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Research article

Seasonal Strength Performance and Its Relationship with Training Load on Elite Runners

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Abstract

The aim of this study was to analyze the time-course of force production of elite middle and long-distance runners throughout an entire season and at the end of the off-season, as well as its relationships with training load and hormonal responses. Training load was recorded daily throughout an entire season by measuring and evaluating the session distance (km), training zone and session-RPE in a group of 15 elite middle and long-distance runners (12 men, 3 women; age = 26.3 ± 5.1yrs, BMI = 19.7 ± 1.1). Also, basal salivary-free cortisol levels were measured weekly, and 50-metre sprints, mean propulsive velocity (MPV), mean propulsive power (MPP), repetition maximum (RM) and peak rate of force development (RFD) of half-squats were measured 4 times during the season, and once more after the off-season break. There were no significant variations in force production during the season or after the off-season break, except for the RFD (-30.2%, $p = 0.005$) values, which changed significantly from the beginning to the end of the season. Significant correlations were found between session-RPE and MPV ($r = -0.650$, $p = 0.004$), MPP ($r = -0.602$, $p = 0.009$), RM ($r = -0.650$, $p = 0.004$), and the 50-metre sprint ($r = 0.560$, $p = 0.015$). Meanwhile, salivary-free cortisol correlated significantly with the 50-metre sprint ($r = 0.737$, $p < 0.001$) and the RM ($r = -0.514$, $p = 0.025$). Finally, the training zone correlated with the 50-metre sprint ($r = -0.463$, $p = 0.041$). Session-RPE, training zone and salivary-free cortisol levels are related to force production in elite middle and long-distance runners. Monitoring these variables could be a useful tool in controlling the training programs of elite athletes.

Key words: Endurance, exercise, testing, physiology.

Introduction

Currently there is great interest in assessing the force production of middle and long-distance runners, because the benefits of resistance training for such athletes have been demonstrated (Aagaard and Andersen, 2010; Beattie et al., 2014; Ronnestad and Mujika, 2013; Saunders et al., 2004; Taipale et al., 2013). For example, it has been demonstrated that well-trained long-distance runners increased their running economy, as well as the time until exhaustion at the maximal aerobic velocity, after 8 weeks of a maximal strength training program using 4 sets of 4 RM conducted three times a week (Støren et al., 2008). Also, concurrent endurance and strength-endurance training (i.e., exercises with 3 sets of 20 repetitions at 40%RM) has shown to increase running economy on well-trained runners, although to a lesser extent than maximal or explosive strength (Sedano et al., 2013). Thus, given that elite athletes probably cannot affect much of an improvement to their maximal oxygen consumption (Losnegard et al., 2013, Legaz-Arrese et al., 2005), strength training has been proposed as a necessary complement to increase performance in endurance events by improving other factors, such as running economy (Jung, 2003, Legaz-Arrese et al., 2005). Moreover, it has been demonstrated that strength and muscular power are related to running performance (Dumke et al., 2010; (Nummela et al., 2006). For example, the 50m sprint test has shown significant correlations with the 10-km performance on trained distance runners (Sinnett et al., 2001).

Monitoring the training process of distance runners is essential in order to observe their adaptations to training load and to avoid overtraining syndrome (Borresen and Lambert, 2009; Halson, 2014). Specifically, session-RPE and salivary-free cortisol have been proposed as time-efficient, non invasive methods to monitor training load because of its relationships with fatigue or stress (Crewther et al., 2009; Esteve-Lanao et al., 2005; Garcin et al., 2002; Papacosta and Nassis, 2011). Meanwhile, studying the evolution of force production throughout a whole season provides information about the effects of different training periods on athletic performance, which could prove very useful when programming training loads (Gorostiaga et al., 2006; Rousanoglou et al., 2013). Therefore, many studies have analyzed the evolution of force production throughout one or more seasons, especially in athletes whose sports demand high levels of strength, such as rugby, wrestling or football (Argus et al., 2009; Ratamess et al., 2013). However, to the best of our knowledge, there are no studies that analyze force production and its relationship with the training load of elite middle and long-distance runners during a whole season of concurrent endurance and strength training.

