Title: Dose-Response Relationship between Training Load and Changes in Aerobic Fitness in Professional Youth Soccer Players

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Abstract

Purpose: The aim of this study was to compare the dose-response relationship between, traditional arbitrary speed thresholds versus an individualised approach, with changes in aerobic fitness in professional youth soccer players. **Methods:** Fourteen youth soccer players, completed a 1500 metre time trial to estimate maximal aerobic speed (km.h-1, (MAS)) at the start and the end of a six week period. Training load was monitored on a daily basis during this study. External load measures were; total distance covered (TD), total acceleration and deceleration distance > 2m.s^{-2} (A/D Load). Arbitrary high speed running measures were; metres covered and time spent > 17 km.h^{-1} (m>HSD, t>HSD) and 21 km.h^{-1} (m>VHSD, t>VHSD). Individualised high speed running measures were; metres covered and time spent > MAS km.h-1 (m>MAS, t>MAS) and 30% anaerobic speed reserve (m>30ASR, t>30ASR). In addition, internal load measures were also collected; heart rate exertion (HRE) and rating of perceived exertion (RPE). Linear regression analysis was used to establish the dose-response relationship between mean weekly training load and changes in aerobic fitness. **Results:** Substantial very large associations were found between t>MAS and changes in aerobic fitness (R^2 = 0.59). Substantial large associations were found for t>30ASR (R^2 = 0.38) and m>MAS (R^2 = 0.25). Unsubstantial associations were found for all other variables. **Conclusion:** An individualised approach to monitoring training load, in particular t>MAS, may be a more appropriate method than using traditional arbitrary speed thresholds when monitoring the dose-response relationship between training load and changes in aerobic fitness.

Introduction

The physiological response to a given training load is commonly called the dose-response relationship and is considered a fundamental component of training.[1] It has been suggested that a valid measure of training load should show a strong dose-response relationship with a particular training outcome, such as, fitness level, fatigue status or injury risk.[2] Training load measures that demonstrate a strong dose-response relationship will provide practitioners with a greater understanding of how their athletes may respond to a given training stimulus.[3] Giving them an ability to prescribe training with confidence, and that it will produce a predictable outcome within a defined period.[1] Improving a practitioner's understanding of the dose-response relationship will allow them to optimally plan training to maximise fitness, whilst minimising fatigue and injury risk.

There is a wealth of information within the scientific literature about soccer players training and match loads.[4] Equally, there are numerous studies documenting specific responses to training, whether it be fitness,[5] fatigue[6] or injury risk.[7] However, there is still very limited evidence about the dose-response relationship between training load and specific training outcomes in soccer players. It is well established that the internal response to a given external load is what drives training adaptation.[8] A comparison of methods used to establish internal load was investigated by Akubat et al[9], with an individualised training impulse (iTRIMP) showing the strongest relationship with changes in fitness. However, given the time associated with conducting the assessments needed to use iTRIMP, this method may not be the most practically applicable for a squad of soccer players. Two other examples of dose-response studies within the literature have investigated the relationship between training load and fatigue. Thorpe et al[10] found a large relationship between high intensity running (>14.4 km.h-1) and next day subjective fatigue. Scott and Lovell[11] built upon this work and compared the dose-response relationship between arbitrary high intensity running (>17.8 km.h-1) and various individualised methods of assessing high speed running, with subsequent fatigue. Although, relationships were classified as small, there was no difference between arbitrary and individualised methods of quantifying training load. However, the literature on the relationship between external training load and fitness is sparse, particularly with regards to individualising external load.

Abt and Lovell[12] first proposed that high intensity speed thresholds, used during soccer match-play, should be individualised based on the second ventilatory threshold in a similar manner to the methods proposed by Lucia et al[13]. They found the median velocity at the second ventilatory threshold to be 15 km.h^{-1}. This resulted in a three-fold increase in the high intensity distance covered when compared to the arbitrary distance covered above 19.8 km.h^{-1}, meaning practitioners are substantially underestimating the amount of high intensity running their players are undertaking during training and match play. Although these findings show the need to individualise training loads based on physiological characteristics, the methods used by Abt and Lovell[12] require extensive laboratory testing which may not be applicable in an applied environment. Other methods have been employed to assess players training load with reference to individual fitness characteristics gained via field based assessments. Percentage of maximal sprint speed (MSS)[14] has been used previously, however, it has been highlighted that using one single fitness characteristic may not reflect the complete locomotor profile of a player.[15,16] Alternatively, Mendez-Villanueva et al[17] used a technique which encapsulated field based testing data to estimate a players' aerobic (maximal aerobic speed [MAS]) and anaerobic capabilities (MSS). This technique allows for an estimation of a players' anaerobic speed reserve (ASR) and has been used to establish a players' transition (>30ASR) into sprint work.[17,18] Furthermore, Hunter et al[15] stated that a method using field based measures of MAS, MSS and ASR poses a more ecologically valid, economical and practical technique for individualising thresholds.

