10]. These measurements were used as objective values to quantify internal training loads. Bannister's, Morton's and Stagno's TRIMPS were analyzed in "same week" and "subsequent week" blocks.

Bannister's TRIMP is calculated as the length of the session (in minutes) multiplied by an intensity factor which is defined differently for male and female subjects. The Bannister's TRIMP weighs the duration using a weighting factor according to the following formula in (Table 1). Morton's TRIMP is a variation of Bannister's TRIMP, where a greater weight is given to high-intensity training [9]. Stagno's TRIMP is a recent modified version of Bannister's TRIMP [10].

Table 1: *Summary of player demographics including position played, age, resting heart rate, maximum heart rate, height and body mass.*

	Age (yrs)	HR Rest (bpm)	HR Max (bpm)	Height (cm)	Body mass (kg)
Mean ± SD	20.5 ± 1.3	55.6 ± 6.2	197.2 ± 0.9	177.6 ± 5.3	75.6 ± 7.2

Yrs: Years, bpm: Beats Per Minute, cm: Centimetres, kg: Kilograms, SD: Standard Deviation

Rating of Perceived Exertion (RPE)

Within 30 min after the end of each practice session, players completed a Borg's Category Ratio-10 RPE questionnaire [7]. Players were familiarized with the scale and provided with standardized anchoring procedures before the start of the study. Session rating of perceived exertion (sRPE) was determined by multiplying the practice duration in minutes with the assessed RPE [6]. This determined a measurement of subjective internal training loads.

Injuries

For the purpose of this study, injuries were defined as all acute and chronic non-contact, soft tissue injuries, including illness [2]. Injury lists were updated and maintained by the team's senior athletic therapist.

Acute: chronic workload ratio

Data were categorized into weekly blocks from Monday to Sunday. For Bannister's TRIMP, Morton's TRIMP, Stagno TRIMP and sRPE, one-week totals were calculated and represented the acute workload for each training load variable. Chronic workload was calculated and distributed in 3 different ways – as 2-week, 3-week and 4-week rolling average acute workloads. The acute:chronic ratio was then calculated by dividing the acute workload by the chronic workload. This provided the relative size of acute workload compared with chronic workload. This allowed for an investigation into the effects of varying the acute and chronic time windows on the ability of the acute:chronic workload ratio to inform injury risk.

Data analysis

For each combination of chronic time window and load variable, acute:chronic workload ratio was calculated for each player. Workload ratios were binned into 6 quantile groups and injury likelihood in each bin was calculated as the proportion of training sessions resulting in injury either during the same or consequent week [21]. All figures were produced using the same quantile bins for clarity of presentation.

Workload ratios were modelled against injury risk using a quadratic regression [15]. The independent variable was taken to be the mean of workload ratios within each bin and the associated injury likelihood was the dependent variable. The ability of each workload ratio to explain injury likelihood was assessed using the R2 statistic. All models were created using GraphPad Prism (version 7.0d for Mac OS X, GraphPad Software, La Jolla California USA, www.graphpad.com).

Results

Injuries

Injuries over the last 5 weeks of the season, reported by the senior head athletic therapist, are listed in (Table 2). This study excluded injuries occurring during the first 2 weeks of the season as they were irrelevant to acute:chronic workload ratio calculations. Injuries included: 3 hip flexor strains, 4 occurrences of sickness, 2 patellar tendinitises and 3 groin strains for a total of 12 non-contact soft-tissue injuries and illnesses (Table 3).

Training load variables

The data collected and displayed in (Table 4) shows that during practices the players had an average RPE of 6.1 AU (±0.3), an average sRPE of 1 596.8 AU (±410.0), and an average exercise HR of 137bpm (±2.5). The different HR indices averaged at 93 AU (±11.3), 56.9 AU (±7.0) and 394.7 AU (±48.0) for Bannister's TRIMP, Stagno TRIMP and Morton's TRIMP respectively. The variations in the respective TRIMPs over the season are shown in (Figure 2).

