The efficacy of downhill running as a method to enhance running economy in trained distance runners

Original investigation

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Abstract

Running downhill, in comparison to running on the flat, appears to involve an exaggerated stretch shortening cycle (SSC) due to greater impact loads and higher vertical velocity on landing, whilst also incurring a lower metabolic cost. Therefore, downhill running could facilitate higher volumes of training at higher speeds whilst performing an exaggerated SSC, potentially inducing favourable adaptations in running mechanics and running economy. This investigation assessed the efficacy of a supplementary 8 week programme of downhill running as a means of enhancing running economy in well trained distance runners. Nineteen athletes completed supplementary downhill (-5% gradient; *n*=10) or flat (*n*=9) run training twice a week for 8 weeks within their habitual training. Participants trained at a standardised intensity based on the velocity of lactate turnpoint (vLTP), with training volume increased incrementally between weeks. Changes in energy cost of running (E_C) and vLTP were assessed on both flat and downhill gradients, in addition to maximal oxygen uptake ($\dot{V}O_{2max}$). No changes in E_C were observed during flat running following downhill (1.22±0.09 vs 1.20±0.07 $Kcal \cdot kg^{-1} \cdot km^{-1}$, P=0.41) or flat run training (1.21±0.13 vs 1.19±0.12 $Kcal \cdot kg^{-1} \cdot km^{-1}$). Moreover, no changes in E_C during downhill running were observed in either condition (P>0.23). vLTP increased following both downhill (16.5±0.7 vs 16.9±0.6 $km \cdot h^{-1}$, P=0.05) and flat run training (16.9±0.7 vs 17.2±1.0 $km \cdot h^{-1}$, P=0.05), though no differences in responses were observed between groups (P=0.53). Therefore, a short programme of supplementary downhill run training does not appear to enhance running economy in already well-trained individuals.

Key words: Athletes, Athletic performance, energy cost, exercise training

Introduction

For distance running, maximal oxygen uptake ($\dot{V}O_{2max}$), the proportion of $\dot{V}O_{2max}$ that can be sustained prior to the onset blood lactate accumulation (lactate thresholds) and running economy (RE) are the primary physiological factors that underpin performance (Ingham et al. 2008). In populations where the differences in athletic capabilities are small, the combination of RE and maximal oxygen uptake ($\dot{V}O_{2max}$) can account for >90% of the variability in performance (McLaughlin, Howley, Bassett, Thompson, & Fitzhugh, 2010). However, improvements in $\dot{V}O_{2max}$ for athletes with already high capacities can be difficult to achieve (Hopker, Coleman, & Passfield, 2009; Iaia et al., 2009; Jones, 2006), therefore methods to enhance RE are sought after to maximise an athlete's performance. Yet, established training interventions that can improve RE in already well trained runners are limited.

Previous investigations have explored the use of strength/plyometric training to enhance RE in trained distance runners. The addition of lower-limb strength and/or plyometric training to endurance running programmes for ~10 weeks, has been noted to stimulate improvements in RE of 4-8% (Johnston, Timothy, Kertzer, & Vroman, 1997; Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999; Saunders et al., 2006; Sedano, Marín, Cuadrado, & Redondo, 2013). It has been speculated that such training methods promote neuromuscular adaptations, namely an increase muscle-tendon stiffness, that facilitate greater exploitation of the stretch shortening cycle (SSC), in addition to improved running mechanics (Paavolainen et al., 1999; Saunders et al., 2006). Downhill running might facilitate a more pronounced SSC stimulus above habitual/flat running, and thus promote adaptations in SSC function, running mechanics and economy.

Downhill running involves lowering the centre of mass within a stride cycle, releasing gravitational potential energy. When compared to flat or uphill running, downhill running is associated with greater impact loads and higher vertical velocity on landing (Gottschall & Kram, 2005; Neves, Johnson, Hunter, & Myrer, 2014), resulting in greater eccentric contractions of the extensor muscles of the lower limbs. Consequently, there is greater potential for elastic energy storage and return (Snyder & Farley, 2011). Frequent exposure to these higher impact loads and exaggerated stretch-shortening cycle activity could induce a range of neural, physiological and mechanical adaptations that promotes more effective energy storage and return. In addition, running downhill incurs a lower metabolic cost compared to flat or uphill running (Margaria, Cerretelli, Aghemo, & Sassi, 1963), such that higher velocities can be achieved for the same E_C and a greater volume of training at higher speeds may be possible with downhill running compared to running on the flat. Consequently, downhill running appears to involve an exaggerated SSC stimulus, from both the downhill gradient and higher velocities, whilst also facilitating greater exposure compared to running on the flat, and therefore might benefit running mechanics and economy.

