UNIVERSITY OF AGDER

Annual training characteristics in elite long-distance runners

A descriptive study on training volume and intensity distribution

By

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This Master's Thesis is carried out as a part of the education at the University of Agder and is therefore approved as a part of this education. However, this does not imply that the University answers for the methods that are used or the conclusions that are drawn.

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Abstract

Purpose: The aim of the present study is to describe and quantify annual training characteristics in elite long-distance runners, based on training volume and intensity distribution.

Method: Fifteen elite long-distance runners (nine males and six females) with personal best times >90 % of the world record in current competing distance, were included in the study. Questionnaires concerning training volume and examples of training weeks were used to describe training volume and intensity distribution during different periods of training.

Results: Annual training volume was 7089.5±1064 km/660±111hours in male athletes and 4019.5±529km/502±18 hours in female athletes.

During the build-up period, athletes trained 159±19 and 140±28 km/week, male and female respectively. The volume slightly decreased in both genders throughout the season.

In the build-up period athletes trained 77 % of their total volume in zone 1, whereas high intensity training was mainly done in zone 3. The majority of the training was done in zone 1 throughout the season. As the season progressed the training became more polarized due to a decrease of the training done in zone 3 and an increase in zone 4 and 5.

Conclusion: This study shows that elite long-distance runners attain a high annual training volume, where the majority of training is specific to running. The training volume remained relative constant, but were reduced during the competition period. The majority of training was trained at low intensities throughout the season, but the amount of high intensity training increased during the season.

Sammendrag

Formål: Formålet med denne studien er å beskrive og kvantifisere egenskaper ved treningen blant elite langdistanseløpere, basert på treningsvolum og intensitetsfordeling.
Metode: Femten elite-langdistanseløpere (ni menn og seks kvinner) med personlig rekordtid > 90 % av nåværende verdensrekord innen de ulikes konkurransedistanse, ble inkludert i studien. Spørreskjemaer om treningsvolum og eksempler på treningsuker ble brukt til å beskrive treningsvolum og intensitets distribusjon i de ulike treningsperiodene.
Resultat: Årlig treningsmengde var 7089,5 ± 1064 km/660 ± 111 timer blant de mannlige idrettsutøverne og 4019,5 ± 529km/502 ± 18 timer blant de kvinnelige idrettsutøverne.
I den forberedende perioden trente idrettsutøverne 159 ± 19 og 140 ± 28 km/uke, henholdsvis menn og kvinner. Det opplevdes en mindre redusering av dette volumet blant begge kjønn gjennom de resterende periodene i sesongen.
I den forberedende perioden ble 77 % av utøvernes totale volum rapportert som sone 1, mens høy-intensitetstrening hovedsakelig ble gjort i sone 3. Majoriteten av treningen ble utført i sone 1 gjennom hele sesongen. Utover i sesongen ble treningen mer polarisert på grunn av en reduksjon av treningen utført i sone 3 og en økning av trening i sone 4 og 5.
Konklusjon: Denne studien viser at elite-langdistanseløpere har et høyt årlig treningsvolum, majoriteten av treningen er spesifisert til løping. Treningsvolumet holdt seg relativt konstant, men ble redusert under konkurranseperioden. Majoriteten av treningen ble utført ved intensitet gjennom hele sesongen, men mengden av høy-intensitetstrening økte i løpet av sesongen.

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It has been a fascinating experience writing this thesis and learning about the training regimes of some of Norway's greatest endurance athletes. I am very grateful for being able to research such an interesting topic.

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Introduction

There are several factors that are essential in order for endurance athletes to perform at an elite level, such as VO2 max, lactate threshold and running economy (Jones & Carter, 2000; Lucia, Olivan, Bravo, Gonzalez-Freire, & Foster, 2008; Midgley, McNaughton, & Jones, 2007) In order to obtain good results such factors must be improved, which is an objective met through the organizing of training. Training volume and training intensity are important factors to be considered when optimizing training. Their importance increases with the performance level, which shows their relevance for elite athletes (Stephen Seiler & Tønnessen, 2009).

Concerning the training volume of elite long-distance runners current research suggests that athletes train with high volumes and that training volume seems to increase linear with performance (Ferreira & Rolim, 2006; Karp, 2007; Noakes, 1986; Slovic, 1977). In studies quantifying training over different periods during an annual cycle it seems like the training volume remains relatively constant throughout the entire season (Enoksen, Tjelta, & Tjelta, 2011; Tjelta & Enoksen, 2010)

Research on training intensity in elite long-distance runners has shown that the majority of the training is done at a low intensity with a smaller portion of high intensity training. It is suggested that elite endurance athletes train towards an 80-20 % distribution between low and high intensities (K. S. Seiler & Kjerland, 2006; Stephen Seiler & Tønnessen, 2009). However, it appears to be unclear how elite athletes distribute their training intensity during different periods of the season.

Current research on training volume and intensity distribution in elite long-distance runners are mainly focused on either a single training period or a few weeks of training. The few studies conducted over an entire season are mainly case studies. This creates a theory gap on the subject of annual training cycles. The main purpose of this study is therefore to quantify the training volume and intensity distribution in several elite long-distance runners in an annual training cycle and during different periods. The research question is threefold:

- *How do elite long-distance runners distribute training volume specific to running during an annual cycle?*
- *How do elite long-distance runners distribute their training volume during the different training periods?*
- *How do elite long-distance runners distribute their intensity during an annual cycle as well as in different periods?*

Theory:

Training volume

Training volume is defined as the duration and distance covered by athletes per unit (day, week, month or year) (Bangsbo, Institute of, & Sport Sciences, 2001) Endurance athletes are known for a high training volume, and when the performance level of the athlete increases the total volume increases as well (Stephen Seiler & Tønnessen, 2009).

As early as in 1954 it was reported that the world champion on 10.000m Emil Zatopek, ran a total of 8064 kilometers per year. Reports from 1972-1981 show that the total volume of world record holders varied from 5900 to 8790km (Karikosk, 1984). Noakes (1986) suggested that an elite athlete who trained between 150-200 km/week per year would achieve best results in long-distance running. This statement is supported by a case study conducted on Kenyan elite marathon runners, where Stellingwerff (2012) found that the total training volume of the individual athletes varied from 159 to 213 km/week during 48 weeks of the season. Another study supporting this statement found that American elite marathon runners trained an average of 155 km/week in the year leading up to the Olympic trials (Karp, 2007). It is argued that the total weekly training distance is an important variable for performance time in marathon running (Dotan et al., 1983). Figure 1 shows a linear relationship between training kilometers/week and performance level in athletes

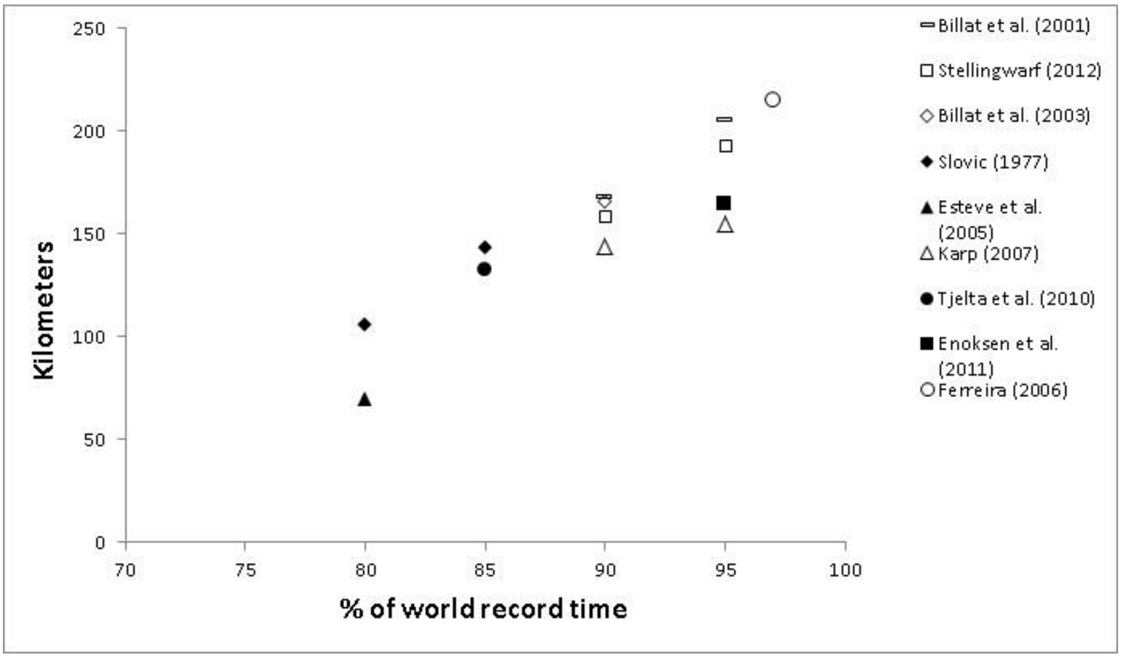

Figure 1: Total weekly training volume reported by different studies based on performance of participants.

The training volume in long-distance runners is mainly measured by kilometers, and not by hours. Therefore there are relatively few studies mentioning total hours trained during an annual cycle of training. However, a study reported that three elite marathon runners trained an average of 13 hours/week during the researched season, which is a total of ~ 676 hours (Stellingwerff, 2012). A similar case study was conducted on a female athlete who was a former world record holder in 5km, reported 550 training hours during her competitive season (Tønnessen, 2009).

Apart from the abovementioned research, there are relatively few studies conducted on the total annual training volume of elite long-distance runners. Current research on the topic mainly focuses on periodical training volume; hence there is a need for descriptive studies throughout an entire season.

Long-distance runners often divide their season into separate periods with a different training load in order to optimize their training. These periods are called macrocycles and for athletes they are often categorized as preparatory, competition, transition and active recovery period which can span over several months (Issurin, 2008). During these periods the intensity and volume of training varies with the purpose of optimizing performance (Stephen Seiler & Tønnessen, 2009).

During the pre-competition period of 20 elite Kenyan runners, V. Billat et al. (2003) reported a training volume of 158 ± 13 km/week in male athletes and 127 ± 8 in female athletes. These results are in agreement with results from a study on six Norwegian elite track & field and marathon runners (Enoksen et al., 2011). The elite track and field athletes reported a training volume of 161 ± 11 km and 167 ± 3 km/week during preparation and pre-competition periods respectively. The marathon athletes reported a higher volume with an average of 186 km/week in both periods which is consistent with another study done on elite marathon runners that reported an average of 180 km/week during the pre-competition period (V. L. Billat, Demarle, Slawinski, Paiva, & Koralsztein, 2001). Both studies showed that during the preparatory and pre-competition period, the training volume remained relatively constant. Ferreira and Rolim (2006) however, found that the weekly training volume increased from the preparation period to the pre-competition period, from 185km/week to 215km/week in elite marathon runners. Similar patterns of increased km/week over the different periods are also observed in elite junior track and field runners (Tjelta & Enoksen, 2010).

Karikosk (1984) hypothesized that a further increase in total volume may not translate to a enhancement in performance and can rather bring negative results. This is supported by studies examining the effect of increased training volume in well trained middle and long – distance runners (Lehmann et al., 1992; Lehmann, Jakob, Gastmann, Steinacker, & Keul, 1995). In the first study, a group of long-distance runners increased their total training volume from 85.9 km/week to 176.6 km/week within three weeks, with 96 % of the training at 67 % of maximum capacity. After the period was completed an incremental test showed a significant decrease in performance. The researcher hypothesized that the cause of the decrease was an imbalance between training and recovery due to the high volume of training (Lehmann et al., 1992). The latter study reported similar results with decreasing performance after a period with significant higher training volume in sub-elite athletes (Lehmann et al., 1995). Mujika (1998) concluded in a review that an increase in training volume did not appear to be directly related to an increase in performance of highly trained individuals.

