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The influence of external load variables on creatine kinase change during preseason training period

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ABSTRACT

Objective: The aim of the present study was to analyse the relationships between creatine kinase (CK) concentration, an indirect marker of muscle damage, and global positioning system (GPS)-derived metrics of a continuous two-week-long preseason training period in elite football. *Design:* Twenty-one elite male professional soccer players were assessed during a 14-day preseason preparatory period. CK concentrations were determined each morning, and a GPS system was used to quantify the external load. A generalized estimating equation (GEE) model was established to determine the extent to which the external load parameter explained post-training CK levels. *Results:* The GEE model found that higher numbers of decelerations ($\chi^2 = 7.83$, $P = 0.005$) were most strongly associated with the post-training CK level. Decelerations and accelerations accounted for 62% and 11% of the post-training CK level, respectively, and considerable interindividual variability existed in the data. *Conclusion:* The use of GPS to predict muscle damage could be of use to coaches and practitioners in prescribing recovery practices. Based on GPS data, more individualized strategies could be devised and could potentially result in better subsequent performance.

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KEYWORDS

creatine kinase, preseason, external load, generalized estimating equations, football

INTRODUCTION

Football is a contact team sport played over a duration of approximately 90 min and is characterized by repeated high-intensity passages of play interspersed with active recovery periods [1]. These high-intensity passages consist of numerous intensive accelerations and decelerations and a series of high-intensity activities, such as sprinting, jumping, and changing direction [2, 3]. The tactical evolution of the game has seen increases in the numbers of activities such as sprints, accelerations and decelerations [4–6]. Sprints, accelerations and decelerations generate large eccentric-based contractions [7, 8], which are major contributors to muscle damage [7, 9, 10]. As a result of these combined physical loads in elite football, there is potential for significant muscle damage to occur.

The concentration of plasma creatine kinase ([CK]) is used as a marker of muscle damage [9–11]. The possible mechanism behind an elevated [CK] is a function of the damage to muscle cell membranes during exercise [12]. The eccentric activation of the muscle results in a higher tension per cross-sectional area and causes damage to cell membranes [13]. These actions are common during intense bouts of activity in football matches [14]. Therefore, the serum [CK] is a marker of player fatigue and may be useful when monitoring the recovery status of football players. Most studies have focused on the post-match CK response. Studies have shown that markers of muscle microtrauma, such as [CK], increase within 48–72 h after a game [15, 16]. Most studies on this topic have determined CK levels at only one time point after the game [14], investigated friendly games [15], or analysed one or two games separately [8, 15, 17]. The interpretation of CK monitoring as a basis for making practical adjustments to athlete training and recovery practices over the course of a preseason training period (PTP) has not been established.

Accordingly, PTP is seen as a crucial period to develop physical abilities to meet the physical demands of the football season. The accurate management of training loads during this period is essential to both maximize training adaptations and minimize injury occurrence. Quantifying the muscle damage associated with measures of training load has direct implications for the weekly modification of recovery. The purpose of this study was to document the changes in serum [CK] as a result of a two-week-long PTP and to investigate the extent to which indices of training load can explain [CK] changes in elite football.

MATERIALS AND METHODS

Study design

This 2-week study was designed to investigate the effects of training load on the biochemical marker status of professional elite male football players during the preseason training period. During the off-season period, the physical activity of the football players was not controlled, but

an individualized training programme was applied (supplementary content 1). The training programme implemented during the PTP was planned by team staff and was not influenced by the researchers, and no modifications were applied based on the CK level. During the PTP, systematic resistance training was not included in the training schedule.

Subjects

Twenty-one elite male professional soccer players (mean ± SD: age: 25.4 ± 4.8 years; height: 179.5 ± 6.9 cm; body mass: 75.6 ± 8.1 kg; and body mass index: 23.4 ± 1.5) representing a single club participated in the study. The inclusion criteria were attending at least 75% of the training sessions and undergoing all sample collections. The exclusion criteria were any type of injury that caused additional CK elevation, modification of the training or non-attendance. Players with any ongoing rehabilitation programme or medical treatment were excluded from the analysis. All participants provided written informed consent for this study, which was approved by the local Ethics Committee (University of Physical Education) in accordance with the Helsinki Declaration.

Procedures

Biomarker status. Plasma [CK] was measured using a fingertip blood sample obtained using a disposable spring-loaded lancet. A heparinized capillary tube was used to collect a 32 µL sample of capillary blood, which was pipetted onto commercially available Reflotron strips employing a Reflotron Plus Apparatus (Roche Diagnostics, Germany). During the preseason training period (15 days), blood samples were collected each day (before breakfast, between 7:00 am and 8:00 am) to determine the extent of muscle damage as a result of the training.

