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Original Article

Influence of a concurrent strength and endurance training intervention on running performance in adolescent endurance athletes: An observational study

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ABSTRACT

The purpose of the present work was to present a case study on the influence of implementing a structured strength training intervention in adolescent middle distance athletes. An 8 wk strength training intervention was implemented concurrent to the group's middle distance training. Prior to and following the intervention a testing battery was implemented and the following physical qualities were assessed: aerobic capacity, lactate threshold, economy, time trial performance, lower body power and vertical stiffness. The concurrent strength and endurance training intervention was an effective training paradigm for improving economy, running performance and strength phenotypes in elite adolescent middle distance athletes. **Keywords:** Middle distance; Economy; Youth; Plyometric; Time trial.

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INTRODUCTION

Middle distance (800 – 1500 m) running performance is multi-factorial and dependent on numerous physical qualities. These include; aerobic capacity ($\dot{V}O_{2max}$), maximal speed, speed endurance, anaerobic capacity and fatigue resistance as well as the velocity associated with $\dot{V}O_{2max}$ (Bassett & Howley, 2000; Houmard, Costill, Mitchell, Park, & Chenier, 1991; A. M. Jones & Carter, 2000; Midgley, McNaughton, & Jones, 2007; Rogers, Whatman, Pearson, & Kilding, 2017). Amongst junior or lessor trained athletes, $\dot{V}O_{2max}$ has been used for predicting performance and for talent identification purposes (McLaughlin, Howley, Bassett, Thompson, & Fitzhugh, 2010; Noakes, Myburgh, & Schall, 1990). However, more recent work on well trained and elite athletes has indicated that running performance in such distances is more likely influenced by the combination of running economy (RE), lactate threshold, velocity at lactate threshold and body composition rather than aerobic capacity alone (Morgan & Craib, 1992). For this reason, training programmes for middle distance runners should not be focused only in improving aerobic capacity but also running technique (Folland, Allen, Black, Handsaker, & Forrester, 2017) and lactate clearance to seek improvements in RE and running speed. There has been a considerable amount of research work detailing the effectiveness of various endurance training methods with particular reference to polarized vs. threshold models *etc.* (Neal et al., 2013; Seiler & Kjerland, 2006; Stöggl & Sperlich, 2014). Recent work seems to suggest greater effects of polarized training in recreational adult runners (Muñoz et al., 2014) when compared to between threshold training. However, a review of the literature has concluded that there is no "optimal" training distribution to maximise endurance performance in well trained and elite athletes (Stöggl & Sperlich, 2014). While such studies provide insight in the training content of endurance activities they don't provide information about other training elements typically experienced by elite/fulltime endurance athletes. In recent years, it also has been acknowledged that strength training may have a beneficial effect on middle distance running performance (Berryman, Maurel, & Bosquet, 2010; Hoff, Gran, & Helgerud, 2002; Rønnestad & Mujika, 2014), in particular strength training performed concurrently to endurance training (Balsalobre-Fernández, Santos-Concejero, & Grivas, 2016; Barnes & Kilding, 2015; Denadai, de Aguiar, de Lima, Greco, & Caputo, 2017) despite the potential for combining such modalities to impair some adaptations at the skeletal muscle level (Fyfe, Bishop, & Stepto, 2014).

Despite, the conflicting results in mechanistic studies, a recent meta-analysis conducted by Berryman *et al*. (Berryman et al., 2017) concluded that the inclusion of strength training alongside sport specific training improves endurance performance to a greater extent than sport specific training performed in isolation. Strength training is nowadays part of the training regime of endurance athlete and middle distance runners mainly because of its beneficial effect on endurance performance due to the reduction in the energy cost of locomotion, [therefore improving "RE" (A. M. Jones & Carter, 2000; Rønnestad & Mujika, 2014)]. Additional meta-analyses have reported large beneficial effects of strength training on RE in highly trained middle and long distance runners (Balsalobre-Fernández et al., 2016), as well as the positive effects of explosive and heavy strength training in improving RE (Beattie, Carson, Lyons, Rossiter, & Kenny, 2017; Beattie, Kenny, Lyons, & Carson, 2014; Denadai et al., 2017). There is also further evidence that adding strength training in a concurrent manner to an existing endurance programme has been further shown to improve the RE of athletes as well as provide protection against musculoskeletal running injuries (Munekan & Ellapen, 2015). Both heavy strength training and explosive strength training was shown to improve running speed, running power and $\dot{V}O_{2max}$ possibly due to an improved musculo-tendinous unit stiffness, fibre type conversion and improved neuromuscular efficiency (Denadai et al., 2017; Rønnestad & Mujika, 2014).