Acute:chronic workload ratio and injury risk

Morton's TRIMP, being an exponentiated version of Bannister's TRIMP, was excluded from the acute:chronic workload ratio analysis due to the replication of results that Bannister's TRIMP provides. (Figures 3,4) show the best performing (highest R2) risk models for each acute:chronic workload ratio time window.

Table 2: *Equations of Bannister's, Morton's and Stagno's TRaining IMPulse (TRIMP).*

Bannister's TRIMP	D * (factor A * ΔHR * exp (factor B * ΔHR))	D = duration of training session (min)
Morton's TRIMP	D * ΔHR * 2.718 * exp (factor B * ΔHR)	Factor A= 0.64
Stagno TRIMP	D * ΔHR * 0.1225 * exp (3.9434 * ΔHR)	Factor B= 1.92

Table 3: *Injury Report*

Injury	Hip Flexor Strain	Sickness	Patellar Tendinitis	Groin Strain	Total
Occurrence	3	4	2	3	12

Table 4: *Summary of variables measured and calculated, including RPE, sRPE, HRex, Bannister's TRIMP, Morton's TRIMP and Stagno TRIMP. Mean values are reported as Mean ± Standard Deviation.*

Week	RPE (Au)	sRPE (Au)	HRex (bpm)	Bannister (AU)	Morton (AU)	Stagno (AU)
1	6.5	2 028	135.67	106.67	452.33	63
2	6	1 720	134.67	93	395.33	54.33
3	5.8	1 360	136	77.33	328.67	45.67
4	5.8	1 917	137.5	86.75	368	55.5
5	6.5	1 885	139.33	108.67	461.33	67
6	6.3	872	142	93	393.67	59.67
7	5.8	1 395	136.67	85.67	363.67	53
	6.1 ± 0.3	1 596.8 ± 410.0	137.0 ± 2.5	93.0 ± 11.3	394.7 ± 48.0	56.9 ± 7.0

