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The Effect of Downhill Running Training on 200m and 2000m Running Performance

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The Effect of Downhill Running Training on 200m and 2000m Running Performance.

(TITLE)

BY

Jacquilyn L. Gallagher

THESIS

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ABSTRACT

Downhill running as a method of training for improved running performance is an option which has rarely been explored. The purpose of this study was to explore the idea that downhill interval training may be an effective form of improving efficiency and thus, performance time, in 200m and 2000m level running by producing increases in both stride length (SL) and stride frequency (SF).

To test this hypothesis, twelve fit male subjects were divided into two training groups, downhill (D) and level (L), matched on the basis of a 2000m time trial performance and $\dot{V}O_{2max}$. The dependant variables of time, SL and SF for both 200m and 2000m time trials were measured before and after a six week training program which consisted of an 8x300m interval session run twice per week. The L and D groups performed these intervals, on a grass surface, with a level and a 3.8% downhill grade, respectively.

No significant improvements in performance or differences between the two groups were found for either criterion distance on any of the variables. Significant correlations, however, were found between increases in both SL and SF and decreases in both run times between pre- and post-training tests for both groups. Increases in SF were significantly correlated ($r=0.918$, $p<0.01$) with improvements in 2000m run time in the D group. SF was also found to significantly correlate with 200m time, as was both SL and SF with 2000m run time. It was concluded that neither the D or L training program implemented in this study yielded significant improvements in 200m or 2000m run times. However, the results did imply that increasing both SL and SF may be factors in improving running performance. In addition, the results suggest

that downhill running may be beneficial for enhancing middle distance (2000m) running performance, particularly in increasing SF.

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LIST OF ABBREVIATIONS

AT	- Anaerobic Threshold
ANOVA	- Analysis of Varience
bpm	- Beats Per Minute (Measure of Heart Rate)
D	- Downhill Training Group
DOMS	- Delayed-Onset Muscle Soreness
HR	- Heart Rate
HRR	- Heart Rate Reserve
IEMG	- Integrated Electromyogram
J	- Joules
L	- Level Training Group
maxHR	- Maximum Heart Rate
r	- Pearson Product Moment Correlation Coefficient
RER	- Respiratory Exchange Ratio
RPE	- Ratings of Percieved Exertion
SL	- Stride Length
SF	- Stride Frequency
TT	- Time Trial
$\dot{V}_E$	- Volume of Expired Air
$\dot{V}CO_2$	- Volume of Carbon Dioxide Output
$\dot{V}O_2$	- Volume of Oxygen Uptake
$\dot{V}O_{2max}$	- Maximal Oxygen Uptake

Chapter I

INTRODUCTION

As standards of performance in athletics increase, methods of training are constantly being refined in order to optimize results. In middle and long distance running, training is focused on, 1) producing maximum muscular force to propel the athlete's body forward across the ground and 2) optimizing the resistance to fatigue of the human organism - the working muscles in particular - so the fastest possible running pace can be maintained (Lydiard, 1970; Costill, Thomason & Roberts, 1973; Noakes, 1991).

Interval training has been found to be a successful method for achieving these training goals (Freeman, 1975) and as such, has long been employed as an integral part of training for competitive running. Interval training consists of a number of repetitions of a shorter than race distance but, of equal or higher intensity, with pre-specified rest intervals (Freeman, 1975; Coe, 1991). Interval work enables the accomplishment of more total work at a high pace, than is possible with continuous running (Dolgener & Brooks, 1978). This type of training has been shown to improve both maximum oxygen uptake ($\dot{V}O_{2max}$) and the theoretical level at which one can maintain running speed without the, fatigue causing, lactic acidosis (Costill, 1968; Moffatt, Stamford, Weltman & Cuddihee, 1977; Coe, 1991). (This level is referred to as the "anaerobic threshold" (AT) and is often expressed as a percentage of $\dot{V}O_{2max}$). Interval training has also been shown to positively influence other performance affecting variables such as the patterns and number of muscle fiber recruitment.

However, interval training alone has been shown to have no effect on increasing leg speed (Ragg, 1979). Longer stride length and/or increased leg turnover rate have been indicated as characteristics of downhill running (Davies & Barnes, 1972a; Pivarnik & Sherman, 1990), particularly at faster running speeds. This observation is supported by studies involving downhill running which show greater muscle activity in the extensor muscle groups (Dick & Cavanagh, 1987), which are important during the drive and support phases of the running action (Martin & Coe, 1991).

Running repetitions on a negative gradient, rather than a level surface, is a training option which has rarely been explored. The revolutionary New Zealand coach, Arthur Lydiard, included a session of both uphill and downhill repeats as a method of increasing leg speed by enhancing stride length and frequency, in his highly successful training program (Lydiard, 1970). This facet of Lydiard's program is not well known or documented, however, and there is negligible evidence that downhill running has been included in run training programs since that time.

It has been conclusively shown that there is a greater involvement of eccentric muscle action in downhill running than in level running (Stauber, 1989). Since an eccentric component is present in all types of running and evidence suggests that muscle fiber recruitment patterns are similar during level and downhill running (Dick & Cavanagh, 1987), training downhill may be an ideal form of overload training to enhance leg strength and efficiency (in terms of energy expended) for the eccentric phase of level running.

It is concluded, therefore, that interval training on a downhill gradient may have some merit in optimizing performance. Increased stride length and frequency experienced during downhill running, could result in changes in motor neuron patterns and translate to similar adaptations during level running, thus enhancing speed. In addition, eccentric muscle actions have been shown to elicit greater strength gains than concentric contractions (Singh & Karpovich, 1967), thus resulting in a subsequently higher power output. Finally, the similarity of the downhill running action to that of level running makes it a very specific method of training.

Purpose

The purpose of this study was to examine the effectiveness of a six week downhill interval training program on 200m and 2000m run times. These criterion distances were selected to represent speed and aerobic power, respectively. Stride length and stride frequency were also measured before and after training, to indicate whether changes in motor neuron patterns had taken place. It was felt that the results of such a study would be directly applicable to athletes in a training setting.

Hypothesis

It was hypothesized that six weeks of downhill interval training would elicit a greater improvement in both 200m and 2000m time trial performances, than that achieved on an equivalent level interval training program. Stride length and stride frequency were also expected to increase after the downhill training.

Limitations

1. Being a training study, the limited amount of control over extraneous variables such as other forms of physical activity, training, racing, etc., as well as everyday lifestyle factors, was a major limitation of this study.

2. Due to a relatively small available running population in the area, the number of subjects involved in the study was limited to twelve males. Time pressures and training injuries contributed to a decrease in availability of subjects. In addition, the fact that subjects were limited to those not on track or cross country teams, resulted in only two of the subjects being seasoned, competitive runners. This caused limitations in the direct applicability of results to the population that would most benefit from the findings of the study.