It is well established that aerobic capacity is an important physiological factor during soccer performance.[19,20] The assessment of MAS is therefore warranted within soccer as a performance indicator. Given MAS has been used as a measure of change in physical fitness in previous studies[21] and its usefulness in an applied setting when being used to prescribe training loads[22], MAS was selected as a dependent variable, alongside MSS, in the present study.

To our knowledge there has yet to be a study comparing the dose-response relationship between arbitrary and individualised methods for assessing training loads and a specific training outcome, such as changes in aerobic fitness. It was therefore the aim of this study to compare the dose-response relationship between traditional arbitrary speed thresholds versus an individualised approach utilising MAS and MSS with changes in aerobic fitness in professional youth soccer players.

Methods

Subjects

Fourteen male youth soccer players (age: 17.1 ± 0.5 years, height: 178.3 ± 4.6 cm, body mass: 70.9 ± 5.8 kg) (defenders = 5, midfielders = 6, forwards = 3), competing in the English Under-18 Premier League agreed to participate in the study. Data were collected over a 6-week period, during an in-season competition phase (August-September).

Design

For this observational research, players took part in normal team training throughout the 6-week period as prescribed by club coaching staff. This included 6 competitive matches, 23 training sessions, and 13 rest days. No structured conditioning was conducted throughout this study. Physical assessments were completed at the start and the end of the 6-week period, with training load monitored throughout. Before inclusion in the study, players were examined by the club medical staff and were deemed to be free from illness and injury. The study was granted institutional ethics approval prior to commencement and conformed to the declaration of Helsinki. Informed consent was provided by all players and by their parents for players under 18 years of age.

Methodology

Prior to the start of the 6-week in-season period, players completed a testing battery to estimate MSS and MAS. Following a standardised warm up players completed two maximal 40 metre sprints, with three minutes recovery between efforts. Split times were recorded at 30 and 40 metres (Brower Timing Systems, Draper, UT), with the time taken to complete this 10 metre split used as MSS (km.h^{-1}).[17] The best MSS over the two sprints was used for the purpose of this study (minimum detectable change [MDC] 1.7%, unpublished observations). Following 10 minutes of rest players then completed a 1500-metre time trial (TT) on an outdoor artificial pitch. The time taken to complete this TT was recorded and the average speed calculated to estimate MAS (km.h^{-1}) (MDC 1.3%, unpublished observations). This method of assessing aerobic fitness has previously been validated.[23,24] Additionally, ASR was calculated from this data in accordance with previous literature[17] (MDC 1.2%, unpublished observations).

Training load was calculated for every training session and match played during the 6-week period, using a number of different methods; global positioning system (GPS), heart rate telemetry (HR) and session rating of perceived exertion (sRPE). External load was measured using GPS units (MinimaxX S4, Catapult Sports, Melbourne, Australia) sampling at a frequency of 10 Hz. GPS devices were switched on at least 15 minutes prior to each training session and match to ensure a full satellite signal (number of satellites: 14.4 ± 0.5; horizontal dilution of precision: 0.81 ± 0.10). Players were fitted with the same device for each session.

