Trekking Poles Reduce Exercise-Induced Muscle Injury during Mountain Walking

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ABSTRACT

HOWATSON, G., P. HOUGH, J. PATTISON, J. A. HILL, R. BLAGROVE, M. GLAISTER, and K. G. THOMPSON. Trekking Poles Reduce Exercise-Induced Muscle Injury during Mountain Walking. *Med. Sci. Sports Exerc.*, Vol. 43, No. 1, pp. 140–145, 2011. Temporary muscle damage precipitated by downhill walking affects muscle function and potentially exposes muscle to further musculoskeletal injury. **Purpose**: We hypothesized that the use of trekking poles would help maintain muscle function and reduce indices of muscle damage after a day's mountain trekking. **Methods**: Thirty-seven physically active males ($n = 26$) and females ($n = 11$) volunteered to participate and were divided into either a trekking pole (TP) or no pole (NP) group. Participants carried a day sack (5.6 ± 1.5 kg) and made the ascent and descent of the highest peak in England and Wales (Mount Snowdon). HR and RPE were recorded during the ascent and descent. Indices of muscle damage, namely, maximal voluntary contraction, muscle soreness, creatine kinase (CK), and vertical jump performance, were measured before, immediately after (except CK), and 24, 48, and 72 h after trek. **Results**: HR was not different between groups, although RPE was significantly lower in TP during the ascent. The TP group showed attenuation of reductions in maximal voluntary contraction immediately after and 24 and 48 h after the trek; muscle soreness was significantly lower at 24 and 48 h after the trek, and CK was also lower at 24 h after the trek in the TP group. No differences in vertical jump were found. **Conclusions**: Trekking poles reduce RPE on mountain ascents, reduce indices of muscle damage, assist in maintaining muscle function in the days after a mountain trek, and reduce the potential for subsequent injury.

Key Words: DOWNHILL WALKING, LENGTHENING CONTRACTIONS, RECOVERY, MUSCLE DAMAGE

Physical activity has been shown to be an important factor in the maintenance of health and has been demonstrated to reduce risk factors associated with several clinical pathologies (4,20). Walking provides a very popular mode of physical activity that is accessible to most individuals regardless of age, sex, or physical condition (26,28). The popularity of walking is clearly demonstrated in a recent review, showing that the number of Americans pursuing hiking activity increased to nearly 30 million in the year 2004 (7), making hiking activity one of the fastest-growing outdoor activities in the United States (8).

Trekking in mountain areas poses many challenges, especially for those who are novices or those who make visits to these regions infrequently. Principally, mountain trekking will involve substantial uphill and downhill elements on uneven and rugged terrain. The uphill ambulation tends to result in a greater exercise intensity and hence an increased metabolic cost (21). Conversely, downhill walking results in a lower metabolic cost than level and uphill walking at the same absolute speed (19), but it imposes greater forces on the lower limbs (27), resulting in greater eccentric loading. These eccentric muscle actions during downhill ambulation (1,24) can result in temporary exercise-induced muscle damage (EIMD), which is manifested as reduced muscle function, muscle soreness (DOMS), efflux of intramuscular enzymes, limb swelling (12), and reduced reaction time and position sense (25) that may last for several days after the exercise bout. The amalgamation of these damaging effects can be problematic for activity on subsequent days, and there may be a greater risk of injury due to residual soreness and perturbations in muscle function (9). Therefore, any intervention that may help to reduce the negative effects of EIMD precipitated from trekking could assist in exercise participation in the days after the initial damaging bout.

Trekking poles are being used with increasing frequency and are purported to provide increased stability and balance while trekking on uneven surfaces (13). Much of the research examining trekking poles has focused on biomechanical investigations where reduced loading and, hence, stress to the lower limb, particularly at the ankle, knee, and hip, have been demonstrated (2,17,27). Pole manufacturers have suggested that trekking poles can reduce lower limb

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joints forces by as much as 25%, whereas other works from the literature suggest that the use of poles resulted in a load reduction per stride of 7 kg on level ground, 10 kg uphill, and 13 kg downhill (23), which equates to 13,500, 28,800 and 33,600 kg·h^{-1}, respectively (17). In addition, a recent study (18) that investigated the prevalence of ankle fractures sustained during mountain walking has presented a strong rationale and made recommendations for the use of walking poles to reduce ankle injury incidence.