In summary, literature suggests that the total training volume in elite athletes during an annual cycle is located at > 7000km and > 600 hours. Divided into weeks this means a total of > 135 km/week and ~ 12 hours/week. The total training volume appears to remain relatively constant during different periods of training during a season.

Training intensity distribution

A large amount of low intensity training in combination with high intensity training seems to be important in order to achieve maximum training benefits while at the same time avoiding overtraining in elite endurance athletes (Guellich, Seiler, & Emrich, 2009; Laursen, 2010). The most common way to describe intensity distribution during training is by the use of different intensity scales based on different measurements like heart rate monitoring, blood lactate concentration and velocity of different competition paces. Due to the fact that different methods of quantification can provide different results, care must be taken when evaluating studies quantifying intensity (K. S. Seiler & Kjerland, 2006).

It is suggested that elite endurance athletes organize approximately 75 % of their training at low intensities below the lactate threshold (K. S. Seiler & Kjerland, 2006), and that they incorporate small doses of approximately 20 % at high intensities at or above lactate threshold (Stephen Seiler & Tønnessen, 2009). This distribution of low intensities seems to be a beneficial approach, which is shown in Esteve-Lanao, San Juan, Earnest, Foster, and Lucia (2005), who conducted a study on eight national long-distance runners during six months of training. They found a significant correlation between training performed at low intensities (< 70% of HR_{max}) and performance in competition. These athletes trained 71 % of their total training below 70 % of HR_{max}. Even though this study was done on national level athletes, this distribution is widely supported in the literature on elite long-distance athletes (Table 1).

Relatively few studies have investigated how the training intensity of elite long-distance runners is distributed across a total season as well as in different periods during a season. These studies are often either case studies or contain few athletes at an elite level. A case study conducted by Stellingwerff (2012) on three elite marathon runners analyzed training data from 606 training sessions over 42 weeks of training. The intensity distribution was divided into three zones based on rated perceived exertion on a scale from 1 to 10.The findings showed that athletes performed 74 % of the training sessions at zone 1. The distribution between zone 2 and 3 were relatively equal with 11 % and 15 % respectively. In studies reporting training through a total season it seems that the high volume at low intensity training is maintained, but an increase has been observed in high intensity training during the pre-competition and competition period (Enoksen et al., 2011; Karp, 2007; Tjelta & Enoksen, 2010).

In a study focusing on 6-8 weeks of training during the build-up period, the intensity distribution in 13 elite athletes was investigated (Robinson, Robinson, Hume, & Hopkins, 1991). Heart-rate measurement and blood lactate concentration were recorded and used to convert the training sessions into mean training speeds (TS). Their findings suggest that only 4 % of all the training sessions were at or exceeded the lactate threshold, while the remaining training sessions were at an average 77 % of lactate threshold, which could be translated to about 60 % of VO_{2max}. Similar results concerning a high volume of low intensity has been found in the build-up period in a case study done on six elite Norwegian long-distance runners. By analyzing their training diaries the authors reported that 76 % of the weekly volume was trained at zone 1 (65-82 % HR_{max}) and the majority of the intensive training between 82-92 % of HR_{max}, which was slightly below or at the lactate threshold (Enoksen et al., 2011). The large amount of low intensity steady state training during the build-up period seems to serve the purpose of building an endurance platform from which further enhancements can be elicited (Laursen, 2010).

Research has suggested that athletes increase their amount of high intensity training as the season progresses into the pre-competition period (Hewson & Hopkins, 1996). During 8-

weeks in the pre-competition period, elite marathon runners showed an enhancement in their VO_2peak after the training period (V. Billat, Demarle, Paiva, & Koralsztein, 2002). The authors hypothesized that the increase in VO_{2max} was due to the high amount of training at velocity of 3000m and 10000m competition, which represented 11 % of weekly distance trained. These velocities translates to approximately zone 4 (87-92 % of HR_{max}) and 5 (94-100 % HR_{max}) in a 5 zone scale.

By assessing the training diaries and typical weeks of 20 elite Kenyan marathon runners who were divided into two groups based in their training characteristics, V. Billat et al. (2003) quantified the training intensity during the final 8 weeks prior to 10km trials. One group consisted of "high-speed training" (HST) runners and the other of "low-speed training" (LST) runners. The HST group trained towards a more polarized training model, where high volumes of training were trained at low intensity (below lactate threshold) and a more intensified approach to high intensity training with more training at vVO_{2max} instead of training at lactate threshold. The LST group performed high volumes of lactate threshold intensities, and no training at $vVO_{2max.}$ The latter approach has similarities with the threshold model, where much training is done at lactate threshold intensities. When comparing the performance of the two groups in a 10km competition, the results showed that the athletes in the HST achieved better results than that of the LST group. The author hypothesized that this was mainly due to the fact that HST group had a higher vVO_{2max}, which could be a benefit of training at higher intensities.

Similar results of improved performance when utilizing a more polarized training model were shown by Ingham, Fudge, and Pringle (2012) when they analyzed the training volume and intensity distribution of an elite 1500m runner over two years of training. The athlete distributed his training in favor of the threshold training model the first year, with little focus on low-intensity training and more training at moderate intensity. During the second year the athlete shifted towards a more polarized model, which emphasized training at a low intensity, less at a moderate intensity and a slightly increase in high intensity training. The change in intensity distribution seemed to cause an enhancement in physiological factors such as increased VO_{2max} and velocity at lactate threshold. Additionally, the athlete increased his performance by 1.4 % during the second year.

Esteve-Lanao, Foster, Seiler, and Lucia (2007) researched the effect on shifting from a typical polarized intensity distribution of 80 % at zone 1, 10 % zone 2 and 10 % at zone 3, towards a threshold model of 65 %, 25 % and 10 % in zone 1, 2 and 3 respectively. The research showed that polarized training caused a significantly greater enhancement in performance. Similar findings were reported in a study conducted on elite Kenyan long-distance runners where the subjects were divided into groups of low-speed (LST) and high-speed training (HST). The LST group ran 14 % of weekly distance at lactate threshold while the HST group ran 7 % at lactate threshold. When the personal best performances on 10km were analyzed between the two groups, the LST group ran 1.4 % slower than the HST group (V. Billat et al., 2003). These results may indicate that increasing the training time spent at a lactate threshold intensity instead of training at high intensities may inhibit well-trained athletes to perform at their potential. Another problem with high volume of threshold training may be the delay in autonomic recovery after training, which in turn can disrupt the balance between training and recovery (S. Seiler, Haugen, & Kuffel, 2007).

Table 1: Overview of the literature done on intensity distribution among long-distance runners. TM=Threshold model, PM=Polarized model. Intensity distribution converted into 3 zone model

Study	Subjects	Intensity distribution	Duration	Training model	Period of training
Esteve-Lanao et al. (2005)	8 sub – elite runners	71-21-8	24wk	TM	Build-up, pre-competition and competition
V. L. Billat et al. (2001)	20 elite-runners	78-12-10	12wk	PM	Pre-competition
V. Billat et al. (2003)	20 elite-runners (divided into 2 groups)	84-7-9 85-14-1	8wk	PM TM	Pre-competition
Tjelta and Enoksen (2010)	4 elite junior runners	78-20-2 81-12-7 78-18-4	12 months	TM	Build-up, pre-competition and competition
Enoksen et al. (2011)	6 elite runners (3 track runners and 3 marathon runners)	T M 76-19-4 83-13-4 79-14-6 85-11-4 80-13-6 80-17-3	12 months	PM	Build-up, pre-competition and competition
Stellingwerff (2012)	3 elite marathon runners	74-11-15	42 weeks	PM	Build-up, pre-competition and competition
Karp (2007)	3 elite marathon runners	83-12-5	12 months	TM	Build-up, pre-competition and competition

There is unison in the literature concerning elite long-distance runners leaning towards a more polarized training model with emphasis on low intensity training. Moreover, the majority of the research have found that elite long-distance runners spend >75 % of their total training volume at intensities below lactate threshold. There is however some disagreement concerning the distribution of higher intensities. Some studies favor higher intensities and have shown its benefits in elite long-distance runners, while others suggests that intensity training should be done at lactate threshold. One of the main causes of this disagreement could be the existence of different methods for quantifying training intensities and different definitions of intensity zones and velocities. There are few studies using a 5 zone scale for quantifying training intensity among elite long-distance runners, and those who do are based on a relatively small sample of athletes in case studies (Enoksen et al., 2011; Tjelta & Enoksen, 2010). Using a 5 zone scale can be beneficial in obtaining a more detailed picture of how elite athletes distribute their training. Current research on elite long-distance runners mainly focuses on a single period or few weeks during a period of training. Research on training through an annual cycle is mainly case studies with few athletes, which shows the need for studies with more athletes.

The benefits of current training regime

Low intensity

There is a general agreement in the literature that athletes spend approximately 75 % of their training below the first ventilatory threshold, even though most competitions are performed at higher intensities. In a meta-analysis on the subject the author reported that low intensity training failed to improve endurance in highly trained athletes (Londeree, 1997).This however, may be due to the relatively short period of time investigated with interventions in researching the improvements done by low-intensity training (Laursen, 2010).

Athletes can sustain a high volume of training at low intensities (55 – 65% of VO_{2max}) and a high volume of training seems to elicit enhancement in mitochondrial biogenesis. This in turn results in reduced lactate production and improved lactate disposal (Brooks, 1991). Additionally, an increase of mitochondrial function contributes to a better capacity of oxygen consumption (Hood, 2001).

Endurance athletes competing in long distance running tend to have more muscle type 1 fibers (H. Rusko, Havu, & Karvinen, 1978), which is characterized by higher oxidative capacity. It is suggested that the high volume of training at a lower intensity is beneficial to this adaptation (Costill et al., 1976). Research has also shown that long distance runners attain a higher lactate threshold than middle-distance runners, even though middle-distance runners train more at higher intensities (MacDougall, Ward, Sale, & Sutton, 1977) It has been hypothesized that the reason why long distance runners attain a high lactate threshold even though most of their training are low intensity training is because of the high percentage of slow twitch muscle fiber (Ivy, Withers, Van Handel, Elger, & Costill, 1980). A study on cross-country found an increase in lactate threshold during the summer training period where the training volume is high with main emphasize on low intensity training. During the winter period, where there was less low intensity training, a minor decrease in the lactate threshold was observed (H. K. Rusko, 1992). The author hypothesizes that the decrease could be due to more high intensive training and competition.

The total volume at lower intensities may serve the purpose of maintaining rather than enhancing the physiological adaptation obtained during training in highly trained athletes..

