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SUMMARY

Problem.

Unaccustomed mountain hiking or downhill running (i.e., eccentric leg exercise) can result in severe muscle soreness, injury to muscle tissue, and strength loss that can last for several days following the activity. Prolonged muscle soreness and strength loss caused from repeated eccentric muscle contractions can potentially result in reduced physical performance and effectiveness during missions in mountainous terrain or athletic competitions.

Objective.

The purpose of this study was to determine the effects of downhill running (once per week for 8 weeks) on muscle soreness and strength, and on tissue damage. The work was performed to provide military personnel with guidelines for downhill running in preparation for future operations in the mountains where missions often involve repeated eccentric leg exercise.

Approach.

Eight U.S. Navy and Marine Corps males (29 ± 1 yr, 81.3 ± 1.7 kg, 179.0 ± 1.9 cm, 10.0 ± 1.3 % body fat, and 57.4 ± 2.6 $\mathrm{mL \cdot kg^{-1} \cdot min^{-1}}$) ran on a treadmill (-10% grade, ~55% $\dot{V}O_{2peak}$) for 30 minutes once per week for 8 weeks. Muscle soreness, peak isokinetic concentric and eccentric torque during knee extension, and plasma levels of creatine kinase (CK), hydroxyproline (HYP), and hydroxylysyl-pyridinoline (HP) were measured before and after the downhill running bouts.

Results.

Muscle soreness and muscle damage (measured by plasma levels of CK) were attenuated by the third bout of downhill running. At the same time, this protocol did not increase the breakdown of connective tissue (measured by plasma HYP and HP) or reduce maximal eccentric isokinetic leg strength. Small, but significant decreases were observed for concentric isokinetic leg strength (angular velocity=1.05 $\mathrm{rad \cdot sec^{-1}}$) at bouts five and seven compared to bout one.

Conclusions.

As few as two eccentric training bouts (e.g., two downhill runs, one week apart) can significantly reduce muscle soreness and muscle damage. This method of conditioning leg muscles prepares individuals for future missions or events involving downhill exercise.

INTRODUCTION

Military operations are conducted in a variety of environments and geographical locations. This includes mountain regions where operations typically require marching over hilly terrain for long durations often while carrying heavy packs. Mountain hiking and long, hilly road marches are often accompanied by acute and chronic physical injuries including blisters, ankle sprains, and tendonitis (Knapik & Vogel, 1992; Tek & Mackeny, 1993). Personnel may also experience muscle soreness, loss of muscle strength, and a decreased ability to replace energy stores after unaccustomed hiking (Costill et al., 1990; Stauber, 1989). This last category of symptoms results from repeated high-intensity contractions of the muscles while they lengthen (e.g., as in the landing phase of marching), called eccentric contractions.

Other activities, such as weight lifting, also involve a significant amount of eccentric contraction. Studies have shown that activities involving repeated high-intensity eccentric exercise often result in the loss of maximal voluntary strength and cause extensive muscle damage (Clarkson & Tremblay, 1988; Friden, Seger, Sjostrom, & Ekblom, 1983; Golden & Dudley, 1992; Newham, Jones, & Clarkson, 1987). In most cases, strength returns to preexercise levels within 24 hours after exercise (Davies & White, 1981; Newham, Jones, & Edwards, 1983). However, postexercise decrements in leg strength (one repetition maximum) have been reported from 4 to 10 days after the eccentric bout (Golden & Dudley, 1992; Sargent & Dolan, 1987). Similarly, muscle damage after unaccustomed eccentric exercise may persist for several days after completion of exercise. The damage is characterized by micro tears to skeletal myofibers and elevated levels of specific muscle proteins in the blood (Friden, et al. 1983). Plasma levels of muscle proteins, such as creatine kinase (CK), can increase by as much as 300% after an initial eccentric exercise bout (Clarkson & Trembly, 1988).

Effective prevention and treatment strategies to reduce pain, performance losses, and tissue damage are paramount to the successful execution of military missions. A preliminary study by Hasson et al. (1993) contradicts earlier reports (Almekinders, 1993; Kuipers, Keizer, Verstappen & Costill, 1985) and suggests that appropriate prophylactic and therapeutic doses of anti-inflammatory medications may reduce muscle soreness and attenuate losses in muscular function. Hasson et al. (1993) also caution against the dangers of repetitive use of such drugs and admit further research is required before conclusive statements can be made about their use.

Prior eccentric exercise has also been shown to prevent or significantly reduce exercise-induced muscle soreness, damage, and strength loss. As few as one eccentric exercise bout (performed 2 to 6 weeks before a similar eccentric exercise bout) can significantly reduce symptoms associated with unaccustomed eccentric contractions (Byrnes, Clarkson, White, Hsieh, Grykman, & Maughan, 1985; Friden et al., 1983; Nosaka, Clarkson, McGuiggin, & Byrnes, 1991; Stauber, 1989). For example, a significantly smaller decrement in leg strength was measured 24 hours after eccentric exercise compared to an identical exercise set completed 3 weeks earlier (Golden & Dudley, 1992). Maximal isometric leg strength is also recovered more rapidly by the 6th week of eccentric leg training (Balnave & Thompson, 1993). Furthermore, muscle soreness and elevations in CK, which occur after an initial eccentric exercise bout, are virtually undetectable following a second eccentric bout completed 1 to 8 weeks later (Balnave & Thompson, 1993; Pierrynowski, Tudus, & Plyley, 1987; Schwane, Williams, Sloan, 1987).

Appropriate pretraining is necessary for military personnel who must successfully complete mission tasks requiring a high level of muscular performance. Premission training should include exercising muscles in a deliberate manner to adapt them to the stresses associated with a specific activity. Training the muscles eccentrically, for example, can attenuate symptoms that follow a novel eccentric exercise bout and may maintain the level of performance during the remainder of the mission.

While current evidence supports the use of eccentric training to prepare for subsequent eccentrically biased events (Byrnes et al., 1985; Nosaka, et al., 1987; Pierrynowski et al., 1987), the amount, intensity, and frequency of training needed to acquire and maintain a protective effect requires more research. The present study was conducted to evaluate the potential of adding downhill running to the physical training program of military personnel to prepare for future missions involving repeated eccentric contractions of the leg muscles.

Unique to this study, connective tissue (CT) markers, hydroxyproline (HYP) and hydroxylysyl-pyridinoline (HP), were measured to provide information on the dynamics of CT during and following eccentric exercise. Cyclic overuse of CT without adequate recovery can produce pain, stiffness, or decreased range of motion of the limbs. Chronic eccentric training can also lead to overuse injuries such as tendonitis, bursitis, and ligament strains (Stauber, 1989). HYP is an amino acid virtually unique to collagen (an abundant protein of CT), and represents collagen degradation from precursor and mature collagen sources when measured in the blood. HP is a small compound formed during the final stages of CT maturation by a chemical reaction known as crosslinking. Unlike HYP, HP is not found in precursor collagen, not metabolized by the liver, nor influenced by the diet. Therefore, HP is a more specific marker of CT breakdown.