To our knowledge, no previous investigation has examined the physiological responses to extended periods of downhill run training. A one off bout of running down steep gradients (-12-15%) has been shown to cause severe exercise induced muscle damage (EIMD) that has been associated with a transient worsening of RE (Baumann et al., 2014; Chen, Nosaka, Lin, Chen, & Wu, 2009). However, the use of shallow gradients and a progressive exposure (LaStayo, Pierotti, Pifer, Hoppeler, & Lindstedt, 2000) would be expected to circumvent any EIMD. Therefore, the aim of the current investigation was to assess the efficacy of a supplementary 8 week programme (16 training sessions) of progressive downhill running as a means of enhancing RE in well trained distance runners. The downhill running intervention was compared to an equivalent supplementary 8-week programme of intensity matched flat running to isolate the effect of surface gradient. It was hypothesised that prescribed regular downhill running would improve RE compared to running on the flat.

Methods

Participants

Nineteen highly trained athletes (males, *n* =17; Age: 25±6 years; stature: 179±5 cm; body mass: 68.2±7.2 kg; $\dot{V}O_{2max}$: 73.9±5.5 $mL \cdot kg^{-1} \cdot min^{-1}$; females *n*=2; Age: 24±5 years, stature: 168±4 cm, body mass: 58.3±6.6 kg, $\dot{V}O_{2max}$: 62.6±1.4 $mL \cdot kg^{-1} \cdot min^{-1}$) completed the current investigation. Participants' best performance times over the preceding two seasons were 118 ± 6% of the current British record as of May 2015 in their primary event between 800m and marathon, equating to an IAAF points score of 773±140 (Spiriev 2017). All participants were treadmill habituated, and provided written informed consent prior to participating in this study that had Loughborough University Ethics committee approval.

Overview

Participants were required to visit the laboratory on two occasions per week for 11 consecutive weeks (Figure 1). Prior to the initial visits, participants provided an overview of their ‘typical’ weekly training in the lead up to the investigation, that was categorised based on exercise intensity in accordance with previous investigations (Seiler & Kjerland, 2006) (Table 1).

All participants performed 1-2 gym-based conditioning session per week as part of their habitual training. Participants were pair matched (habitual training, competitive distances and sex), and randomly allocated to the flat (n=9) or the downhill (n=10) groups. During week 1, participants completed a submaximal flat running assessment followed by a maximal running assessment, with ~15 minutes of rest in between, and returned to complete a submaximal downhill running assessment. Participants then completed two blocks of 4 weeks of supplementary flat (1%) or downhill (-5%) run training (outlined below), interspersed with a week to complete submaximal running assessments to reassess appropriate training speeds. Finally, participants returned to complete post training assessments in an identical format to pre-training. Participants wore appropriate clothing and racing shoes, and with laboratory conditions remaining consistent throughout all sessions (temperature, 19 ± 1°C; relative humidity, 43 ± 12%).

Protocol

Submaximal running assessments

Prior to submaximal running assessments, body mass was measured using digital scales to the nearest 0.1 kg. Stature was recorded to the nearest 1 cm using a stadiometer. Using calibrated callipers (Harpenden, Holtain Limited, UK), body composition was assessed at pre- and post-intervention using an 8 site skinfold method (bicep, tricep, subscapular, illiac crest, supra-illiac, abdonmen, thigh and calf). The total of the 8 sites was then calculated and used as an index of fat mass.