Lactate threshold training

Training at intensities at or near lactate threshold has proven to be very effective in terms of enhancing endurance performance and lactate threshold in untrained subjects. However, the potential beneficial enhancement in endurance performances of highly trained athletes who train at intensities below or at lactate threshold is not well documented (Londeree, 1997). Well-trained athletes are able to sustain intensities close to lactate threshold for 20 min – 1.5 hours, and in the literature this velocity is called maximal lactate steady state (MLSS) (Hoogeveen, Hoogsteen, & Schep, 1997). V. Billat, Sirvent, Lepretre, and Koralsztein (2004) investigated the effect of training at $MLSS_v$ over a period of 6 weeks in 11 male veteran (48 ± 2.9 years) long-distance runners. They found that the duration at $MLLS_v$ significantly increased by 50 % from 44 ± 10 to 63 ± 12 min. The VO_{2max} were slightly increased, but the lactate concentration during the test was not improved. It is suggested that the improvement in time until exhaustion at lactate steady rate could be caused by an increase in lactate clearance rate (Brooks, 1991; MacRae, Dennis, Bosch, & Noakes, 1992). An intervention study was conducted on two groups of elite cross-country skiers during a period of five months, with one group performing 86 % of their training at a moderate intensity (zone 1 and 2) and the other group 83 % of the total training time at high intensities (zone 3-4). The result was that the high intensity group significantly improved their running speed at lactate threshold by 3.2 ± 0.9% (Evertsen, Medbo, & Bonen, 2001) This improvement is a clear advantage during long endurance competitions, seeing as one of the best predictions for performance appears to be velocity at lactate threshold (Grant, Craig, Wilson, & Aitchison, 1997).

High intensity training

In order to perform at an elite level, endurance athletes should have a relatively high aerobic capacity, lactate threshold and running economy. This in turn suggest that an viable way of improving their performance is through high intensity training (Laursen & Jenkins, 2002).

It is well known that high intensity training does not yield the same benefits for well-trained endurance athletes as it does for untrained individuals. The main performance adaptations of high intensity training in untrained individuals are increased VO_{2max}, plasma volume, capillary density and oxidative enzyme activity (Laursen, 2010; Laursen & Jenkins, 2002). It seems that well-trained athletes do not experience a significant increase in all of these factors when increasing the intensities of their training. High intensity training needs to be handled with care in well-trained endurance athletes, and overuse could lead to a down regulation of the central nervous system (Esteve-Lanao et al., 2007). It does however seem to be a necessity to incorporate a certain amount of training at high intensities to enhance physiological adaptations (Londeree, 1997). According to Lehmann et al. (1992) high volumes of high intensity training could be endured if there was sufficient variation in intensity. The implementation of high intensity training in well-trained athletes that already attained high volumes of training seemed to be very beneficial (Laursen, 2010). By examining the pre-competition period (8 weeks) in elite marathon runners, V. L. Billat et al. (2001) found that when 10% of the total training distance was spent at intensities equal to 3000m or 10000m competition velocities, the athletes significantly improved their VO_2peak. Similar results were shown in well-trained subjects when the amount of interval/high intensity sessions increased (Denadai, Ortiz, Greco, & de Mello, 2006). This suggests that high intensity training during a limited period of time may improve endurance performance in elite long-distance runners.

Method

Subjects

The process of finding eligible participants was done by reviewing personal records set by Norwegian athletes during the last decade, as well as those having experienced success in the latest years. We contacted athletes that fit the criteria of participating in either World Championships (WC) or European Championships (EC) at senior level or U23 in long distance running ranging from 1500m to marathon or cross country races.

A total of 21 athletes received the questionnaire and 15 athletes were able to answer satisfactorily to the majority of the questions. Athletes who did not answer one or more questions were not excluded entirely from the study, but were not considered in the variables where they were unable to answer.

Table 2: Inclusion and exclusion criteria for participation in present study

Inclusion criteria	Exclusion criteria
- Participated in WC or EC at senior level or U23 - Set personal best the last 20 years - Kept a training diary from their best season	- Unable to answer in detail about their training - Did not compete in distance ranging from 1500 to marathon

Fifteen top national level athletes (10 male and six female) with an average age of 26 ± 4.6 (male) and 28 ± 5.5 (female) years during the year of their greatest achievements participated in this study. Their best performance time averaged 93.5 and 90.6 % of the world record, male and female athletes respectively. All subjects received a written information sheet explaining the purpose of the study and the voluntary nature. The athletes provided their informed consent either via email or by a pre-paid letter. The procedures of this study were approved by the Department of Health and Sport, Agder University College, and by Norwegian Social Science Data Services.

Data collection

All data were collected by questionnaire, and the participants were also encouraged to provide their self-reported training diaries if possible.

The majority of the questionnaires were distributed to athletes during the Norwegian Championship (August 24 - 26, 2012). The athletes who did not receive the questionnaire during these days received their questionnaire and information sheet via e-mail. To maximize the response rate, the questionnaire was sent by mail to all athletes that had not responded after one month and a reminder e-mail every month until the questionnaire was returned to the researchers. After six months of data collection all athletes had answered the questionnaire. We collected 15 questionnaires, and four of the participants also provided their self-reported training diaries.

In both the received questionnaires and training diaries athletes had registered training intensity using "a modified session goal heart rate analysis" (K. S. Seiler & Kjerland, 2006), where each session is divided into different zones based on the purpose of different parts of the training session.

The intensity zones are based on a five zone scale established by the Norwegian Olympic Committee (OLT) (Table 2). Athletes were asked to describe their own modified five-zone intensity scale, and their intensity distribution was quantified based on a self-reported typical week of training. The intensity of a training session was described in various ways by the athletes, including min/km, time spent in zone, average heart rate and lactate measurements.

Table 3: Example of a five zone intensity scale based on OLT recommendations

Zone	% of HF max	Lactate	Running speed	Perceived exertion
1	60 – 72	0.8 – 1.5	5 – 4 min/km	Easy
2	72 – 82	1.5 – 2.5	4 – 3.30 min/km	Easy medium
3	82 – 87	2.5 – 4	3.30 – 3.10 min/km	Medium
4	87 – 92	4 – 6	3.10 – 3.00 min/km	Hard
5	94 – 100	6 – 10	3.00 – 2.40 min/km	Very hard

Questionnaire

The questionnaire was developed through discussion in the research group and by reviewing earlier research (Karp, 2007)**.** A pilot-test was conducted in order to eliminate potential problems concerning the reliability of the questionnaire. The questionnaire was first trialed on colleagues, and then on an athlete participating in the study. After the pilot-test we eliminated unnecessary questions and altered questions that were difficult to understand. We chose to use open-ended questions so that the athletes could better describe their training and explain in greater detail if necessary. The athletes were asked to report training data from the season where they achieved their best results.

The questionnaire involved questions concerning:

- Physical characteristics (age, weight and height)
- Competition related questions (competing distance and personal best time)
- General training descriptions (intensity scale, HR_{max} and running experience), different intensity zones description and measurement of intensity during training.
- Training characteristics during an annual year
    - Total hours and distance trained
    - Amount of endurance training (running or alternative training)
    - Total days away from training due to sickness/injury
    - Number of intensive sessions (zone 3 – 5) during weekly training
    - Training periods definition (total months in each period)
- Training characteristics during different periods of training (Build-up, pre-competition and competition period)
    - Total training hours, average hours per week, hours running training and average kilometers per week and total
    - A detailed typical week of training during each period of training

Data analysis

Training data described in the questionnaires and diaries were systematically calculated in order to estimate total volume through an annual cycle (hours and kilometers), specific training related to running, average training volume per week during build-up (23±6.5 weeks), pre-competition (8.9±4.6 weeks) and competition period (14.9±4.2 weeks), and intensity distribution in the total season and each period of training.

Training volume

Training volume was quantified by analyzing the data reported by the athletes concerning total hours and kilometers trained during a year and during different periods of training. The total hours and kilometers where compared with the answers given in different periods. If the athlete reported only average km/week or hours/week in one period, we estimated by multiplying with the total of weeks during this period.

Training intensity

The training intensity distribution in the different periods was calculated by using the athletes' description of a typical week as reported in the questionnaire. Each training session was analyzed with the assistance of an elite long distance runner with extensive experience in the field and relevant knowledge about the details in training sessions. The athlete assisted in determining certain guidelines (Table 3) about the training, thereby improving the accuracy of the calculations done by the researcher, which in turn could minimize errors during the analysis.

Table 4: Guidelines for analyzing training details in the questionnaire

Athletes reported	Registered training
- Zone 1 – 2	- Split 2/3 in zone 1 and the rest in zone 2
- Zone 3 – 4	- Split 50/50 between zones
- If the athlete did not mention warm up or cool down	- 40 min zone 1 - 1km = 4.30 min
- 4 short sprints	- 30 sec each sprint/zone 5
- 200m	- 1 min
- Competition: 1500m - 10.000m - Competition: Half marathon - Marathon	- Zone 5 - Zone 4 - Zone 3

Total endurance training volume in each zone was summarized, and percentages in the different zones were calculated. The total duration in different zones were described either by hours or by kilometers spent in the zone during each session. If only the kilometers were reported, we calculated the time spent in the zone by using the median value of the training zone described. During interval sessions pauses between intervals were registered as zone 1 training. Training forms such as strength, plyometrics and stretching were eliminated from the training analysis.

Statistical analysis

Descriptive statistical analysis was performed on the sample to obtain measures of central tendency (means and median) and dispersion (standard deviation) of the training data. A nonparametric independent t-test (Mann Whitney U) was used to compare means between genders and a Wilcoxon signed-rank test was used to identify the difference between periods of training. All descriptive data are presented as mean ± standard deviation. Calculation and analysis were conducted through Microsoft Excel or SPSS 19.0. The level of significance was set at $P<0.05$ for all statistical analyses.

Results

Annual training volume

Annual training hours during a season (52 weeks) for male (n=8) and females (n=4) were 660±111 and 502±18 hours (P=.004) (Figure 1). On average male athletes reported training 12.7 hours/week and female athletes 9.6 hours/week during their best season.

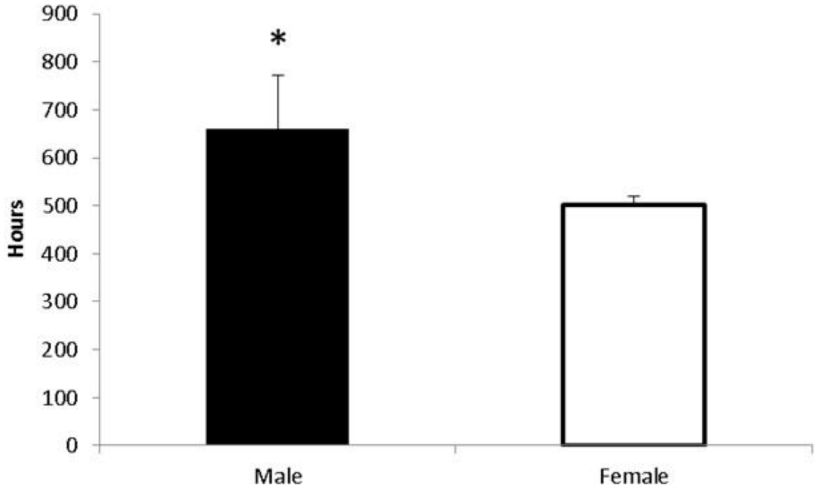

Figure 2: Mean (±SD) training hours during a total season in male (n=9) and female (n=5) athletes. ****P*=.004 difference between genders.**

Of the total training hours male athletes trained 600 hours specific to running, while female athletes trained a total of 398 hours specific to running which represent 91 and 79 % of specific training, male and female athletes respectively.

Annual kilometers run during a season (52 weeks) for male (n=8) and female athletes (n=3) were 7089.6±1064 km and 4019.5±529 km, respectively. Male athletes trained a total of 132 km/week and female athletes trained 77 km/week during an annual cycle.