Training load. The players' physical activity during each training session was monitored using an athlete monitoring system with a 10-Hz GPS unit integrated with a 100-Hz triaxial accelerometer (firmware version v6.01, Vector S7, Catapult Sports, Melbourne, Australia). The receiver was positioned on each player in the centre area of the upper back and slightly superior to the shoulder blades by a tightly fitted vest manufactured by Catapult. The reliability [18] and validity [19] for velocity-based and accelerometer-derived data [20] of the device have previously shown acceptable levels. The use and collection of the GPS data process were in accordance with the recommended guidelines for the use of GPS data in sports [21]. To avoid interunit error, each player wore the same GPS device for each training session [18]. The minimal effort duration was set to 0.4 s for all data files to detect velocity. After recording, the data were downloaded to a computer and analysed by the manufacturer's software (Openfield v2.3.1, Catapult Sports, Melbourne, Australia). The analysis only included data from the team's field-based training sessions, and all rehabilitation or individual fitness sessions were excluded from the analysis. Based on the literature [13, 22, 23], combinations of expert knowledge regarding which variables hold superior practical or clinical importance, and discussions focusing on the likely predictors of muscle damage, the following indices of training and match physical load were used in the analysis: player physical load data were recorded from the period of the investigation as total distance (TD), high-speed running distance (HSR; >19.8 km h^{-1}), and sprint distance (SP; >21.5 km h^{-1}) [24, 25]. Based on the characteristics of football, the

mechanical load of each player was investigated as the number of accelerations ($2/ms^{-2}$) and decelerations ($-2/ms^{-2}$) [26]. Session duration was also recorded (minutes), and total distance and high-speed running distance covered were divided by session duration (minutes) to obtain the intensity values per minute.

Statistical analysis

Preliminary analyses included assessments of normality, linearity, and homoscedasticity, along with calculations of descriptive statistics (mean ± SD and range) and 95% confidence intervals (CIs). All analyses were undertaken in R statistical computing software version 3.4.1 [27]. To determine the extent to which nine training-load indices explained CK levels, a generalized estimating equation (GEE) model was built using the Geepack package [28]. For this, an exchangeable correlation structure, Gaussian distribution of the response variable (CK), and identity link function were assumed. For the GEE models, the predicted CK for each instance was outputted and visualized for comparison with the observed values, whereas the overall model performance was determined as the root mean square error (RMSE) of the prediction.

RESULTS

Tables 1a and b show the training-load distribution day by day. Considerable variability in CK was observed within and between players (Fig. 1) and between days (Tables 1a and b). The results from the GEE revealed one index of training-load explanatory of [CK] (Table 2). Specifically, higher numbers of decelerations ($\chi^2 = 7.82$, $P = 0.005$) were strongly associated with higher CK values. The RMSE of the model was 413 U L^{-1}. Generalized estimating equation χ^2 values for each match-load index were converted to a relative format (Fig. 2A) in an attempt to apportion the percent contribution. The relative contribution of decelerations to changes in [CK] was 62%, that of accelerations was 11%, and that of total distance was 5%, but 21% of the contribution was still unfitted to the model. The prediction error plotted against each observed CK value in the GEE model is shown in Fig. 2B.

DISCUSSION

In the present study, the number of accelerations and decelerations was shown to be a main contributor to changes in [CK], with 11% and 62% relative contributions, respectively. This suggests that greater changes in mechanical demands of the training are associated with greater muscle damage. These findings highlight the physically demanding nature of the preseason training period and the challenges of individual player load management and recovery.

The high contribution of deceleration and acceleration may be a consequence of muscle strain during the accelerating or decelerating phase of high-intensity movement, which exacerbates the damage response [7, 8]. Our research is in accordance with a previous study [22] in Australian rules football (AF) showing that changes in [CK] following AF matching were correlated with high acceleration metres covered ($r = 0.75$). Furthermore, deceleration measures were significantly greater in the high [CK] group than in the low [CK] group, supporting the hypothesis that eccentric muscle activity is more strongly associated with high CK levels [29, 30].