3. This investigator found no studies which have been performed to determine the optimum negative gradient for downhill training. Several authors have, however, warned of the possibility of injury associated with intense eccentric exercise (Stauber, 1989; Harris et al., 1990; Nike, Inc., 1991). For this reason a modest slope (3.8%) on a grass surface was chosen for the downhill training in this study. The moderate slope coupled with the more uneven and slower nature of the grass surface, may have been limiting factors in the magnitude of results obtained.

4. This study was conducted during the fall semester. During the course of the training, temperatures fluctuated approximately 30 °C, with snow on the ground for part of the final week of training. Changes in wind (strength and direction) also added to condition difficulties and variability.

5. The inability to find an adequate method of measuring the presence of strength changes due to the downhill training program, was also a limitation of this study.

Definition of Terms

Delayed-Onset Muscle Soreness (DOMS). Perceived feelings of soreness and tightness in the muscles which is experienced in the 24 - 48 hours after mechanical muscle trauma associated with unaccustomed eccentric exercise.

Eccentric Muscle Action. Muscle tension which is produced in response to an external force (of which gravity is often a component), which overcomes the ability of the muscle to actively resist, resulting in the lengthening of the muscle - "resisted muscle lengthening".

Interval Training. A method of running training where numerous repetitions over a pre-determined distance are performed in a certain time (usually race pace or faster), with pre-specified rest periods.

Muscle Fiber Recruitment Patterns. The process of nerve stimulus, via motor neurons, to muscle fiber units, in a select pattern distinct to the nature of the desired muscle action.

Stride Frequency (SF). Also known as leg turnover rate. Expressed as number of complete strides (of one leg) per second.

Stride Length (SL). The length (in meters) of one complete running stride cycle, i.e., the distance from toe off of one foot to the next toe off of the same foot.

Chapter II

REVIEW OF LITERATURE

An eccentric muscle action has been defined as one "...in which the muscle is lengthened, i.e. net muscle moment is in the opposite direction to the change in joint angle, and mechanical work is negative" (The Encyclopedia of Sports Medicine, 1988, p. 23). During downhill running, which has been well documented as having a high eccentric component (Friden, Seger, Sjostrom & Ekblom, 1983; Schwane, Johnson, Vandernakker & Armstrong, 1983; Byrnes et al., 1985; Evans, 1987; Stauber, 1989; Hamill, Freedson, Clarkson & Braun, 1990), this translates to deceleration and shock absorbing functions where gravity and contraction of antagonist muscles force the agonist muscle groups to lengthen (The Encyclopedia of Sports Medicine, 1988; Stauber, 1989). The direct results of this 'negative' work on muscle function have been the subject of much research (Stauber, 1989).

Traditional studies on eccentric muscle actions were concerned with comparing strength gains due to concentric, eccentric and isometric resistance training (Singh & Danielson, 1975). There has been increased interest within the last ten years, however, in the occurrence and mechanisms of delayed-onset muscle soreness resulting from eccentric work, muscle kinematics and fiber recruitment patterns during eccentric muscle action, and the related phenomenon of upward drift of oxygen uptake ($\dot{V}O_2$) during prolonged downhill running (Stauber, 1989). An area in which negligible research has been conducted is the application to a performance setting of the combined effect of these factors, i.e. the chronic adaptations of muscle to repetitive eccentric work such as that experienced during downhill running.

Background: Studies on Downhill Running

Since a paucity of studies have investigated downhill training, four factors related to eccentric muscle actions are reviewed and projections are made as to the applications of these factors to repeated downhill work bouts.

Delayed-Onset Muscle Soreness

Occurrence

Regardless of the mode or intensity of exercise, soreness has consistently been found to occur in the working muscles involved in unfamiliar activities requiring eccentric actions (Schwane et al., 1983; Byrnes et al., 1985; Evans et al., 1986; Evans, 1987; Clarkson & Tremblay, 1988; Stauber, 1989; Harris, Wilcox, Smith & Quinn, 1990). This soreness has been shown, repeatedly, to peak at 24 to 48 hours after the eccentric exercise bout and, as such, has been termed, "delayed-onset muscle soreness", or DOMS (Byrnes et al., 1985; Evans et al., 1986; Evans, 1987; Hamill et al., 1990; Harris et al., 1990).

Quantification

DOMS is commonly quantified by both subjective ratings of soreness (e.g., on a ten point scale) and plasma creatin kinase levels (Newham, Jones & Clarkson, 1987; Evans, 1987; Clarkson & Tremblay, 1988; Hamill et al., 1990), the latter having been established as a clear sign of delayed muscle damage (Stauber, 1989). Decreases in muscle strength and muscle shortening, assessed by decreases in joint angle or flexibility, have also been associated with, and used to quantify, DOMS (Clarkson & Tremblay, 1988; Hamill et al., 1990; Harris et al., 1990). These criterion measures have been used to indicate that the degree of DOMS is directly related to both the intensity and duration of exercise (Stauber, 1989).

Mechanisms

Lesions in Z-bands (especially in fast twitch fibres), swollen mitochondria, increases in plasma interleukin-1, dilated T-tubules, sarcomere derangement, impaired calcium transport, abnormal energetics and decreased force production have been associated with acute eccentric muscle action and DOMS (Evans et al., 1986; Evans, 1987; Stauber, 1989; Nike, Inc., 1991). Despite the uncertainty as to the exact mechanisms of DOMS, these findings seem to suggest that direct myofiber damage is the cause (Stauber, 1989). The most well documented evidence of this is increases of up to 351% in plasma levels of the muscle-specific enzyme, creatin kinase (Schwane et al., 1983), which has been shown to correspond directly to subjective ratings of DOMS (Evans et al., 1986; Evans, 1987; Hamill et al., 1990).

Functional Effects

Much of the research has focused on the functional results of an acute bout of eccentric activity such as downhill running. Such studies have reported DOMS in the gluteal, quadriceps, and anterior and posterior leg muscles (Schwane, et al., 1983). There has been contrary results, however, as to the effect of this soreness on subsequent running performance. Hone, Siler & Schwane (1990) found no significant differences between the pre- and post-test variables of oxygen uptake ($\dot{V}O_2$), stride length, power, and hip, knee and ankle ranges of motion. The post-test runs were fixed-speed, six minute treadmill runs, performed 24 and 48 hours after a 45 minute run at -12% grade. However, in a study of similar design, Harris et al. (1990) found that runners experiencing DOMS 24 and 48 hours after a three mile run at -10% grade, exhibited shortened stride length and reduced excursion of the lower leg. Hamill et al. (1990) and a review on muscle soreness by Nike, Inc. (1991), report similar findings to those of Harris et al. (1990).