Training volume during different periods

Average hours/week decreased during different periods of training in both genders. Male athletes (n=9) trained an average of 14±1.6 hours/week during the build-up period, which decreased to 12±2.7 hours/week in the pre-competition period. The total hours decreased further into the competition period, where the male athletes trained an average of 10.4±1.3 hours/week. Similar results were reported by the female athletes (n=5) who trained an average of 12.4±3.1 hours/week during the build-up period. Their training hours/week decreased throughout the season, and in the pre-competition period female athletes trained 10.5±2.4 hours which decreased to 8.5±0.5 during the competition period.

A similar decrease as the one found in hours was found in average trained kilometers/week and the results are presented in figure 2. There was a significant (*P*= .012) difference between km/week run in build-up period compared to the competition period in male athletes. There was no significant difference between the genders across the different periods. The minimum and maximum range of weekly distance between all athletes is described in table 1.

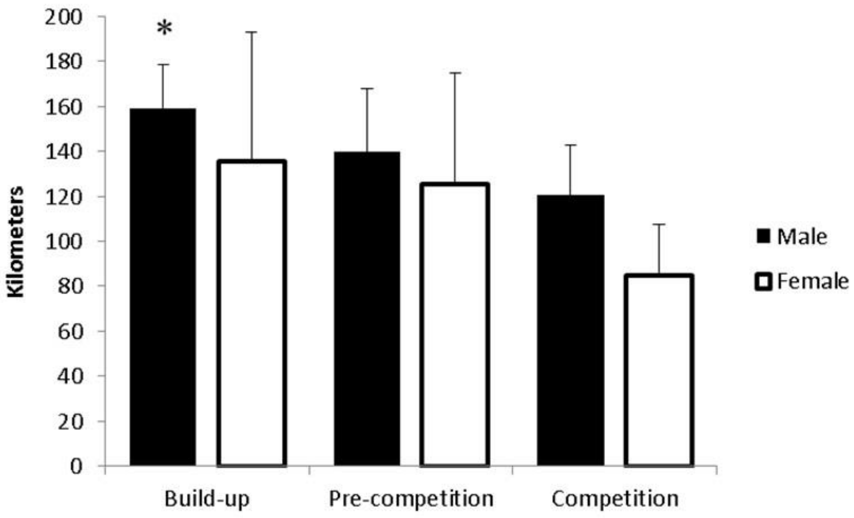

Figure 3, Mean (±SD) weekly kilometers trained during different periods of training in male (n=9) and female athletes (n=5).**P*=.012 **difference between the build-up and competition period in male athletes.**

Table 5: Volume of weekly kilometers trained during different periods (range minimum and maximum)

Gender (N)	Build–up	Pre-competition	Competition
Male (9)	Min. 130 Max. 182 Average. 159	Min. 100 Max. 190 Average.139.5	Min. 85 Max. 151.5 Average. 120.5
Female (5)	Min. 90 Max. 217 Average.135.5	Min. 80 Max. 187.5 Average. 125.5	Min. 60 Max. 104.5 Average. 84.8

Intensity distribution during an annual cycle

The total training throughout a season for all athletes (n=11) was mainly trained at a low intensity with 79.5 ± 6.1 % being continuous running with heart rates between 55-75 % of HR_{max} (zone 1). The percentage of training performed at heart rates between 75-85 % of HR_{max} (zone 2) was 6.5 ± 5.4 %, and between 85-90 % of HR_{max} was 10.5 ± 4.6 % of total training. The athletes performed only 1.8 ± 1.6 at zone 4 (90-95% of HR_{max}) and 1.7 ± 1 % at zone 5 (95-100% HR_{max}).

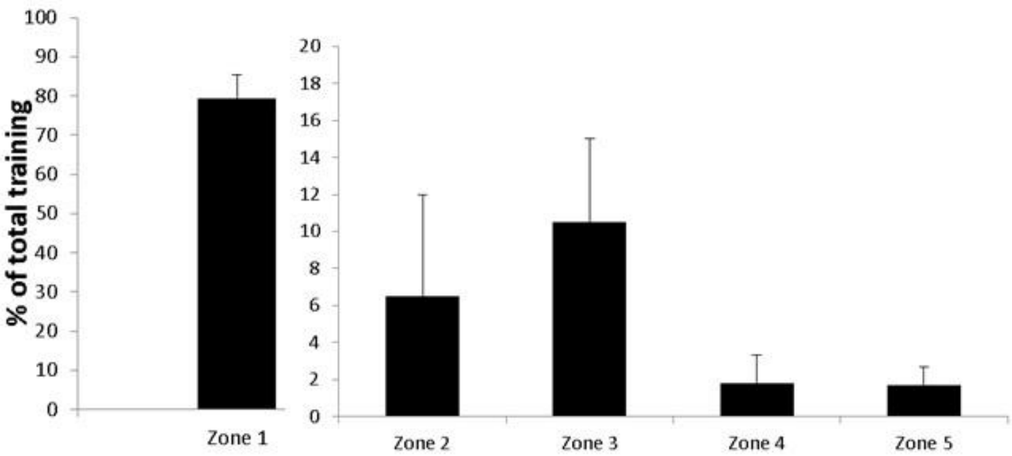

Figure 4: Mean percentage of total training volume in each zone during an annual cycle, n=11 (male and female athletes)

Intensity distribution during different periods

During the build-up period the majority of training was performed at lower intensities (zone1-2), and high intensity training was mainly performed at lactate threshold (zone 3). As the season progressed into the pre- competition period, time spent in zone 3 decreased and more focus was directed to the high intensity zones 4 and 5. This trend continued into the competition period with even more focus on both zone 1 and 5 (Figure 5).

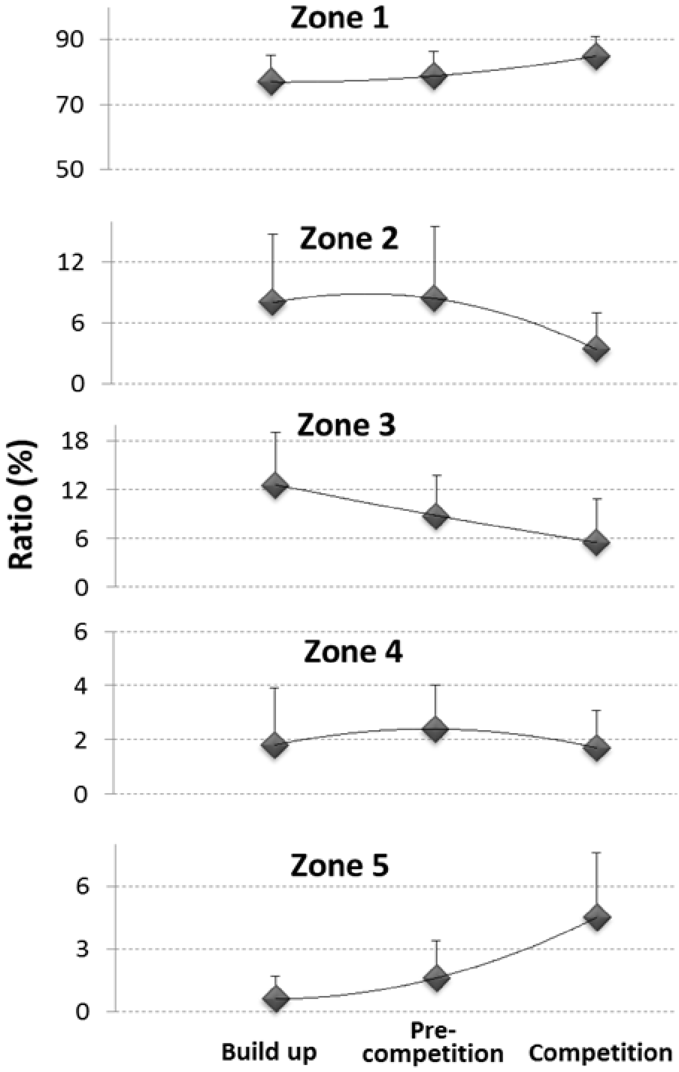

Figure 5: Mean percentage of training intensity distribution during build-up, pre-competition and competition period (n=14)

Typical weeks during different periods

Table 3-5 describes example weeks during three different periods of training.

Table 6: A typical training week during the build-up period. Intensity described as heart rate (HR) and zone.

Day	Morning session	Afternoon session
Monday	8km/40min easy continuous run, 130-145 HR, zone 1	Interval 12x3min (11km) zone 3, 180-185 HR + 35 min (7km) warm up/cooldown, zone 1
Tuesday	8km/40min, easy continuous run, 130-145 HR, zone 1	12km/60min easy continuous run 130-145 HR, zone 1
Wednesday	10km/35min Fast paced continuous run, 170-185 HR, zone 2-3 (10 min in zone 2)	7km/35 min easy continuous run 130-145 HR, zone 1
Thursday	8km/40min easy continuous run 130-145 HR, zone 1	12km/60min easy continuous run 130-145 HR, zone 1
Friday	8km/40min easy continuous run 130-145 HR, zone 1	Interval 8x5min (12km) 180-185 HR, zone 3 + 35 min (7km) warm up/cooldown, zone 1
Saturday	8km/40min easy continuous run, 130-145 HR, zone 1	12km/60min easy continuous run, 130-145 HR, zone 1
Sunday	20km/95min easy continuous run, 130-145 HR, zone 1	

Table 7: A typical training week during the pre-competition period. Intensity is described as zone and min/km.

Day	Morning session	Afternoon session
Monday	18 km moderate continues run, zone 1-2	13km/60min easy continues run, zone 1
Tuesday	18 km moderate continues run, zone 1-2	Interval 8x5min, p.60, zone 3 – 4
Wednesday	13km/60min easy continues run, zone 1	11km/45min moderate continues run, zone 2
Thursday	18 km moderate continues run, zone 1-2	Interval 8-7-6-5-4-3-2-1 min, p.60, zone 3
Friday	Aqua jog, zone 2	Interval 10x3min, p.60, zone 3-4
Saturday	60 min fast continues run, zone 3-3.15 min/km	45min moderate continues run, zone 1-2
Sunday	26km/120min continues run, zone 1 - 2	

Table 8: A typical training week during the competition period. Intensity is described as zone

Day	**Morning session**	**Afternoon session**
Monday	45 min continues run, zone 1	10x1000m, zone 3-4, pause 60 sek, 4x1000, zone 5 pause 90 sek. Warm up/cooldown zone 1
Tuesday	45-60 min continues run, zone 1 + 30 min strength training, 10x60m sprint	
Wednesday	45 min continues run , zone 1	20x200m, zone 5, pause 20 sek. Warm up/cooldown, zone 1
Thursday	45 min continues run, zone 1	
Friday	40 min continues run + 2x2 min easy threshold run, zone 3, + 4x60m sprint	
Saturday	30 min warm up, 2x2 min zone 3	**Competiton** 5000 m track and field, zone 5. Cooldown 20 min, zone 1
Sunday	90 min continues run, zone 1	

Discussion

The findings in this study have shown that elite long-distance runners attain a high annual training volume, where the majority of training is specific to running. The training volume remained relative constant, but were reduced during the competition period. The present study also showed that the majority of training was trained at low intensities throughout the season, and that the amount of high intensity training increased during the season.