The purpose of this study was to document the responses of the musculoskeletal system to repeated bouts of downhill running and to provide military personnel with guidelines for downhill running in preparation for future operations in the mountains where missions often involve repeated eccentric leg exercise. To accomplish this, measurements of tissue metabolism, in parallel with measurements of muscle performance during eccentric training, can provide a more complete picture of recovery and adaptation. Therefore, peak leg strength, muscle soreness, and plasma markers of muscle and CT damage were measured while training with downhill running once per week for eight consecutive weeks.

METHODS

Subjects and Pretraining Measures.

Eight trained males from the U.S. Navy and Marine Corps participated in this study. The physical characteristics of the subjects are listed in Table 1.

Table 1. Physical Characteristics of Subjects (N=8)

Characteristic	Mean ± SE
Age (yr)	29 ± 1
Height (cm)	179.0 ± 1.9
Weight (kg)	81.3 ± 1.7
Body Fat (%)	10.0 ± 1.3
$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	57.4 ± 2.6
HR_{max} (beats·min^{-1})	192 ± 3
% $\dot{V}O_{2peak}$ (Bout 1)	55 ± 3
Treadmill speed (mph)	8.3 ± 0.3

Volunteers signed an informed consent document approved by the Committee for the Protection of Human Subjects at the Naval Health Research Center, San Diego, California, and were medically screened to ensure they were free from cardiovascular and orthopaedic disorders.

Subjects were currently participating in moderate to high-intensity aerobic training (3 to 7 days per week), but had not engaged in lower extremity weight training or downhill running for at least 3 months before the study and agreed to abstain from these activities throughout the study. Prior to the first downhill run, age, height, and weight were recorded, and percent body fat was estimated from seven-site skinfold thickness (Jackson & Pollock, 1978; Siri, 1961). Peak oxygen uptake ($\dot{V}O_{2peak}$) was measured during a progressive intensity treadmill protocol using open-circuit spirometry (Vista Metabolic System, Vacumed, Ventura, CA). Expired gas was analyzed with Applied Electrochemistry O_2 and CO_2 analyzers (Models S-3A/I and CD-3A, Ametek, Pittsburgh, PA). Heart rate (HR) was determined from electrocardiograph tracings recorded from three electrodes placed in the CM-5 position.

Downhill Running Protocol.

Eight downhill running sessions were completed on a treadmill (-10% grade for 30 min) at a frequency of once per week. Each individual's downhill running speed was calculated based on an average gross efficiency (20%) for downhill running (Davies & Barnes, 1972). If necessary, adjustments in the treadmill speed were made during the first bout to elicit an oxygen uptake of 50 to 60% $\dot{V}O_{2peak}$. Oxygen uptake was measured during the first bout and during the first 15 minutes of the last bout. Subjects completed the first downhill running bout at an average intensity and running speed of 55 ± 3% $\dot{V}O_{2peak}$ and 8.3 ± 0.3 mph, respectively. HR and whole body ratings of perceived exertion (RPE) were recorded at 5 minute intervals during each downhill run. During the first and last bouts, HR was recorded in the same manner used in the $\dot{V}O_{2peak}$ test. HR was monitored during bouts two to seven using a Polar Vantage® XL. Following standardized instructions, subjects reported RPE on a 6 to 20 scale with verbal anchors from "very, very light" to "very, very hard" (Borg, 1962).

Leg Strength.

Strength of the left thigh muscles (quadriceps) was measured before and 24 hours after each training bout. An isokinetic dynamometer (Kin-Com, Model 500H, Chattecx Corp, Chattanooga, TN) recorded torque during maximal voluntary eccentric (knee flexion) and concentric (knee extension) muscle contractions. Peak torque, measured at angular velocities of 0.52 and 1.05 rad·sec^{-1} (concentric) and 1.05 and 3.14 rad·sec^{-1} (eccentric), respectively, was recorded while the subjects sat upright with their arms across their chest. The rotation axis of the dynamometer was aligned to the lateral femoral epicondyle of the left knee while the knee was flexed at 90°. Velcro® straps were firmly secured across the chest, pelvis, and thigh to isolate the quadriceps muscle group (Griffin, Tooms, Vander Zwagg, Bertorini, & O'Toole, 1993). A warm-up set (five submaximal efforts, 50 to 70% of maximum, at 1.05 rad·sec^{-1}) was performed 2 to 5 minutes prior to the maximal efforts. Muscle actions were performed through a 70° range of motion, 90° to 20° (concentric) and 20° to 90° (eccentric). The best of three maximal efforts was used for statistical analysis.

Muscle Soreness.

Subjects indicated the degree of muscle soreness on a 0 to 4 scale (Table 2) following a standard application of force to specific sites on the gluteal, quadriceps, hamstring, gastrocnemius, and anterior tibialis muscle groups (Schwane, Johnson, Vandenakker, & Armstrong, 1983). Approximately 80 N of force was applied to each site with a 4 cm diameter plastic disc from a 60 cc syringe. First, the rubber plunger of the syringe was set at the 40 cc mark and the hole, opposite the disc, was sealed. The plastic disc was then placed on the skin and the plunger moved to the 20 cc mark. Muscle soreness was evaluated preexercise, 24, and 48 hours postexercise. The muscle soreness ratings for all sites were combined and reported as total leg soreness (Appendix A).

Table 2. Subjective Muscle Soreness Scale (Schwane, 1983)

0 = COMPLETE ABSENCE OF SORENESS
1 = LIGHT PAIN (only felt with applied pressure)
2 = MODERATE PAIN (some stiffness and/or weakness, especially during movement)
3 = SEVERE PAIN (limits the range of motion)
4 = THE WORST SORENESS I HAVE EVER EXPERIENCED

Determination of Plasma Muscle and Connective Tissue Proteins.

The time course of HP and HYP concentrations in the blood following exercise has not been determined, although peak circulating levels of CK occur 24 to 48 hours after prolonged exercise (Noakes, 1987). Therefore, venous blood samples were collected immediately prior to and 24 hours after each downhill run. The concentrations of CK, and the two CT proteins, HYP, and HP were measured from blood collected in 10 mL tubes treated with EDTA to prevent coagulation and then centrifuged (5°C, 3000 rpm, 10 min). Plasma was removed, transferred to cryotubes, and stored at -70°C until biochemical analysis.