Adaptation

There is even less clarity surrounding the mechanisms of the rapid adaptation of the muscle groups to downhill running (and eccentric muscle actions). Stauber (1989) stated that since soreness is negligible after the second or third bout of eccentric exercise, the muscle damage from eccentric muscle actions are either insignificant or serve as a stimulus for repair and adaptation to resist further insult. It is possible that the initial muscle fiber damage triggers a process whereby connective tissue of a higher quality and quantity is laid down (Evans, 1987; Stauber, 1989). Another theory is that weak fibers are injured and degenerate due to eccentric muscle actions, and only the stronger fibers survive, with additional, more resilient fibers produced (Newham et al., 1987).

In a study by Clarkson & Tremblay (1988), involving 22 subjects (male and female), DOMS was found to be significantly greater after an exercise bout involving 70 maximal eccentric bicep curls than after a bout involving 24 identical muscle actions with the contralateral arm. An additional 70 maximal bicep curls were performed two weeks later by the arm which had originally performed the 24 maximal actions and DOMS was again found to be significantly less than that experienced in the arm which had performed only the initial 70 maximal curls. It was concluded that adaptation had occurred, with the muscle becoming more resilient to damage and faster to repair, after only one relatively small bout of eccentric work.

Several other studies have found, similarly, that resistance to damage increases rapidly after the first bout of eccentric exercise (Friden et al., 1983; Byrnes et al., 1985; Newham et al., 1987; Stauber, 1989). Byrnes et al. (1985) found that an initial bout of eccentric exercise (downhill running) significantly decreased the amount of DOMS experienced in a subsequent bout performed up to six weeks later. A study by Friden et al. (1983), examining DOMS during eight weeks of progressively harder eccentric training (downhill treadmill running), resulted in the finding that after two to three sessions, soreness disappeared despite increases in training loads.

Evans (1987, p. 100) states, "because training eccentrically has been shown to prevent delayed-onset muscle soreness and muscle damage, athletes should pay particular attention to the eccentric component of their event. Many runners train hard for the uphill component of a race but devote little time to downhill running". This is particularly relevant since running has an eccentric component under all conditions. DOMS can be experienced not only after downhill running, but also after level running of higher than normal intensity. It makes sense then to train at the extreme end of the eccentric spectrum (downhill running) and enhance adaptation to performance-limiting muscle damage which may occur during race situations.

Upward Drift of Oxygen Uptake

Contrary to level running, there exists strong evidence that oxygen uptake ($\dot{V}O_2$) does not reach a steady-state, but continues to drift upwards throughout continuous downhill running, or other similar exercises involving primarily eccentric action (Dick & Cavanagh, 1987). This phenomenon has been observed in eccentric exercise at intensities ranging from 35% to 60% of $\dot{V}O_{2max}$, for durations of up to 50 minutes (Dick & Cavanagh, 1987).

The upward drift of $\dot{V}O_2$ has been found to be independent of blood lactate concentrations and respiratory exchange ratio (RER), however, it is closely linked to integrated electromyogram (IEMG) activity (Davies & Barnes, 1972b; Dick & Cavanagh, 1987; Stauber, 1989). The current theory, therefore, is that the increases in $\dot{V}O_2$ as exercise continues (with constant intensity) is due to increases in muscle fiber recruitment, which is believed to be necessary in order to replace the muscles undergoing intracellular damage and, thus, to maintain force output (Dick & Cavanagh, 1987). This idea is supported by Stauber's (1989) review of the eccentric actions of muscles. It is thought that the damaged muscle fibers still use energy, but with diminishing force output (Stauber, 1989).

Despite the upward drift of $\dot{V}O_2$ during downhill running, the oxygen cost of equated work loads has been shown to be significantly less for downhill running (or eccentric work) than for level running (Dick & Cavanagh, 1987; Stauber, 1989; Pivarnik & Sherman, 1990). Furthermore, the differences in physiological cost between negative and positive work increases at higher speeds (Stauber, 1989). It is suggested that this is due to reduced muscle activation in negative (downhill) work (Stauber, 1989).

The fact that the oxygen cost for the downhill work is lower than for level running at the same speed may be a result of less muscle fibers being initially recruited in negative work than during positive muscle actions (Dick & Cavanagh, 1987). It is suggested that this is due to the effect of gravity which assists in the forward momentum of the body running downhill. Additional muscle fibers are recruited throughout an eccentric exercise bout, however, to compensated for extra forces generated on the muscle, which cause lengthening and are responsible for causing muscle damage (Stauber, 1989).

Since most of the studies examining the upward drift of $\dot{V}O_2$, involved eccentric exercise at submaximal workloads, it is theorized that slow twitch muscle fibers (which would be preferentially recruited during prolonged submaximal running) are initially damaged. As a result, less economical and less fatigue resistant, fast twitch fibers must then be recruited to maintain the force output (Dick & Cavanagh, 1987). The idea that muscle fibers are recruited in this way during downhill running, is supported by the decrease in efficiency found with time, but it is not a necessary occurrence to explain the upward drift of $\dot{V}O_2$. The implications of this theory are that downhill running could be a useful method for training fast twitch fibres to function more aerobically. The findings of Davies & Barnes (1972a), that efficiency increased ($\dot{V}O_{2max}$ decreased) with subsequent bouts of downhill training, supports this projection.

Kinematics and Muscle Fibre Recruitment During Downhill Running

"Evidence suggests that motor unit recruitment patterns in selected muscles are similar during level and downhill running ... Slow-twitch muscle fibers are similarly and preferentially recruited during level and downhill runs at the same speed or intensity" (Dick & Cavanagh, 1987, p. 315). Thus the basic movement patterns of running downhill are the same as for running on level ground.

However, Several studies have shown significant differences in gait kinematics between level and downhill running (Buczek & Cavanagh, 1990; Hamill et al., 1990; Harris et al., 1990). It has been suggested that stride length and frequency are greater in downhill than level running of the same speed (2.7 $m \cdot s^{-1}$) and complimentary grades (-10% and 10%) (Pivarnik & Sherman, 1990). Dick & Cavanagh (1987) found no significant difference in stride length between level and downhill treadmill runs, however the controlled speed (3.83 $m \cdot s^{-1}$) of the treadmill may have influenced this. An extensive study performed by Buczek & Cavanagh (1990), found that during downhill running (as compared to level running at the same speed - 4.5 $m \cdot s^{-1}$), knee flexion angle at footstrike was reduced and there was a greater maximum knee flexion angle and relative time to peek knee flexion angle. Similar observations were made regarding ankle kinematics. This greater range of motion of the lower limb tends to suggest increased stride length over that of level running. As stance time was found to be similar (downhill = 0.219 sec., level = 0.222 sec.), a longer stride would necessitate higher stride frequency. Peak flexion velocity was also observed to be greater during downhill running, however this value was not statistically significant.

Furthermore, power absorption, both at the knee (downhill = 48.5 J, level = 28.6 J) and at the ankle (downhill = 24.6 J, level = 12.4 J), has been found to be significantly greater in downhill running (Buczek & Cavanagh, 1990). The total power absorption expressed as a percentage of stance time was also greater for downhill running (Buczek & Cavanagh, 1990). This finding reflects the greater eccentric component of downhill running.