It is also of interest to study how the off-season break affects such athletes. For example, the off-season break has been observed to produce significant decreases in the vertical jump or short-sprint performance of well-trained athletes (Caldwell and Peters, 2009). In this regard, information about the changes in force production after the off-season break may help to design strategies to minimize the decrease in these performance indicators so athletes could start the season in optimum physical condition (McMaster et al., 2013; Smart and Gill, 2013). To this end, the assessment of force production on elite middle and long-distance runners throughout a whole season and at the end of the off-season break is of great importance for programming their training loads. Therefore, the purpose of this investigation was to analyze force

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production and its relationship with the training load of such athletes during a whole season of concurrent endurance and strength training

Methods

Subjects

Fifteen elite middle and long-distance runners were assessed for 50-metre sprint and force production of half-squats 4 times during a competitive season (October - July). Each measurement was taken at the end of each training period. These variables were also measured once more at the end of the off-season (September). Training load (assessed daily, using distance run, training zones and session-rate of perceived effort, RPE) and basal salivary free cortisol levels (once a week) were measured throughout the whole season. Average values for both training load and basal salivary free cortisol levels were calculated for each training period. Differences between periods with respect to 50-metre sprint, half-squat, training load and basal salivary free cortisol levels, as well as the correlations between these variables, were analyzed. The study protocol complied with the Declaration of Helsinki for Human Experimentation, and the Ethics Committee of the first author's University approved all procedures.

Participants

The study participants were 15 elite middle and long-distance runners from the High Performance Sports Center Madrid (12 men, age = 25.6 ± 5.4 yrs., body mass index [BMI] = 20.0 ± 1.0 kg·m^{-2}; 3 women; age = 29 ± 2.0 yrs, BMI = 18.6 ± 0.2 kg·m^{-2}), with personal bests in outdoor 1500-metres between 3:38 - 3:58 min (men, i.e., 84-94% of the world record) and 4:12 – 4:18 min (women, i.e., 87-90% of the world record). Participation of the athletes was voluntary and anonymous. All participants signed an informed consent form prior to participation in the study.

Instrumentation

A pair of Racetime 2 Light phothocells (Microgate Srl, Italy) were used to measure the 50-metre sprint and the half-squat force production was measured with a T-Force linear velocity transducer (Ergotech, Spain). Saliva samples were collected using Salivette® tubes (Sarstedt, Germany). Salivary free cortisol values were obtained using Free Cortisol in Saliva ELISA Assay kits (Demeditec Diagnostics, Germany).

Procedures

Training periods

The season was divided into 4 training periods, each approx. 2 - 3 months long. The season was periodised so that Periods 1 (P1) and 2 (P2) focused on long-distance runs while Periods 3 (P3) and 4 (P4) had more interval training sessions with short-distance runs (i.e., sets of 200 - 300 metres). Athletes completed 7 - 10 endurance training sessions per week. See Figure 1 for more details. Also, athletes completed two 90min. resistance training sessions per week consisting of 9 upper and lower body exercises with 3 sets of 15 - 20 RM, with rest between sets of 90s. Training exercises used were: half-squats, jump squats, leg extension, leg curl, calf raises, bench press, lat-pull down, biceps curl and push press. The exact resistance training program was used in every training period with no tapering phases. Resistance training intensity (i.e., 15 - 20 RM) was chosen to work strength-endurance capacities (Sedano et al., 2013).

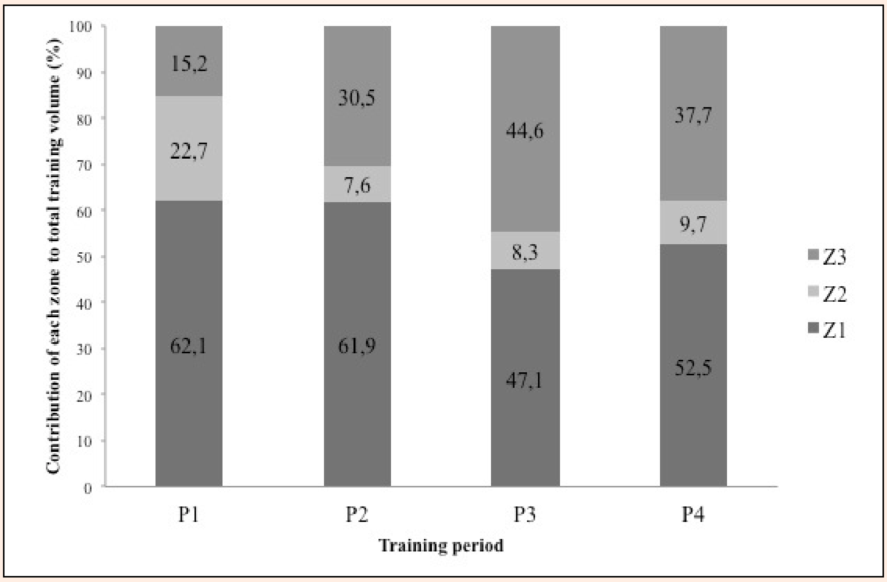

Figure 1. Distribution of endurance training zones throughout the season (% of total training distance, in km). Z1: training zone 1 (long-distance continuous training or interval training [sets with 4 - 6 km], running paces between 3:45 - 3:10 min/km); Z2: training zone 2 (middle-distance interval training [sets with 1 - 3 km], running paces between 3:10 - 2:50 min/km); Z3: training zone 3 (short distance and sprint interval training [sets with 200 - 600 m], with running paces of sub 2:50 min/km up to maximum sprint).