Plasma CK, an indicator of muscle tissue damage, was determined spectrophotometrically using an enzymatic method (Szazs, Gruber, & Berndt 1976) (Sigma Kit No. 47-UV, Sigma Chemical Co., St. Louis, MO). Both HYP and HP were measured by high pressure liquid chromatography (HPLC). Plasma samples were hydrolyzed (12N HCl at 110°C for 24 hours) and then filtered (Murguria et al., 1988). For the analysis of HYP, the precolumn derivatizing reagent was added to an aliquot of the hydrolyzate according to the method of Dunphy, Bhide, and Smith (1987). A second aliquot was used for the extraction of HP as described for the separation of elastin crosslinks (James, Crowley, & Perrett, 1993; Skinner, 1982). The HP crosslinks were measured by paired-ion C_{18} reverse-phase HPLC using a variable wavelength fluorometer at excitation 290 nm and emission 395 nm (Eyre, Koob, & VanNess, 1984). HYP and HP samples were eluted and integrated using Maxima 820 software (Dynamic Solutions, Ventura CA).

Statistical Analyses.

A two-way analysis of variance with repeated measures was used to identify time (pre and post) and bout effects. When a significant effect was identified ($p<0.05$), Student-Newman-Keuls test was performed. Friedman analysis of variance on ranks was used to determine the effects of downhill running on muscle soreness and RPE scores. Pearson product moment correlation was used to determine associations between HYP and HP. The level of statistical significance was set at $p<0.05$. Values are reported as mean ± standard error (SE).

RESULTS

Eight consecutive downhill running bouts were completed by all subjects. An average of 7 days separated the treadmill runs. No muscle or connective tissue injuries (apart from transient muscle soreness and stiffness) were reported during the 8 weeks of training. There were no significant differences among bouts for HR or RPE; however, both variables increased during each downhill run. HR progressively increased at every interval from 5 minutes to 30 minutes, and RPE was significantly greater at 25 and 30 minutes compared to 5 minutes (Figure 1).

Muscle Soreness.

The lateral portion of the thigh was consistently reported as the site of greatest soreness. Total leg soreness at 24 and 48 hours postexercise did not differ significantly, and therefore were combined for each bout. Total leg soreness after the first downhill run and was significantly greater than the remaining bouts. No significant difference in muscle soreness, compared to baseline, was reported after the second to eighth downhill runs (Figure 2).

Plasma Indicators of Tissue Damage.

Mean values for plasma CK, HYP, and HP are presented in Figures 3, 4, and 5. Plasma levels of CK at 24 hours postexercise were significantly elevated from preexercise levels except for bout six (F=4.52, df=1, p=0.071) and bout seven (F=4.93, df=1, p=0.068). The second downhill run resulted in the largest CK concentration 24 hours after exercise. Compared to the second bout, CK dropped to significantly lower levels for the remaining downhill runs. There were no differences between pre and postexercise measurements for HYP; however, HYP was significantly lower for bout seven compared to all other bouts. The level of HP did not change significantly from pre to postexercise, and was not significantly different among bouts (Figure 5). Plasma levels of HYP and HP were not significantly correlated (r=-0.062, p=0.507).

Leg Strength.

Concentric and eccentric leg strength (peak torque) did not change significantly at any angular velocity from preexercise to 24 hours postexercise (Figure 6). The only significant change in leg strength among downhill running bouts was a decrease in peak concentric torque at 1.05 rad·sec^{-1} for bouts five and seven compared to bout one (Figure 6). A statistically significant interaction between time (pre to post) and bout was observed for concentric leg strength at 3.14 rad·sec^{-1} (Table 3). However, further examination of the values for the main effects did not reveal a meaningful explanation. Peak leg strength for bout two was not analyzed due to equipment failure.

Table 3. Two-way analysis of variance with repeated measures.

	Main Effects		Interaction
Variable	Time	Bout	Time x Bout
CK	F=15.68, p=0.006	F=4.56, p<0.001	F=1.57, p=0.173
HP	F=0.56, p=0.480	F=0.68, p=0.690	F=1.41, p=0.230
HYP	F=0.03, p=0.856	F=3.88, p=0.002	F=1.44, p=0.215
Concentric 3.14 rad·sec^{-1}	F=0.02, p=0.905	F=0.49, p=0.812	F=2.83, p=0.024
Concentric 1.05 rad·sec^{-1}	F=2.66, p=0.147	F=2.66, p=0.028	F=0.21, p=0.972
Eccentric 1.05 rad·sec^{-1}	F=1.74, p=0.229	F=0.82, p=0.559	F=0.40, p=0.654
Eccentric 0.52 rad·sec^{-1}	F=0.10, p=0.758	F=0.69, p=0.660	F=0.70, p=0.654

DISCUSSION

This study demonstrates that one to two downhill running bouts significantly reduce muscle soreness (one bout) and muscle damage measured by CK (two bouts) in subsequent eccentric exercise bouts. Furthermore, weekly bouts of downhill running do not impair eccentric isokinetic muscle strength or connective tissue integrity (i.e., no change in CT markers following repeated eccentric bouts).

During downhill running, an increase (or upward drift) in oxygen consumption, HR, and RPE is observed without a change in exercise intensity (Randall, & Cavanagh, 1987; Westerlind, Byrnes, Harrins, & Wilcox, 1994). Similar upward drifts in HR and RPE were observed in the present study. Repeated bouts of downhill running did not reduce this upward drift. This finding supports Albert (1991) who demonstrated that repeated eccentric exercise does not appear to produce adaptations in the cardiorespiratory system.

The musculoskeletal system, however, does exhibit training adaptations with repeated eccentric exercise. Reductions in markers of muscle damage (e.g., plasma levels of CK and myoglobin) and ratings of muscle soreness are common with repeated eccentric exercise

(Armstrong, 1984; Balnave & Thompson, 1993; Byrnes et al., 1985; Pierrynowski et al., 1987; Stauber, 1989). Our findings support Pierrynowski (1987), and Byrnes (1985), who reported a significant reduction in muscle soreness occurring after a second eccentric exercise bout repeated 4 days to 6 weeks later. Elevated levels of muscle soreness at both 24 and 48 hours are also consistent with other investigations (Armstrong, 1984; Ebbling & Clarkson, 1989; Smith, McCammon, Smith, Chamness, Israel, & O'Brien, 1989). A single downhill running bout was sufficient to significantly attenuate muscle soreness in the subsequent bouts. Postexercise levels of CK after the first downhill running session and the decline of this marker with subsequent downhill running bouts are in agreement with previous investigations (Balnave & Thompson, 1993; Byrnes et al., 1985). While the decreases in CK and soreness were dramatic, Evans and Cannon (1991) caution that their occurrence may not indicate a functional or measurable change in performance. This is suggested by the persistence of micro tears and focal damage several days after muscle function has recovered and muscle soreness is absent (Clarkson & Tremblay, 1988; Friden, Sjostrom, & Ekblom, 1983; Newham, McPhail, Mills, & Edwards, 1983). Direct measurements of performance (e.g., peak or maximal strength), therefore, are essential for a more complete discussion of eccentric exercise.