Eccentric Muscle Actions and Strength Gains

The increase in negative work, characteristic to downhill running, is hypothesized to result in adaptations which lead to strength gains. Training studies (of seven and eight weeks) involving eccentric muscle actions revealed strength gains superior to those measured after training muscles concentrically or isometrically (Singh & Karpovich, 1967; Komi & Buskirk, 1972). Contrary to this, Singh & Danielson (1975) found that isometric training was the most effective, however, their results show superior strength gains with the eccentric training program, over concentric and isometric programs, in all but the eighth and final week of training. In an earlier study, involving maximum training of forearm extensors, four times per week for eight weeks, in was found that the eccentric program was marginally more effective than the isometric program in increasing extensor strength and significantly more effective in strengthening the antagonistic flexor muscle group (Singh & Karpovich, 1967).

It is commonly accepted that maximum eccentric strength is significantly greater than either concentric or isometric strength (Singh & Danielson, 1975; The Encyclopedia of Sports Medicine, 1988; Stauber, 1989). More dynamic tension is generated during eccentric muscle action and, therefore, there is a greater effective force (Stauber, 1989). For this reason, eccentric muscle actions involve the lowest energy consumption per unit of tension exerted and are capable of producing the greatest maximum tension (Komi & Buskirk, 1972). This is supported by the earlier stated notion that $\dot{V}O_2$ is lower at a given workload during eccentric muscle actions than during concentric actions.

This greater force and power production capacity of the eccentric muscle action should be seen as beneficial for specific purposes of muscle training. The high efficiency properties are especially attractive to the performance of the running action.

Proposed Applications to Downhill Running Training and Resulting Performance Effects

All of the literature reviewed on downhill running, addressed the biochemical changes, the physical adaptations or the physiological responses associated with acute bouts of eccentric exercise. Furthermore, a large amount of literature has focused on the perceived negative effects of downhill running. Apart from some strength training studies, there has been a dearth of research examining the long term adaptations to dynamic eccentric exercise and the possible effects of these on performance.

In light of the above literature review, the following projections are made in relation to the chronic effects of downhill running:

1). Initial insult due to eccentric muscle actions will result in adaptation to the increased mechanical stress and the synthesis of new muscle tissue. The overall result of this should be strengthening of muscle and connective tissue.

2). Due to the higher metabolic efficiency of eccentric muscle actions, a greater amount of work is able to be performed during bouts of downhill running. It is thought then, that training by running downhill should be more time effective in producing the physiological adaptations characteristic to downhill running.

3). Overloading the system with eccentric running should result in an enhanced ability to cope with the relatively smaller eccentric components of level running. Thus, fatigue due to eccentric muscle actions should decrease, at all gradients.

4). Greater stride length and frequency characteristics of running fast downhill repeats may translate into new motor patterns at the level of the neuron and result in faster leg turnover and increased stride length even while running on level surfaces.

The net result of these projections, if valid, is enhanced running performance, both in terms of power and speed. The idea of downhill interval training, therefore seems to optimally satisfy the two goals for training outlined at the beginning of this paper, i.e. maximizing muscular force and optimizing the resistance to fatigue of the working muscles.

Chapter II

METHODS

Subjects

Twelve volunteer male college students, aged 20 to 33 years (mean = 23.08 ± 3.87 years), were recruited through class announcements and posted advertisements. All were recreational athletes who were performing some form of aerobic activity at least three times per week. Running was either a current part of their weekly program or had been within the preceding twelve months.

The subjects were matched, on the basis of performance in a 2000m time trial and on a $\dot{V}O_{2max}$ treadmill test, and divided into a level (L), for control purposes, and a downhill (D) training group. Characteristics of the two groups are provided in Table 1. There were no significant differences between the two groups on any physical characteristics or pre-training variables.

Procedure

Prior to commencement of testing, the procedures, purpose and possible risks of the study were explained to the subjects, who then signed statements of informed consent (Appendix A). At this time, subjects were instructed to take their resting pulse upon waking and report this at the first experimental session for use in calculating heart rate reserve (HRR) values (see p. 18).

On the first visit to the laboratory, subjects were weighed to the nearest 0.1 kg on a Health-o-Meter balance scale. In addition, height (cm) and blood pressure (mm Hg) measurements were taken.

Table 1: Mean (± standard deviations) values of physical characteristics and pre-training variables for the downhill (D) and level (L) groups.

	Age (yrs)	**Weight** (kg)	**Height** (cm)	**$\dot{V}O_{2max}$** (ml/kg/min)	**maxHR** (bpm)	**200m** (sec)	**2000m** (min)
D	21.67	71.4	177.6	62.68	190.0	27.98	7:46.5
(n=6)	(0.82)	(7.0)	(6.7)	(10.33)	(8.6)	(1.83)	(0:54)
L	24.50	71.8	182.2	61.14	196.8	28.80	7:42.4
(n=6)	(5.24)	(8.2)	(2.6)	(10.78)	(10.8)	(2.20)	(0:59)

Test of Maximal Oxygen Uptake ($\dot{V}O_{2max}$)

Maximum heart rate (maxHR) and $\dot{V}O_{2max}$ of each subject was measured during a maximal treadmill test. The $\dot{V}O_{2max}$ data was later used to match the subjects according to fitness level. Maximal HR was used, with resting HR (taken by the subjects), to determine the appropriate training intensity for each individual, using the formula for heart rate reserve (HRR) proposed by Karvonen (ACSM, 1991, p. 99-100).

The graded exercise tests were performed in an air-conditioned laboratory (temperature = 25°C, humidity = 50%), on a Quinton Q65 motorized treadmill. The speed and grade of the treadmill were controlled electronically via the Quinton Q2000 unit. A nine-minute mile run protocol (Appendix B), used for all subjects, was programmed into this computerized system. During the test, subjects breathed through a mouthpiece which was attached to a suspended, Hans Rudolph (series 2700), large two-way non-return valve. This was attached, via plastic tubing, to both the gas analysis equipment and the Rayfield RAM-9200 Ventilometer. The Applied Electrochemical Inc. (Sunnyvale, California) gas analysis equipment consisted of O_2 (S-3A) and CO_2 (CD-3A) analyzers, O_2 (22M) and CO_2 (P-61B) sensors and a flow control (R-1), and was connected on-line to an Apple IIe computer terminal. The gas analysis equipment was calibrated prior to experimentation, in accordance with the manufacturer's instructions, using a certified gravimetric gas mixture.

Subjects were familiarized with the treadmill and breathing apparatus prior to test commencement. A Polar Vantage XL heart rate belt monitor was secured around the subject's chest, and a watch monitor displayed HR readings. During the test, HR values were recorded every minute and a computer printout recorded volume of expired air ($\dot{V}_E$), $\dot{V}O_2$, $\dot{V}CO_2$ and respiratory exchange ratio (RER) values every 30 seconds.