Annual training volume

One of the key finding in this study is that male athletes train 7089.6 ± 1064 and female athletes trained a total of 4019.5 ± 529 km, which represent 135.5 km/week and 77 km/week for men and female respectively. However, the data presented on total kilometer in females should be interpreted with caution. To generalize the result on female may not be impropriate due to a couple of reasons. Firstly the number of female athletes in this variable is very low (n=3) and is probably not representative for this group of athletes. Another reason which could explain the low training kilometers may be the fact that these three female athletes experienced weeks and months of injury and sickness during their best season, and a large volume of alternative training was conducted. As well as much interrupted training during their season, two of the female athletes specialized in middle-distance running, but they have achieved success in long-distance running as well. By looking at the total training done by male athletes in the present study, they trained an average of 135.5 km/week during a year of training. This is slightly below the recommendations by Noakes (1986), which stated that a training volume between 150-200 km/week is needed to perform at an elite level in long-distance running. Karikosk (1984) however, reported that world record holders in long-distance running during the 1970's to 1980' trained between 113 – 169 km/week when converted from total kilometers trained during a season to km/week, which is in accordance with the findings in this study.

Athletes in the present study trained an average of 660±111 and 502±18 hours, male and females respectively. This provides a better picture of how much the female athletes in this study actually trained compared to male athlete. In addition there was a standard deviation of only 18 hours between all female athletes, which could be evidence that this may be representative to other elite female athletes. It has previously been shown that male elite marathoners train 676 hours through an annual cycle (Stellingwerff, 2012), and a former female world record holder in 10km trained 550 hours/year. (Tønnessen, 2009). These results are in accordance with the findings in the present study. It is unconventional to report training of long-distance runners by hours, since the specificity of training seems to be very important for adaptation to the ballistic load of running. The athletes in this study showed a great amount of specificity during training with 92 % and 79 % of the total training time directly related to running, male and female respectively. Compared to other endurance sports such as speed-skating, where athletes may perform as low as 31 % training directly related to skating (Yu, Chen, Zhu, & Cao, 2012), there is a clear difference and need of specificity among long-distance runners.

Training volume during different periods

Another key finding in the present study was how the training volume changed in different training periods during a season. The highest total training volume was reported during the build-up period for both genders and it decreased slightly throughout the season (Figure 3). This contradicts with other findings in the literature, where there has been observed an increase in kilometers/week during each period in elite marathon runners, and the highest volume was reported during the competition period (Ferreira & Rolim, 2006). The findings in the present study is in accordance with the research by Enoksen et al. (2011), who presented that km/week remained unchanged until the competition period where it decreased by approximately 10 %. Even though the reduction by the athletes in the present study was slightly higher (~25 %), a reduction between 20-40 % of total training volume have shown to be beneficial during two to four weeks prior to competition (Bosquet, Montpetit, Arvisais, & Mujika, 2007). The high amount of competitions during the competition period can be a viable reason for the reduction in kilometers trained per week, seeing as it requires athletes to perform more short race-specific training at higher intensities and focus more on adequate recovery. Table 6 describes a typical week for an athlete during the competition period. When compared to the other periods (Table 4-5), we see a clear shift from longer intensive sessions, to more intensified and shorter intervals.

Annual intensity distribution

The present study shows that the intensity of the total training volume with both male and female athletes was mainly performed at a low intensity (zone 1), where the percentage of total training volume was 79.5 ± 6.1 %. This observation is similar to findings in elite marathon runners, where 74 % of their total training was spent in zone 1 (Stellingwerff, 2012). The large amount of zone 1 training may be beneficial in order to achieve a high total volume. Research has also shown that substantial amounts of low intensity training elicit enhancement in performance by improved mitochondrial function (Hood, 2001) as well as the efficiency of muscle fiber type 1 (Costill et al., 1976). It is also hypothesized that high volumes at low intensity may enhance the running economy of elite athletes (Midgley et al., 2007). The athletes in the present study also trained 6.5 ± 5.4 % at zone 2 which is a fast paced continues run lasting from 30 min – 1.5 hours. This type of training is not well quantified in the literature seeing as studies using a 5 zone intensity scale tends to combine training done at zone 1 and 2 into a single zone (Enoksen et al., 2011; Tjelta & Enoksen, 2010), and also because zone 2 training is not underlined by a specific physiological event (K. S. Seiler & Kjerland, 2006).

The high intensity training done during an entire season is mainly based on zone 3 training (82-87 % of HR_{max}), and consisted of 10.5 ± 4.6 % of the total training volume. This type of training may enhance performance due to improved velocity at lactate threshold and the ability to withstand high volumes of training at relatively high intensities (Hoffman, 1999). The findings in the present study are in accordance with previous research done on a total year of training (Karp, 2007; Stellingwerff, 2012).

Intensity distribution during different periods

The findings in this study show that the athletes emphasized low-intensity training during the build-up period. Of the total training volume 77 % was done in zone 1 (60-72 % HR_{max}), while 8 % was trained with slightly higher intensities in zone 2 (72-82 % HR_{max}). These two zones constitute the low intensity training done by the athletes. This distribution of low intensity is supported by studies investigating this specific period of training (Enoksen et al., 2011; Karp, 2007). When athletes perform most of their training at low intensities they are able to sustain a high volume of training during each session. This could in turn lead to an enhancement of physiological factors like increased mitochondrial function, which leads to a better capacity of oxygen consumption (Hood, 2001). By creating a foundation through high volumes of low intensity training during the build-up period, athletes could be able to further enhance their physiological attributes later on in the season when the training becomes more intensified In addition to this, athletes may adapt to the ballistic loading on muscles during periods of intense and prolonged exercise as well as protect themselves from under-recovery when exposed to high intensity training later on in the season (Midgley, McNaughton, &

Wilkinson, 2006). The training at low intensities remained relatively constant throughout the season, with only a small increase in the training in zone 1 and a decrease in the training in zone 2 during the competition period. This could be due to the amount of competitions during this period, and that the low intensity training is more focused towards training with the purpose of maintaining and also recovering between competitions. The distribution of low intensity training in the present study is supported by several studies done on elite athletes during single periods of training (Table 1).

In addition to the high volume of low intensity training, athletes in the present study trained with relatively high volumes at or near the lactate threshold (zone 3) during the build-up period (Figure 5). One of the main benefits of high volumes of training at the lactate threshold is that athletes can sustain a relatively high training volume of intensive workloads during each training session. This way of creating an endurance foundation, is one of the main goals with the build-up period (Hawley, Myburgh, Noakes, & Dennis, 1997). Similar results are reported in the literature during the build-up and pre-competition period in elite long-distance runners (V. Billat et al., 2003; Enoksen et al., 2011). However, in the present study training volume at lactate threshold decreased during the season from 12.5 % to 5.5 % in the competition period. These results are dissimilar to earlier findings in elite junior long-distance runners, where athletes increased their lactate threshold training during the competition period (Tjelta & Enoksen, 2010). This increase could be due to the fact that the authors placed competitions between 5km and 10km at lactate threshold intensities (zone 3).

The decrease in zone 3 in the present study appears to be related to the increase in high intensity training (zone 4 and 5) as the season progressed from the build-up to competition period. The training at zone 5 increased from 0.5 % in the build-up period to 4.5 % during the competition period. This increase could be explained by an attempt to further enhance the physiological factors affecting long-distance running performance. It is suggested that in order to enhance physiological factors such as VO_{2max} and velocity at lactate threshold there is a need for intensities above the lactate threshold (Laursen, 2010). An increase in high intensity training during the pre-competition period is in accordance with the literature, where it is suggested that this approach could enhance athletes' VO_2peak and decrease the utilization of VO_2peak at marathon pace (V. Billat et al., 2002). The contribution of zone 4 and 5 may have been underestimated in this study due to the registration of training done by athletes. Many athletes reported training that was conducted with a heart rate close to 90 % as zone 3, when it in fact may have been zone 4 training. One example of this is shown in table 6 where the athlete performed an interval session with heart rates of 180-185 b·min and this athlete attain a max HR at 204 b·min. This means an 88-90 % of HR_{max}, which is defined as zone 4 at the present intensity scale.

In this chapter, the findings have been discussed in relation with to the existing theory on training volume and intensity distribution.

Methodological limitations

The purpose of this study was to describe and quantify training in elite long-distance runners with the use of questionnaire and training diaries. The main limitation lies within the choice of method for collecting data. By using a questionnaire there are some weaknesses that have to be considered. The first complication may be the subjective nature of the answers given in a questionnaire, such as questions may be misunderstood, faulty answers intentionally or unintentionally, or the subjects do not remember details and report false data.
The validity of data collected on intensity distribution when using a typical week from the diaries in each period is questionable, because the reported weeks are selected by athletes and they represent an optimal week. This could give a wrong impression due to the fact that we do not know how this week compares to other weeks during the specific training period. There is also a probability that some of the data on intensity is underestimated due to the intensity scale and the reported loading of the athletes. Some sessions that athletes reported were conducted at the upper limit intensity between zone 3 and 4 when reporting heart rate measurement of the session, while it was described as zone 3 intensity. This could have led to an underestimated time spent in zone 4.

The small sample of athletes in some variables is a weakness that is needed to take into consideration. Presenting data collected from questionnaire based on a sample of three athletes could lead to a question about the validity of the data presented. This is a clear limitation in the variable of kilometers trained during an annual cycle in female athletes. However, this is what these athletes reported and may show us that even though the athletes suffered from injury and sickness they achieved their personal best that season.

To ensure a better reliability of the questionnaire we conducted a pilot-test on one athlete during the construction of the questionnaire, to make sure there were no unclear questions and to decrease the amount of time needed to fill out this questionnaire.

A physiological monitor or direct observation of the athletes was not conducted in this study. This could have increased the validity of the data. However, four athletes delivered their training diaries in addition to the questionnaire. These data were then analyzed and matched to try and find some significant difference, which there was not. This means that athletes used their training diaries to help them remember the details about their training. Athletes that did not have a detailed dairy from their best season were excluded from the study, based on the inability of remembering details about training

Conclusion

By accessing training data from the complete season of the individual elite long-distance runners this study was able to address the issues of volume and intensity in a broader manner, thereby enhancing the possibility of getting a holistic overview of their training regimes.

This study shoes that elite long-distance runners attain a high annual training volume, where the majority of training is specific to running. The training volume remained relatively constant, but was reduced during the competition period. The present study also shows that the majority of training was conducted at low intensities throughout the season, and that the amount of high intensity training increased during the season.

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Annual training characteristics in elite long-distance runners–a descriptive study of training volume and intensity distribution.

This is an original investigation with 2 tables and 3 figures. *The abstract consists of 244 words and the text 2709 words.*

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Abstract

Purpose: The aim of the present study is to describe and quantify annual training characteristics in elite long-distance runners, based on training volume and intensity distribution.

Method: Fifteen elite long-distance runners (nine males and six females) with personal best times >90 % of the world record in current competing distance, were included in the study. Questionnaires concerning training volume and examples of training weeks were used to describe training volume and intensity distribution during different periods of training.

Results: Annual training volume was 7089.5±1064 km/660±111hours in male athletes and 4019.5±529km/502±18 hours in female athletes.

During the build-up period, athletes trained 159±19 and 140±28 km/week, male and female respectively. The volume slightly decreased in both genders throughout the season.

In the build-up period athletes trained 77 % of their total volume in zone 1, whereas high intensity training was mainly done in zone 3. The majority of the training was done in zone 1 throughout the season. As the season progressed the training became more polarized due to a decrease of the training done in zone 3 and an increase in zone 4 and 5.

Conclusion: This study shows that elite long-distance runners attain a high annual training volume, where the majority of training is specific to running. The training volume remained relative constant, but were reduced during the competition period. The majority of training was trained at low intensities throughout the season, but the amount of high intensity training increased during the season. The findings in the present study can contribute to an enhanced understanding of the total training volume and intensity distribution done by elite athletes during an annual cycle.