The GPS devices were worn between the scapular in a tight-fitting vest to reduce movement artefact. Following each training session and match, data were downloaded using the manufacturer's software (Catapult Sprint, Version 5.1.7, Catapult Sports, Melbourne, Australia). This GPS system has previously been shown to provide valid and reliable estimates of instantaneous velocity during acceleration, deceleration, and constant-velocity movements during linear, multidirectional, and soccer-specific activities.[25,26]

The external load measures used for analysis were; total distance (TD), acceleration and deceleration distance >2m.s^{-2} (AD Load). Arbitrary high speed running measures were; metres covered above 17 km.h^{-1} (m>HSD) and 21 km.h^{-1} (m>VHSD) and time spent above 17 km.h^{-1} (t>HSD) and 21 km.h^{-1} (t>VHSD). These arbitrary speed thresholds were selected to match the group mean thresholds for MAS and 30% ASR. Individualised high speed running measures were; metres covered above MAS (m>MAS) and time spent above MAS (t>MAS). As suggested by previous research,[15,17] to define a players transition into anaerobic work, metres covered above 30% ASR (m>30ASR) and time spent above 30% ASR (t>30ASR) were also calculated.

Measurements of HR were collected using a short-range telemetry HR transmitter strap recording at 5 s intervals (Polar T34, Polar Electro, OY, Finland). Data were downloaded and analysed using specific software (Catapult Sprint, Version 5.1.7, Catapult Sports, Melbourne, Australia). A heart rate exertion (HRE) score was calculated based on Edwards[27] training impulse, using the time spent in five HR zones and multiplied by a zone specific weighting factor.

Approximately 30 minutes after each training session and match, players reported their RPE using the method of Foster et al[28] Each player was asked verbally, in private, how hard they found each session, reporting their subjective perception of effort using the Borg 10-point category-ratio scale. sRPE was subsequently calculated by multiplying the RPE by the number of training or match minutes played. Players were familiarised with the use of the RPE scale prior to the start of the six-week study period.

Statistical Analysis

Descriptive statistics are presented as means ± standard deviations. Pre-and post-measures of MAS and MSS were compared via standardised changes in the mean (effect size; ES) using a custom spreadsheet.[29] The following criteria were adopted to interpret the magnitude of change; >0.2–0.6, small; >0.6–1.2, moderate; >1.2–2, large; >2, very large.[30] The magnitude of change was classified as a substantial increase or substantial decrease when there was a 75% or greater likelihood of the change being equal to or greater than the ES ± 0.2 (small).[30] To understand the strength and direction of the dose-response relationship between the mean weekly training load and changes in fitness, Pearson's product moment correlation coefficients (r) were calculated. Where the 90% confidence interval overlaps both the positive and negative threshold by ≥5% the relationship was deemed unclear.[30] The following criteria were adopted to interpret the magnitude of the relationship; 0.0-0.1 trivial; >0.1-0.3 small; >0.3-0.5 moderate; >0.5-0.7 large; >0.7-0.9 very large; >0.9-0.99 nearly perfect; 1.00 perfect.[25]

Linear regression analysis was conducted following visual inspection of all relationships to identify a linear or curvilinear relationship. To determine the level of variance in the dependent variable explained by training load the coefficient of determination (R^2) was calculated via linear regression analysis. Additionally, to understand the error associated with each does-response relationship the standard error of prediction (SEP) was calculated.[31]

Results

A total of 387 training and match files were analysed for the 14 players during the 6-week in-season training period. Mean ± SD weekly training loads are displayed in Table 1. Mean ± SD weekly and daily t>MAS during the training period are displayed in Figure 1.

The mean change in MAS over the training period was 0.11 ± 0.12 $km.h^{-1}$ (ES: 0.15, possibly trivial, 31/69/0) and the mean change for MSS was 0.27 ± 0.20 $km.h^{-1}$ (ES: 0.16, possibly trivial, 26/74/0).

A *very large* linear relationship was found between t>MAS and changes in MAS (r = 0.77 [90% CI 0.48 to 0.91], R^2 = 0.59) (Figure 2). Also, *large* relationships were found between t>30ASR (r = 0.62 [90% CI 0.22 to 0.84], R^2 = 0.38), m>MAS (r = 0.50 [90% CI 0.06 to 0.78], R^2 = 0.25) and changes in MAS. Relationships between all other mean weekly arbitrary and individualised training load measures and changes in fitness parameters were found to be *unclear* (Tables 2 & 3).