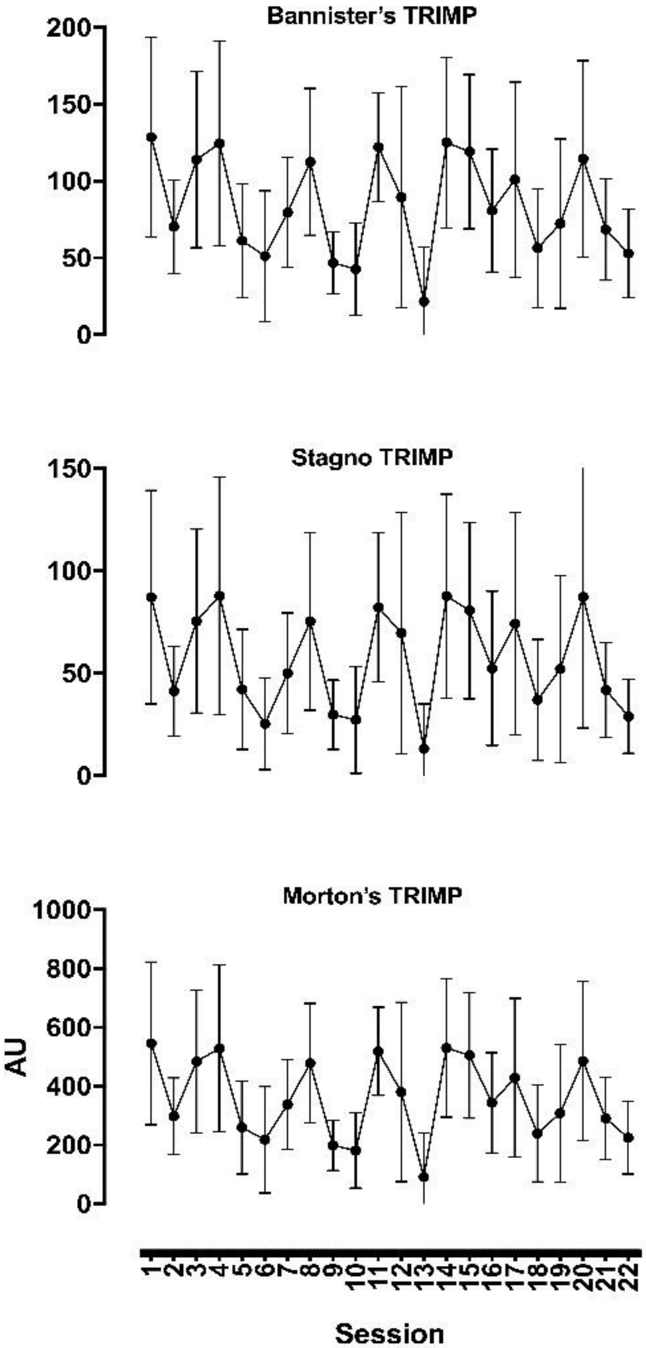


Figure 2: Frequency polygon of variations of Bannister's TRIMP, Stagno TRIMP and Morton's TRIMP over the course of the season.

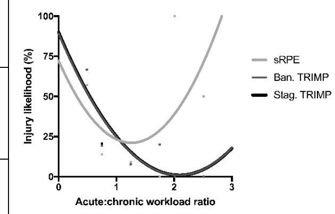
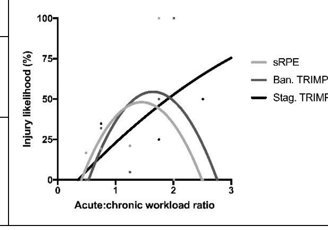
Injury Occurred	Rank	Workload Variable	R^2	
Same Week	1	Stagno TRIMP	0.74	
	2	BannisterTRIMP	0.72	
	3	sRPE	0.22	
Subsequent Week	1	Stagno TRIMP	0.40	
	2	BannisterTRIMP	0.34	
	3	sRPE	0.27	

***Figure 3:** Injury likelihood profiles of the top three performing workload variables for explaining injuries occurred during the same week and subsequent week using 2-week rolling average Acute:Chronic Workload Ratio*

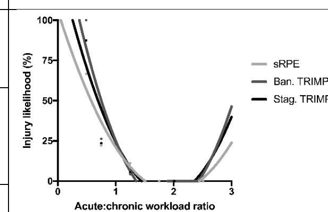
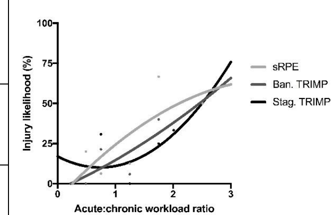
Injury Occurred	Rank	Workload Variable	R^2	
Same Week	1	Stagno TRIMP	0.89	
	2	BannisterTRIMP	0.85	
	3	sRPE	0.85	
Subsequent Week	1	Stagno TRIMP	0.76	
	2	BannisterTRIMP	0.62	
	3	sRPE	0.56	

***Figure 4:** Injury likelihood profiles of the top three performing workload variables for explaining injuries occurred during same week and subsequent week using 3-week rolling average Acute:Chronic Workload Ratio*

Discussion

This is the first study to investigate injury risk relative to HR-derived acute and chronic workloads in university soccer players. The top 3 HR-derived acute and chronic workloads included: same week injury Stagno TRIMP 4-week rolling average acute:chronic workload ratio (R2 = 0.89), same week injury Bannister TRIMP 4-week rolling average acute:chronic workload ratio (R2 = 0.87) and subsequent week Bannister TRIMP 4-week rolling average acute:chronic workload ratio (R2 = 0.86). These HR-derived acute:chronic workloads were able to explain 86 to 89 percent of the variation in the outcome (injury likelihood). This was similar to the sRPE variable, which was able to explain 84 to 97 percent of the variation in outcome within the same acute:chronic time window. Previous studies have found the sRPE variable to be effective in explaining injury risk outcomes within the same acute:chronic time window for Australian football [13] and rugby players [2]. In this context, HR-derived variables therefore become a potential tool to assess injury risk in male university varsity soccer players when using the 4-week rolling average acute:chronic time window.