There are relatively few studies documenting the effects of eccentric leg exercise on muscle performance. Some investigators have reported a decrease in maximal isometric leg strength 24 to 96 hours following a novel eccentric exercise bout (Balnave & Thompson, 1993; Hasson et al., 1993; Pierrynowski et al., 1987; Sargent & Dolan, 1987). In contrast, this and other investigations showed no change in leg strength at 24 hours postexercise (Davies & White, 1981; Newham et al., 1983). The results from leg strength measurements recorded during eccentric exercise training (eccentric bouts repeated two or more times) are equally conflicting. Eccentric cycling (1 to 2 times per week for eight weeks) did not improve isokinetic concentric strength, but did increase maximal eccentric work capacity (Friden, et al. 1983). During our downhill running program, peak isokinetic concentric and eccentric leg strength did not increase; instead, a small, but significant decrease in concentric strength (only at the slower contraction velocity) was observed in two of the four remaining bouts. Although participants were instructed to maintain their regular activities throughout this study, it is possible that small changes in their weekly physical activity (e.g., increased exercise duration) may have contributed to the decrease in strength. The decrease in concentric strength after four bouts in our study contrasts a similar study by Balnave & Thompson (1993). They reported continued deficits in maximal isometric leg strength below pretraining levels throughout a downhill walking program (eight consecutive weekly bouts at -25% grade, 4 mph) (Balnave & Thompson, 1993).

These differences may be attributed to several factors, including subjects fitness level, training mode and performance measures. For example, trained individuals appear to be less susceptible than sedentary individuals to the insults associated with unaccustomed eccentric work. This results in less soreness and lower levels of plasma CK after eccentric exercise in trained individuals (Evans, et al., 1986). Activities such as running or lower body weight training appear to provide some protection to the leg muscles against the stresses of high-intensity eccentric exercise (Clarkson & Tremblay, 1988; Evans, et al., 1986). Furthermore, eccentric training with downhill running or walking involves multiple muscle groups and provides less stress to specific muscles (Clarkson, Nosaka, & Braun, 1992; Hasson et al., 1993). In contrast, eccentric cycling and resistance training involve more isolated contractions of the quadriceps and have been shown to increase concentric and eccentric strength with repeated bouts (Colliander & Tesch, 1990). Therefore, future investigations should include measures of muscle performance associated with endurance and fatigue to provide a more comprehensive evaluation of eccentric training and muscle performance. Results obtained from laboratory investigations should also be tested in field studies where performance measures such as vertical jump and time to complete a running task are included with measures of tissue adaptation.

Unlike muscle tissue, CT does not appear to undergo measurable damage during eccentric exercise. Our findings support Seaman and Iannuzzo (1988) who also measured HYP in the blood and found no change in this marker following repeated bouts of eccentric exercise. In contrast, Abraham (1977) reported higher urine concentrations of HYP 48 hours after arm and leg eccentric exercise in subjects who reported muscle soreness compared to those reporting no muscle soreness. He concluded the eccentric exercise protocol caused overstretching and damage to CT. The difference in results may be explained by the measurement of HYP in urine compared to blood. The concentration of HYP in the urine represents only 10% of the HYP released following collagen breakdown, suggesting plasma or serum concentrations of HYP offer a more precise determination of collagen metabolism (Kivirikko, 1970). There is no clear explanation for the lower concentration of HYP at week seven in the current study since plasma HYP reflects both intracellular and extracellular CT events. While this result was not expected, collagen production and/or the removal of intra or extra-cellular collagen may have been decreased after this bout.

HP provides a more specific measurement of CT breakdown. Elevated levels of this collagen crosslink are present in patients with degenerative bone disease or other CT conditions (e.g., Pagets disease, osteoporosis) (Delmas, Schlemmer, Gineyts, Riis, & Christiansen, 1991; Uebelhart, Gineyts, Chapuy, & Delmas, 1990). The present study was the first attempt to monitor changes in plasma HP in response to exercise. These results suggest that our training protocol was not of sufficient magnitude, intensity, or duration to cause increased CT breakdown. The range of plasma HP (4.1 to 8.4 nM) was higher than in plasma and serum from healthy sedentary males: 2.38 to 2.85 nM and 3.26 to 3.62 nM, reported by James, Crowley, and Perrett (1993), and Abbiati, et al. (1994), respectively. The higher concentrations of HP in our subjects may be related to their level of training (i.e., average $\dot{V}O_{2peak} = 57.4$ mL·kg^{-1}·min^{-1}); similar to the elevated levels of CK observed in competitive runners (Armstrong, 1984; Evans, 1986). The nonsignificant relationship between plasma levels of HYP and HP suggests these markers represent different sources of connective tissue removal.

When developing a premission training strategy, factors such as training intensity, frequency, duration, and training status must be considered. Clarkson and Tremblay (1988) suggest that training does not have to be severe to provide a significant protective effect for a subsequent eccentric bout. They demonstrated that although an eccentric exercise bout of 24 maximal contractions produced only small changes in criterion measures (e.g., strength, soreness, CK) after the initial bout, it provided the same protection as a bout of 70 maximal contractions when a second bout of 70 maximal contractions was performed 2 weeks later. This suggests that our training protocol may provide protection for future eccentric bouts of even greater intensity or duration.

Another important factor in the design of an eccentric training program is the frequency of training, or time between bouts. Two bouts of eccentric weight training, 3 weeks apart, resulted in a smaller loss of quadriceps muscle strength after the second bout compared to the initial bout (Golden & Dudley, 1992). However, 8 weeks between downhill running sessions did not change maximal leg strength or recovery of strength in the quadriceps (Balnave & Thompson, 1993). These studies measured static (isometric) strength on sedentary subjects and thus may not be relevant to our study which measured dynamic (isokinetic) strength on trained individuals. The training frequency of one bout per week in the present study significantly reduced muscle soreness and CK, maintained CT integrity and maximal eccentric isokinetic muscle function. Thus, once per week appears to be an appropriate training frequency to achieve measurable levels of protection. Clearly the present study supports the principle that eccentric exercise training benefits individuals preparing for eccentrically biased events (e.g., hiking, downhill running).

An important component of military mission planning is terrain evaluation and the subsequent premission planning to increase the probability of mission success. Personnel preparing for short-term training missions in the mountains or long-term assignments to mountain duty stations could benefit by including eccentric training in their preparation. Eccentric training must include eccentric contractions of the specific muscles that will be stressed and be performed no less than 3 weeks prior to the mission to allow for recovery and adaptation. In conclusion, this study demonstrates that two downhill running bouts, separated by one week, can significantly reduce symptoms associated with subsequent eccentric exercise. The protocol used in this study could provide an effective method of preparing personnel for activities involving downhill exercise.