The test was terminated when the subject reached volitional fatigue. Other indicators that $\dot{V}O_{2max}$ had been reached were, RER values in excess of 1.0, subjective ratings of perceived exertion levels (Borg's RPE) of 18 - 20 and HR's within ten beats per minute of the age-predicted maximum. The highest 30 second $\dot{V}O_2$ value attained was taken as $\dot{V}O_{2max}$.

Familiarization Time Trials

Two days to a week after the $\dot{V}O_{2max}$ test, each subject performed familiarization runs of the individual time trials (TT's), which were the dependant variables in this study. The TT's consisted of maximal efforts over distances of 200m and 2000m, run on the Eastern Illinois University indoor track. The temperature (22.5 °C) and conditions in this facility were constant throughout all testing. Timing was done by hand.

Each subject ran the two TT's on the same day. The 200m was followed by as much recovery as deemed necessary by the subject (at least 10 minutes), before performing the 2000m. Split times were called out to the subjects at every 200m during the 2000m run. Where necessary, additional TT's were run in order to make adjustments in pace judgement and to ensure subjects were adequately familiarized with the experience of running solo TT's indoors.

Pre-Training Time Trials

Actual pre-training TT's were conducted one week after the familiarization TT's. The procedure was essentially the same as that employed during the familiarization runs, except that 200m split times were recorded during the 2000m run. All TT's were videotaped using a Panasonic AG-180 VHS Reporter video camera. Each 200m run was timed a total of four times from the video recordings, by the investigator. The 200m time was taken as the average of these four timings. Any error in timing due to the speed of the film was constant across all 200m runs. The tapes were later analyzed for stride length and frequency during the 200m and the second, sixth and ninth

200m sections of the 2000m. Data from the 200m sections were averaged to give representative values for the whole 2000m TT. Stride frequency (SF) was defined as the number of strides (complete contact-to-contact cycle of one leg) in a 200m interval, divided by the time taken for that section (i.e., # strides / t). Stride length (SL) was found by dividing the number of strides by the distance (# strides / 200m).

Training

After completion of the TT's, subjects were divided into two groups, matched on the basis of 2000m TT performance and $\dot{V}O_{2max}$ values. The groups were randomly assigned as either the level (L) or the downhill (D) training group. Subjects were instructed precisely as to the nature of the training which was commenced, under the supervision of the experimenter, in the week following the pre-training TT's.

The training for both groups involved running 8x300m intervals with 3:30 minute walk recoveries (to ensure no extraneous training effect from the D group jogging back up the incline), twice per week for six weeks. (Six weeks of training has been shown to be sufficient to elicit expected physiological changes by Nehlsen-Cannarella, et al., 1991). It was required that the repetitions be run individually at 85 - 95% of HRR (ACSM, 1991, p. 99-100). Intensity was ensured by the use of HR monitors during the first two training sessions. The resulting training speed was in the range of 5.3 to 6.0 $m \cdot s^{-1}$ for both groups. The L and D groups performed the intervals on level and downhill (grade = 3.8%) strips, respectively. In order to minimize the increased risk of injury said to be associated with the higher eccentric component of downhill running, all intervals (both groups) were run on grass surfaces.

The first week of training was fully supervised by the investigator. During the other five weeks of training, the investigator was in weekly contact with the subjects and occasionally observed a training session. In addition, the subjects were required, for control purposes, to keep a daily diary of all strenuous physical activity engaged in during the six week period. It was emphasized to the subjects that activity patterns should remain the same over the course of the study and that no new training or recreational activities should be undertaken.

Post-Training Time Trials

In the week following the completion of the six weeks of training, the 200m and 2000m TT's were repeated. The procedure was identical to that of the pre-training TT's, with video taping again undertaken to determine SF and SL. The results of the pre- and post-training TT's were then compared to determine the effect of training on the two groups. Post-training body weight was also measured.

Analysis of Data

One-factor analyses of variance (ANOVA's) were used to compare D and L training groups on all subject data, pre-training and post-training variables.

Two-factor repeated measures ANOVA's were performed for the variables, time, SL and SF, to determine the difference between the pre-training and post-training results and the two groups for the two time trial distances. The Newman-keuls posthoc method was used to determine the source of any significant differences.

A Pearson product-moment correlation was performed on all the dependant variables to determine the relative interactions and the contributions of SL and SF to run time for the 200m and 2000m TT's. Correlations were also performed on the pre-training - post-training TT (200m and 2000m) differences and both, respective pre-training TT times and $\dot{V}O_{2max}$.

The 0.05 alpha level was used to determine significance on all statistical analyses.

Chapter I V

RESULTS

Subjects

As stated earlier (p. 17), there were no significant differences found between the two training groups on pre-test variables (See Table 1, p. 18). As expected there were no significant differences in pre- and post-training body weight for either group, although the mean body weight values for both groups did increase slightly (D: 71.4 ± 7.0 to 71.6 ± 7.7 kg; L: 71.8 ± 8.2 to 72.4 ± 9.3 kg).

The training diaries kept throughout the six weeks of training indicated that all subjects kept their training habits fairly consistent and nobody introduced any new activities. Four of the twelve subjects reported missing one or two of the training sessions due to a cold or a minor injury problem.

Time Trial Performances

200m Run Time

In both the pre- and post-training 200m TT's, times for the D group were almost a second faster than those of the L group (see Table 2), however these differences were not statistically significant.

As can be seen from Table 2, the mean time of both training groups

Table 2. Mean (± standard deviation) values of downhill (D) and level (L) groups on the pre-training (#1) and post-training (#2) variables of 200m run time, stride length (SL) and stride frequency (SF).

	200m #1 (sec)	**200m #2** (sec)	**SL #1** (m)	**SL #2** (m)	**SF #1** (S/s)	**SF #2** (S/s)
D (n=6)	27.89 (1.84)	27.66 (1.64)	3.85 (0.5)	3.87 (0.1)	1.87 (0.1)	1.88 (0.2)
L (n=6)	28.86 (2.21)	28.47 (1.74)	3.84 (0.2)	3.84 (0.2)	1.81 (0.1)	1.84 (0.1)

Where, sec = seconds; m = meters; and S/s = strides per sec.

Table 3. Mean (± standard deviation) values of downhill (D) and level (L) groups on the pre-training (#1) and post-training (#2) variables of 2000m run time, stride length (SL) and stride frequency (SF).