Much of the previous research into the impact of strength training on middle distance performance and RE has been conducted in senior level athletes (Barnes, Hopkins, McGuigan, Northuis, & Kilding, 2013; Doma

& Deakin, 2015; Marcello, Greer, & Greer, 2016; Vikmoen et al., 2016; Vorup et al., 2016). Limited data are available in junior populations. Mikkola *et al*. (Mikkola, Rusko, Nummela, Pollari, & Häkkinen, 2007) reported no improvements in RE after 8 weeks of replacing 1 endurance session a week with explosive strength training. Previous work (albeit not in adolescent populations) has reported RE and endurance performance to be improved by 2-3 strength type sessions per week (Guglielmo, Greco, & Denadai, 2009; Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999; Rønnestad & Mujika, 2014; Taipale et al., 2010). As such, it may be reasonable to suggest that a higher frequency of strength training combined with typical endurance training may elicit improvements in running performance. While this seems to be established, it is difficult for coaches to translate the applicable training plans. In most studies in fact, training load was only quantified in terms of training time, as such the details of the training performed during the experimental period are somewhat vague. Despite there being limited data on training and endurance performance available in adolescent athletes it has been proposed that the beneficial effects of strength training on endurance performance occur irrespective of the athletes level (Berryman et al., 2017). As such, it feasible to suggest that a structured strength training intervention involving 2 strength sessions per week, conducted concurrently with middle distance training can contribute to improvements in endurance performance and RE and it is unlikely to influence performance impairments.

The purpose of the present work is to present a retrospective study on the influence of implementing a structured strength training intervention (alongside middle distance specific training) in full time adolescent middle distance athletes on RE and other running and physical performance indicators. The study was conducted to analyse middle distance and strength training performed by the athletes and assess their progress. It was hypothesised that the implementation of a structured strength training intervention would improve running economy and other running performance indicators. It is hoped that the data presented here will provide practitioners, supporting junior middle-distance athletes, information on what performance increments can be expected following 8 weeks of combined strength and endurance training.

MATERIAL AND METHODS

Participants
Nine adolescent male middle distance athletes (mean ± standard deviation, age 15.8 ± 1.5 years, stature 173.2 ± 9.5 cm, body mass 56.1 ± 10.3 kg, ∑7 skinfolds 41.5 ± 5.6 mm, $\dot{V}O_{2max}$ 60.4 ± 6.2 ml·kg·min^{-1}, PHV status 1.4 ± 1.5 years) from an elite sports academy in the middle east participated. Peak height velocity (PHV) was calculated via the Mirwald method (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002).

Procedures
Data collection commenced at the start of the Sports Academy's academic year (September 2015), prior to which participants had performed minimal structured training of any kind for ≥4 wk. At the start of the observation period many participants had minimal or no exposure to structured strength training. A comprehensive testing battery was implemented and the following physical qualities were assessed: aerobic capacity, lactate threshold, RE, time trial performance on the track, lower body power and vertical stiffness. Following these assessments participants completed 8 wk of structured training.

Middle distance specific training was prescribed by the group's Head Coach, details of training content and intensity distribution are presented in Table 1 and Figure 1. Throughout training sessions participant's heart rate (HR) was recorded using Polar RS800CX monitors (Polar Electro, Kempele, Finland) for the purposes of quantifying training load using Bannister and Edwards approaches (for details see 2,12). The aforementioned training load quantification methods were also used to calculate acute and chronic training loads and training stress balance (Hulin et al., 2014). Distances covered, peak and average velocities achieved were also quantified via Polar RS800CX global positioning satellite (GPS) systems (Polar Electro, Kempele, Finland) recording at 60 Hz.

Table 1. Summary of middle distance type training performed over the 8 wk experimental period. Data are reported as mean ± SD per athlete unless otherwise specified.