In light of the decrease in lower limb joint stress afforded by trekking poles, it makes the expectation tenable that the load on skeletal muscle is also reduced and, hence, may provide a suitable tool to attenuate the muscle damage associated with trekking, particularly on the downhill elements. Furthermore, the research has been restricted to laboratory or nonmountainous outdoor settings, and there are no data examining the efficacy of trekking poles in ecologically valid environments, where they are suggested to be of most benefit. Given previous evidence from biomechanical investigations, the aim of this investigation was to examine the effects of trekking poles on indices of muscle damage; we hypothesized that the use of trekking poles would help maintain muscle function and reduce indices of muscle damage after a day's mountain trekking.

METHODS

Subjects. After approval from the institutional research ethics committee in accordance with the Helsinki Declaration, 37 recreationally active men (n = 26) and women (n = 11) volunteered for the investigation (mean ± SD; age = 25 ± 7 yr, stature = 1.75 ± 0.10 m, mass = 78.0 ± 16.4 kg, respectively). Participants completed a health screening questionnaire and provided written informed consent; furthermore, all participants were instructed to refrain from strenuous exercise, pharmacological, or therapeutic interventions for the duration of the investigation.

Protocol overview. Participants were assigned either to a trekking pole (TP) group (n = 19) or to a no trekking pole (NP) control group (n = 18) during the ascent and descent of the highest mountain peak in England and Wales while carrying a day pack (5.6 ± 1.5 kg). During the trek, HR and RPE were recorded. Indices of muscle damage were creatine kinase (CK), DOMS, maximal voluntary contraction (MVC), and vertical jump (VJ) performance and were taken before, immediately after the trek (except CK), and 24, 48, and 72 h after the trek.

Group allocation. Group allocation was based on two parameters (sex and current physical activity). Males and females were separated and ranked according to current physical activity and were then randomly but equally assigned to groups. None of the participants was familiar with this specific trekking task or was habituated to mountain trekking. Independent-samples t-test showed no significant difference between groups for subjects' characteristics and physical activity (Table 1). The day before the trek, the group allocation was disclosed to the participants. Those in the TP group were issued with a pair of trekking poles (LEKI, Buffalo, NY); subsequently, a mountain leader with approximately 27 yr of experience of UK and Alpine mountain trekking provided detailed instruction and coaching on the correct use until demonstrable competency was attained.

TABLE 1. Descriptive information of the TP and NP groups.

Group	Sex (M/F)	Age (yr)	Height (m)	Mass (kg)	PA (h·wk^{-1})	Pack Mass (kg)
TP	13:6	26 ± 9	1.75 ± 0.10	78.0 ± 16.7	7.5 ± 3.5	5.8 ± 1.4
NP	13:5	25 ± 5	1.75 ± 0.11	78.1 ± 16.5	7.8 ± 4.1	5.5 ± 1.7

There were no significant differences between groups. Values are presented as means ± SD.

F, number of females; M, number of males; PA, physical activity.

Dependent measures. A 200-mm visual analog scale was used to determine DOMS with "no soreness" indicated on one end and "unbearably painful" on the other. Each participant was asked to squat at 90° and rise to stand and indicate on the VAS the soreness felt in the lower limbs (10). A fingertip capillary puncture sample of approximately 100 μL was obtained to determine CK concentration. The sample was spun in a centrifuge to separate the cell mass from the plasma supernatant; 30 μL of the plasma was analyzed immediately using a colorimetric slide assay procedure (Reflotron Plus; Roche Diagnostics, Una Health Ltd., Stoke on Trent, UK). Intra-assay reliability (CV) for this method is reported as <3%. VJ height was determined using a jump mat (Swift Performance Equipment, Lismore, Australia). Participants stood with feet approximately shoulder-width apart with hands on hips. On command, they were instructed to complete a countermovement jump (22). The best of three efforts was recorded for data analysis. MVC of the nondominant knee extensors was determined using a strain gauge (MIE Medical Research Ltd., Leeds, UK). The strain gauge was attached to the nondominant ankle while seated on a plinth with the internal knee joint angle at 80° (verified by a goniometer). Three submaximal trials at approximately 50%, 70%, and 90% of perceived maximum followed by two maximal trials, each separated by 1 min, were completed. If there were >5% variation between the two MVC trials, a third trial would be administered; the highest output recorded on the strain gauge was used for data analysis. Each contraction lasted for approximately 3 s, and all participants were given standardized verbal encouragement throughout (11). HR was recorded throughout the trek using short-wave telemetry. A combination of team systems and individually coded HR monitors were used (Polar S610, S810, first-generation Polar Team system; Polar Electro, Kempele, Finland). The Borg Scale was used to ascertain RPE (3) on the ascent at approximately one-third, two-thirds distance, and the summit; on the descent, it was measured at approximately one-third, two-thirds distance, and at the start-finish line.