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Key words: Training distribution, periodization, endurance, specific training, questionnaire

Introduction

For endurance athletes there are several factors that are essential in order to perform at an elite level, such as $VO_{2\ max}$, lactate threshold and running economy [1-4] In order to obtain good results these factors must be improved, which is an objective met through the organizing of training. Training volume and intensity distribution are important factors to be considered when optimizing training. Their importance increases with the performance level, which shows their relevance for elite athletes[5-7].

Training volume in elite long-distance runners is shown to be between 150-200 km/week and >600 hours during a season[5,6,8-11] and it differs throughout the season. In elite long-distance runners, the majority (~75 %) of the training volume is performed at low intensities (55-85 % HR_{max}) [12-14], while there seems to be a lack of unison concerning the distribution of high intensities at or above lactate threshold.

Current research on training volume and intensity distribution among elite long-distance runners mainly focuses on either a single training period or a few weeks of training[5,6,13]. The few studies conducted on elite long-distance runners and training characteristics over an entire season are mainly case studies with relatively few athletes[9,14,15]. This creates a theory gap on the subject of annual training characteristics.

The main purpose of this study is therefore to quantify training volume and intensity distribution in elite long-distance runners annually and during different periods of training. The research question is threefold:

How do elite long-distance runners distribute training volume specific to running during an annual cycle?

How do elite long-distance runners distribute their training volume during the different training periods?

How do elite long-distance runners distribute their intensity during an annual cycle as well as in different periods?

Methods

Subjects

Fifteen Norwegian long-distance runners (age: 27±5, n=9 and n=6, male and female respectively) competing the last decade participated in the study. Athletes have competed or are competing in distances ranging from 1500m to marathon, and their personal best averaged 93.5 and 90.5 of the world record in their main distance, male and female respectively. All athletes participating in this study had either competed in World Championship or European Championship as senior or U23. Each athlete received an information sheet explaining the purpose of the study and the voluntary nature. All procedures of this study were approved by the Department of Health and Sport, Agder University College, and by The Norwegian Social Science Data Service.

Methodology

All data was collected by questionnaire, and the participants were also encouraged to provide their self-reported training diaries. A total of 15 questionnaires and four training diaries were included in the study after a period of six months.

The questionnaire was developed through discussion in the research group and by reviewing earlier research [16]. A pilot-test was conducted in order to eliminate unnecessary questions as well as potential reliability problems. All athletes reported their training from the season where they performed their personal best result.

The questionnaire involved questions concerning:

- Physical characteristics (age, weight and height)
- Competition related questions (competing distance and personal best time)
- General training descriptions (intensity scale, HR_{max} and running experience), different intensity zones description and measurement of intensity during training.
- Training characteristics during an annual cycle and in different periods of training (Build-up, pre-competition and competition period)
- Total hours and distance trained
- Amount of endurance training (running or alternative training)
- Total days away from training due to sickness/injury
- Number of intensive sessions (zone 3 – 5) during weekly training
- Training periods definition (total months in each period)
- Training characteristics during different periods of training (total training hours, average hours per week, hours running training and average kilometers per week and total)
- A detailed typical week of training during each period of training

In the received questionnaire and training diary athletes registered training intensity using “a modified session goal heart rate analysis” [12] where each session is divided into intensity zones based on the purpose of different parts of the training session. The intensity zones are based on a five zone scale, and athletes were asked to fill out their own modified zones based on reference scale from the Norwegian Olympic Committee (OLT) (Table 1).

(Table 1)

Training analysis

Analysis of the collected training data were used to calculate total training volume (hours and kilometers), percentage of specific training, average total and weekly training volume during build-up (23±6.5 weeks), pre-competition (8.9±4.6 weeks) and competition period (15±4.0 weeks), and intensity distribution during an entire season as well as the different periods.

Training intensity distribution was calculated by using the athletes’ description of a typical week and based on percentage of hours trained.

Statistical analysis

Descriptive statistical analysis was performed on the sample to obtain measures of central tendency (means and median) and dispersion (standard deviation) of the training data. A nonparametric independent t-test (Mann Whitney U) was used to compare means between genders and a Wilcoxon signed-rank test were used to identify the difference between periods of training. All descriptive data are presented as mean ± standard deviation. All of the calculations and analyses were conducted through Microsoft excel or SPSS 19.0. The level of significance was set at $P<0.05$ for all statistical analyses.

Results

Training volume

Annual training hours during a total season (52 weeks) for male (n=8) and female (n=4) athletes are presented in figure 1.
On average male athletes trained 12.7 hours/week and female athletes trained 9.6 hours/week during their season.

(Figure 1)

During the reported year, male athletes trained 600 hours specific to running, while female athletes trained a total of 398 hours specific to running, which represent 91 and 79 %, male and female athletes respectively.

Male athletes (n=8) ran a total of 7089.6±1064km during their season, which represent an average of 136km/week during an annual cycle of training. Female athletes trained 4019.5±529 km during their season, which translate to an average of 77 km/week.

Training volume during different periods

Average hours/week decreased during different periods of training in both genders as the season progressed. Male athletes (n=9) trained an average of 14±1.6 hours/week during the build-up period, which decreased to 12±2.7 hours/week in the pre-competition period. The total hours decreased further into the competition period where male athletes trained an average of 10.4±1.3 hours/week. Similar results were reported by the female athletes (n=5) who trained an average of 12.4±3 hours/week during the build-up period. Their training hours/week decreased in the pre-competition period where the female athletes trained 10.5±2.4 hours. In the competition period hours/week had decreased to 8.5±0.5.
The total kilometers trained by both genders each week during different periods are presented in figure 2.

(Figure 2)

Table 1 presents the range of which the athletes trained during different periods. Values are presented with minimum, maximum and range in all periods.

(Table 1)

Intensity distribution

All athletes (n=11) trained a total of 79.5±6.1% continuous running in zone 1 (55-75% HR_{max}). Training in zone 2 (75-85% HR_{max}) represented 6.5±5.4% of the total training hours and 10.5±4.6% in zone 3 (85-90% HR_{max}). The athletes trained

1.8±1.6 in zone 4 (90-95% HR_{max}) and 1.7±1% in zone 5 (95-100% HR_{max}).

Intensity distribution during different periods

Figure 2 illustrates the changes in intensity distribution as the season progressed from the build-up period to the competition period. During each period of training the majority of training was performed in zone 1 throughout the season. Time spent in zone 3 decreased, while there was an increase in zone 4 and 5.

(Figure 3)

Discussion

This study shows that elite long-distance runners attain a high annual training volume, where the majority of training is specific to running. The present study also shows that the majority of training was trained at low intensities throughout the season, and that the amount of high intensity training increased during the season.

Annual training volume

One of the key findings in the present study was that athletes trained 660±111 and 502±18 hours/year, male and female respectively. Previous research has shown that male elite marathoners train 676 hours through an annual cycle, which is similar to what was found in this study[8]. A former female world record holder in 10km trained 550 hours/year when competing [17], which also is in accordance with findings in present study. It is unconventional to report training of long-distance runners by hours, since the specificity of training is very important for adaptation to the ballistic loading of running. The athletes in this study showed a great amount of specificity during training with 92 % and 79 % of the total training time directly related to running, male and female athletes respectively. Compared to other endurance sports such as speed-skating, where athletes may perform as low as 31 % training directly related to skating[18], there is a clear difference and need of specificity among long-distance runners.

Male athletes in this study performed 135.5 km/week during an annual cycle. This is slightly below the recommendations by Noakes [10], who stated that a training volume between 150-200 km/week is needed to perform at an elite level in long-distance running. Karikosk [19] however, reported that world record holders in long-distance running during the 1970' and 1980' trained between 113 – 169 km/week when converted from total kilometers, which is in accordance with the findings in the present study.

Training volume during different periods

The highest total training volume was reported during the build-up period for both genders and it decreased slightly throughout the season (Figure 2). This contradicts with findings in the literature, where an increase in kilometers/week during each period in elite marathon runners was observed, and the highest volume was reported during the competition period[11]. The findings in the present study is in agreement with those of Enoksen, Tjelta, Tjelta [9] who presented that km/week did not change until the competition period, where it decreased by approximately 10 %. Even though the reduction by the athletes in the present study was slightly higher (~25 %), a reduction between 20-40 % of total training volume during two to four weeks prior to the competition has proved to be beneficial for performance [20].

Annual training intensity distribution

The present study shows that the majority of training was conducted in low intensity zones, with a total of 79 % in zone 1. This observation is similar to findings on elite marathon runners, where it was reported that 74 % of the total training volume was done at the lowest intensity[8]. The large amount of zone 1 training may be beneficial in order to achieve a high total volume and it is shown in the literature that substantial amounts of low intensity training elicit enhancement in performance by improved mitochondrial function[21] as well as the efficiency of muscle fiber type 1 [22]. It is also hypothesized that high volumes of low intensity training may enhance the running economy of elite athletes [2].The high intensity training done by the athletes in this study mainly consisted of zone 3 training, which is at or near the lactate threshold. The high amount of lactate threshold training could be advantageous due to the ability of an athlete to run for relatively long periods slightly below lactate threshold, and therefore achieving a high total volume[14], which is beneficial to a long-distance runner[10].

Intensity distribution during different periods of training

The present study shows that athletes mainly focused on training at intensities between zones 1 and 2 (55-82 % HR_{max}) during the build-up period, with a small amount of training above lactate threshold (Figure 3). The high volume at low intensities in the present study is in accordance with findings by other studies conducted on elite long-distance runners.[5,6]

In addition to the high volume of low intensity training, athletes in the present study trained with relatively high volumes at or near the lactate threshold during the build-up period. When athletes perform a majority of their training in the first three zones, they are able to perform high volumes of training during each session, that could lead to an enhancement of physiological factors such as increased mitochondrial function, which in turn leads to better capacity of oxygen consumption[21]. By creating a foundation through high volumes of training during the build-up period, athletes are able to enhance their physiological attributes later on in the season, and get used to the ballistic loading on muscles during periods of intense and prolonged exercise as well as in competitions. Additionally it could decrease the chance of under-recovery when exposed to high intensity training [23]. As the season progressed towards the competition period, training volume done in zone 3 decreased. The athletes appeared to shift their training towards a more polarized model as the competition period began where more training was done at the highest intensities (zone 4 and 5) and less training near the lactate threshold. These findings are dissimilar to prior research on elite long-distance runners, where the amount of training near lactate threshold increased in the competition period by 6 % [14]. However, one of the main reasons for the increase in lactate threshold training in the abovementioned study is because of the categorization of competitions at 5km-8km as lactate threshold training. In the present study competitions is categorized as zone 5 in distances ranging from 1500m to 10km, and marathon is categorized as zone 3.

Practical applications

The findings in the present study can contribute to an enhanced understanding of the total training volume and intensity distribution done by elite athletes during an annual cycle. In addition it could help to understand how elite athletes distribute their training in different periods, in order to maximize performance during a competitive season.

Strengths and limitations

This study is not without limitations, one of which being the choice of method for collecting data. A central weakness with the questionnaire may be the subjective nature of the answers given in a questionnaire, seeing as questions may be misunderstood, faulty answers can intentionally or unintentionally be given, or the subjects do not remember details and report false data. The validity of data collected on intensity distribution when using a typical week from the diaries in each period can be disputed. This could give a wrong impression due to the fact that we do not know how this week relates to other weeks during the specific training period. There is also a probability that segments of the intensities are underestimated due to the intensity scale and the reported loading of the athletes. Some of the reported sessions were conducted at the upper limit intensity between zone 3 and 4 when reporting heart rate measurement of the session, but was described as zone 3 intensity. This could have led to an underestimating of the time spent in zone 4.