Table 1a. Training load indices and creatine kinase levels across the preseason training camp

	Creatine kinase [U L^{-1}]		Duration [min]		Total Distance [m]		Total distance per minute [m min^{-1}]		Sprint distance (>21.5 km h^{-1}) [m]	
	Mean ± SD	95%CI	Mean ± SD	95%CI	Mean ± SD	95%CI	Mean ± SD	95%CI	Mean ± SD	95%CI
Day 1			Rest	Rest	Rest	Rest	Rest	Rest	Rest	Rest
Day 2	403 ± 262	288–518	140 ± 0	140–140	8,401 ± 2,249	7,332–9,470	60 ± 16	52–67	1 ± 3	0–3
Day 3	802 ± 557	538–1,067	119 ± 2	118–120	6,582 ± 2,133	5,567–7,596	59 ± 14	52–65	8 ± 12	2-14
Day 4	991 ± 606	731–1,250	97 ± 28	84–108	7,894 ± 2,881	6,525–9,264	81 ± 20	72–90	51 ± 47	29–73
Day 5	888 ± 504	672–1,104	45 ± 3	43–46	4,691 ± 2,103	3,691–5,691	105 ± 46	83–127	52 ± 54	27–78
Day 6	737 ± 409	561–912	Rest	Rest	Rest	Rest	Rest	Rest	Rest	Rest
Day 7	409 ± 238	307–511	178 ± 17	170–185	11,586 ± 1,016	11,103–12,070	66 ± 5	63–68	8 ± 8	4-12
Day 8	613 ± 220	518–708	110 ± 19	102–119	6,356 ± 2,379	5,225–7,488	58 ± 20	48–68	22 ± 25	10-34
Day 9	621 ± 274	504–738	46 ± 19	38–54	5,673 ± 2,798	4,343–7,003	123 ± 30	108–137	60 ± 52	35–84
Day 10	625 ± 421	445–806	47 ± 18	39–55	5,238 ± 2,398	4,098–6,379	111 ± 28	98–124	51 ± 45	30–73
Day 11	582 ± 360	428–735	Rest	Rest	Rest	Rest	Rest	Rest	Rest	Rest
Day 12	460 ± 254	352–569	79 ± 0	79–79	5,308 ± 1,260	4,709–5,908	67 ± 16	59–75	0 ± 1	0–1
Day 13	529 ± 350	379–679	61 ± 2	61–62	4,364 ± 1,493	3,655–5,075	71 ± 24	59–82	4 ± 6	1-7
Day 14	348 ± 241	245–452	86 ± 0	86–86	8,841 ± 1,264	8,241–9,443	102 ± 15	95–109	65 ± 47	42–88
Day 15	554 ± 334	396–713	Rest	Rest	Rest	Rest	Rest	Rest	Rest	Rest

Table 1b. Training load indices and morning creatine kinase levels across the preseason training camp

	Creatine kinase [U L^{-1}]		High speed distance (>19.8 km h^{-1}) [m]		High speed distance per minute [m min^{-1}]		Acceleration [n]		Deceleration [n]	
	Mean ± SD	95%CI	Mean ± SD	95%CI	Mean ± SD	95%CI	Mean ± SD	95%CI	Mean ± SD	95%CI
Day 1			Rest	Rest	Rest	Rest	Rest	Rest	Rest	Rest
Day 2	403 ± 262	288–518	138 ± 73	104–174	1 ± 1	1-1	87 ± 31	72–102	105 ± 38	87–123
Day 3	802 ± 557	538–1,067	150 ± 76	114–186	1 ± 1	1-2	72 ± 31	55–89	90 ± 45	68–111
Day 4	991 ± 606	731–1,250	142 ± 68	203–338	3 ± 2	2-4	67 ± 31	52–81	90 ± 38	72–108
Day 5	888 ± 504	672–1,104	144 ± 68	204–340	4 ± 2	4-8	28 ± 13	22–35	38 ± 21	28–48
Day 6	737 ± 409	561–912	Rest	Rest	Rest	Rest	Rest	Rest	Rest	Rest
Day 7	409 ± 238	307–511	178 ± 60	150–206	1 ± 0	1-1	115 ± 36	98–132	160 ± 42	140–180
Day 8	613 ± 220	518–708	175 ± 76	139–211	2 ± 1	1-2	58 ± 33	42–73	86 ± 41	66–106
Day 9	621 ± 274	504–738	296 ± 137	230–361	7 ± 3	5-8	30 ± 21	20–39	47 ± 27	34–60
Day 10	625 ± 421	445–806	303 ± 188	214–392	6 ± 3	5-8	30 ± 17	22–38	40 ± 24	29–51
Day 11	582 ± 360	428–735	Rest	Rest	Rest	Rest	Rest	Rest	Rest	Rest
Day 12	460 ± 254	352–569	52 ± 31	37–66	1 ± 0	0–1	55 ± 18	47–64	75 ± 27	62–88
Day 13	529 ± 350	379–679	60 ± 36	43–77	1 ± 1	1-1	35 ± 15	28–42	53 ± 23	42–64
Day 14	348 ± 241	245–452	327 ± 82	288–366	4 ± 1	3-4	65 ± 20	56–74	81 ± 33	65–97
Day 15	554 ± 334	396–713	Rest	Rest	Rest	Rest	Rest	Rest	Rest	Rest