	Bike	Fartlek	Hills	Lab test	Long run	Strides	Tempo	Track	[a]Sum / [b]Average
Training time (hh:mm:ss)	0:53:49 ± 0:49:25	6:37:37 ± 3:26:28	5:12:12 ± 1:54:53	0:58:00 ± 0:25:47	22:32:50 ± 8:10:36	1:03:45 ± 0:26:59	0:55:13 ± 0:42:26	10:20:34 ± 3:45:39	[a]47:53:00 ± 13:21:22
% training time	0.8 ± 0.2	13.8 ± 0.8	10.9 ± 0.4	2.0 ± 0.1	47.1 ± 1.9	2.0 ± 0.1	1.8 ± 0.3	21.6 ± 0.9	-
Distance covered (km)	*	45.8 ± 28.7	32.6 ± 12.8	*	163.4 ± 71.4	6.6 ± 1.9	16.9 ± 3.0	28.9 ± 7.8	[a]294.3 ± 104.4
Ave velocity ($m\cdot s^{-1}$)	*	2.3 ± 0.4	1.8 ± 0.2	*	2.3 ± 0.3	1.2 ± 0.3	1.9 ± 0.2	6.1 ± 0.3	[b]2.6 ± 1.8
% time spent in HR zone 5	0.5 ± 0.5	11.3 ± 5.0	5.7 ± 3.5	13.8 ± 9.3	2.6 ± 4.1	0.2 ± 0.8	17.9 ± 10.9	8.1 ± 4.0	-
% time spent in HR zone 4	14.2 ± 13.7	17.9 ± 5.1	14.0 ± 4.3	32.7 ± 3.9	16.3 ± 10.9	6.5 ± 7.2	7.1 ± 5.1	13.9 ± 2.6	-
% time spent in HR zone 3	12.4 ± 10.2	22.4 ± 6.7	25.9 ± 7.6	25.1 ± 10.2	34.6 ± 9.8	30.7 ± 12.2	15.9 ± 13.4	21.3 ± 6.4	-
% time spent in HR zone 2	17.5 ± 8.8	25.7 ± 4.3	30.2 ± 6.0	15.0 ± 5.6	27.8 ± 9.6	27.4 ± 8.6	24.4 ± 2.2	31.1 ± 7.8	-
% time spent in HR zone 1	55.4 ± 21.2	22.7 ± 3.8	24.2 ± 7.7	13.4 ± 6.9	18.7 ± 5.9	35.2 ± 12.5	34.7 ± 7.2	25.5 ± 5.7	-
Edwards TRIMP (AU)	69.2 ± 35.6	150.7 ± 22.3	152.6 ± 33.9	101.1 ± 13.0	136.0 ± 21.1	118.7 ± 57.6	126.0 ± 19.9	143.9 ± 24.4	[b]138.6 ± 21.4

*AU = arbitrary units, Ave = average, Edwards TRIMP = Edwards training impulse, HR zone 5 = ≥90% HRmax, HR zone 4 = 80 - 89% HRmax, HR zone 3 = 70 - 79% HRmax, HR zone 2 = 60 - 69% HRmax, HR zone 1 = 50 - 59% HRmax, * training conducted indoors, as such, GPS data are unavailable.*

Alongside the track specific training, the athletes were prescribed a structured strength training intervention by an accredited strength and conditioning coach. Strength training was a combination of total body strength training exercises with a focus on lower body development alongside plyometric activity designed to develop qualities beneficial to middle distance running performance (Giovanelli, Taboga, Rejc, & Lazzer, 2017). Exercise sets and repetitions were prescribed to focus on strength development across multiple training sets. During the programme, loading progression and volume prescription was based on athlete exercise quality and maintaining values that would elicit training progression. The training session data was administered and recorded through an online software (VisualCoaching® Pro, Visual Coaching Pty, Melbourne, Australia, V. 2.0.45.0) and each training session was supervised by at least one coach and the athletes were required to tick the completed set/reps schemes and/or correct the weights lifted. All data is reported as exercise volume load (load per set x number of repetitions), average exercise load (average load per exercise) and average repetitions completed per training set. Plyometric exercises were differentiated as either slow or fast stretch-shortening cycle based on the ground contact/movement time of above/below 250ms. (Slow -Vertical box jumps, broad jumps, squat jumps. Fast - pogo jumps, depth rebound jumps). All Plyometric data are reported by total contacts per type of exercise. Details are presented in Table 2.