	2000m #1 (min)	**2000m #2** (min)	**SL #1** (m)	**SL #2** (m)	**SF #1** (S/s)	**SF #2** (S/s)
D (n=6)	7:46.5 (0:54)	7:44.9 (0:51)	3.04 (0.3)	3.05 (0.3)	1.41 (0.0)	1.42 (0.0)
L (n=6)	7:42.4 (0:59)	7:34.2 (1:05)	3.15 (0.3)	3.16 (0.3)	1.38 (0.1)	1.39 (0.1)

Where, sec = seconds; m = meters; and S/s = strides per sec.

improved on the variable of 200m run. Only three out of the six subjects in the L group improved, as compared to five out of the six D group subjects, but large improvements by two of the L group subjects resulted in a greater mean improvement for L (0.39 ± 1.3 sec) than for D (0.23 ± 0.4 sec). (See Appendix C for individual subject data). Overall, improvements in 200m run time were small and there were no significant differences between pre- and post-training results for either group.

A moderate but non-significant ($p=0.055$) correlation ($r=0.567$) was found between overall pre-training 200m time and pre-training - post-training difference indicating improvement was more likely in subjects with slower pre-training times. When the results of each group were separately compared, the correlation between these two variables was higher, but due to the smaller degrees of freedom, the probability values were also higher (D: $r=0.626$, $p=0.183$; L: $r=0.616$, $p=0.193$). A small, non-significant correlation ($r=0.36$) was found between $\dot{V}O_{2max}$ and improvement in 200m time.

200m Stride Length

Stride length improved in three out of six subjects in both training groups. All but one of the subjects who improved in 200m run time with training had SL longer than or equal to that of the pre-training TT (See Appendix C). Increases in SL after training, consequently correlated significantly ($r=.768$; $p<0.01$) with decreases in 200m run time. As can be seen in Table 2, however, mean increases in SL were minimal, with D group having a 0.02 ± 0.08 m improvement and L group actually having a 0.002 ± 0.11 m decrement. There were no significant differences between SL for groups or for pre-training post-training measures.

No significant correlation was found between pre-training SL and SL improvement.

200m Stride Frequency

Mean stride frequency during the 200m TT increased for both training groups, with three of the D and five of the L subjects having equal or higher post-training SF (Appendix C). Mean increases were of the magnitude, 0.025 ± 0.04 and 0.008 ± 0.03 strides per sec for the L and D groups, respectively. Again, no significant main effects were found for either group or repeated measures (Table 2).

Increases in SF were significantly ($p<0.05$) correlated with decreases in 200m run time ($r=0.614$), but not with pre-training SL values. There was also a significant correlation ($p<0.01$) found between all 200m run times and SF's during the 200m TT's ($r=-0.775$).

2000m Run Time

Table 3 shows mean pre- and post-training 2000m TT performances. As can be seen both groups improved as a result of the training. Mean improvement was greater for the L group (8.22 ± 43.7 sec) than for the D group (1.62 ± 7.7 sec) which was largely due to the 90 sec improvement of one of the subjects in the L group. All but one of the D group and four out of six of the L group subjects improved their 2000m time after the six weeks of training (Appendix C). Improvements, however, were not significant for either group, nor was there a significant pre-training to post-training difference or interaction between the groups.

Overall values of improvement in 2000m time correlated significantly ($p<0,05$) with pre-training 2000m time ($r=0.605$), again indicating that slower pre-training times increase the likelihood of post-training improvement. However, when the improvements within each of the groups were compared to pre-training time, the correlations were relatively low (D: $r=0.478$; L: $r=0.224$). Overall 2000m time also significantly correlated to $\dot{V}O_{2max}$ ($r=-0.727$, $p<0.01$), but $\dot{V}O_{2max}$ was not significantly correlated to improvements in run time.

There were no significant correlations between run times for the two TT distances, nor between post-training improvements in 200m and 2000m TT's.

2000m Stride Length

As with the SL variable in the 200m TT's, SL during the 2000m TT's improved after training in the majority of subjects, but the group mean increases were no more than a cm or two (See Tables 2 & 3 and Appendix C). There were no significant main effects or interactions for 2000m SL.

Correlational results were again similar to those of the 200m SL variable. There was no significant interaction between initial 2000m SL and improvements in SL. The high correlation ($r=0.91$) between increase in stride length and decrease in 2000m run time across both groups was significant ($p<0.001$). The correlations between 200m and 2000m performances and SL, however, were quite low with only 200m post-training and 2000m post-training result having a significant correlation ($r=-0.611$, $p<0.05$).

There was also a high, significant ($p<0.001$) correlation between all 2000m TT performances and SL ($r=-0.886$) (which was not found with the 200m TT's).

2000m Stride Frequency

Table 3 shows small non-significant increases in SF with training for both groups. All subjects in the D group who improved their 2000m run time (n=5), had the same or faster SF's (Appendix C). This was reflected in the finding of a significant ($p<0.01$) correlation between 2000m time improvement and SF for the D group ($r=.918$). Three of the L subjects maintained or bettered their SF in the post-training 2000m, but there was no significant correlation between increases SF and decreased 2000m time for this group.

SF was moderately correlated with 2000m run time. All but pre-training SF and post-training time were significantly correlated ($p<0.05$), but the overall result was a non-significant correlation ($r=-0.56$).

Chapter V

DISCUSSION

The comparison of downhill and level interval training methods in this study failed to yield any significant improvements in either sprint or middle distance running performance. Five out of the six subjects in the downhill (D) group, however, had faster times in both the post-training 200m and 2000m TT's as opposed to only three and four subjects, respectively, in the level group. With the exception of the 200m SF variable, a larger number of subjects in the downhill group improved on all six dependant variables. Slightly greater mean time improvements for the level group on both TT's were found, but these were due, in each case, to one or two subjects with relatively large decreases in run times. Therefore, although no conclusions can be made regarding the benefits or superiority of downhill interval running, these results do not discount the use of this training.

The findings of significant correlations between overall improvements in TT times and increased SL and SF values may have important implications for running training. These results suggest that SL and SF are indicators of running performance, both in sprints and in middle distance. This is in part supported by the findings of significant correlations between SF and 200m times, SL and 2000m times and all but one SF-2000m time combination. It is implied from the results that since all other forms of training were kept constant throughout the training period, the twice per week, 8x300m interval program employed in this study brought about increases in SL and SF which positively influenced run time. Therefore it seems plausible to conclude that training programs designed to optimize SL and SF, such as the interval training used in this study, should be an integral part of training for enhanced performance. Furthermore, these correlations between increases in SL and SF with improvements in run time were found regardless of initial SL and SF levels. This suggests that improvements in these variables are not limited by initial levels, at leasts in the moderately trained subjects used in this study.

A significant correlation between increased SF and decreased 2000m run time was found in this study for the downhill group only. This supports the projections for downhill running training stated earlier (p. 15-16), despite the failure to find a significant improvement in performance from downhill training. This finding may suggest that downhill interval running training is more beneficial than equivalent level training in increasing SF and producing improvements in performance. Whether this result is due to adaptation to eccentric muscles actions, the ability to overload the muscles with negative work, strengthening of the muscle tissue, or the development of new motor patterns cannot be ascertained from this study and further work is needed to clarify this area.