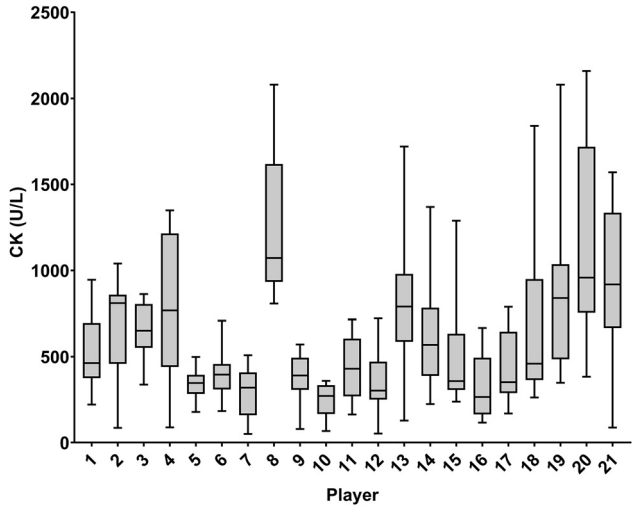

Fig. 1. Individual player (n = 21) creatine kinase concentrations during the preseason training camp. Data are presented as box and whisker plots with median, 25th to 75th percentiles and the whiskers as the minimum and maximum

Table 2. Generalized estimating equation model for creatine kinase concentration

	β (mean ± SE)	χ^2	P
Intercept	439.70 ± 267.40	2.7	0.1
Duration [min]	0.25 ± 3.75	0.01	0.95
High speed distance (>19.8 km h^{-1}) [m]	−0.07 ± 0.60	0.014	0.91
Deceleration [n]	−2.64 ± 0.94	7.82	0.005
Total distance [m]	0.05 ± 0.06	0.61	0.435
Total distance per minute [m min^{-1}]	−0.23 ± 3.46	0.01	0.95
Acceleration [n]	1.87 ± 1.57	1.41	0.23
Sprint distance (>21.5 km h^{-1}) [m]	0.04 ± 0.77	0.01	0.96
High speed distance per minute [m min^{-1}]	1.61 ± 24.99	0.01	0.95

*β = beta coefficient; $\chi 2$ = Wald chi-square.

However, in previous studies, acceleration and deceleration were identified as contributors to muscle damage, and sprint distance (r = 0.42–0.89), sprint number (r = 0.86) and high-intensity running (r = 0.92) showed strong associations with CK changes [13, 22]. These studies analysed only match situations where these loading parameters occurred more frequently compared to our technical staff-driven PTP period, which may result in the fact that we did not find a high contribution of these parameters to CK change.

Interestingly, in our study, even though the subjects had not yet begun PTP, the mean CK level was 403.1 ± 262.0 U L^{-1}, which is higher than the published CK norms for healthy men

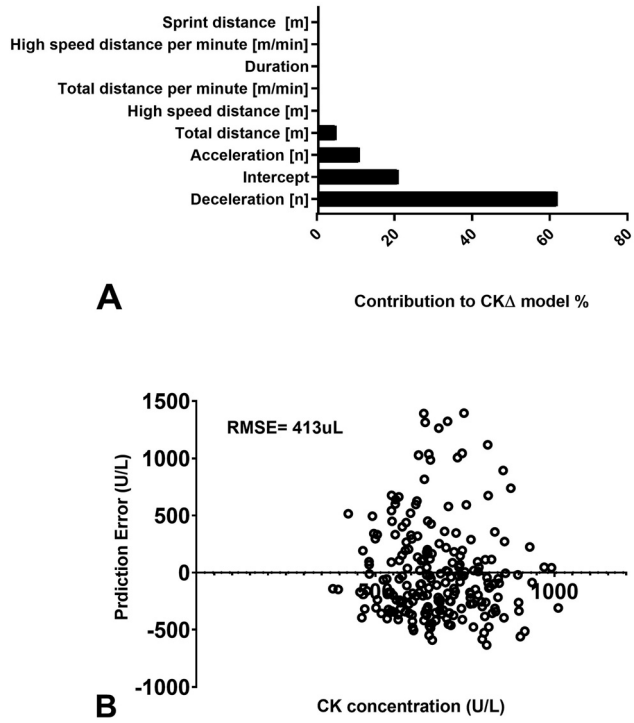

Fig. 2. Relative importance of the match-load variables (A) and model error (B) to predict creatine kinase concentration from the GEE model. GEE = generalized estimating equation; RMSE = root mean square error