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Figure 1. Average heart rate (HR) and ratings of perceived exertion (RPE) for all bouts during downhill running (no significant difference between bouts, $p>0.05$). *Progressive increase in HR at every 5 minute interval ($p<0.05$). § RPE significantly different from 5 min ($p<0.05$). Values are mean ± SE.

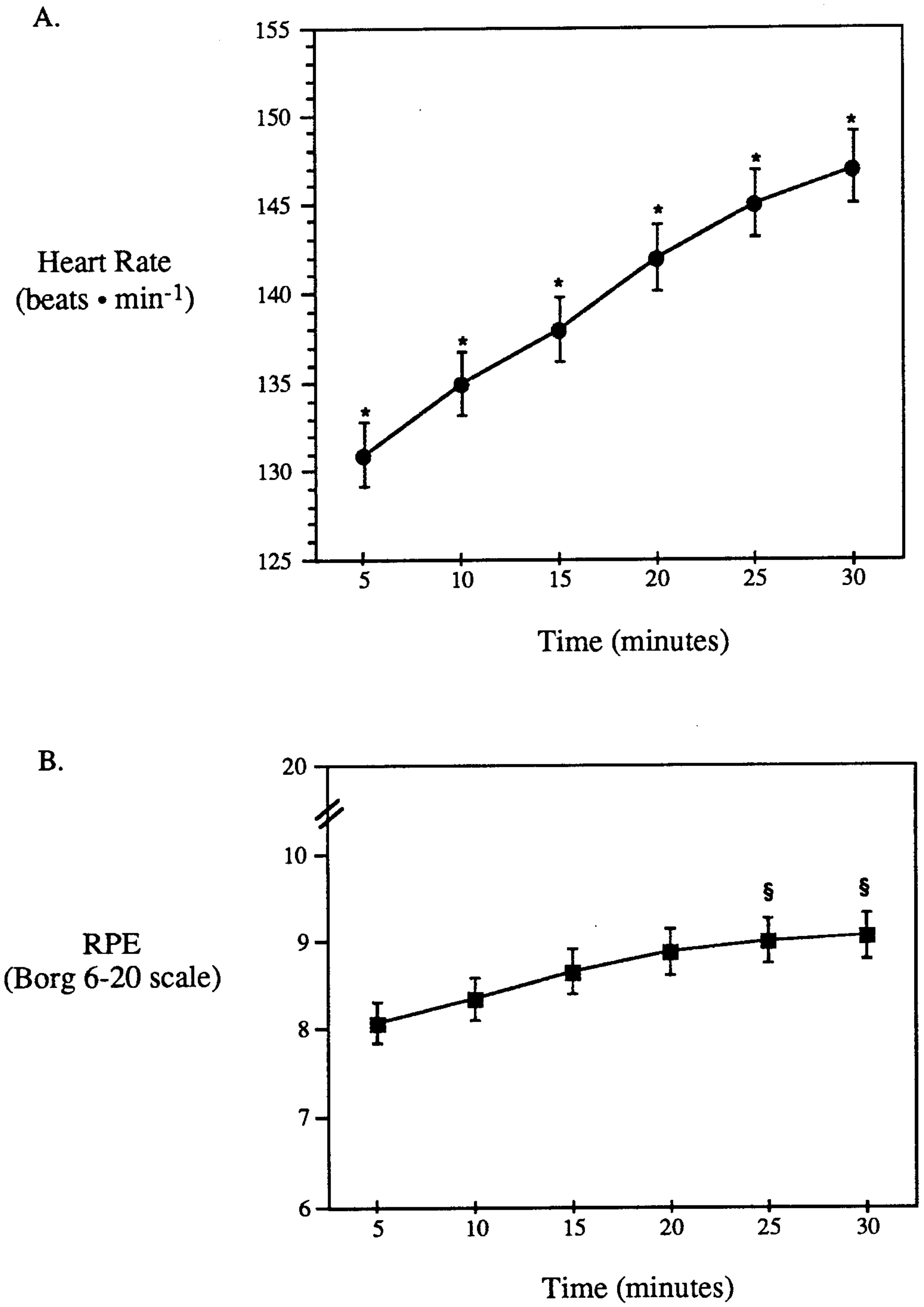


Figure 2. Subjective muscle soreness after downhill running. *Soreness significantly greater following bout 1 compared to all other bouts ($p<0.05$). No significant differences bewtween 24 and 48 hour postmeasures, or for bouts 2 to 8 compared to baseline ($p>0.05$). Values are mean ± SE.