Testing

The 50-metre sprint and half-squat force production were measured, in that order, at the end of each training period and at the end of the off-season break (OS) (i.e., five assessment points during the study). All measurements were performed at the same time of the day, on the same day of the week and in the same facilities of the High Performance Sports Center Madrid.

50-metre sprint measurement: After a standard 20-minute warm-up, consisting in 10 minutes of continuous running, plus dynamic stretches and preparatory vertical jumps, athletes completed 2 progressive 50-metre sprints, firstly at moderate, then at high speed as a warm-up exercise. They then completed two maximal speed 50-metre sprints from a standing start, located 1 metre before the starting photocell. Timing gates were placed at 0m and 50m. Athletes were instructed to run as fast as possible without stopping until they passed the finish photocell. Attempts were separated by two minutes of passive rest. The faster of the two attempts was recorded in seconds. The coefficient of variation (CV) of the two attempts was 0.33 - 1.2%.

Half-squat force production: A progressive test from 50 to 100 kg was employed to measure half-squat force production, increasing the load by 10 kg for each new attempt, giving a total of 6 different loads (50, 60, 70, 80, 90 and 100 kg loads). Half-squats were performed on a Smith machine, with the linear position and velocity transducer attached to the barbell and the cable perpendicular to the floor. Athletes performed two repetitions of each load (CV = 5.4 - 6.7%) with the barbell on their upper-back, with feet hip-width apart, flexing the knees at 90º for the eccentric phase and executing the concentric phase as quickly as possible. Two minutes of passive rest separated each attempt. Total mean propulsive velocity (MPV), mean propulsive power (MPP), and peak rate of force development (RFD) were recorded. Also, the repetition maximum (RM) was estimated by the linear transducer software, which uses the relationship between barbell MPV and relative intensity (i.e., percent of RM) to calculate the values (Sanchez-Medina and González-Badillo, 2011). Using the MPV has been observed to be the most accurate method for estimating the RM with submaximal loads (González-Badillo and Sánchez-Medina, 2010).

Salivary free cortisol

To establish the basal cortisol concentration (in ng·mL^{-1}), athletes collected a saliva sample when they awoke, with an empty stomach, once a week throughout the whole of the competitive season corresponding to the study. Athletes chewed the cotton inside the Salivette® tube for 60 seconds, and then they stored the sample at -20 ºC (according to manufacturer's instructions) until they brought it to the High Performance Sports Center. All measurements were taken on the same day of the week, at the same time and under the same environmental conditions (i.e., athletes homes). Average values for each training period of the study, as well as for the whole season were calculated. All samples were stored at -20 ºC and analyzed at the Biochemical Laboratory of the Polytechnic University of Madrid (Official Lab. Number 242 in the Region of Madrid).

Training load

Distance run (in km) training zones (according to session mean running speed) and session-RPE (Foster, 1998) (0-10) were used to measure the daily training load. Daily distance run was registered using each athlete's training program. If an athlete didn't meet the training program, the daily distance run was modified according to what the athlete did actually complete. Daily training zone was registered according to session running paces: training zone 1 (running paces between 3:45 - 3:10 min/km); training zone 2 (running paces between 3:10 - 2:50 min/km); training zone 3 (running paces of sub 2:50 min/km up to maximum sprint). Session-RPE was assessed 10 minutes after the training session by asking: "How hard was the training session today, with 0 being very, very light and 10 being very, very hard?" Average values were calculated for each training period in the study, as well as for the whole season.

Statistical analyses

The normality of the variables was tested using the Kolmogorov-Smirnov (K-S) test. One-way repeated measures analysis of variance (ANOVA) was used in order to analyze possible differences between the average values of the variables for each training period. The main effects were compared using the post-hoc Bonferroni method, estimating the percentage of change (%) between P1-P2, P2-P3, P3-P4, P1-P4 and P4-OS. The Pearson correlation coefficient, unilateral contrast, was used to analyze the relationship between the variables. The level of significance was set at $p \leq 0.05$. All calculations were performed using IBM® SPSS® Statistics 22 software (IBM Co., USA).

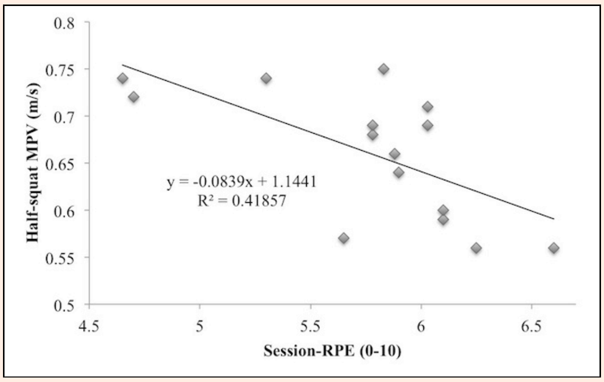

Figure 2. Correlation between session-RPE and half-squat mean propulsive velocity (MPV).