[31]. The high CK levels found on day one of the PTP can likely be explained by uncontrolled summer conditioning programmes. Furthermore, Hortobagyi and Denahan [12] showed that it is not uncommon for healthy exercising athletes to have blood CK levels ranging from 100 to 1000 U L^{-1}. The [CK] was substantially elevated until the first rest day of the PTP (on the sixth day), with an average 212% increase in the [CK] from the first day of PTP. In the next four (7^{th}–10^{th}) days of PTP, there was only a 149% increase in the [CK], and in the final phase (12^{th}–14^{th} day) of PTP, the average CK response was only 118% of that on the first day. The reduction in [CK] observed over time in this study may be ascribed to the repeated bout effect. The repeated bout effect is a phenomenon in which the magnitude of muscle damage is attenuated in a subsequent exercise bout after performing a single bout of exercise. Because of the repeated bout effect, the recovery of muscle from eccentric exercise-induced muscle damage is not retarded by additional eccentric exercise bouts performed in early recovery days [32–34]. These findings suggest that protective mechanisms take place soon after the first exercise bout and further muscle damage is prevented.

In this study, high individual variability was observed in [CK] day by day (Fig. 1), which is similar to previously published results [9, 35, 36]. The literature suggests that differences exist between individuals in the context of CK response with the level of training, fibre type, and

muscle size [10]. In fact, a higher increase in CK levels is to be expected in individuals with lower physical fitness, as during initial training periods [10], athletes with a chronically low [CK] exhibit predominantly low variability (men up to 200 U L^{-1}, whereas athletes with chronically higher values (men up to 400 U L^{-1}) exhibit considerable variability in CK response [37]. This inherent variability may limit its usefulness as a monitoring tool in elite team sports beyond understanding the overall demands of this congestive period. Alternately, and provided individual baselines and player characteristics are taken into account [35], it may provide useful insights into instances when certain players, or the team as a whole, have experienced muscle damage greater than usual or are displaying residual levels of fatigue. As with any monitoring tool to facilitate coach decision-making, data need to be analysed using appropriate techniques and interpreted individually and cautiously, and this type of monitoring is best undertaken with a suite of practical, sport-specific measures [38].

Several limitations in the conduct of this study should be acknowledged and considered when interpreting the findings. Compared to venous blood sampling, the capillary blood collection method was found to be a less reliable method and tended to overestimate the [CK] [39]. In contrast, capillary blood sampling rather than venipuncture provides a less invasive sampling method with minimal disturbance to routine athletes. During this two-week sample collection period, capillary blood collection was the more "real-word" solution, despite its lower reliability. As an additional limitation, [CK] was the only marker of muscle damage used, and using more than one marker from both blood and urine could provide a better estimation of muscle stress [11]. In our study, blood collection was performed on mornings, 14–22 h after training during a 14-day interval; however, peak CK levels occur after 48 h of a game and persist for 42–72 h [8, 15]. Thus, we speculate that there is an overlap of the individual training effects, which increases the predictive error of the model. This consideration combined with repeated bout effect-induced adaptation and highlighted the limitation of parametric, linear analyses when modelling complex, dynamic phenomena.

The use of GPS to predict muscle damage could be of use to coaches and practitioners to control the training workload. The relationship between training workload and injury risk has been widely studied in the sports science literature [40, 41]. The findings may be important for conditioning professionals. For example, [CK] cut-off value-based recovery strategies can be quickly established (practitioners can establish group and individual predictions during the season from the best external load metrics) through specific predictive GPS-derived indices such as the number of accelerations and decelerations. This predictive strategy may be an additional method for decision-making and monitoring directions for profiling the fatigue and recovery process of athletes. These new findings can serve as examples of the predictive usefulness of commonly used wearable tracking devices every day and thereby establish strategies to monitor performance, fatigue and recovery.

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Data availability: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. Please contact the authors for data requests.

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