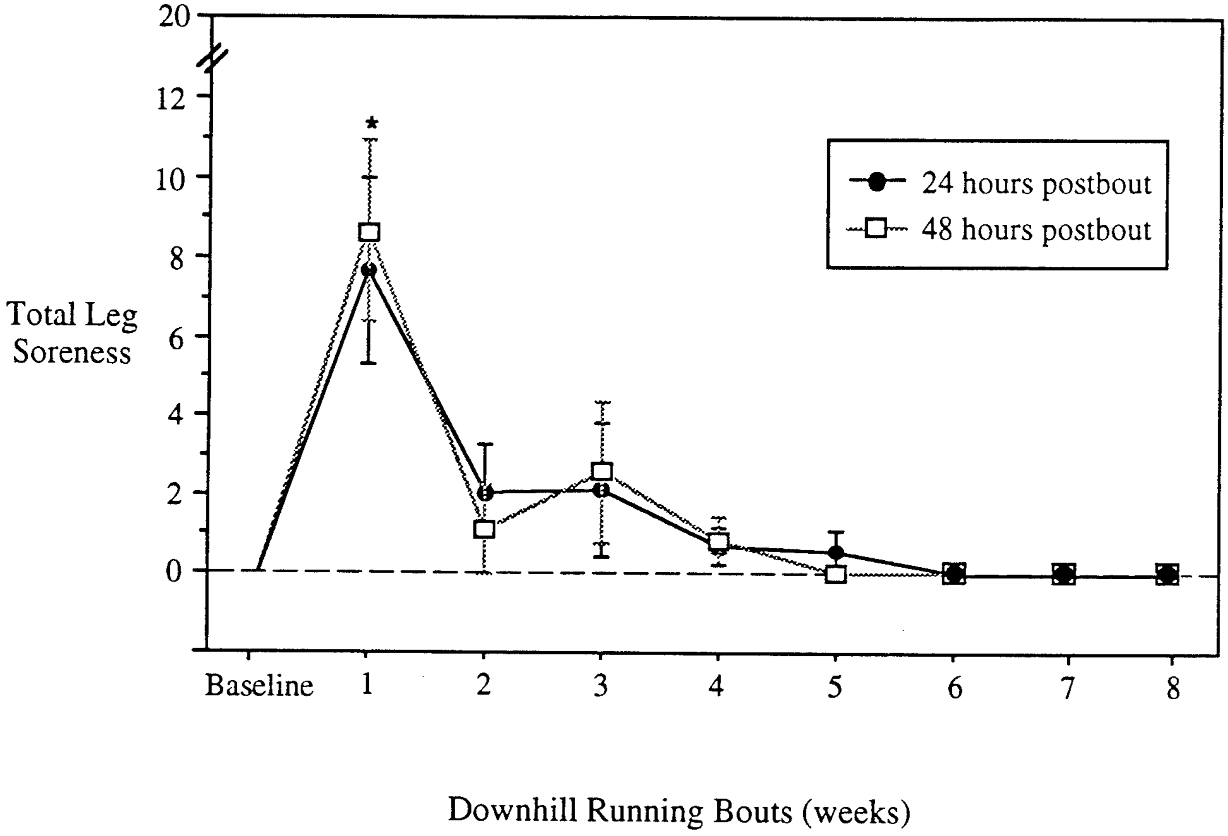


Figure 3. Plasma concentration of creatine kinase (CK) before and 24 hours after downhill running. *Post values significantly greater than pre values. §Bout 2 significantly greater than subsequent bouts ($p<0.05$). Values are mean ± SE.

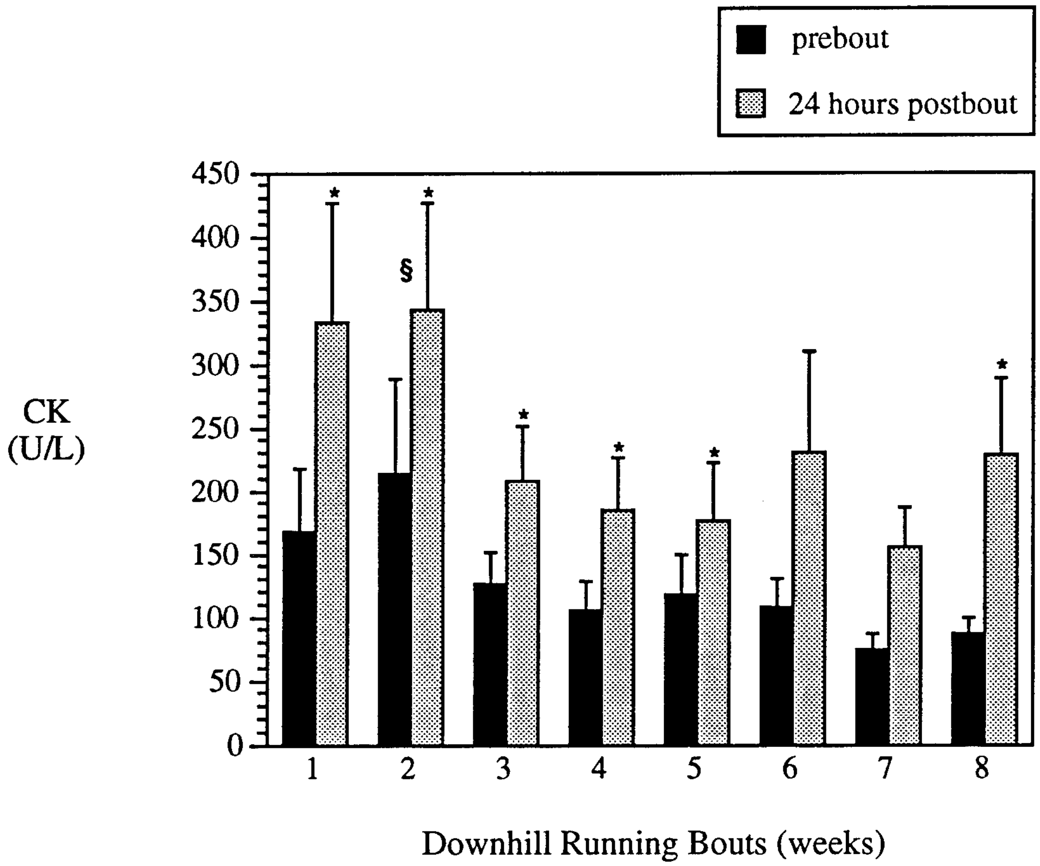


Figure 4. Plasma concentration of hydroxyproline (HYP) before and 24 hours after downhill running. § Bout 7 significantly lower than all other bouts ($p<0.05$). Values are mean ± SE.

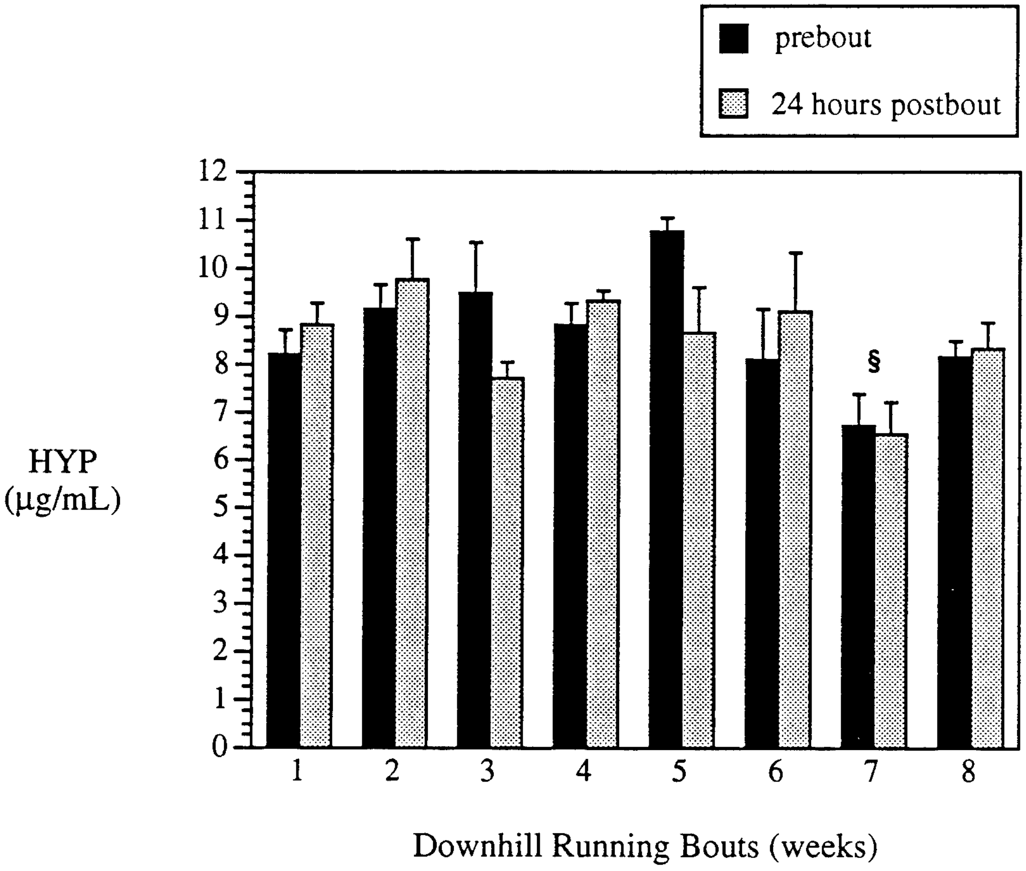


Figure 5. Plasma concentration of the collagen crosslink, hydroxylysylpyridinoline (HP) before and 24 hours after downhill running. There were no significant differences pre to post, or between bouts (p>0.05). Values are mean ± SE.