Following a warm-up (~10 min at 10-12 km·h^{-1}), participants completed a discontinuous submaximal incremental test consisting of six to nine stages of 3 minutes continuous running, with increments of 1 km·h^{-1} on a motorised treadmill of known belt speeds (HP cosmos Saturn, Traunstein, Germany), as has been shown to produce reliable assessments of RE (Shaw, Ingham, Fudge, & Folland, 2013). During downhill running assessments, the same procedure was followed with the treadmill belt maintained at -5%. Runners ran with their self-selected running style during all downhill training and testing. Breath-by-breath gas exchange data were quantified via an automated open circuit metabolic cart throughout the running assessments (Oxycon Pro, Carefusion, San Diego, USA), calibrated according to the manufacturers guidelines. A photoelectric cell system (Optojump, Microgate, Bolzano, Italy) was used to measure ground contact time, flight time, stride length and stride frequency over the final 60s of submaximal running at 16 km·h^{-1} during flat and downhill running , both pre and post the interventions, as these variables have recently been related to RE and performance in a large cohort of runners (Black, Handsaker, Allen, Forrester, & Folland, 2017). Due to equipment limitations, observations were restricted to 12 athletes during flat assessments (downhill training group, n=7; flat training group, n=5) and 11 athletes during downhill assessments (downhill training group, n=7; flat training group, n=4). Between submaximal running stages 20µL of capillary blood was sampled from the earlobe for analysis of blood lactate (Biosen C-line, EKF diagnostics, Germany). The velocity at lactate turnpoint vLTP was identified based on the Thoden model (Thoden, 1991). The utilisation of $\dot{V}O_{2max}$ at vLTP (%$\dot{V}O_{2max}$), was calculated by expressing $\dot{V}O_2$ at vLTP as a percentage of $\dot{V}O_{2max}$ (see below). The four stages prior to vLTP were identified for each participant during flat ($vLTP_F$) and downhill running ($vLTP_D$), with an average of these four stages used to quantify energy cost (E_C) for both flat (RE_F) and downhill running (RE_D) in accordance with procedures outlined in previous studies (Shaw, Ingham, & Folland, 2014).

Training velocities were based on vLTP, as this speed represents the highest speed where valid measures of RE are still achievable. The vLTP from baseline flat and downhill assessments were used to infer appropriate training velocities for the flat and downhill conditions, respectively, during the first training block, with the vLTP from the mid-assessment used to infer training paces during the second training block.

Maximal running assessments

$\dot{V}O_{2max}$ was determined by a continuous incremental treadmill running ramp test to volitional exhaustion. Participants initially ran at a speed 2 km·h^{-1} below the final speed of the submaximal test and at a 1% gradient. Each minute, the incline was increased by 1% until volitional exhaustion. The test duration was typically 6-8 minutes. $\dot{V}O_{2max}$ was defined was the highest average breath-by-breath $\dot{V}O_2$ over a continuous 30s sample during the maximal running assessment, expressed relative to body mass (mL·kg^{-1}·min^{-1}). The regression equation describing the $\dot{V}O_2$ and speed relationship during the submaximal flat running assessment was used to calculate the velocity associated with $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$).

Supplementary training interventions

Two progressive 'tempo' training sessions were included in athlete's weekly training (Figure 1), typically replacing an existing session of a similar intensity. During the first session, following a warm up (~10 mins at ~11-12 $km{\cdot}h^{-1}$), participants completed 7 min of running at 90% of the gradient specific vLTP, followed continuously by 5 mins at 100% vLTP. Participants then rested for 3 min, followed by a final 3 min at 110% vLTP. The same session was then repeated within 7 days, with volume incrementally increasing for each additional week. For the following 3 weeks, 2 min were added to each intensity (i.e. by week 4: 13 min at 90%vLTP, 11 min at 100%vLTP and 9 min at 110%vLTP). To ensure athletes could achieve the total duration prescribed at 110%vLTP this period was divided into intervals that were ≤ 3 min with 90s rest between intervals (i.e. 7 min spilt into 3 x 2 min 20 second intervals, 9 min into 3 x 3min intervals). During the second 4-week block the duration at each intensity was only increased by 1 $min{\cdot}week^{-1}$. As a result, the final two training sessions involved 17 min at 90% vLTP, 15 min at 100% vLTP and 13 min (5 x 2 min 36 s) at 110% vLTP. All supplementary training sessions were supervised by the principle investigator.