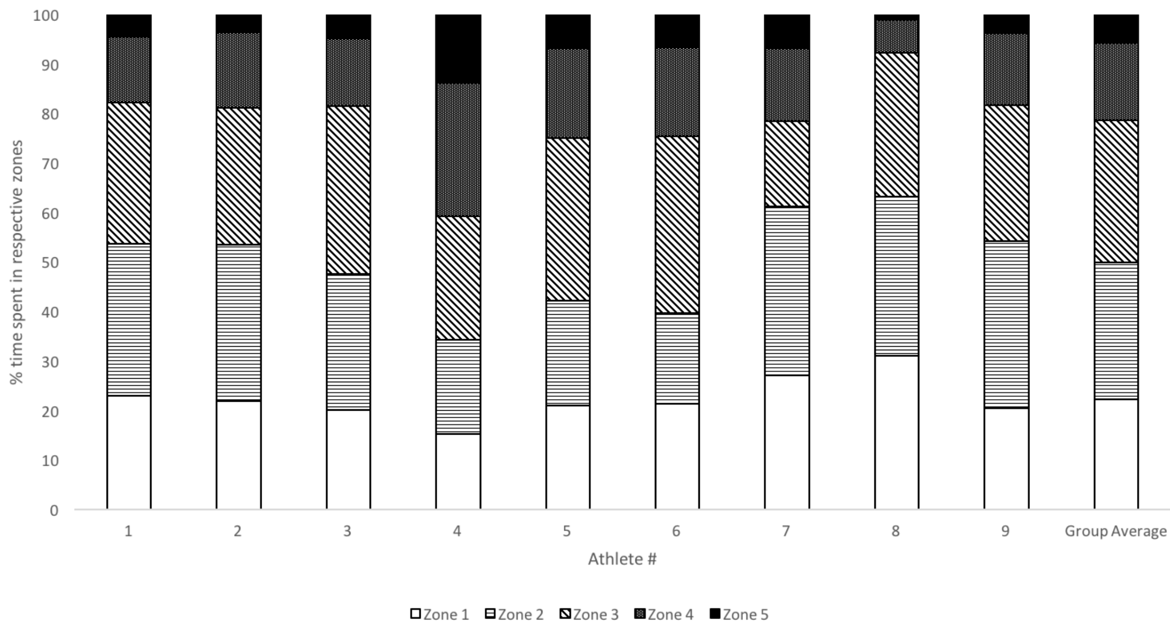

Figure 1. Distribution of middle distance training intensity over the experimental period. Zone 1 = 50 – 59% HRmax, zone 2 = 60 – 69% HRmax, zone 3 = 70 – 79% HRmax, zone 4 = 80 – 89 HRmax and zone 5 = ≥90% HRmax.

Table 2. Summary of strength and plyometric type training performed over the 8 wk experimental period. Data are reported as mean ± SD per athlete unless otherwise specified.

Strength training loading	Load
Lower Body Average Volume Load per set (reps*load kg)	134.0 ± 158.3
Lower Body Exercise Average Weight (kg)	15.6 ± 19.9
Lower Body Average Repetitions per set	7.4 ± 7.2
Upper Body Average Volume Load per set (reps*load kg)	37.8 ± 116.8
Upper Body Exercise Average Weight (Kg)	3.2 ± 10.0
Upper Body Average Repetitions per set	13.0 ± 4.6
Lower Body Bilateral Average Volume Load per set (reps*load kg)	167.4 ± 162.9
Lower Body Bilateral Exercise Average Weight (kg)	19.5 ± 21.3
Lower Body Bilateral Average Repetitions per set	8.4 ± 7.7
Lower Body Unilateral Average Volume Load per set (reps*load kg)	90.8 ± 151.3
Lower Body Unilateral Exercise Average Weight (kg)	10.8 ± 17.5
Lower Body Unilateral Average Repetitions per set	5.9 ± 6.2
Core Exercise Average Volume Load per set (reps*load kg)	6.8 ± 7.7
Core Exercise Average Repetitions per set	6.8 ± 7.7
Fast SSC[1] Plyometric contact per session	204.1 ± 184.2
Slow SSC[2] Plyometric contact per session	26.9 ± 12.4

[1]Fast SSC = Stretch shortening cycle (ground contact under 250 $m{\cdot}s^{-1}$), [2]Slow SSC = Stretch shortening cycle (ground contact over 250 $m{\cdot}s^{-1}$)

Following the 8 wk intervention all variables analysed at baseline were assessed to examine the influence of the training intervention on the physical qualities of interest, in particular RE.