Other external load measures, TD (r = 0.26 [90% CI -0.23 to 0.64]) and AD Load (r = 0.20 [90% CI -0.29 to 0.60]) displayed *unclear* relationships with changes in MAS. Similarly, internal load measures, HRE (r = -0.21 [90% CI -0.61 to 0.28]) and sRPE (r = 0.22 [90% CI -0.26 to 0.62]) were also *unclear*. In contrast, relationships with changes in MSS were identified for TD (r = 0.46 [90% CI 0.00 to 0.76] *possibly* moderate, R^2 = 0.21), AD Load (r = 0.57 [90% CI 0.15 to 0.81] *possibly* large, R^2 = 0.32) and HRE (r = 0.40 [90% CI -0.07 to 0.73] *possibly* moderate, R^2 = 0.16). However, sRPE (r = 0.37 [90% CI -0.11 to 0.71]) displayed an *unclear* relationship with changes in MSS.

Discussion

The aim of the present study was to examine the dose-response relationship between a range of measures quantifying training load and changes in aerobic fitness using a field based test of MAS. The training load was quantified using both arbitrary speed thresholds and an individualised approach utilising MAS and MSS. The key finding from the present study is that the use of individualised thresholds, specifically t>MAS, demonstrated a stronger dose-response relationship with changes in aerobic fitness than commonly used arbitrary thresholds.

This is the first study to assess the relationships between various measures of external training load and changes in aerobic fitness in youth soccer players. It has previously been shown that using individualised thresholds may better represent the true physiological demands

of soccer training and match play placed on the individual.[12,15] However, linking these individualised measures to specific training outcomes, such as improvements in aerobic fitness, had not previously been researched. The present study found that using an individualised approach, in which players training and match load was assessed based on the time spent above their MAS, has the strongest relationship with changes in aerobic fitness. This provides practitioners with important information for planning training loads, allowing them to more clearly understand the physical outcome from a given training dose.

It has been shown that high intensity distance covered (>19.8 $km.h^{-1}$) is one of the most commonly used measures of training load in elite soccer.[32] This study has demonstrated however, that arbitrary thresholds of 17.0 $km.h^{-1}$ and 21.0 $km.h^{-1}$ presented *unclear* correlations with changes in MAS and MSS (Table 2). This should call into question the usefulness of these measures for assessing training load. Furthermore, as the dose-response relationship between these measures is unclear, it is very difficult for practitioners to make informed decisions about the desired training outcome based on arbitrary speed thresholds, which could lead to over/under-training, injury or illness. The authors acknowledge that the use of arbitrary thresholds is required to make comparisons between players possible, from a performance and talent identification standpoint. It could therefore be suggested that a joint approach, utilising both arbitrary and individualised thresholds is most advantageous.

Another novel aspect of the present study was the inclusion of time spent above both arbitrary and individualised speed thresholds. When analysing external training loads the most commonly used measure is distance covered above a specific threshold, this is evident in both research[33] and practice.[32] However, the present study would suggest that time spent above a high speed threshold may be a more robust measure of training load, given the stronger associations between time variables compared to distance variables. This would seem to be in line with research on endurance athletes were time spent around $V{\bullet}O_2$ max is an important consideration when looking to improve aerobic fitness.[34] The differences between time spent and distance covered above a threshold may be a consequence of players running at higher speeds, this will lead to a large number of metres covered in a small amount of time. Therefore if t>MAS is the parameter practitioners are looking to target, even paced running at a speed just above MAS (100-110%) may be a key factor when looking to improve aerobic fitness.

Depicted in Figure 1 is the mean weekly and daily training load for t>MAS across this 6-week study period. Although this study was conducted over a relatively short period, the data may suggest that t>MAS follows a similar weekly variation to that of other external load variables previously described.[35] It is worth noting the limited amount of time players spend above this threshold during match play (2.3 min). This was lower than during a match day -4 training session (3.0 min). Future research should look to assess t>MAS longitudinally to confirm weekly training and match loads. It could be suggested that given the mean weekly t>MAS of 7.4 min and the trivial mean change in fitness, that greater t>MAS is needed throughout the training week, if players are to improve their fitness throughout the in-season. Furthermore, given the low t>MAS acquired during soccer match play, specific running based interventions could be used to increase mean weekly t>MAS and therefore improve aerobic fitness.

A limitation of the present study is the small sample size (n=14), although this is common in studies of players at a professional level. Moreover, this study was conducted over a relatively small in-season period; future work should look to replicate these results over longer training periods. Additionally, intervention studies looking to specifically target t>MAS in order to improve aerobic fitness in soccer players would be warranted.