Statistical analyses

Data analysis was conducted using SPSS (v21; IBM Corporation, Armonk, NY). Normal distribution of the dependent variables was confirmed via Shaprio-wilk tests. Paired sample t-tests were used to assess any differences between groups at baseline for the training, anthropometrical, physiological and stride characteristics assessed. Within group changes in physiological variables and stride parameters were assessed via paired samples t-tests. Between group effects were assessed with mixed measures ANOVA (Group; downhill vs flat training × Time; Pre vs Post). Data are presented as mean ± SD, with significance differences accepted at $P \leq 0.05$.

Results

The training groups were well matched, with no differences observed in age (27±6 and 23±5 yrs) or stature (177±5 and 179±5cm), nor were any differences noted in other anthropometrical, training, physiological or biomechanical characteristics (Table 1; Table 2). Body mass remained consistent across the study period for both flat and downhill groups ($P>0.10$). Skinfolds decreased after flat training ($P=0.05$), but did not change in the downhill group ($P=0.14$). However, no time x group interaction occurred ($P=0.48$).

Flat running assessments

RE_F demonstrated no within group changes after downhill ($P=0.41$) or flat training ($P=0.68$), with no group x time interaction effect (ANOVA, $P=0.89$; Figure 2). $vLTP_F$ increased after the flat ($P=0.05$) and downhill training ($P=0.05$), however no interaction effect was present (Table 3). When running at vLTP an increase in $\%\dot{V}O_{2max}$ was evident when groups were combined (ANOVA, main effect of time, $P=0.05$), however no interaction effect was present. Further, no within group changes were evident in $\%\dot{V}O_{2max}$ at vLTP after downhill (86.2±8.0% vs 89.4±7.8%, $P=0.19$) or flat training (86.5±4.5% vs 89.1±4.5%, $P=0.11$). No differences in $\dot{V}O_{2max}$ or $v\dot{V}O_{2max}$ were noted between pre and post assessments in either condition (Table 3), nor were any group x time interaction effects present ($P=0.38$ and $P=0.55$).

Flight time, stride length and stride frequency remained unchanged between pre to post assessments (Table 3). ANOVA revealed a significant group x time interaction effect for ground contact time. However, post hoc analysis revealed no differences in contact time between groups pre and post intervention ($P=0.64$) and within group t-tests showing contact time displayed a non-significant increase in the flat training group ($P=0.09$) and a non-significant decrease in the downhill training group ($P=0.18$) post training.

Downhill running assessments

RE_D showed no within group changes after downhill ($P=0.23$) or flat training ($P=0.87$), with no interaction effect (ANOVA, $P=0.61$; Figure 2). $vLTP_D$ increased after downhill ($P=0.02$) and flat training ($P=0.04$), however no interaction effect was present (Table 3). Moreover, the $\%\dot{V}O_{2max}$ at vLTP remained consistent for both the downhill (82.5±7.9% vs 85.3±6.9%, $P=0.21$) and flat training groups (82.7±5.2% vs 84.4±3.6%, $P=0.43$) when running downhill. Flight time, stride frequency, stride length and ground contact time remained unchanged during downhill running assessments following training in both groups (P>0.11), with no group x time interactions (Table 3).

Discussion

The aim of the current investigation was to evaluate the efficacy of a supplementary downhill run training programme as a means to enhance the RE of well-trained distance runners. We found that 8 weeks of supplementary downhill or flat run training at vLTP did not change RE. Both training groups showed improvements in vLTP of both flat and downhill running, and therefore these improvements were not specific to the training gradient. Contrary to our hypothesis, a short programme of supplementary downhill run training did not enhance RE in already well-trained individuals.

The influence of chronic downhill training on RE has not previously been documented. It was proposed that downhill running could facilitate greater training time at high running velocities involving prolonged exposure to high impact forces and an exaggerated SSC, potentially leading to adaptations in SSC function, running mechanics and economy. Due to the reduced E_C for a given exercise intensity, training velocities were ~2 $km \cdot h^{-1}$ greater in the downhill group compared to the flat training group. However, despite the exposure to the higher running velocities and greater impact forces of downhill running, no changes in RE were observed after the 16 sessions of downhill run training in already well-trained individuals. It is possible that, the distinct biomechanical characteristics of downhill running, particularly the higher braking forces and decreased propulsive forces (Gottschall & Kram, 2005) may have produced specific neuromechanical adaptations that did not transfer to level running.