Another weakness is based on the small sample of athletes in some of the variables. Presenting data based on a sample of three athletes could lead to a question about the validity of the data presented, albeit the purpose of doing so is justified by the process of excluding inadequate data reported.

The relatively high large number of participants can also be considered a strength concerning the data on annual training characteristics among elite long-distance runners.

To ensure a better reliability of the questionnaire we conducted a pilot-test on one athlete during the construction of the questionnaire, to exclude any unclear questions and reduce the amount of time needed to fill out the questionnaire. Four athletes delivered their training diaries in addition to the questionnaire. These data were then analyzed and matched to try and find some significant difference to their responses in the questionnaire, which there was not. This indicates that athletes used their training diaries to help them remember the details about their training. Athletes that did not have a detailed diary from their best season were excluded from the study, based on the inability of remembering details about training

Conclusion

This study shows that elite long-distance runners attain a high annual training volume, where the majority of the training is specific to running. The training volume remained relatively constant throughout the different periods, but was reduced during the competition period. The present study also shows that the majority of training was performed at low intensities throughout the season, and that the amount of high intensity training increased during the season.

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TABLES

Table 1: Example of a five zone intensity scale based on OLT recommendations.

Table 2: Range of weekly kilometers trained during different periods

FIGURES

Figure 1: Mean (±SD) training hours during a total season in male (n=9) and female (n=5) athletes. **P*= .004 difference between genders.

Figure 2: Mean (±SD) weekly kilometers trained during different periods of training in male (n=9) and female athletes (n=5).**P*= .012 difference between the build-up and competition period in male athletes

Figure 3: Mean percentage of training intensity distribution during build-up, pre-competition and competition period (n=14)

Figure 1:

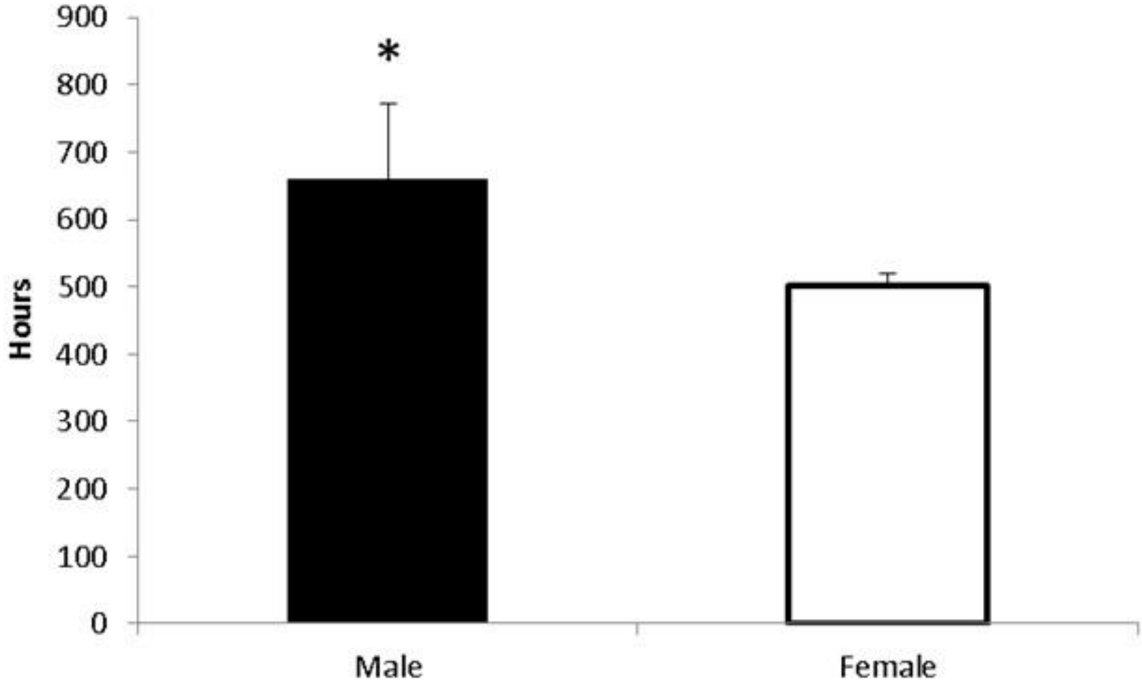
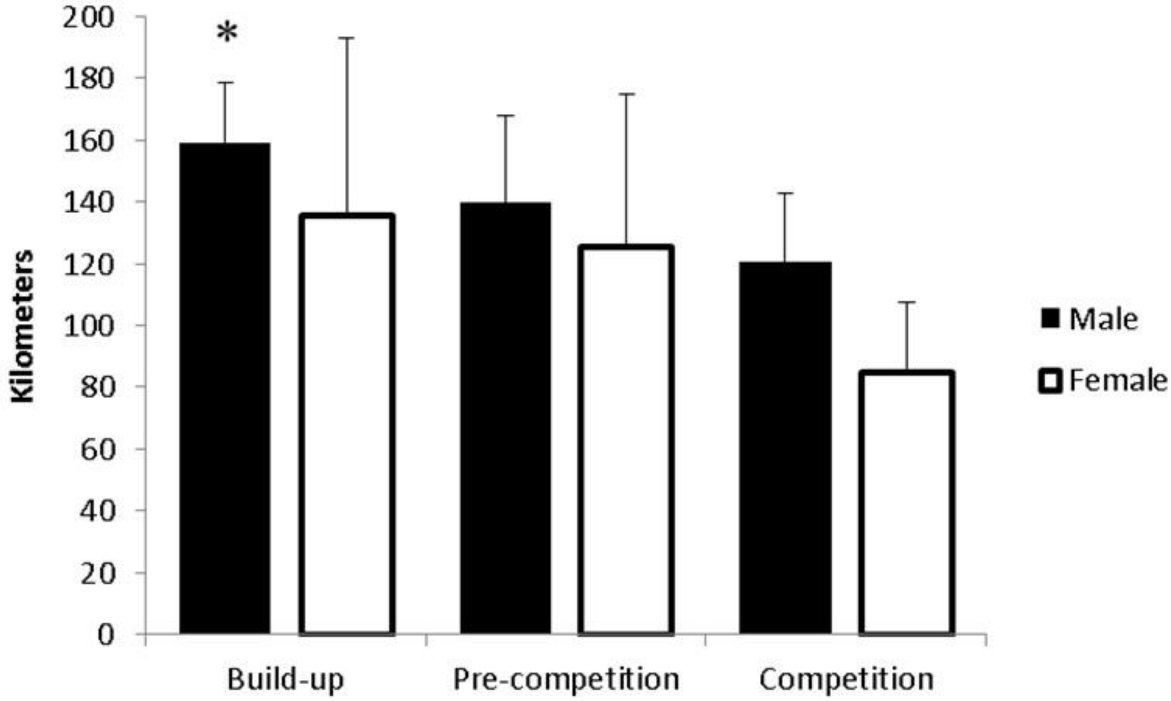


Figure 2:



200
180
160
140
120
100
80
60
40
20
0
Kilometers
*
Build-up
Pre-competition
Competition
Male
Female

Figure 3:

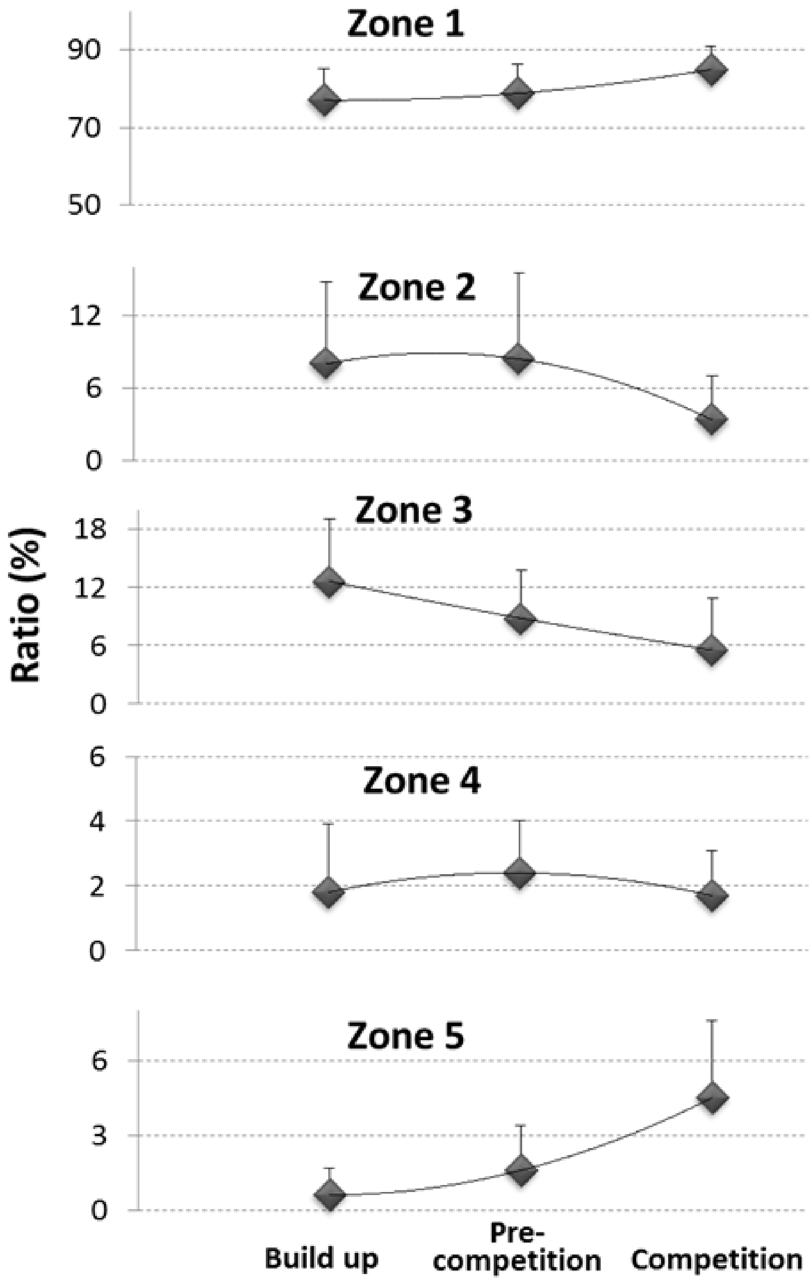

Zone 1
90
70
50
Zone 2
12
6
0
Zone 3
Ratio (%)
18
12
6
0
6
Zone 4
4
2
0
Zone 5
6
3
0
Build up
Pre-
competition
Competition

Table 1:

Zone	% of HF max	Lactate	Running speed	Perceived exertion
1	60 – 72	0.8 – 1.5	5 – 4 min/km	Easy
2	72 – 82	1.5 – 2.5	4 – 3.30 min/km	Easy medium
3	82 – 87	2.5 – 4	3.30 – 3.10 min/km	Medium
4	87 – 92	4 – 6	3.10 – 3.00 min/km	Hard
5	94 – 100	6 – 10	3.00 – 2.40 min/km	Very hard

Table 2:

Gender (N)	Build–up	Pre-competition	Competition
Male (9)	Min. 130 Max. 182 Average. 159	Min. 100 Max. 190 Average.139.5	Min. 85 Max. 151.5 Average. 120.5
Female (5)	Min. 90 Max. 217 Average.135.5	Min. 80 Max. 187.5 Average. 125.5	Min. 60 Max. 104.5 Average. 84.8

Attachments

Information sheet

Forespørsel om deltakelse i forskningsprosjekt

Hva kjennetegner treningen til norske elite langdistanseløpere?