Practical Applications

There are a number of practical applications which practitioners may take from the present study. The results have shown a *very large* dose-response relationship between weekly t>MAS and changes in aerobic fitness. This may allow the implementation of specific training programs from which practitioners can understand the expected outcome. By using the regression analysis data displayed in Table 3 and Figure 2 an estimated percentage change in aerobic fitness can be obtained from a given mean weekly t>MAS. For example, 6.5 minutes per week over a 6-week period would estimate a 0% change in fitness, which may be the target of an in-season maintenance phase. However, it is important to appreciate the error associated with that estimate, for t>MAS this is 1% (Table 3), meaning 6.5 minutes per week may result in a -1% to +1% change in aerobic fitness. Therefore, if the desired outcome is to maintain fitness a target that is greater than the MDC may be more appropriate. 8.3 minutes per week would predict an improvement of 1.3% ± 1.0%, giving a range of 0.3% to 2.3% change in aerobic fitness (Table 3.). It should be noted that this study was conducted on a small sample, and the specific results are cohort specific, however, practitioners may still use this information to help inform their training programs and to ensure their athletes are going to achieve the desired outcome.

Conclusion

This is the first study to examine the dose-response relationship between a range of measures quantifying training load and changes in aerobic fitness, using a field based test of maximal aerobic speed in professional youth soccer players. Results show a *very large* relationship between time above maximal aerobic speed and changes in aerobic fitness compared to a unclear relationships with arbitrary thresholds. The practical applications provided may help practitioners to effectively plan their training programs based on the desired training outcome. Detailed practical recommendations have been given on how linear regression analysis and standard error of the estimate can be used to help improve the training process.

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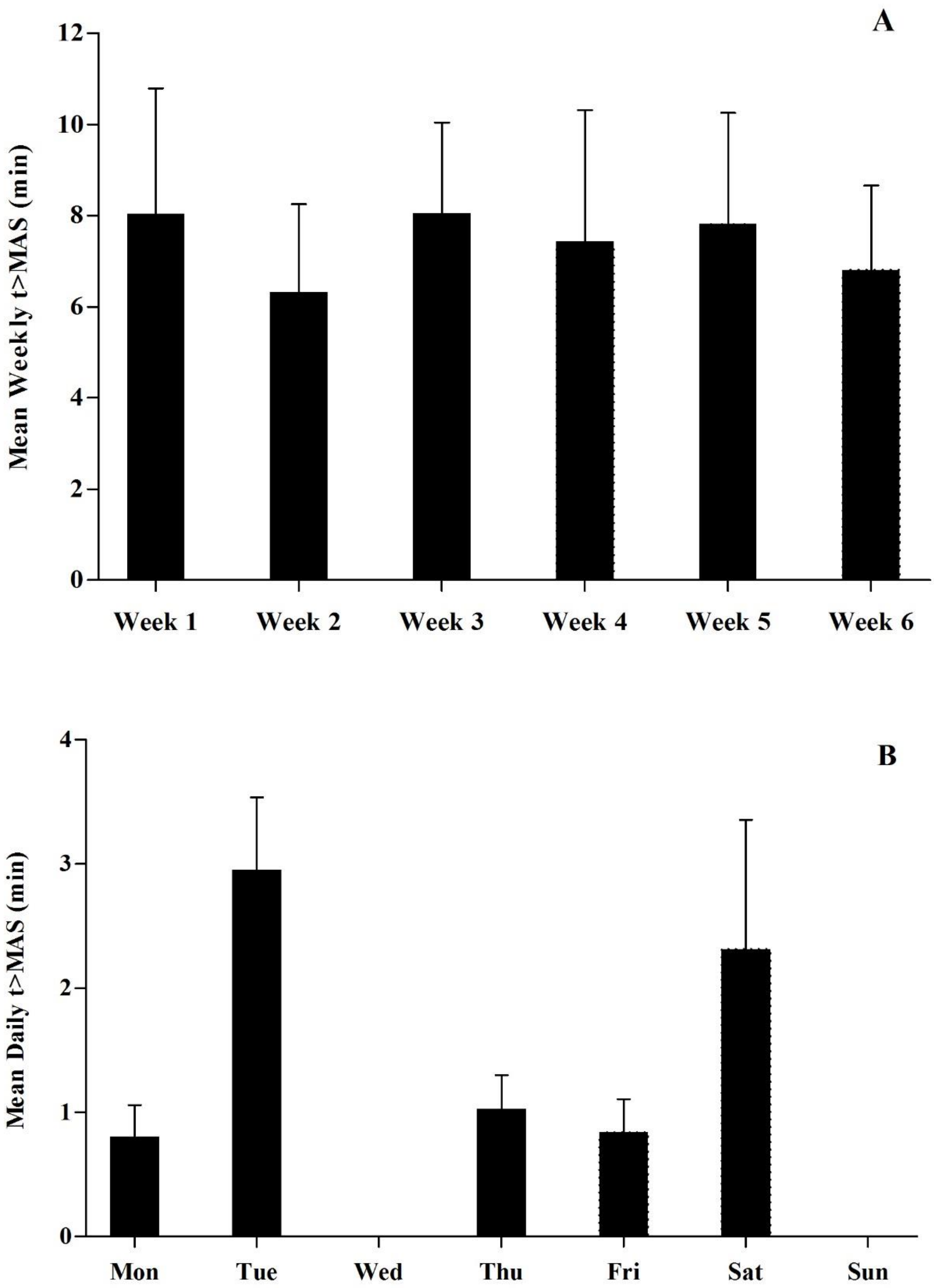