In contrast, traditional plyometric training has been shown to increase RE in trained endurance athletes over a similar time frame (Paavolainen et al., 1999; Saunders et al., 2006), attributed to concurrent changes in surrogate measures of neuromuscular adaptations (i.e. ground contact times, 5 jump plyometric test performances) that might suggest a greater exploitation of the SSC. In contrast, in the current study there were no changes in running mechanics following downhill run training. The SSC that occurs during downhill running is likely less pronounced and slower than the SSC during traditional plyometric exercises. Specifically, a short amortization/transition phase between eccentric and concentric activity is widely considered optimal to subsequent concentric force generation (Wilson et al. 1991). It is possible that the SSC during downhill running involves a relatively long amortization phase with little enhancement of subsequent concentric force production and thus may be a relatively weak stimulus for SSC improvements.

The highly trained status of the current cohort could also, in part, explain the lack of change in RE in the current investigation. Despite no previous exposure to structured downhill running, participants all performed high intensity training and resistance based conditioning sessions in their habitual training; matching previous observations from high performance endurance runners (Esteve-Lanao, Juan, Earnest, Foster, & Lucia, 2005; Ingham, Fudge, & Pringle, 2012). In contrast, previous investigations reporting an enhanced RE to short term strength/resistance training interventions have commonly observed athletes with minimal resistance training experience (Guglielmo, Greco, & Denadai, 2009; Saunders et al., 2006; Taipale, Mikkola, Vesterinen, Nummela, & Häkkinen, 2013), or following extended periods (> 6 weeks) of no resistance training (Johnston et al., 1997). Consequently, the changes in RE reported could reflect the rapid neural adaptations and learning effect that occur in response to initial bouts of resistance training in unaccustomed athletes (Folland & Williams, 2007). Indeed, when additional strength and/or plyometric training has been incorporated into the training programmes of resistance trained endurance athletes, no change or small improvements (~3%) in RE have been reported after comparably long exposures of 12-14 weeks (Millet, Jaouen, Borrani, & Candau, 2002; Sedano et al., 2013). Though changes did not reach significance in the current study, the group response to downhill training was a 1.5% increase in RE, which is comparable to the smallest worthwhile change in this variable (Shaw et al., 2013) - the threshold for when a change is viewed as meaningful. It is therefore plausible that the short-term intervention with a comparatively modest downhill running stimulus was insufficient to promote any additional neuromuscular adaptations beyond the habitual training of the current cohort.

It has been proposed that an athlete’s RE varies according to their competitive distance and habitually training velocity (Daniels & Daniels, 1992; Jones & Carter, 2000). Consequently, it could be argued that training at a prescribed velocity itself could provide an efficacious method to enhance RE at that given velocity. However, in line with the downhill training group, no change was observed in RE at speeds close to vLTP for athletes performing intensity matched flat running. These findings support previous investigations where no improvement in RE at vLTP was noted following prescribed training at vLTP in recreational(Yoshida et al., 1990) and highly trained runners(Sjödin, Jacobs, & Svedenhag, 1982). Whilst it is possible that a longer exposure could be required due to the highly trained status of the cohort, no changes in

RE at speeds close to vLTP have been observed across a competitive season in highly trained runners, despite a notable training volume around this velocity (Galbraith, Hopker, Cardinale, Cunniffe, & Passfield, 2014). Overall, our findings and several other studies suggest that structured flat run training at speeds around vLTP does not improve RE in a velocity specific manner in already well-trained athletes.