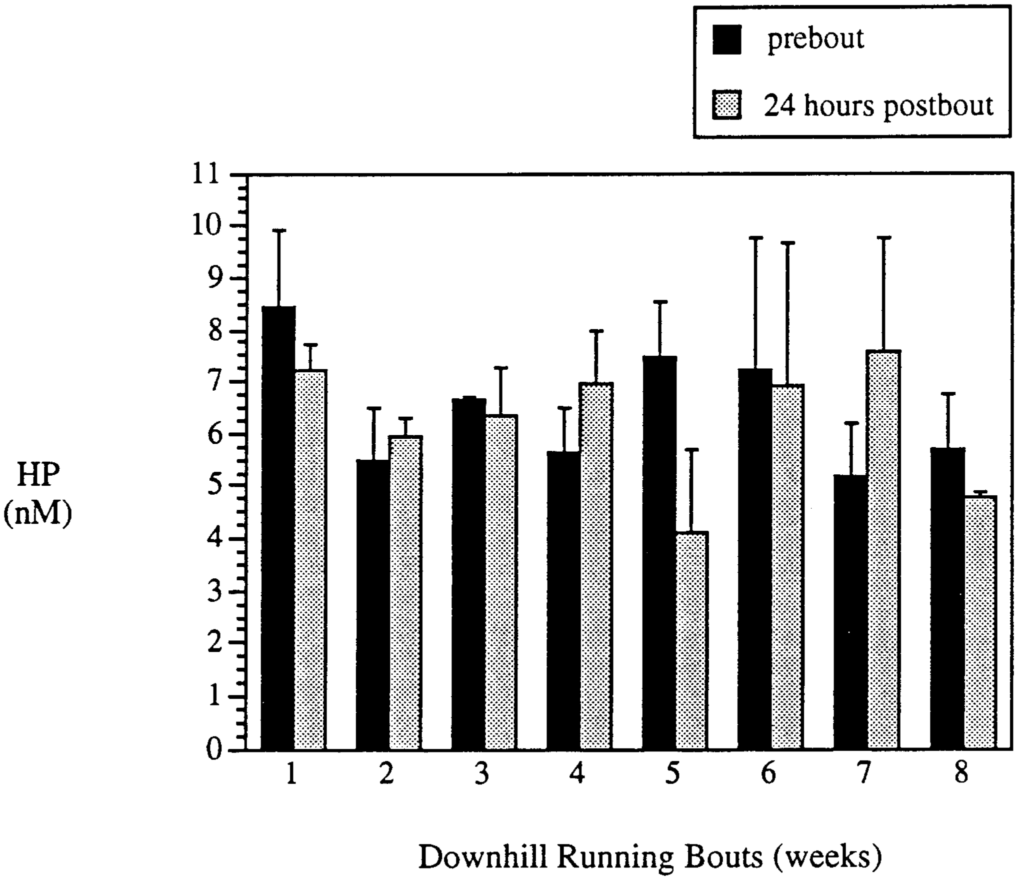
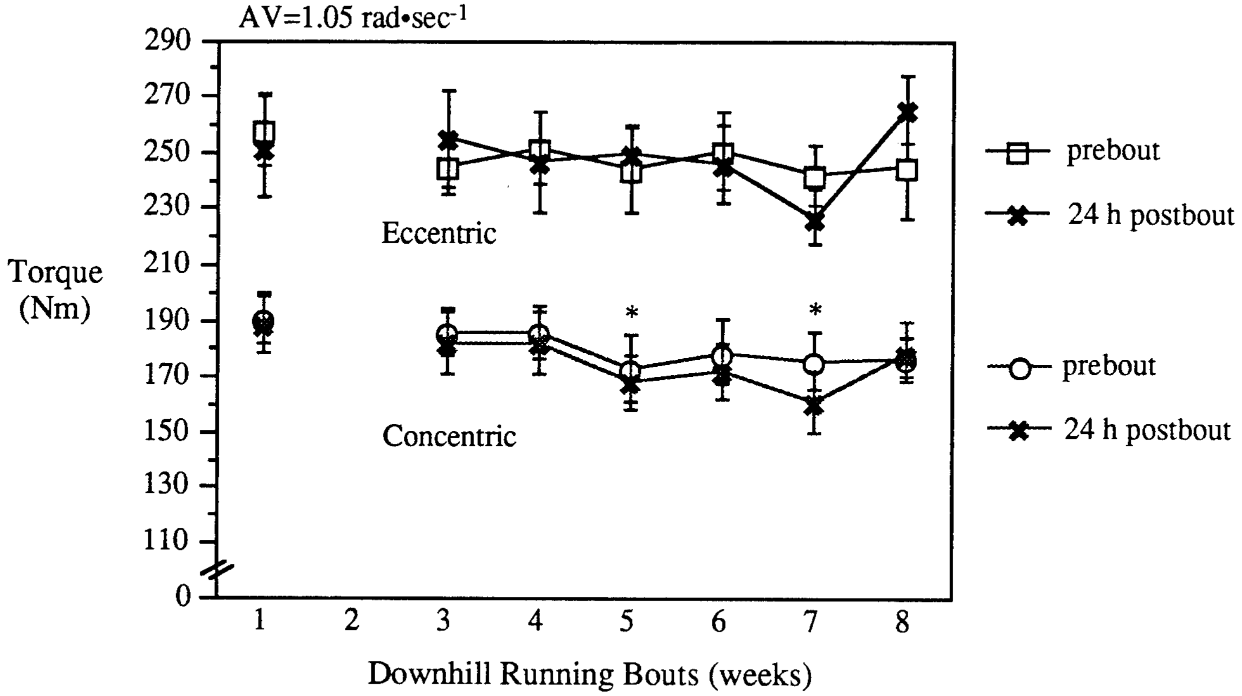
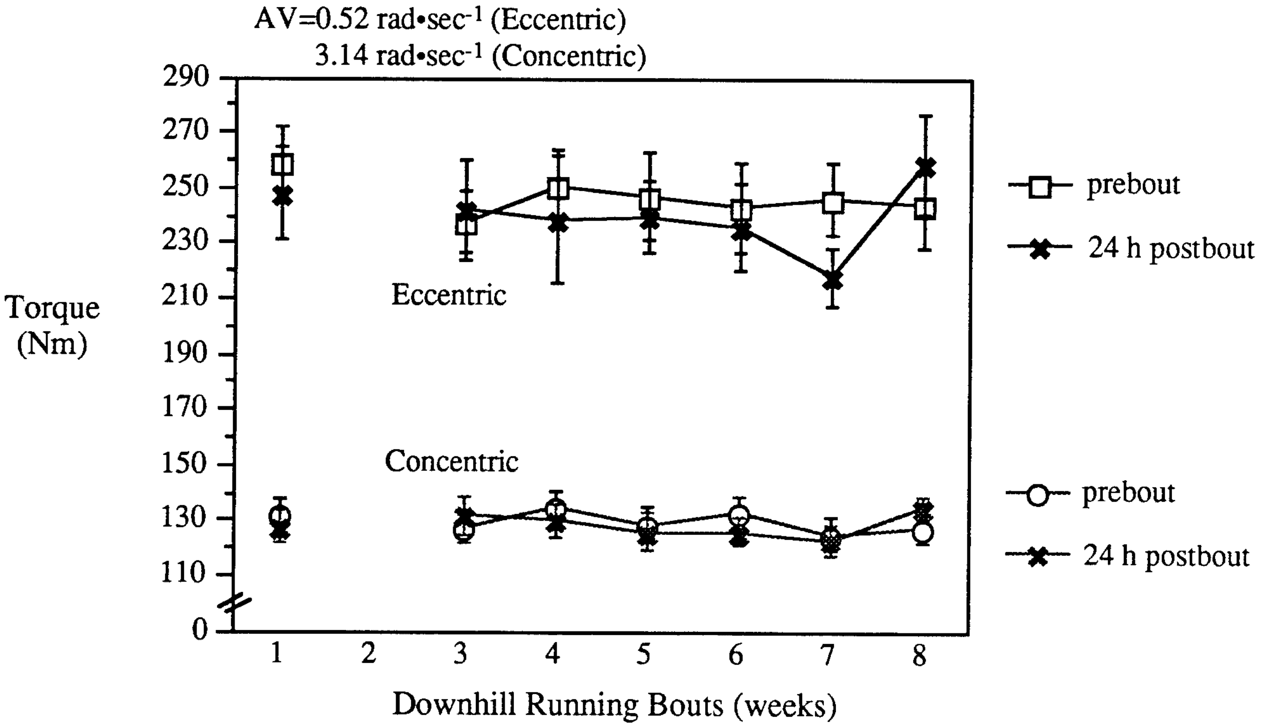