Results

Descriptive data is presented for each training period on Table 1. With respect to strength-related variables, the repeated measures ANOVA reported that, throughout the course of the season, there were no significant differences in the following variables: time in the 50-metre sprint,

Table 1. **Periods and season average values for each variable. Data are means (±SD).**

Variables			P1	P2	P3	P4	Off-season	Season average
Strength-related variables	**Sprint (s)** [N]	Men	6.56 (.28)	6.55 (.30)	6.63 (.30)	6.55 (.20)	6.58 (.40)	6.57 (.32)
		Women	7.21 (.41)	7.07 (.50)	7.18 (.56)	7.35 (.56)	7.40 (.36)	7.17 (.46)
		Total	6.69 (.40)	6.65 (.40)	6.75 (.44)	6.72 (.49)	6.69 (.41)	6.70 (.41)
	MPV ($m \cdot s^{-1}$) [N]	Men	.66 (.60)	.68 (.70)	.69 (.80)	.65 (.60)	.65 (.80)	.67 (.06)
		Women	.58 (.03)	.59 (.04)	.62 (.06)	.60 (.07)	.57 (.01)	.60 (.04)
		Total	.64 (.06)	.66 (.06)	.67 (.09)	.66 (.08)	.64 (.08)	.65 (.07)
	MPP (W) [N]	Men	602 (73)	588 (92)	606 (101)	568 (84)	568 (100)	588 (77)
		Women	498 (29)	512 (66)	523 (66)	494 (69)	439 (13)	501 (52)
		Total	586 (86)	573 (109)	584 (110)	571 (78)	543 (116)	571 (79)
	RM (kg) [N]	Men	115 (6)	112 (5)	112 (6)	111 (6)	109 (5)	112 (5)
		Women	104 (7)	105 (7)	106 (6)	104 (8)	100 (4)	105 (6)
		Total	112 (8)	111 (9)	109 (8)	110 (7)	107 (7)	110 (6)
	RFD ($N \cdot s^{-1}$) [N]	Men	1704 (601)	1564 (622)	1359 (501)	833 (166)	1080 (452)	1396 (465)
		Women	1296 (331)	1043 (118)	1137 (378)	1193 (144)	834 (121)	1076 (324)
		Total	1378 (251)	1164 (87)	1188 (308)	962 (212)	842 (192)	1173 (410)
Training load	**KM (week)** [N]	Total	95.2 (.9)	89.6 (8.7)	85.6 (8.1)	66.6 (12.5)	---	83.7 (5.3)
	Zone (week) [N]	Total	1.50 (.03)	1.70 (.08)	2.00 (.14)	1.80 (.11)	---	1.80 (.09)
	Session-RPE (week) [N]	Men	5.9 (.7)	5.9 (.3)	5.4 (1.0)	5.3 (1.1)		5.6 (.5)
		Women	6.0 (.7)	6.2 (.5)	6.3 (.5)	6.3 (.3)	---	6.2 (.3)
		Total	6.0 (.7)	6.0 (.4)	5.6 (.6)	5.5 (1.1)		5.9 (.4)
Salivary-free cortisol	**CORT** [N] **($ng \cdot ml^{-1}$)**	Men	11.1 (2.2)	8.9 (2.4)	11.1 (2.6)	19.3 (3.6)		12.0 (1.8
		Women	12.1 (1.7)	10.9 (2.3)	10.7 (3.7)	17.2 (.7)	---	3.6 (4.3)
		Total	11.3 (2.2)	9.4 (2.4)	11.0 (2.8)	18.9 (3.4)		12.1 (2.3)

N = Normally distributed variable (Kolmogorov-Smirnov test, p > 0.05). Abbreviations: Sprint = 50-metre sprints; MPV = mean propulsive velocity of half-squats; MPP = mean propulsive power of half-squats; RM = Repetition Maximum of half-squats; RFD = peak rate of force development of half-squats; KM (week) = average training distance in km per week; Zone (week) = average training zone per week; Session-RPE (week) = average session-rate of perceived exertion per week; CORT = Average basal salivary free cortisol levels.

MPV, MPP or RM of half-squats (all > 0.05). In contrast, a 30.2% decrease in the RFD of half-squats ($p = 0.005$) was observed between the beginning (P1) and the end (P4) of the season (Table 2).

Based on the season-long average value of each variable, several correlations were apparent. RPE correlated significantly with MPV ($r = -0.650$, $p = 0.004$) (Figure 2), MPP ($r = -0.602$, $p = 0.009$) and RM ($r = -0.650$, $p = 0.004$) of half-squats, and also with the 50-metre sprint ($r = 0.560$, $p = 0.015$). Meanwhile, salivary free cortisol correlated significantly with the 50-metre sprint ($r = 0.737$, $p < 0.001$) and the half-squat RM ($r = -0.514$, $p = 0.025$). Finally, the average training zone correlated with the 50-metre sprint ($r = -0.463$, $p = 0.041$). See Table 3 for more details.