The significant correlation between increases in SF and decreases in 2000m run time was the only significant difference in the findings between the D and L training groups. It can be speculated then that the only variable downhill interval training was found to influence, based on the results of this study, was SF during middle distance running performances. No advantage in sprint performance or in improving time or SL for middle distance performance can be implied from downhill interval training over level interval training.

Overall, 200m run times were significantly correlated with SF, but not SL. This leads to the implication that SF is the more important factor in sprint performance. 2000m run times were found to be significantly correlated with both SL and SF. It is suggested from these two findings that SL may not be as important in 200m run performance as SL's for both groups were similar at those speeds. SL, requiring high contraction forces, can be maintained for the short duration of a sprint, however it is possible that SL is more of a limiting factor in middle distance running as strength (aerobic power) is required to maintain stride length for the entire distance. It seems, therefore that SF could be the greater predictor of performance in sprinting, but that middle distance performance relies on a combination of SL and SF. This supports the ideas of Lydiard (1970), Costill et al., (1973) and Noakes (1991) stated earlier in the paper, that middle distance running training should focus on producing maximum muscular force (SL) and optimizing muscular resistance to fatigue in order to maintain pace (SF).

Chapter V I

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The findings of this study did not support the hypothesis that six weeks of downhill training would elicit greater improvements in time, stride length and stride frequency on criterion variables of 200m and 2000m time trials, than those achieved on an equivalent level training program. Small improvements were found in the performance of both time trials by both groups. Related improvements were also found in the variables of stride length and stride frequency. The improvements were not, however, enough to show the advantage of a downhill training program in directly enhancing performance.

The results did suggest that stride frequency may be an important factor in predicting 200m (sprint) performance and that possibly a combination of both stride length and stride frequency are important in 2000m (middle distance) performance. It seems from the results that downhill running may be a highly feasible way to gain improvements in stride frequency, which are in turn related to decreased in performance times in middle distance running. Further research needs to be done in this area.

Recommendations

The results of this study gave some indication to the relationship between stride length, stride frequency and run performance in 200m and 2000m time trials and, subsequently allowed the suggestions of possible implications of downhill interval training on these factors. It is clear, however, that further research needs to be done in order to clarify the effects of a downhill interval training program. The following recommendations are made pertaining to such further investigations:

1). The use of a much larger sample size to increase statistical power and reduce the probability of making a type II error due to the small improvements in run times.

2). An alternative / additional way of increasing statistical power would be to decrease the within-subject variability. The subjects who participated in this study ranged from competitive triathletes to recreational athletes who were not regularly running. Even though all subjects were well above average in fitness status (as is evidenced by their $\dot{V}O_{2max}$ values - see Appendix C), there was quite a variation in TT performance ability. It is recommended that a homogeneous group of trained runners be used for this type of study.

3). In this investigation, the minimal (3.8%) slope of the downhill gradient may have lessened the eccentric training effect. Only slight muscle soreness was reported by the subjects and no injuries occurred as a result of the downhill training. Thus, it is recommended that a greater slope be used in future studies.

4). Determination of the optimal downhill grade for producing training adaptations without causing injury.

5). Training three times, instead of twice, per week.

6). Closer monitoring of training sessions to ensure precise execution.

7). Stricter controlling of other training activities to limit the influence of these activities on measured variables.

8). Precise measuring of changes in leg strength (torque) may also be an informative addition to the dependant variables in downhill training studies.

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APPENDIX A

STATEMENT OF INFORMED CONSENT

The purpose of this study is to examine the effect of downhill interval training on middle distance running performance. Interval training has long been included as an integral part of training for competitive running. Repetitions over shorter than racing distances have been shown to improve both aerobic and anaerobic capacity, as well as other performance affecting variables such as lactic acid tolerance and the pattern of nerve impulses to the various muscle fibres. Studies on downhill running show that there is greater muscle activity in the extensor muscle groups, which are important in the driving phase of the running action. Longer stride length and/or an increased leg turnover rate have also been identified as characteristics of downhill running (particularly at speed). It is hypothesized that the variables associated with downhill running could result in improved strength and altered rates of nervous system recruitment of muscle fibres, which would lead to more effective forward propulsion during running activities. This study, therefore, will attempt to test this hypothesis by comparing the results of interval training programs on both level and downhill surfaces.

PROCEDURES

$\dot{V}O_{2max}$ Test

The first test performed will be a maximal treadmill test to determine $\dot{V}O_{2max}$ and maximal heart rate. This test will be conducted in the laboratory. It will involve running on a treadmill at nine minute per mile pace, with grade increasing every two minutes. You will be required to breathe through a mouthpiece and wear a heart rate monitor, around your chest, throughout the test. The test will be terminated on your instruction at the point at which you feel you can no longer continue. You will be running for a total of 10 to 20 minutes (depending on your fitness level and determination), with the final two to three minutes being of a very high intensity. As this is a maximal run to exhaustion, there is the risk, in extreme cases, of stroke or heart attack. All precautions will be taken, however, and an experienced, qualified experimenter will monitor the test and ensure your well-being at all times.

Familiarization Time Trials

The second testing session will be held two days to a week later. During this session, familiarization trials of the individual time trials (TT's) will be run. The TT's are the dependant variables in this study. The familiarization TT's, and all subsequent TT's, will be maximal efforts over distances of 200m and 2000m. They will be run on the indoor track to ensure constant conditions. As much time as is desired for recovery will be allowed between

TT's, with the 200m being run first. All running will be done in lane 5. Split times will be called at 200m intervals during the 2000m TT. The TT's will be repeated in the next week if necessary for familiarization purposes.

Pre-Test Time Trials

Two days to one week after the familiarization TT's, actual pre-test TT's will be conducted. The procedure will be identical to that of the familiarization TT's, except that the session will be video taped and, during the 2000m TT, the 200m splits times will be recorded.

Training

After the TT's are completed, all subjects will be divided into two matched (for fitness level and 2000m TT speed) training groups - a "downhill" group(D) and a "level" group(L). You will be informed as to your allocation to one of these groups in the week prior to the commencement of training. You will then be required to train twice per week, for six weeks, on either a downhill slope or on level ground (both on grass). Each training session will consist of 8*300m repetitions with 3:30 minutes walk recovery intervals, for both the D and L groups. The repetitions must be run at 85% to 95% of heart rate reserve. The first week of training will be fully supervised by the experimenter and a heart rate monitor will be used to determine training intensity. It is required that training be logged in a training diary (provided) for the six week period, and that all other training sessions, and related activities, be kept as constant as possible during this time.

Post-Tests

In the week following the completion of the six weeks of training, the 200m and 2000m time trials will be repeated. The procedure will be identical to the pre-tests.

Your individual results will be available to you on completion of the experiment. Please feel free to ask questions at any time. Thank you for your participation.

I, the undersigned, understand the procedures described above, and am aware of the risks involved. I also realize that I am free to withdraw from the study at any time, for whatever reason.