Overall, the injury likelihood profiles in (Figures 3,4) have consistent shapes compared to previous findings [12,15]. The HR-derived 2-week, 3-week and 4-week acute:chronic time windows were all effective in explaining variation in injury likelihood. This study had a high accuracy ($R2 = 0.72$ and 0.74) in assessing injury risk when using the HR-derived acute and chronic workload ratios in a shorter time window (same week injury, 2-week rolling average acute:chronic time window). Similar results were observed by Carey et al. [13]. using GPS-derived variables in a sample of professional Australian football players. This novel finding provides a more practical application for strength and conditioning professionals as well as sports scientists to consider when monitoring HR-derived training loads within a University setting, which usually comprises of short duration seasons and the necessity for time-sensitive solutions.

This study showed that injury risk increases as the acute workload substantially outweighs the chronic workload, a result that supports previous study findings [2]. However, it is important to be reminded that, inversely, when the chronic workload substantially outweighs the acute workload, injury risk also increases. The R2 relationship between acute:chronic workload ratio and injury likelihood stresses the fact that injury risk increases when athletes are subjected to sudden changes in workloads, whether these are high spikes up in workload or low spikes down in workload. Athletes are therefore at minimum injury risk when their acute:chronic workload ratios remain within the range of 0.8-1.3.

As previously mentioned, no study has considered monitoring HR-derived variables when investigation acute:chronic workload ratios and injury likelihood. The results of this study show that, when dealing with injury risk, the use of objective internal workloads such as HR indices to calculate training loads are just as valid as the use of other measures of workload such as sRPE and GPS-derived variables.

Limitations and practical applications

Although one of the main limitations of this study was the exclusion of the in-season games workloads and weight training session workloads, this presents itself as novelty within the literature. In fact, the study represents a practical guide for strength and conditioning practitioners and/or sports scientists that will find it difficult to record HR data during games. Being able to monitor athletes solely during practices is an advantage for practitioners that exercise within the often-confined limits of university varsity settings. The study also demonstrated the relevance of using a 2-week acute:chronic workload ratio in a university team scenario during which seasons are often of short duration and athlete readiness to compete becomes of uttermost importance.

A second limitation of this study was the short time period over which data was gathered, as well as the small sample size. Related to the brevity of the RSEQ university soccer league's season, there was no chance of prolonging data collection. Moreover, the lack of resources within this specific university varsity setting did not allow for a larger sample size to be studied. Future studies should therefore examine different injury risk assessment models by possibly gathering data from a larger amount of teams within a university soccer league over a longer period of time. This study also decided to solely consider injuries classified as either illnesses or non-contact injuries causing the athlete to be unavailable for practices or competition. The specific pathologies of each injury was recorded, however, the examination of injury risk within each subcategory of pathology was beyond the scope of this study. By collecting a larger sample of injuries, future studies will therefore be able to analyze the relationship between the injury risk assessment models and different injury pathologies.

Within the context of this study, HRmax was calculated using an adapted equation. This might not necessarily reflect the true HRmax of each player. However, the use of such an equation allows for a standardization of the HRmax results and eliminates possible false results collected during HRmax measurement protocols, extending its practical applications to the university varsity setting.

Finally, HR monitors being of lower cost than GPS devices, this study reinforces its status as a practical guide for strength and conditioning practitioners and/or sports scientists that exercise within the limits of often-restrained budget university varsity teams. Practitioners are however required to be cautious when generalizing the findings of this study to other university sports as this study specifically collected data from soccer players.

Conclusion

The results of this study suggest that monitoring of acute:chronic workload ratios using HR indices such as Bannister's TRIMP or Stagno TRIMP appears to be a practical method to assess injury likelihood in male university soccer players. The 4-week acute:chronic workload ratio time window appeared to be the most effective for this population. The use of heart rate monitors, calculation of TRIMPs and monitoring of training load require both technical and scientific expertise that needs to be resourced, and these issues should be kept in mind if university varsity teams wish to implement the findings of the current study.

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None.

Author contributions

AB contributed substantially to contributed substantially to study concept, study design, instrument design, data analysis and formulation of manuscript. AB contributed substantially to data analysis, interpretation and formulation of manuscript. AB contributed substantially to study concept, study design, instrument design, data analysis and formulation of manuscript.

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