Figure 1. Weekly (A) and daily (B) time spent above maximal aerobic speed (t>MAS) during the 6-week in-season training period, mean ± SD.

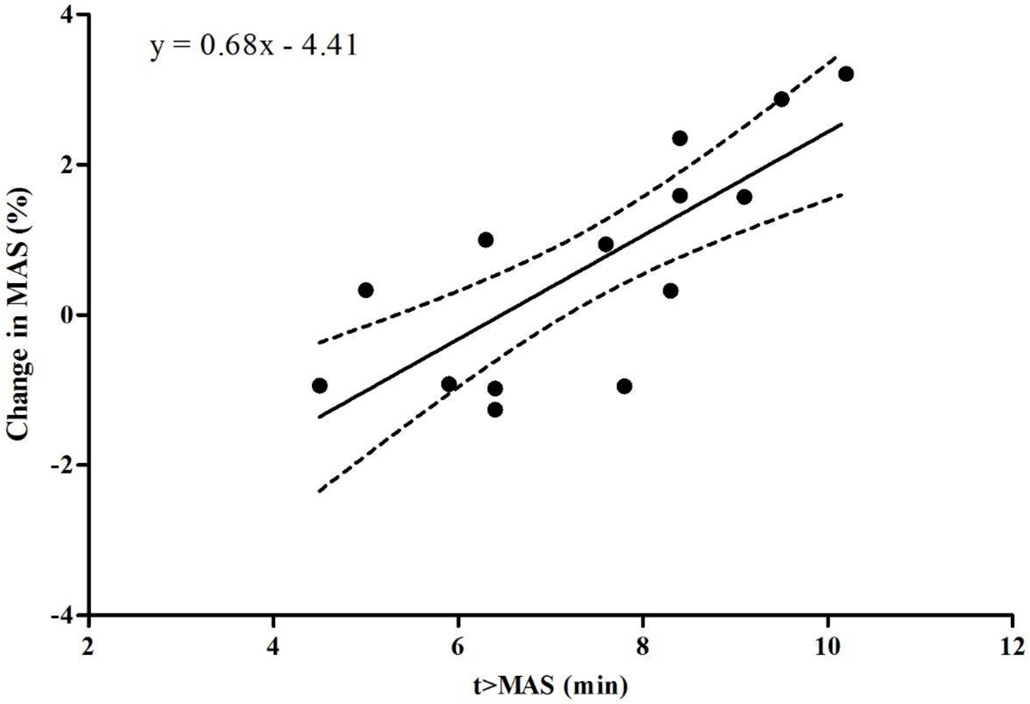

Figure 2. Linear relationship between mean weekly time spent above maximal aerobic speed (t>MAS) and % change in MAS during the 6-week in-season training period.
Intercept = -4.41 (%), Slope = 0.68 (min), SEP = 1.02 (%).

Table 1: Mean ± SD weekly training loads throughout the 6-week training period.