All procedures were part of the routine sports science support provided to the athletes and coaches and were approved by the local review board as part of a wider growth and maturation study on young athletes [E20140000012]. As the participants are all minors, they had their informed consent signed by the parents when enrolling at the school.

Aerobic capacity, lactate threshold and economy assessments

All assessments of aerobic capacity and lactate threshold were conducted via running on a motorised treadmill (Woodway ELG, Woodway Inc, WI, USA) with online breath by breath analysis (Oxycon Pro, Jaeger, Carefusion, Hoechberg, Germany). All assessments were conducted in line with standardised procedures developed in the laboratory, however, a brief description of the testing protocol is provided here:

Initially participants completed a standardised warm up consisting of; 3 min at 2 $km \cdot h^{-1}$ below starting speed of the submaximal lactate threshold test, 2 min at 1 $km \cdot h^{-1}$ below starting speed, 3 min at starting speed and 2 min at 2 $km \cdot h^{-1}$ below starting speed. Following the warm up a 5-min relief period was provided prior to commencing the submaximal lactate threshold protocol. Participants completed 3 min incremental stages with running speed increasing 1 $km \cdot h^{-1}$ upon completion of each stage. Starting speed was selected based on historical data from each participant (if available) and was consistent between observations. The submaximal protocol ended when participants blood lactate concentrations (BLA) reached above 4 $mmol \cdot L^{-1}$. Lactate threshold was established as the running speed at which BLA reached above 4 $mmol \cdot L^{-1}$. RE was calculated in the last minute of each 3-min stage of the submaximal lactate threshold protocol as gross oxygen cost; $\dot{V}O_2$ ($ml \cdot kg \cdot min^{-1}$) / (workload ($km \cdot h^{-1}$) / 60). For analysis purposes RE was reported as the mean RE of all stages of the individual athlete's submaximal test. Following a 10-min rest period participants began the maximal aerobic capacity ($\dot{V}O_{2max}$) assessment. Participants ran at the speed of their individual lactate threshold; treadmill incline was increased $1\% \cdot min^{-1}$ until participants reached volitional exhaustion.

Time trials (TT)

Participants completed 3 time trials on an indoor 200-m athletics track. The 3 trials were over set distances of 1800, 1200 and 600 m (9, 6 and 3 laps) and were kept in the same order for pre-and post-intervention observations. All 3 trials were conducted on the same day with a 10-min relief period between efforts.

Countermovement jump assessment

Participants completed 3 maximal effort jumps with the hands-on hips. The jumps were completed with each foot on series linked force plates (Kistler, type 9281CA, Winterthur, Switzerland). Kinetic data collection was managed through Bioware software (version 5.2.1.3). Only the jump with the greatest height was reported. Jump height was derived from impulse-momentum method and relative power was calculated using body mass measured on the force plate and peak power.

Vertical stiffness assessments

In order to assess vertical stiffness of the lower limb, the repeated hopping test was performed on a dual force plates (Kistler, type 9281CA, Winterthur, Switzerland). Before the hopping test, all participants were instructed to place their hands on their hips, keep their knees straight and land in a similar position to that of take-off from the force plates and minimize ground contact times as possible, which minimize secondary movements in knee and hip joints. Participants performed a series of 30-40 consecutive bilateral hops for the 2.2 Hz sub-maximal hopping test. Hopping frequency was provided with a digital metronome (Seiko DM-50, Seiko sports life Co., Ltd, Tokyo, Japan) in visual and auditory signals. For the maximal hopping test, participant performed a series of 10-15 maximal height hops. Hopping frequency, ground contact time, and aerial time were calculated from the vertical component of ground reaction force (GRF). Vertical stiffness (k_{vert}) was calculated as:

$$k_{vert} = F_{max}/\Delta y$$

where F_{max} is the peak vertical GRF and Δy is maximum vertical displacement of the center of mass, which was calculated by integrating the vertical acceleration twice with respect to time (McMahon & Cheng, 1990). The initial velocity of the first integration was estimated by the aerial time of the previous hop (Hobara et al., 2009) k_{vert} was normalized relative to body weight and leg length. All calculations were processed using custom written Matlab program (version 8.4, Mathworks, Natick, MA).