Figure 6. Peak concentric and eccentric leg strength before and 24 hours (h) after downhill running. There were no significant differences pre to post. *A significant decrease was observed compared to bout one ($p<0.05$). Bout 2 was not included due to equipment failure. Values are mean ± SE. AV=Angular velocity.





APPENDIX A

Muscle Soreness Questionnaire

Muscle Soreness Questionnaire

TO SUBJECT:

Select a number on the Muscle Soreness Scale (0-4) that best describes the amount of soreness you feel when pressure is applied at each location. Pressure will be applied to specific sites on the front and back of your legs and hips.

Name______________________________ Date______________________

______ pre-downhill run

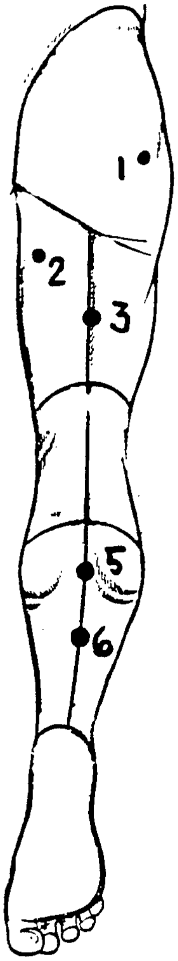
______ 24 hrs post downhill run

Downhill run #__________

______ 48 hrs post downhill run

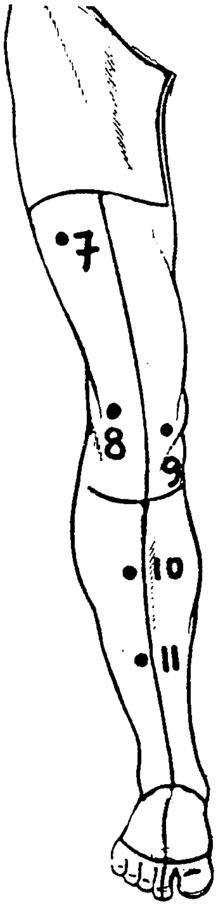
______ 1 week post downhill run

BACK:



RIGHT	LEFT
Buttocks	Buttocks
1. ____	1. ____
Thigh	Thigh
2. ____	2. ____
3. ____	3. ____
Lower Leg	Lower Leg
5. ____	5. ____
6. ____	6. ____

FRONT:



RIGHT	LEFT
Thigh	Thigh
7. ____	7. ____
8. ____	8. ____
9. ____	9. ____
Lower Leg	Lower Leg
10. ____	10. ____
11. ____	11. ____

Area of greatest (peak) soreness :__________________ Left Right Both (mark location with an"X")

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13. ABSTRACT *(Maximum 200 words)*

Military special forces personnel perform missions in a variety of environments, including downhill exercise in the mountains. The purpose of this study was to determine whether a downhill running program (involving eccentric muscle contractions) would reduce damage to musculoskeletal tissue and prevent possible strength loss in preparation for future terrestrial missions. Eight U.S. Navy and Marine Corps males (29 ± 1 yr, 81 ± 2 kg, 179 ± 2 cm, 10 ± 1 % body fat, and 57 ± 3 $ml\cdot kg^{-1}\cdot min^{-1}$) ran on a treadmill (-10% grade, ~60% VO_{2peak}) for 30 min once per week for eight weeks. Plasma levels of creatine kinase (CK), hydroxyproline (HYP), and hydroxypyridinoline (HP; an extracellular collagen crosslink), and peak isokinetic concentric and eccentric torque during knee extension, were measured pre and 24h post exercise. Muscle soreness and muscle damage (measured by plasma levels of CK) were attenuated by the third bout of downhill running. At the same time, this protocol did not reduce maximal eccentric isokinetic leg strength or increase the breakdown of connective tissue (measured by plasma HYP and HP). Eccentric exercise training (consisting of two downhill running bouts, one week apart) can prepare individuals for future missions or events involving downhill exercise by reducing muscle soreness and muscle damage.

14. SUBJECT TERMS
Downhill running; eccentric training; connective tissue; muscle soreness

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