Signed:____________________________________

APPENDIX B

TREADMILL $\dot{V}O2max$ TEST

9 MINUTE MILE RUN PROTOCOL

STAGE	SPEED	GRADE	DURATION
1	3.5 MPH	0.0 %	2 MIN
2	6.0	0.0	2 MIN
3	6.5	0.0	2 MIN
4	6.5	4.0	2 MIN
5	6.5	6.0	2 MIN
6	6.5	8.0	2 MIN
7	6.5	10.0	2 MIN
8	6.5	12.0	2 MIN
9	6.5	14.0	2 MIN
10	6.5	16.0	2 MIN

APPENDIX C

RAW PRE-TRAINING AND POST-TRAINING TEST DATA

Abbreviations:

- SA -Sprint (200m) pre-training
- SB - Sprint (200m) post-training
- SF - Stride Frequency
- SL - Stride Length
- DA - Distance (2000m) pre-training
- DB - Distance (2000m) post-training
- diffs - Differences between pre- and post-training
- SSL - Sprint (200m) stride length
- SSF - Sprint (200m) stride frequency
- DSL - Distance (2000m) stride length
- DSF - Distance (2000m) stride frequency

Training Group	Age	Height	Weight #1	Weight #2
	(years)	(cm)	(kg)	(kg)
DOWN	21	184.5	77.5	78.4
DOWN	22	173	69.5	69
DOWN	21	170	59	58.2
DOWN	21	185	78.3	79.4
DOWN	22	172	72.6	72.5
DOWN	23	181	71.5	72.2
LEVEL	21	183	59.7	58.3
LEVEL	33	183.5	82.5	85
LEVEL	22	183.5	79.3	80.2
LEVEL	22	180	67.3	69.5
LEVEL	29	178	71.4	71.2
LEVEL	20	185	70.6	69.9
Means for downhill	21.7	177.6	71.4	71.6
±SD	0.8	6.7	7.0	7.7
Means for level	24.5	182.2	71.8	72.4
±SD	5.2	2.6	8.2	9.3

Training Group	V̇O2max	maxHR	200m (SA)	200m (SB)
	(ml/kg/min)	(bpm)	(sec)	(sec)
DOWN	52.12	194	28.22	28.02
DOWN	60.57	183	27.8	27.31
DOWN	82.2	191	29.45	28.82
DOWN	56.7	204	30.25	29.97
DOWN	61.98	188	25.88	26.29
DOWN	62.51	180	25.72	25.52
LEVEL	63.31	197	31.05	28.8
LEVEL	59.51	194	29.33	28.11
LEVEL	54.98	216	25.08	26.04
LEVEL	56.76	200	30.5	31.37
LEVEL	61.34	186	27.53	27.72
LEVEL	70.96	188	29.68	28.78
Means for downhill	62.68	190.0	27.89	27.66
±SD	10.33	8.6	1.84	1.64
Means for level	61.14	196.8	28.86	28.47
±SD	5.67	10.8	2.21	1.74

Training Group	SA SL	SB SL	SA SF	SB SF
	(m)	(m)	(S/sec)	(S/sec)
DOWN	3.92	4	1.81	1.78
DOWN	3.67	3.67	1.96	2
DOWN	3.92	4.04	1.73	1.72
DOWN	3.77	3.81	1.75	1.75
DOWN	3.96	3.92	1.95	1.94
DOWN	3.85	3.77	2.02	2.08
LEVEL	3.88	3.96	1.66	1.75
LEVEL	3.7	3.77	1.84	1.89
LEVEL	4.12	4	1.93	1.92
LEVEL	3.64	3.51	1.8	1.82
LEVEL	3.77	3.74	1.93	1.93
LEVEL	3.92	4.04	1.72	1.72
Means for downhill	3.85	3.87	1.87	1.88
±SD	0.11	0.14	0.12	0.15
Means for level	3.84	3.84	1.81	1.84
±SD	0.17	0.20	0.11	0.09

Training Group	2000m (DA)	2000m (DB)	DA SL	DB SL
	(min)	(min)	(m)	(m)
DOWN	8.89	8.8	2.67	2.7
DOWN	8.68	8.62	2.73	2.7
DOWN	6.57	6.55	3.6	3.6
DOWN	7.88	7.82	2.97	2.98
DOWN	7.61	7.46	3.04	3.12
DOWN	7.02	7.24	3.25	3.21
LEVEL	7.01	6.87	3.22	3.22
LEVEL	7.34	7.76	3.22	3
LEVEL	8.7	7.19	2.9	3.18
LEVEL	9.01	9.54	2.85	2.76
LEVEL	7.72	7.65	3.07	3.13
LEVEL	6.46	6.41	3.65	3.64
Means for downhill	7.78	7.75	3.04	3.05
±SD	0.91	0.85	0.35	0.34
Means for level	7.71	7.57	3.15	3.16
±SD	0.99	1.09	0.29	0.29

Training Group	DA SF	DB SF	200m diffs	2000m diffs
	(S/sec)	(S/sec)	(sec)	(min)
DOWN	1.4	1.41	0.2	0.09
DOWN	1.39	1.41	0.49	0.06
DOWN	1.42	1.42	0.63	0.02
DOWN	1.39	1.42	0.28	0.06
DOWN	1.39	1.43	-0.41	0.15
DOWN	1.45	1.42	0.2	-0.22
LEVEL	1.5	1.48	2.25	0.14
LEVEL	1.41	1.41	1.22	-0.42
LEVEL	1.31	1.37	-0.96	1.51
LEVEL	1.28	1.25	-0.87	-0.53
LEVEL	1.41	1.4	-0.19	0.07
LEVEL	1.36	1.41	0.9	0.05
Means for downhill	1.41	1.42	0.23	0.03
±SD	0.02	0.01	0.36	0.13
Means for level	1.38	1.39	0.39	0.14
±SD	0.08	0.08	1.28	0.73

APPENDIX C (cont.)

Training Group	SSL diffs (m)	SSF diffs (S/sec)	DSL diffs (m)	DSF diffs (S/sec)
DOWN	-0.08	0.03	-0.03	-0.01
DOWN	0	-0.04	0.03	-0.02
DOWN	-0.12	0.01	0	0
DOWN	-0.04	0	-0.01	-0.03
DOWN	0.04	0.01	-0.08	-0.04
DOWN	0.08	-0.06	0.04	0.03
LEVEL	-0.08	-0.09	0	0.02
LEVEL	-0.07	-0.05	0.22	0
LEVEL	0.12	0.01	-0.28	-0.06
LEVEL	0.13	-0.02	0.09	0.03
LEVEL	0.03	0	-0.06	0.01
LEVEL	-0.12	0	0.01	-0.05
Means for downhill	-0.02	-0.01	-0.01	-0.01
±SD	0.07	0.03	0.04	0.02
Means for level	0.00	-0.03	0.00	-0.01
±SD	0.11	0.04	0.17	0.04