Trek. The day before the trek, all volunteers were transported to a hostel in the Snowdonia National Park, North Wales, UK. On arrival, all volunteers were provided with

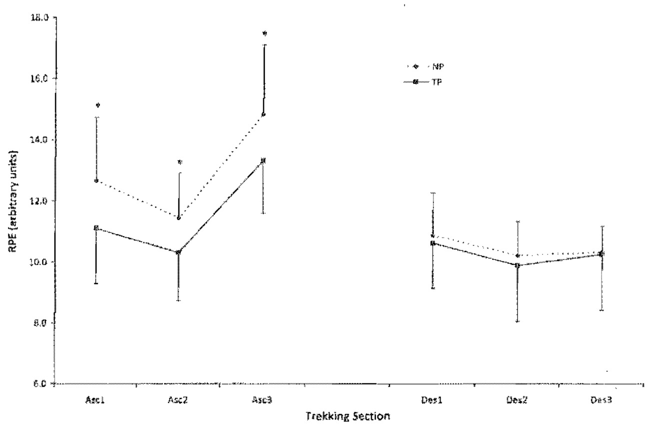

FIGURE 1—RPE for the ascent and descent of Mount Snowdon with the use of trekking poles (TP group) and without (NP group). Values are mean ± SD, n = 37. *Significantly lower RPE in the TP group ($P < 0.05$).

a standardized evening meal and were then rested for the remainder of the evening before retiring. On the following morning, participants were fed breakfast before packing a day sack containing a standardized packed lunch, 2 L of water, and clothing for potential inclement weather conditions; the pack was then weighed. The official environmental conditions, according to the UK Meteorological Office, were as follows: dry with intermittent cloud at 700 m, 11-knot westerly wind, 9.3°C, 74% relative humidity, and 1007-hPa barometric pressure.

The trek was guided and supervised by the aforementioned mountain leader and started on a round trip from Pen-y-Pass (~350 m altitude) following the Pyg Track to the summit of Snowdon (1085 m altitude)—a round trip of 11.2 km and an ascent of 756 m were verified by a global positioning system (eTrex; Garmin, Olathe, KS). The Pyg Track is a combination of steep- and gentle-incline sections on uneven and rough terrain. Participants were transported to the start line, fitted with an HR monitor, and then placed in one of four groups (two TP and two NP); each group was led by a member of the research team departing at 10-min intervals. The groups were instructed to keep an even pace and maintain the distance from the group in front. The ascent and decent were broken into three stages at approximately equal distances at one-third, two-thirds, and summit. At each point, the time and participant RPE were recorded. At each checkpoint, groups took exactly 5 min of rest to adjust clothing and drink/snack *ad libitum*; these points of rest were at the same location during ascent and descent. At the summit, a 20- to 30-min rest was allowed for lunch before departing on the descent on the same path.

Statistical analysis. Data were analyzed using SPSS for Windows v.16 (Chicago, IL). All data are reported as mean ± SD. Independent-samples t-test was used to determine differences for subjects' characteristics, physical activity levels, and pack pass between groups. Damage indices were analyzed using a repeated-measures ANOVA (group, 2 (TP, NP) × time 5 (pre, post [except CK], 24 h, 48 h, and 72 h)). Mean HR and RPE data were analyzed using a repeated-measures ANOVA (group, 2 (TP, NP) × trek section, 6 (asc 1, asc 2, asc 3, des 1, des 2, and des 3)). Mauchly's test of sphericity was used to check homogeneity of variance, and where necessary, violations of the assumption were corrected using the Greenhouse–Geisser adjustment. Significant interaction effects were followed up using least significant difference *post hoc* analysis. A significance level of $P \leq 0.05$ was established before analyses.

RESULTS

Descriptive information regarding subjects' characteristics, physical activity, and pack mass are presented in Table 1. Independent-samples t-test showed no significant differences in any of these variables. The observed power for the significant interaction and group effects for all ANOVA were ≥0.79 and ≥0.51, respectively. The time for ascent and descent (including scheduled stops) was 4 h 36 min and 4 h 42 min for the TP and NP groups, respectively. Participants in each group started together and made the entire ascent and descent together. The total time spent in the ascent and descent for the TP group was 2 h 5 min and 2 h 6 min, and that for the NP group, this was 2 h 17 min and 2 h 0 min, respectively.