Skinfold assessments
All assessments were performed in accordance with those set by the International Society for Advancement of Kinanthropometry (ISAK) (Lohman, Roche, & Martorel, 1988) and all assessments were conducted by practitioners accredited by said professional body. Sum of the following 7 sites (mm) were used for analysis; tricep, bicep, subscapular, abdomen, suprailliac, iliac crest and mid-thigh.

Analysis
Data are presented as mean ± standard deviation. Prior to analysis, dependent variables were verified as meeting required assumptions of parametric statistics. Outcome measures pre and post intervention were analysed using a student's t-test. (SPSS, version 24, Chicago, IL). Pearson's correlation (*r*) analysis was employed to evaluate any relationships between changes in economy and other performance indices. Correlation analysis was also employed to analyse any relationships between middle distance and strength type training load and any changes in outcome measures. The alpha level of 0.05 was set prior to data analysis. Statistical power of the study was calculated post-hoc using G*Power statistical software (v3.1.3, Düsseldorf, Germany) using the effect size, group mean, SD and sample size of the primary outcome measures, in this case being economy variables. Power was calculated as between 0.8 and 1 indicating sufficient statistical power (Cohen, 1992).

In addition, probabilistic magnitude-based inferences about the true value of outcomes were employed (Batterham & Hopkins, 2006). Dependent variables were analysed to determine the effect of the designated condition as the difference in change following each condition. To calculate the possibility of benefit, the smallest worthwhile effect for each dependent variable was the smallest standardized change in the mean – 0.2 times the between-subject SD for baseline values of all participants. This method allows practical inferences to be drawn using the approach identified by Batterham and Hopkins (Batterham & Hopkins, 2006). Furthermore, standardized effect size (Cohen's d) analyses were used to interpret the magnitude of any differences (Cohen, 1992).

RESULTS

A summary of the outcomes measures assessed pre-and post-intervention, including; RE, other physical performance phenotypes, body mass and ∑7 skinfolds are presented in Table 3.

Table 3. Summary of any changes in outcome measure between pre-and post-intervention

Variable	Pre-intervention	Post-intervention	% Δ	P value	Effect size	Qualitative inference
PHV status (years)	1.4 ± 1.5	1.7 ± 0.3	24.4	.003	.33	Very likely trivial
Body mass (kg)	56.1 ± 10.3	57.5 ± 10.5	2.5	.005	.19	Most likely trivial
∑7 skinfolds (mm)	41.5 ± 5.6	39.9 ± 4.8	-3.8	.034	.43	Possibly beneficial
Ave relative economy ($ml·kg·km^{-1}$)	227.2 ± 22.5	217.6 ± 12.4	-4.2	.038	.75	Likely beneficial
600 m TT (mm:ss)	01:42.35 ± 00:08.82	01:39.92 ± 00:08:65	-2.4	.164	.39	Possibly trivial
1200 m TT (mm:ss)	03:53.83 ± 00:15.15	03:41.80 ± 00:11.79	-5.1	.088	1.25	Likely beneficial
1800 m TT (mm:ss)	05:57.77 ± 00:26.96	05:44.30 ± 00:13.69	-3.8	.005	.89	Likely beneficial
CMJ (m)	.31 ± .04	.33 ± .03	6.1	.018	.74	Possibly beneficial
CMJ ($W·kg^{-1}$)	48.4 ± 3.4	50.5 ± 4.4	4.2	.076	.73	Possibly beneficial
Reactive index (AU)	2.2 ± 0.5	2.1 ± 0.4	-4.1	.032	.28	Very likely trivial
Stiffness 2.2 Hz (AU)	38.7 ± 6.1	45.4 ± 7.4	17.3	.003	1.40	Very likely beneficial
$\dot{V}O_{2max}$ ($ml·kg·min^{-1}$)	60.4 ± 6.2	59.8 ± 5.7	-1.1	.348	.15	Possibly trivial
$v\dot{V}O_{2max}$ ($km·h^{-1}$)	16.1 ± 1.6	16.6 ± 1.3	3.0	.167	.47	Possibly trivial
Peak $\dot{V}O_2$($L·min^{-1}$)	3.4 ± 0.9	3.4 ± 0.7	-1.3	.317	.08	Most likely trivial
HRmax ($Beats·min^{-1}$)	194.4 ± 5.5	191.7 ± 6.1	-1.4	.194	.68	Possibly beneficial
Lactate threshold ($km·h^{-1}$)	14.8 ± 2.1	15.4 ± 1.5	3.7	.114	.42	Possibly trivial
Peak lactate ($mmol·L^{-1}$)	6.7 ± 1.6	5.6 ± 1.1	-16.7	.056	1.14	Likely beneficial