Discussion

The analysis of the correlations between variables indicated that training load and salivary free cortisol correlated significantly with force production throughout the season. In average terms, athletes with greater session-RPE values throughout the season had significantly lower levels of MPV, MPP and RM of half-squats, as well as slower times in the 50-metre sprint than those who declared lower session-RPE. In this sense, session-RPE was demonstrated as the training load parameter that correlates most significantly with force production in elite middle and long-distance runners. Using session-RPE to monitor training load has been used widely and in a variety of sports (Haddad et al., 2011; Milanez et al., 2011); however, to the best of our knowledge, this is the first study that analyses the relationship between session-RPE and force production of elite middle and long-distance runners throughout the course of an entire season.

Table 2. **Percentage of change in the studied variables throughout the different training periods.**

	P1-P2	P2-P3	P3-P4	P1-P4	After Off-Season
Sprint	-.5%	+1.5%	-.4%	-.4%	+.4%
MPV	+3.1%	+1.5%	-1.5%	+3.1%	-3.1%
MPP	-2.2%	+1.9%	-2.3%	-2.6%	-4.9%
RFD	-15.5%	+2.1%	-19.9%	**-30.2%***	-12.9%
RM	-.9%	-1.1%	+.4%	-1.6%	-2.39%
CORT	**-16.8%***	+17.0%	**+71.8%***	**+67.2%***	-----
Session-RPE (week)	+.0%	-6.7%	-1.8%	-8.3%	-----
KM (week)	-5.8%	-4.4%	**-22.2%****	-30.0%**	-----
Zone (week)	**+13.3%****	**+17.6%****	**-8.5%****	**+22.0%****	-----

Abbreviations: Sprint = 50-metre sprints; MPV = mean propulsive velocity of half-squats; MPP = mean propulsive power of half-squats; RM = Repetition Maximum of half-squats; RFD = peak rate of force development of half-squats; KM (week) = average training distance in km per week; Zone (week) = average training zone per week; Session-RPE (week) = average session-rate of perceived exertion per week; CORT = Average basal salivary free cortisol levels. * $p < 0.05$; ** $p < 0.001$

Table 3. Pearson correlation coefficient (r) between the average values of the studied variables.

	SPRINT	MPV	MPP	RFD	RM	CORT	RPE	KM	ZONE
SPRINT	---	**-0.769****	**-0.795****	-0.247	**-0.823****	**0.737****	**0.560***	0.072	**-0.463***
MPV		---	**0.910****	0.462*	**0.918****	-0.335	**-0.650****	-0.142	0.288
MPP			---	0.478*	**0.960****	-0.430	**-0.602****	0.013	0.269
RFD				---	0.414	-0.033	-0.415	-0.117	-0.192
RM					---	**-0.514***	**-0.650****	-0.134	0.408
CORT						---	0.318	0.053	**-0.528***
RPE							---	-0.034	-0.082
KM								---	**-0.597****

Abbreviations: Sprint = 50-metre sprints; MPV = mean propulsive velocity of half-squats; MPP = mean propulsive power of half-squats; RFD = peak rate of force development of half-squats; RM = Repetition Maximum of half-squats; CORT = basal salivary free cortisol levels; RPE = session-rate of perceived exertion per week; KM = training distance in km per week; ZONE = training zone per week.* $p < 0.05$; ** $p < 0.001$

With respect to the other variables used to monitor training load (i.e., average weekly distance, in km, and training zone), our study has uncovered a significant correlation between average training zone and the 50-metre sprint; where athletes who trained in higher training zones had significantly faster times in the 50-metre sprint. This agrees with other studies which have proposed that higher training intensities with lower volumes may be more effective in increasing force production in high-level endurance athletes (García-Pallarés et al., 2010). With respect to basal salivary free cortisol levels, our study demonstrates that athletes with significantly lower levels had significantly higher values for half-squat RM and faster times in the 50-metre sprint. Analysis of salivary free cortisol levels has been used widely in the literature because of its capacity to monitor fatigue states and stress levels, coupled with the fact that it is a non-invasive measurement (Gomes et al., 2013). Moreover, it has been demonstrated that salivary free cortisol levels in wrestlers correlate with power production in the power-clean (Passelergue and Lac, 2012). Our results further the knowledge in this respect, showing for the first time that salivary free cortisol correlates significantly with maximum strength and 50-metre sprint performance in elite middle and long-distance runners.