No changes in $\dot{V}O_{2max}$ were apparent following 8 weeks of training in either condition. These findings are in accordance with previous observations from trained runners, where $\dot{V}O_{2max}$ has remained consistent following the introduction of additional training of similar intensities: at vLTP(Sjödin et al., 1982), and interval training at and above vLTP (Barnes, Hopkins, McGuigan, & Kilding, 2013; Billat, Demarle, Paiva, & Koralsztein, 2002). As training at or around $v\dot{V}O_{2max}$ has been postulated to be the most effective way to enhance $\dot{V}O_{2max}$ in well trained athletes (Midgley, McNaughton, & Wilkinson, 2006), it seems likely that the submaximal intensities of the current investigation were insufficient to prompt improvements.

In contrast, increases in both $vLTP_F$ and $vLTP_D$ were noted following the downhill (2.4 and 3.2%, respectively) and flat training (1.8 and 2.0%, respectively). These findings support previous reports where enhancements in $vLTP_F$ have been observed following the incorporation of additional run training around vLTP in trained runners (Billat, Sirvent, Lepretre, & Koralsztein, 2004; Sjödin et al., 1982). Furthermore the improvements at both test gradients after training with both flat and downhill running indicates that these metabolic adaptations in vLTP are not gradient dependant, and are likely mediated by changes in lactate production (e.g. mitochondrial biogenesis and elevated oxidative enzyme concentrations / activity (Holloszy & Coyle, 1984)) or removal.

It should be noted that the current study is not without limitation. Whilst a comprehensive assessment of physiological parameters was conducted, there was no direct measure of performance in either the downhill or flat condition. Though vLTP can provide an index of submaximal performance capabilities, specifically 10km performances (Jones 2006), the sensitivity of this measure could have limited the identification of group x time differences. In addition, more detailed assessment of kinetic parameters such as ground reaction forces might have facilitated a greater understanding of the kinetic alterations following the training period. Therefore, future investigations might look to utilise instrumented treadmills or motion capture systems to shed further light on the biomechanical responses to downhill run training.

Conclusion

In conclusion, our data indicate that 8 weeks of supplementary downhill run training at vLTP within existing training programmes does not enhance the RE of already well-trained runners. Given the importance of running economy to endurance performance, further investigations are required to elucidate practical and accessible methods to enhance running economy in already well-trained athletes.

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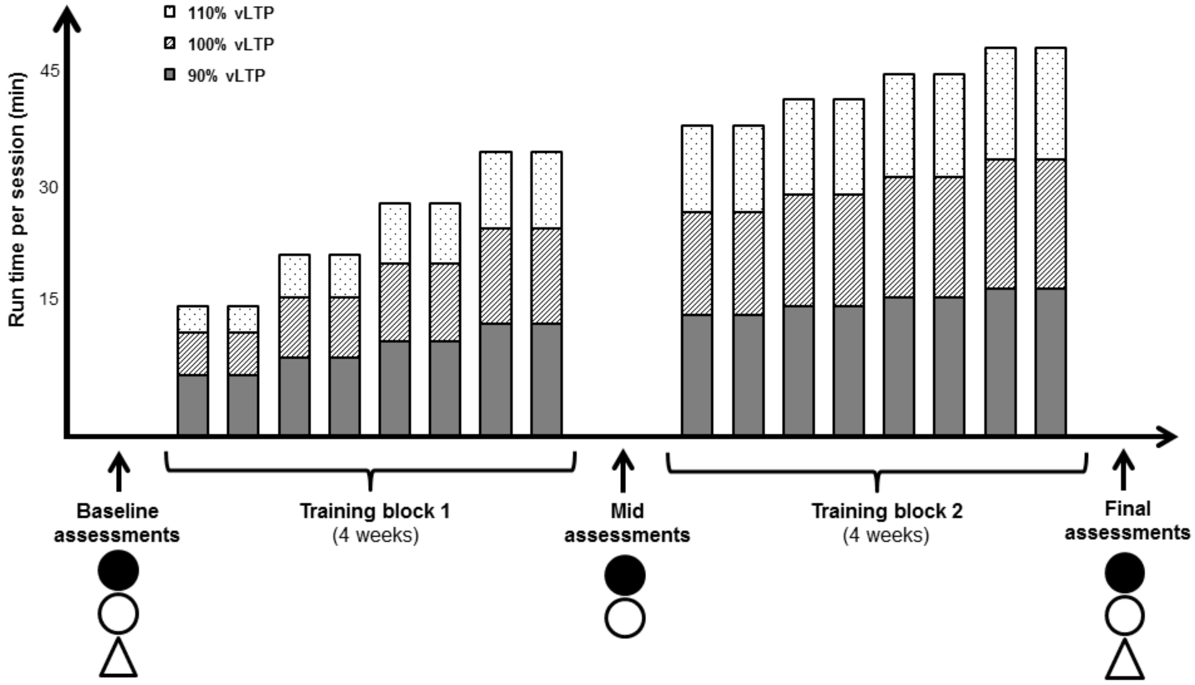