AU = arbitrary units, Ave = average, CMJ = countermovement jump, HRmax = maximum heart rate, PHV = peak height velocity, TT = time trial, vV̇O2max = velocity at V̇O2max

The null hypothesis was rejected and statistically significant differences ($p < 0.05$) between pre-and post-intervention were identified in the following variables; body mass, ∑7 skinfolds, RE, 1800 m TT performance, reactive index and vertical stiffness. Furthermore, large effect sizes (> 0.70) were observed for the following variables; RE, 1200 m TT performance, 1800 m TT performance, CMJ (m), CMJ ($W·kg^{-1}$), vertical stiffness and peak lactate. A summary of inferential statistical analysis is presented in Table 3. % increases in CMJ ($W·kg^{-1}$) were highly correlated with improvements in 1200 m TT performance ($r = 0.977$, $p = 0.023$).

Correlations between strength training loadings and physical performance increments included; 1800 m TT performance and reductions in HRmax during the $\dot{V}O_{2max}$ test and slow stretch-shortening cycle plyometric training volume. Significant correlations between improvements in performance phenotypes and middle distance training loadings were present between; vertical stiffness and % training time in HR zones 4 and 5 and average Edwards TRIMP, 1200 m TT performance and % training time in zone 4 and average velocity during training, reductions in peak lactate during $\dot{V}O_{2max}$ test and time spent performing tempo training, and reductions in peak lactate and total distance covered. Inverse correlations were observed between improvements in; vertical stiffness and % training time in zones 1 and 2, 1200 TT performance and % training time in zone 1, CMJ and time spent performing long runs and in zone 1. A full summary is presented in Table 4.

Table 4. Summary of significant correlations observed between % increase in outcome measures and training load metrics

	1200 m TT	1800 m TT	CMJ ($W \cdot kg^{-1}$)	Stiffness 2.2 Hz	HRmax	Peak lactate
% time spent in HR zone 5						
r				.754		
p				.019		
% time spent in HR zone 4						
r	.965			.803		
p	.035			.009		
% time spent in HR zone 2						
r				-.709		
p				.032		
% time spent in HR zone 1						
r	-.987		-.708	-.867		
p	.013		.033	.003		
Ave Edwards TRIMP						
r				.716		
p				.030		
% time spent performing long run						
r			-.672			
p			.047			
% time spent performing tempo training						
r						.972
p						.028
Ave velocity						
r	.961					
p	.039					
Total distance covered						
r						.783
p						.013
Slow SSC plyometric training volume						
r		.950			.759	
p		.050			.018	

Ave = average, CMJ = countermovement jump, HRmax = maximum heart rate, SSC = stretch shortening cycle, TT = time trial. % Δ peak lactate values are inverted, thus an increase is beneficial.

DISCUSSION

The purpose of this study was to present a retrospective analysis on the influence of a structured strength training intervention concurrent to middle distance training on RE and other performance variables in adolescent middle-distance athletes. The 8 wk period of training resulted in improvements in; 1200 and 1800 m TT performance, RE, vertical stiffness, CMJ, ∑7 skinfolds and peak lactate.

Arguably the most important performance indicator for a middle-distance athlete is the time in which they are able to run a specified distance, or "time trial performance". Therefore, the primary finding of this period of observation was that 8 weeks of concurrent strength and middle distance training intervention improved 1200, and 1800 m TT performance. These findings are in part consistent with those of Berryman *et al*. (Berryman et al., 2017), who reported strength type moderately improves endurance type performance, when conducted alongside endurance training. Large improvements in endurance performance were observed here (ES; 1800 m = .89, 1200 m = 1.25). This may be explained by the fact that at the start of the intervention many participants had performed minimal structured training for ≥4 wk.