	Weekly Mean ± SD
TD (m)	29,324 ± 4037
AD Load (m)	1477 ± 254
m>HSD (m)	2613 ± 576
t>HSD (min)	7.70 ± 1.66
m>MAS (m)	2512 ± 507
t>MAS (min)	7.41 ± 1.72
m>VHSD (m)	940 ± 242
t>VHSD (min)	2.35 ± 0.58
m>30ASR (m)	770 ± 176
t>30ASR (min)	1.95 ± 0.48
HRE (au)	957 ± 107
sRPE (au)	2091 ± 380

Table 2: Relationship between mean weekly arbitrary and individualised training load measures and % changes in fitness. Pearson's product moment correlation coefficients (r) with 90% confidence intervals (CI) and magnitude based inference of the relationship.

		m>HSD (m)	**t>HSD** (min)	**m>VHSD** (m)	**t>VHSD** (min)	**m>MAS** (m)	**t>MAS** (min)	**m>30ASR** (m)	**t>30ASR** (min)
MAS (km.h^{-1})	r	0.22	0.37	-0.07	0.05	0.50 *	0.77 *	0.20	0.62 *
	90% CI	-0.27, 0.62	-0.10, 0.71	-0.51, 0.40	-0.42, 0.50	0.06, 0.78	0.48, 0.91	-0.28, 0.61	0.22, 0.84
	MBI	Unclear	Unclear	Unclear	Unclear	Possibly Large	Possibly Very Large	Unclear	Possibly Large
MSS (km.h^{-1})	r	0.32	0.34	0.25	0.27	0.30	0.21	-0.09	-0.15
	90% CI	-0.17, 0.68	-0.15, 0.69	-0.24, 0.64	-0.22, 0.65	-0.18, 0.67	-0.28, 0.61	-0.53, 0.39	-0.57, 0.33
	MBI	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear

Abbreviations; m>HSD; distance > 17 km.h^{-1}, t>HSD; time > 17 km.h^{-1}, m>VHSD; distance > 21 km.h^{-1}, t>VHSD; time > 21 km.h^{-1}, m>MAS; distance > MAS km.h^{-1}, t>MAS; time > MAS km.h^{-1}, m>30ASR; distance > 30% ASR km.h^{-1}, t>30ASR; time > 30% ASR km.h^{-1}.
* Substantial relationship (90% CI does not overlap both the positive and negative thresholds by ≥5% [Hopkins et al. 2009])

Table 3: Relationship between mean weekly arbitrary and individualised training load measures and % change in fitness. Linear regression coefficient of determination (R^2), slope, intercept and standard error of prediction (SEP). Also displayed is the minimum training load (TL) required to elicit the minimum detectible change (MDC) in fitness.

		m>HSD (m)	**t>HSD** (min)	**m>VHSD** (m)	**t>VHSD** (min)	**m>MAS** (m)	**t>MAS** (min)	**m>30ASR** (m)	**t>30ASR** (min)
MAS ($km.h^{-1}$)	R^2	0.05	0.14	0.00	0.00	0.25	0.59	0.04	0.38
	Slope (%)	0.58	0.34	-0.44	0.13	1.52	0.68	1.77	1.96
	Intercept (%)	-0.86	-1.99	1.07	0.35	-3.17	-4.41	-0.71	-3.16
	SEP (%)	1.55	1.48	1.59	1.59	1.37	1.02	1.56	1.25
	TL to elicit MDC	3672	9.48	-449	7.16	2914	8.30	1116	2.26
MSS ($km.h^{-1}$)	R^2	0.10	0.11	0.06	0.07	0.09	0.04	0.01	0.02
	Slope (%)	0.74	0.27	1.40	0.63	0.80	0.16	-0.67	-0.43
	Intercept (%)	-1.13	-1.29	-0.51	-0.68	-1.21	-0.41	1.32	1.64
	SEP (%)	1.33	1.32	1.36	1.35	1.34	1.37	1.40	1.39
	TL to elicit MDC	3820	10.97	1580	3.77	3626	12.86	-565	-0.14

Abbreviations; m>HSD; distance > 17 $km.h^{-1}$, t>HSD; time > 17 $km.h^{-1}$, m>VHSD; distance > 21 $km.h^{-1}$, t>VHSD; time > 21 $km.h^{-1}$, m>MAS; distance > MAS $km.h^{-1}$, t>MAS; time > MAS $km.h^{-1}$, m>ASR; distance > 30% ASR $km.h^{-1}$, t>ASR; time > 30% ASR $km.h^{-1}$.
Note: Slope for distance measures is unit increase per 1000 metres covered