Figure 1. Schematic overview of the study. Bars represent running volume per training session, split into the 3 running intensities. Filled circles represent submaximal flat running assessments; Unfilled circles represent submaximal downhill running assessments; Unfilled triangles represent maximal running assessments.

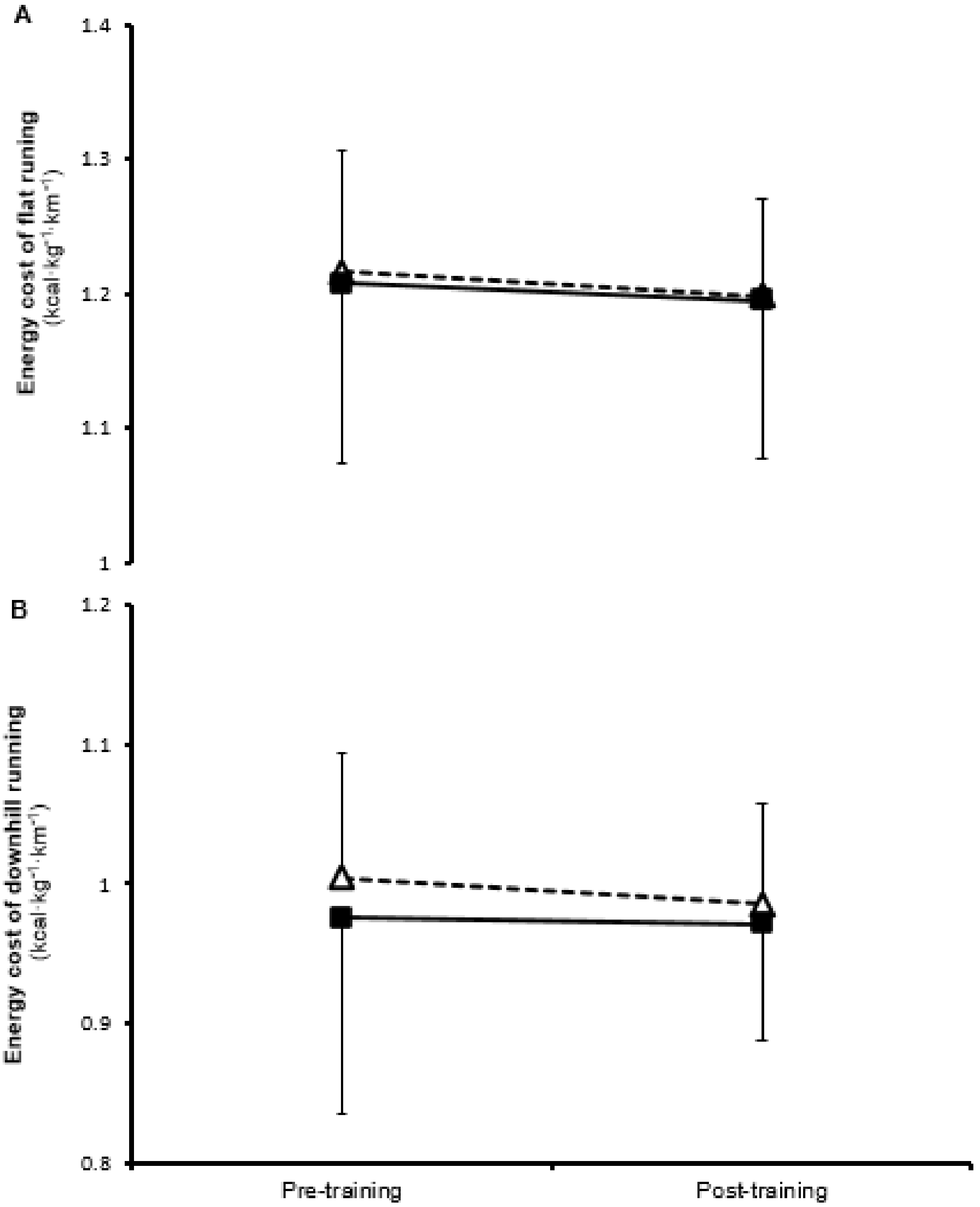

Figure 2. Energy cost pre- and post-8 weeks of supplementary training in the flat (Solid squares, solid line) and downhill (Open triangles, dashed line) training groups during submaximal **A.** flat and **B.** downhill running assessments.

Table 1. Participant's weekly run training prior to intervention, categorised by a 3 zone approach (Seiler et al. 2006). Zone 1 < lactate threshold; Zone 2 > lactate threshold, < lactate turnpoint; Zone 3 > lactate turnpoint.

Group	**Total run volume** (miles)	**Zone 1** (% total volume)	**Zone 2** (% total volume)	**Zone 3** (% total volume)
Flat training	54.6 ± 5.2	69 ± 9	16 ± 10	15 ± 3
Downhill training	53.6 ± 7.6	68 ± 9	18 ± 10	14 ± 3

Table 2. Anthropometric and physiological variables assessed at baseline and post 8 weeks of prescribed training

	Flat training		**Downhill training**	
	Pre	***Post***	***Pre***	***Post***
Body mass (kg)	68.2 ± 7.9	67.2 ± 8.1	66.2 ± 7.7	66.1 ± 7.4
Skinfolds (mm)	55.0 ± 22.9	50 ± 17.9	48.6 ± 15.4	45.7 ± 10.9
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	72.9 ± 6.7	72.6 ± 5.9	72.6 ± 6.7	70.7 ± 4.9