Improvements in 1200 m TT performance were correlated with improvements in relative power output during CMJ ($W \cdot kg^{-1}$). Furthermore, improvements in 1800 m time trial performance were positively correlated with slow stretch-shortening cycle plyometric training volume. Combined, these data may indicate that improvements in explosive strength and accumulated volume of plyometric training may be beneficial for longer distance TT performance in adolescent athletes. Additional credibility is added to the hypothesis that strength training (particularly explosive and plyometric orientated training) is beneficial for endurance performance by the fact that improvements in endurance performance are coupled with improvements in tests assessing neuromuscular function (Berryman et al., 2017). Previous work has also indicated that maximal and explosive strength have been shown to differentiate between running performances across age ranges from young to old (Quinn, Manley, Aziz, Padham, & MacKenzie, 2011). In addition to improvements in TT performance and explosive strength (as assessed by CMJ) vertical stiffness was also improved following the training intervention. Although no correlations between improvements in vertical stiffness and TT performance were observed in our cohort, previous work has suggested that stiffness is related to running speed and possibly economy (Hobara et al., 2009; McMahon & Cheng, 1990). Average RE relative to body mass was improved by the concurrent strength and endurance training intervention also which has possibly contributed to the improvement in running times.

Although TT performance was improved, aerobic variables including; $\dot{V}O_{2max}$, velocity at $\dot{V}O_{2max}$, peak $\dot{V}O_{2max}$, HRmax and lactate threshold were virtually unchanged improved following the 8-week concurrent intervention. This is consistent with a previous study in which endurance athletes completed 8 weeks of explosive type strength training alongside their habitual endurance training and observed improvements in 5 km time trial performance without alterations in $\dot{V}O_2$ kinetics. Combined these data indicate that neuromuscular adaptations and likely increments in strength and power of the trained musculature were mostly responsible for the improvement in TT (Paavolainen, L,. Hakkinen, I,. Hamalainen, A,. Nummela, A,. Rusko, 2003). It has also shown that longer training programmes (>8 wk) are needed to elicit improvements in RE and Aerobic Capacity in growing athletes which may be due to the time it takes for the qualities being trained to develop to an useful level within the movement of running (Denadai et al., 2017; Thomas, Fernhall, & Granat, 1999).

Inverse relationships were observed between improvements in vertical stiffness and CMJ and % time spent performing long runs and % training time in low HR zones (1 & 2). This may indicate that higher volumes of prolonged low intensity endurance type training could have a muting effect on the development of explosive strength and vertical stiffness. This “interference effect” (Hickson, 1980) has previously been reported with strength development being inhibited following higher volumes of endurance type training (Häkkinen et al., 2003; T. W. Jones, Howatson, Russell, & French, 2016; McCarthy, Pozniak, & Agre, 2002). Furthermore, the aforementioned work noted that explosive phenotypes, like CMJ, were more susceptible to the so called “interference effect” than maximal strength indices. Additionally, previous work has reported smaller effects of strength training interventions on maximal power than maximal strength in endurance athletes (Berryman et al., 2017). These data indicate that practitioners seeking to develop explosive strength qualities in adolescent endurance athlete should consider alternative endurance training modalities to long low intensity runs when the focus of the training period is strength. % time spent performing fartlek, hills, tempo and track based training were not associated with any inhibition of explosive strength development, and as such, these methods may be appropriate alternatives.

The data presented here indicate that a concurrent strength and endurance training intervention is an effective training paradigm for improving economy, time trial performance and strength phenotypes in elite adolescent middle distance athletes. These performance gains were coupled with improvements in RE. Strength and explosive indices including CMJ and vertical stiffness were improved, and these increases were correlated with improvements in time trial performance. Furthermore, slow stretch-shortening cycle orientated plyometric training volume was related to magnitude of improvements in time trial performance. As such, it is reasonable to suggest that plyometric type training also contributed to the improvements in performance.

As stated throughout this is an observational account of a real-world intervention implemented in a group of highly trained adolescent middle distance athletes. As such, there are limitations here. The 8-week intervention was relatively short and took place following a 4-week detraining period, as such any improvements in performance may have been exacerbated due to the prior detraining of the athletes. In addition, there was no control group with which to compare any changes in performance with those who were exposed to the concurrent strength and endurance training intervention.

CONCLUSIONS

To optimize performance gains practitioners supporting adolescent middle-distance athletes should consider implementing strength training which includes plyometric activity concurrent to middle distance training. To maximize the benefits of any strength training performed practitioners should consider implementing this in periods in which high volumes of low intensity endurance training are not required.

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