The MPV, MPP and RM of half-squats remained unchanged across the four training periods. Nevertheless, some studies have demonstrated that concurrent strength and endurance training can produce increases in strength whilst avoiding the effects of interference between the different training regimes (García-Pallarés and Izquierdo, 2011; Taipale et al., 2013). For example, it has been shown that concurrent training increases leg-press RM and the running economy of well-trained elite runners (Francesca Piacentini et al., 2013). However, that study used 2 resistance-training sessions plus 4 or 5 endurance sessions per week, whereas the athletes in our study performed 2 resistance-training sessions plus 7 - 10 endurance-training sessions per week. Therefore, in our study the resistance-training was 20-28% of all training sessions (endurance and strength) per week. Some authors have proposed that concurrent training should be composed of a block periodization with about 50% of total training focused on strength in order to increase both strength and endurance capacities (García-Pallarés and Izquierdo, 2011), because high-volume endurance training may have a major influence on strength gains (Rønnestad et al., 2012). The commonest type of concurrent training used in the literature employs heavy-load and low repetitions (i.e., 4 - 5 RM) to develop the neural factors of strength (Aagaard and Andersen, 2010; Francesca Piacentini et al., 2013). This type of strength training appears to avoid the interferences between strength and endurance capacities better than others, and it attenuates the transition to type I fibres produced by endurance training (García-Pallarés and Izquierdo, 2011). However, middle and long-distance runners in our study performed a strength-endurance based resistance-training programme, with multiple exercises and high repetitions per set (up to 20 RM), which seems to be unsuitable for enhancing strength and power of these population because of its low intensity (Hartmann et al., 2009).

Furthermore, although strength variables in half-squats didn’t change, the RFD decreased significantly from the beginning to the end of the season. As demonstrated, the RFD represents the ability of athletes to produce force in a unit time, which is commonly called explosive strength (Holtermann et al., 2007; Taipale et al., 2013). On one hand, it is known that the RFD is positively associated with the quantity of type II muscle fibres (Korhonen et al., 2006) and, on the other hand, endurance training has shown to produce transition to type I fibres (Gehlert et al., 2012; Thayer et al., 2000). In this sense, non-significant changes in force production in the athletes in our study may be the result of the high-volume endurance training, common for elite long-distance runners, and the strength-endurance based resistance-training programmes they conducted throughout the season. However, given the lack of research in this matter, more studies are required to establish optimum, season-long, resistance-training programmes for elite middle and long-distance runners.

At the end of the off-season break, all strength-related variables remained significantly unchanged with respect to the end of the season. During a one-month off-season break, athletes in our study participated in active, unstructured rest in which they conducted non-specific physical activities of their choice, such as cycling, hiking or swimming, 3 times per week. Therefore, our data demonstrates that a month of active rest is not enough to cause a significant decrease in the force production of elite middle and long-distance runners. In this sense, given that resistance-training programmes during the off-season have been shown to be important in avoiding decreases in performance caused by detraining (Smart and Gill, 2013), it would be interesting to study if a resistance-training programme during the off-season that could even increase the force production of such athletes.

However, there are a number of limitations within the study. Strength training has been probed to increase running economy (Beattie et al., 2014; Ronnestad and Mujika, 2013) and thus it would have been useful to measure running economy in order to analyze its relationship with force production throughout the whole season. Additionally, the sample size in our study is too small to allow relevant comparatives between different events (for example, 800m.vs 3000m. steeplechase vs. 10000m.) and genders. Thus, future studies should utilize larger sample sizes and more tests (such as running economy) to analyze the role of force production on the training process of elite middle and long-distance runners. To the best of our knowledge, this is the first study which analyzes the effects of an entire season plus the off-season break, on the force production of elite middle and long distance runners.

Conclusion

In conclusion, our data also demonstrates that session-RPE, training zone and salivary free cortisol levels correlate significantly with many of the strength-related variables studied. Monitoring training loads through session-RPE is a suitable and simple method for controlling the training process in high-level middle and long-distance runners. Also, it has been observed that a month of active rest during the off-season break is enough to prevent decreases in force production of such athletes. These findings further the knowledge about the training process of high-level middle and long-distance runners and its relationship with force production. This could prove very beneficial to both coaches and trainers.

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References

Aagaard, P. and Andersen, J.L. (2010) Effects of strength training on endurance capacity in top-level endurance athletes. *Scandinavian Journal of Medicine & Science in Sports* **20,** 39-47.

Argus, C.K., Gill, N.D., Keogh, J.W.L., Hopkins, W.G. and Beaven, C.M. (2009) Changes in Strength, Power, and Steroid Hormones During a Professional Rugby Union Competition. *Journal of Strength & Conditioning Research* **23,** 1583-1592.

Beattie, K., Kenny, I.C., Lyons, M. and Carson, B.P. (2014) The Effect of Strength Training on Performance in Endurance Athletes. *Sports Medicine* **44,** 845-865.