Bakgrunn og hensikt

Dette er en forespørsel til deg om deltakelse i en forskningsstudie, der data vil bli samlet inn gjennom et spørreskjema. Målet er å øke vår kunnskap om hvordan våre beste utholdenhetsutøvere trener. Dette for å kunne utvikle nåværende og fremtidige idrettsutøvere som ønsker å prestere blant de beste i sin idrett. Utholdenhetstrening innebærer en manipulasjon av treningsvariablene varighet, intensitet, aktivitetsform og frekvens på kort og lang sikt. På dette området finnes det dessverre veldig lite dokumentasjon blant eliteutøvere i ulike utholdenhetsidretter. Du er en av utøverne som har representert Norge i langdistanseløp, og med tanke på dine fantastiske resultater må man anta at du har gjort veldig mye riktig i treningsarbeidet. Det er derfor ønskelig at du deltar i prosjektet for å samle kunnskap om hvordan de beste trener.

Med din hjelp ønsker vi å få økt kunnskap om hva som kjennetegner treningen til de beste langdistanseløperne vi har i Norge, og dette vil i fremtiden kunne hjelpe unge utøvere til å nå sitt fulle potensial med riktig trening fra tidlig alder.

I denne studien vil hovedfokuset være på langdistanseløpere og deres årlige treningsmengde. Det vil også bli gjort en sammenligning i forhold til andre utholdenhetsidretter, samt søkt etter forskjeller ved trening mellom disse. Dette vil bli gjort ved hjelp av spørreskjema hvor du som utøver svarer utfyllende om ulike variabler ved din trening.

Prosjektets problemstilling er «*hvor mye trener elite langdistanse løpere og hvor mye idrettsspesifikk trening blir gjort i løpet av en årlig syklus*»

Hva innebærer studien?

Denne studien er i samarbeid med Universitetet i Agder (UIA). Ved hjelp av data samlet inn av dette spørreskjemaet vil vi kunne belyse problemstillingen på en god og grundig måte.

På bakgrunn av dine resultater både nasjonalt og internasjonalt vil dine treningsdata være til stor hjelp når vi skal karakterisere treningen til de beste langdistanseutøverne i landet. Svar på spørreskjema vil bli analysert slik at vi kan generalisere treningsvariablene treningsvolum, intensitet, aktivitetsform og hyppighet. Dersom det oppstår et behov for utdyping av dine svar på spørreskjema, vil vi som prosjektledere ta kontakt.

Det presiseres at dine treningsdata **IKKE** vil bli presentert som en individuell utøver, og det ikke vil være mulig å gjenkjenne dine data i resultatfremstillingen.

Mulige fordeler og ulemper

Ved deltakelse i denne undersøkelsen vil du kunne få tilgang til en systematisk og fullstendig oversikt over din trening det aktuelle året. I tillegg til egenverdi vil denne studien ha en stor verdi for andre unge topputøvere som ønsker å bli best mulig, og for trenere som jobber målrettet for å utvikle utøvere på et høyt internasjonalt nivå. En eventuell ulempe ved studien kan være at du som deltaker kan bli kontaktet av prosjektlederne med tanke på spørsmål angående svar på spørreskjema.

Hva skjer med informasjonen om deg?

Informasjon som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysninger vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine opplysninger gjennom en navneliste. Det er kun autorisert personell som har tilgang til navnelisten og som kan finne tilbake til deg. Disse personene har også taushetsplikt. Ved eventuelle publikasjoner av resultatene skal dette foregå slik at identiteten til inkluderte forblir anonym.

Data som samles inn vil bli brukt i inneværende studie, doktorgradsarbeid og artikler i internasjonale studier, men det vil også være en mulighet for presentasjon av data på nasjonale og internasjonale konferanser og seminarer, og i forelesninger på høgskoler og universitet.

Som deltaker i denne studien har du full rett til fullstendig innsyn i hvilke opplysninger som blir registrert om deg og brukt i studien. Du har også videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du vil trekke deg fra studien, kan du kreve at all innsamlet informasjon om deg skal slettes. Informasjon blir senest slettet 2023, som er 10 år etter studieslutt.

Frivillig deltakelse

Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke til å delta i studien. Dette vil ikke få konsekvenser for din videre behandling.

Dersom du ønsker å delta i denne studien, og svare utfyllende på spørreskjema om ulike kjennetegn ved din trening gjennom en årlig syklus, ber vi deg fylle ut svararket nederst på denne siden.

Dersom du senere ønsker å trekke deg eller har spørsmål om studien, kan du kontakte:

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Samtykke til deltakelse i studien

JEG GODTAR AT MINE DATA BENYTTES

Jeg har mottatt skriftlig informasjon og **godtar at mine data** benyttes til forskningsprosjektet, og statistiske fremstillinger i internasjonale tidsskrifter

NAVN (med blokkbokstaver):____

Jeg godtar at mine data benyttes til dette forskningsprosjektet: JA ■ NEI ■

_ _ _ _ _ _ _ _ _ _

DATO

Questionnaire

Spørreskjema

Hva kjennetegner treningen til norske elite langdistanseløpere?

Dette er et spørreskjema til deg som er en aktiv løper og har representert Norge på seniornivå. Ta utgangspunkt i din beste sesong, eller det året du oppnådde ditt beste enkeltresultat, og besvar spørsmålene så detaljert du klarer. Hvis du ønsker å legge ved en kopi av din treningsdagbok (pr papir eller elektronisk) er dette frivillig, og vi som prosjektansvarlige vil gjøre en grundig analyse av treningsdataene dine.

Alle spørsmål skal besvares med utgangspunkt i din beste sesong.

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1. **Alder**

2. **Høyde** **cm**

3. **Vekt** **kg**

4. **Årstall på sesongen du tar utgangspunkt i?**

5. **Hvilke distanser konkurrerer du i, og hva er din spesialitetsdistanse?**

6. **Personlig beste tider på de ulike distansene? Skriv først distansen og deretter tid.**

7. Hvor mange år hadde du satset på denne spesifikke idretten før gjeldende sesong? (Erfaringsnivå)

8. Makspuls det aktuelle året:

9. Hvordan deler du inn de ulike sonene ved trening?

Sone	Puls	Laktat	Fart	Subjektiv følelse
1				
2				
3				
4				
5				

10. Hvordan måler/styrer du intensitet ved dine økter? Sett kryss ved et eller flere alternativ.

    1. Fart
    2. Puls
    3. Subjektiv følelse
    4. Laktat målinger

11. Din trening på årsbasis det aktuelle året:

11.1 Hvor mange timer trente du totalt hele året?

11.2 Antall timer løpt totalt hele året?

11.3 Hvor mange kilometer løp du totalt hele året?

11.4 Antall timer annen utholdenhetstrening totalt hele året?

11.5 Antall timer basistrening (styrke, spenst, hurtighet, bevegelighet) totalt hele året?

12. Antall dager borte fra normal trening det aktuelle året?

13. Hvilke aktiviteter brukte du som alternativ trening?

14. **Treningsmengde i ulike perioder av sesongen. Her deler vi inn sesongen i 4 sykluser: Grunntreningsperiode, konkurranseforberedende periode, konkurranseperiode og avkoplingsperiode.**

14.1Grunntreningsperiode

- **Hvilke måneder innebærer dette for deg?**
- **Antall timer trening totalt i hele perioden?**
- **Gjennomsnitt timer pr uke?**
- **Antall timer løpt totalt hele perioden?**
- **Gjennomsnitt timer løpt pr uke?**
- **Antall kilometer løpt totalt hele perioden?**
- **Gjennomsnitt kilometer løpt pr uke?**
- **Antall timer annen utholdenhetstrening totalt?**
- **Gjennomsnitt annen utholdenhetstrening pr uke?**
- **Antall timer basistrening totalt hele perioden?**
- **Gjennomsnitt timer basistrening pr uke?**
- **Hvor mange intensive økter (sone 3-5) trente du pr uke?**
- **Antall økter i ulike soner pr uke (for eksempel 2 økter i sone 3)**

14.2 Konkurranseforberedende periode

- **Hvilke måneder innebærer dette for deg?**
- **Antall timer trening totalt i hele perioden?**
- **Gjennomsnitt timer pr uke?**
- **Antall timer løpt totalt hele perioden?**
- **Gjennomsnitt timer løpt pr uke?**
- **Antall kilometer løpt totalt hele perioden?**
- **Gjennomsnitt kilometer løpt pr uke?**
- **Antall timer annen utholdenhetstrening totalt?**
- **Gjennomsnitt annen utholdenhetstrening pr uke?**
- **Antall timer basistrening totalt hele perioden?**
- **Gjennomsnitt timer basistrening pr uke?**
- **Hvor mange intensive økter (sone 3-5) trente du pr uke?**
- **Antall økter i ulike soner pr uke (for eksempel 2 økter i sone 3)**

14.3 Konkurranseperiode

- **Hvilke måneder innebærer dette for deg?**
- **Antall timer trening totalt i hele perioden?**
- **Gjennomsnitt timer pr uke?**
- **Antall timer løpt totalt hele perioden?**
- **Gjennomsnitt timer løpt pr uke?**
- **Antall kilometer løpt totalt hele perioden?**
- **Gjennomsnitt kilometer løpt pr uke?**
- **Antall timer annen utholdenhetstrening totalt?**
- **Gjennomsnitt annen utholdenhetstrening pr uke?**
- **Antall timer basistrening totalt hele perioden?**
- **Gjennomsnitt timer basistrening pr uke?**
- **Hvor mange intensive økter (sone 3-5) trente du pr uke?**
- **Antall økter i ulike soner pr uke (for eksempel 2 økter i sone 3)**

14.4 Avkoblingsperiode

- **Hvilke måneder innebærer dette for deg?**
- **Antall timer trening totalt i hele perioden?**
- **Gjennomsnitt timer pr uke?**
- **Antall timer løpt totalt hele perioden?**
- **Gjennomsnitt timer løpt pr uke?**
- **Antall kilometer løpt totalt hele perioden?**
- **Gjennomsnitt kilometer løpt pr uke?**
- **Antall timer annen utholdenhetstrening totalt?**
- **Gjennomsnitt annen utholdenhetstrening pr uke?**
- **Antall timer basistrening totalt hele perioden?**
- **Gjennomsnitt timer basistrening pr uke?**
- **Hvor mange intensive økter (sone 3-5) trente du pr uke?**
- **Antall økter i ulike soner pr uke (for eksempel 2 økter i sone 3)**

15 Hvordan ser en typisk uke ut for deg i de ulike fasene? Skriv hver dag så detaljert du klarer (type trening, intensitet, sone, varighet, distanse, puls, gjennomsnittlig treningsmengde og total mengde)

Grunntreningsperiode

- **Mandag**

- **Tirsdag**

- **Onsdag**

- **Torsdag**

- **Fredag**

- **Lørdag**

- **Søndag**

Konk

-

- **Tirsdag**

- **Onsdag**

- **Torsdag**

- **Fredag**

- **Lørdag**

- **Søndag**

Konkurranseperiode

- **Mandag**
- **Tirsdag**
- **Onsdag**
- **Torsdag**
- **Fredag**
- **Lørdag**
- **Søndag**

Avkoplingsperiode

- **Mandag**
- **Tirsdag**
- **Onsdag**
- **Torsdag**
- **Fredag**
- **Lørdag**
- **Søndag**