$v\dot{V}O_{2max}$ ($km \cdot h^{-1}$)	19.7 ± 1.6	19.5 ± 1.3	19.2 ± 1.3	19.1 ± 1.0

$\dot{V}O_{2max}$, maximal oxygen uptake; $v\dot{V}O_{2max}$, velocity associated with maximal oxygen uptake

Table 1. Physiological and biomechanical variables assessed pre and post 8 weeks of prescribed training in the flat and downhill training groups.

	Flat training		**Downhill training**		**ANOVA (group x time; P=)**
	Pre	***Post***	***Pre***	***Post***	
Flat Running					
LTP_F (km·h^{-1})	16.9 ± 0.7	17.2 ± 1.0*	16.5 ± 0.7	16.9 ± 0.6*	0.53
Ground contact (s)	0.20 ± 0.02	0.21 ± 0.01	0.21 ± 0.01	0.20 ± 0.01	0.03
Stride length (m)	3.02 ± 0.21	3.07 ± 0.12	2.96 ± 0.12	3.01 ± 0.19	0.98
Stride frequency (Strides·min^{-1})	176 ± 14	174 ± 7	178 ± 7	179 ± 6	0.64
Flight time (s)	0.14 ± 0.02	0.14 ± 0.02	0.13 ± 0.02	0.13 ± 0.02	0.64
Downhill Running					
LTP_D (km·h^{-1})	19.3 ± 1.0	19.7 ± 1.3*	18.5 ± 0.8	19.1 ± 0.8*	0.53
Ground contact (s)	0.20 ± 0.02	0.21 ± 0.01	0.20 ± 0.02	0.20 ± 0.01	0.21
Stride length (m)	3.10 ± 0.20	3.18 ± 0.15	3.00 ± 0.05	3.05 ± 0.05	0.44
Stride frequency (Strides·min^{-1})	170 ± 12	169 ± 8	176 ± 4	177 ± 5	0.27
Flight time (s)	0.15 ± 0.02	0.15 ± 0.01	0.14 ± 0.02	0.14 ± 0.02	0.74

* - denotes significant difference to pre-assessment ($P \leq 0.05$). RE_D, downhill running economy; LTP_F, lactate threshold for flat running; LTP_D, lactate threshold for downhill running.