Borresen, J. and Lambert, M.I. (2009) The Quantification of Training Load, the Training Response and the Effect on Performance. *Sports Medicine* **39,** 779-795.

Caldwell, B.P. and Peters, D.M. (2009) Seasonal variation in physiological fitness of a semiprofessional soccer team. *Journal of Strength & Conditioning Research* **23,** 1370-1377.

Crewther, B.T., Lowe, T.I.M., Weatherby, R.P., Gill, N. and Keogh, J. (2009) Neuromuscular performance of elite rugby union players and relationships with salivary hormones *Journal of Strength & Conditioning Research* **23,** 2046-2053.

Dumke, C.L., Pfaffenroth, C.M., McBride, J.M. and McCauley, G.O. (2010) Relationship Between Muscle Strength, Power and Stiffness and Running Economy in Trained Male Runners. *International Journal of Sports Physiology & Performance* **5,** 249-261.

Esteve-Lanao, J., San Juan, A.F., Earnest, C.P., Foster, C. and Lucia, A. (2005) How Do Endurance Runners Actually Train? Relationship with Competition Performance. *Medicine & Science in Sports & Exercise* **37,** 496-504.

Foster, C. (1998) Monitoring training in athletes with reference to overtraining syndrome. *Medicine & Science in Sports & Exercise* **30,** 1164-8.

Francesca Piacentini, M., De Ioannon, G., Comotto, S., Spedicato, A., Vernillo, G. and La Torre, A. (2013) Concurrent strength and endurance training effects on running economy in master endurance runners. *Journal of Strength & Conditioning Research* **27,** 2295-2303.

García-Pallarés, J., García-Fernández, M., Sánchez-Medina, L. and Izquierdo, M. (2010) Performance changes in world-class kayakers following two different training periodization models. *European Journal Of Applied Physiology* **110,** 99-107.

García-Pallarés, J. and Izquierdo, M. (2011) Strategies to Optimize Concurrent Training of Strength and Aerobic Fitness for Rowing and Canoeing. *Sports Medicine* **41,** 329-343.

Garcin, M., Fleury, A. and Billat, V. (2002) The ratio HLa:RPE as a tool to appreciate overreaching in young high-level middle-distance runners. *International Journal of Sports Medicine* **23,** 16-21.

Gehlert, S., Weber, S., Weidmann, B., Gutsche, K., Platen, P., Graf, C., Kappes-Horn, K. and Bloch, W. (2012) Cycling exercise-induced myofiber transitions in skeletal muscle depend on basal fiber type distribution. *European Journal of Applied Physiology* **112,** 2393-2402.

Gomes, R.V., Moreira, A., Lodo, L., Nosaka, K., Coutts, A.J. and Aoki, M.S. (2013) Monitoring training loads, stress, immune-endocrine responses and performance in tennis players. *Biology of Sport* **30,** 173-180.

González-Badillo, J. and Sánchez-Medina, L. (2010) Movement Velocity as a Measure of Loading Intensity in Resistance Training. *International Journal of Sports Medicine* **31,** 347-352.

Gorostiaga, E.M., Grandados, C., Ibanez, J., Gonzalez-Badillo, J.J. and Izquierdo, M. (2006) Effects of an Entire Season on Physical Fitness Changes in Elite Male Handball Players. *Medicine & Science in Sports & Exercise* **38,** 357-366.

Haddad, M., Chaouachi, A., Castagna, C., Wong, D.P., Behm, D.G. and Chamari, K. (2011) The Construct Validity of Session RPE During an Intensive Camp in Young Male Taekwondo Athletes. *International Journal of Sports Physiology & Performance* **6,** 252-263.

Halson, S.L. (2014) Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine***,** in press.

Hartmann, H., Bob, A., Wirth, K. and Schmidtbleicher, D. (2009) Effects of different periodization models on rate of force development and power ability of the upper extremity. *Journal of Strength & Conditioning Research* **23,** 1921-1932.

Holtermann, A., Roeleveld, K., Vereijken, B. and Ettema, G. (2007) The effect of rate of force development on maximal force production: acute and training-related aspects. *European Journal of Applied Physiology* **99,** 605-613.

Jung, A.P. (2003) The impact of resistance training on distance running performance. *Sports Medicine* **33,** 539-552.

Korhonen, M.T., Cristea, A., Alén, M., Häkkinen, K., Sipilä, S., Mero, A., Viitasalo, J. T., Larsson, L. and Suominen, H. (2006) Aging, muscle fiber type, and contractile function in sprint-trained athletes. *Journal of Applied Physiology* **101,** 906-917.

Legaz-Arrese, A., Serrano-Ostariz, E., Casajus-Mallen, J.A. and Munguia-Izquierdo, D. (2005) The changes in running performance and maximal oxygen uptake after long-term training in elite athletes. *Journal of Sports Medicine & Physical Fitness* **45,** 435-440.

Losnegard, T., Myklebust, H., Spencer, M. and Hallen, J. (2013) Seasonal variations in VO2Max, O2Cost, O2Deficit, and performance in elite cross-country skiers. *Journal of Strength & Conditioning Research* **27,** 1780-1790.

McMaster, D., Gill, N., Cronin, J. and McGuigan, M. (2013) The Development, Retention and Decay Rates of Strength and Power in Elite Rugby Union, Rugby League and American Football. *Sports Medicine* **43,** 367-384.

Milanez, V.F., Spiguel Lima, M.C., Gobatto, C.A., Perandini, L.A., Nakamura, F.Y. and Ribeiro, L.F.P. (2011) Correlates of session-rate of perceived exertion (RPE) in a karate training session. *Science & Sports* **26,** 38-43.

Nummela, A.T., Paavolainen, L.M., Sharwood, K.A., Lambert, M.I., Noakes, T.D. and Rusko, H.K. (2006) Neuromuscular factors determining 5 km running performance and running economy in well-trained athletes. *European Journal of Applied Physiology* **97,** 1-8.

Papacosta, E. and Nassis, G.P. (2011) Saliva as a tool for monitoring steroid, peptide and immune markers in sport and exercise science. *Journal of Science & Medicine in Sport* **14,** 424-434.

Passelergue, P.A. and Lac, G. (2012) Salivary hormonal responses and performance changes during 15 weeks of mixed aerobic and weight training in elite junior wrestlers. *Journal of Strength & Conditioning Research* **26,** 3049-3058.

Ratamess, N., Hoffman, J., Kraemer, W., Ross, R., Tranchina, C., Rashti, S., Kelly, N., Vingren, J., Kang, J. and Faigenbaum, A. (2013) Effects of a competitive wrestling season on body composition, endocrine markers, and anaerobic exercise performance in NCAA collegiate wrestlers. *European Journal of Applied Physiology* **113,** 1157-1168.

Rønnestad, B., Hansen, E. and Raastad, T. (2012) High volume of endurance training impairs adaptations to 12 weeks of strength training in well-trained endurance athletes. *European Journal of Applied Physiology* **112,** 1457-1466.

Ronnestad, B.R. and Mujika, I. (2013) Optimizing strength training for running and cycling endurance performance: A review. *Scandinavian Journal of Medicine & Science in Sports***,** in press.

Rousanoglou, E.N., Barzouka, K.G. and Boudolos, K.D. (2013) Seasonal changes of jumping performance and knee muscle strength in under-19 women volleyball players. *Journal of Strength & Conditioning Research* **27,** 1108-1117.

Sanchez-Medina, L. and González-Badillo, J.J. (2011) Velocity Loss as an Indicator of Neuromuscular Fatigue during Resistance Training. *Medicine & Science in Sports & Exercise* **43,** 1725-1734.

Saunders, P.U., Pyne, D.B., Telford, R.D. and Hawley, J.A. (2004) Factors affecting running economy in trained distance runners. *Sports Medicine* **34,** 465-485.

Sedano, S., Marin, P.J., Cuadrado, G. and Redondo, J.C. (2013) Concurrent training in elite male runners: the influence of strength versus muscular endurance training on performance outcomes. *Journal of Strength & Conditioning Research* **27,** 2433-2443.

Sinnett, A.M., Berg, K., Latin, R.W. and Noble, J.M. (2001) The relationship between field tests of anaerobic power and 10-km run performance. *Journal of Strength & Conditioning Research* **15,** 405-412.

Smart, D.J. and Gill, N.D. (2013) Effects of an off-season conditioning program on the physical characteristics of adolescent rugby union players. *Journal of Strength & Conditioning Research* **27,** 708-717.

Støren, Ø., Helgerud, J., Støa, E.M. and Hoff, J. (2008) Maximal Strength Training Improves Running Economy in Distance Runners. *Medicine & Science in Sports & Exercise* **40,** 1087-1092.

Taipale, R., Mikkola, J., Vesterinen, V., Nummela, A. and Häkkinen, K. (2013) Neuromuscular adaptations during combined strength and endurance training in endurance runners: maximal versus explosive strength training or a mix of both. *European Journal Of Applied Physiology* **113,** 325-335.

Thayer, R., Collins, J., Noble, E. G. and Taylor, A.W. (2000) A decade of aerobic endurance training: histological evidence for fibre type transformation. *Journal of Sports Medicine & Physical Fitness* **40,** 284-289.

Key points

- Session-RPE, training zone and salivary free cortisol levels correlate significantly with strength-related variables in middle and long-distance elite runners.
- A month of active rest during the off-season break is enough to prevent decreases in force production of such athletes.
- Monitoring training loads through session-RPE is a suitable and simple method for controlling the training process in elite middle and long-distance runners.

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