Seven HR monitors from the team system (two from the TP and five from the NP group) failed to collect data during the trek; consequently, HR data reported here reflect this. During the trek, there was no significant difference ($P > 0.05$) in the mean HR response at any section during the ascent or descent between groups (both absolute HR and age-predicted percentage HR_{max}). The mean HR responses for the ascent and descent were 133 and 113 bpm (69%–58% HR_{max}) for the TP group and 137 and 121 bpm (70%–62% HR_{max}) for the NP group. There was a significant group effect ($F = 4.196$, $P = 0.048$) and interaction ($F = 2.585$, $P = 0.028$) for RPE (Fig. 1). *Post hoc* analysis revealed significantly

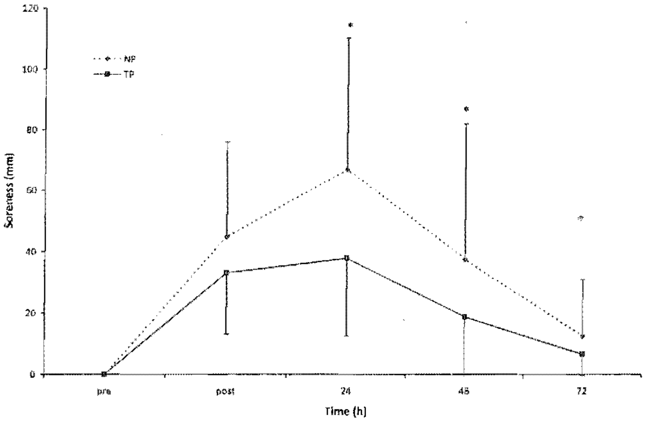

FIGURE 2—DOMS ratings after the ascent and descent of Mount Snowdon with the use of trekking poles (TP group) and without (NP group). Values are mean ± SD, n = 37. *Significantly lower DOMS in the TP group ($P < 0.05$).

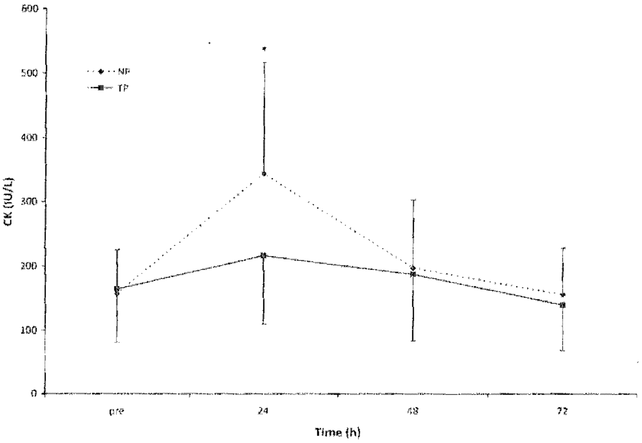

FIGURE 3—CK concentration after the ascent and descent of Mount Snowdon with the use of trekking poles (TP group) and without (NP group). Values are mean ± SD, $n = 37$. *Significantly lower CK in the TP group at 24 h ($P < 0.05$).

lower RPE for the TP group during sections 1, 2, and 3 of the ascent ($P \leq 0.041$) than those for the NP group; there were no differences in the descent.

All indices of damage showed a significant time effect ($P < 0.05$). There was significantly less DOMS in the TP group ($F = 4.444$, $P = 0.042$). A rise in soreness was observed after the trek, which peaked at 24 h in both groups. A significant interaction effect ($F = 3.155$, $P = 0.016$) and subsequent *post hoc* analysis showed a reduction in DOMS at 24 h ($P = 0.001$) and 48 h ($P = 0.027$) in the TP group (Fig. 2). No group effect was shown for CK activity (Fig. 3); however, there was a significant interaction ($F = 8.668$, $P = 0.001$); *post hoc* analysis revealed lower CK efflux at 24 h in the TP group ($P < 0.001$). Although no significant differences were observed in VJ, isometric MVC (Fig. 4 showed a significant attenuation of isometric strength loss in the TP group ($F = 9.710$, $P = 0.004$). A significant interaction ($F = 2.494$, $P = 0.046$) and *post hoc* analysis showed a reduced loss of strength and a faster recovery in the TP group immediately after the trek ($P = 0.008$) and at 24 h ($P < 0.001$) and 48 h ($P = 0.033$) after the trek.

DISCUSSION

We hypothesized that the use of trekking poles would maintain function and reduce the extent of muscle damage after a day's mountain trekking. This is the first investigation to examine the effect of trekking poles on muscle damage and clearly demonstrates that they can help to maintain muscle function and reduce EIMD indices after a day's mountain trek.

Previous literature has highlighted the importance in being accustomed to damaging exercise to attenuate the negative effects of EIMD (12). It was therefore important that both groups were similarly matched to ensure that the damage response was comparable. The subjects' characteristics and the physical activity levels between groups were similar in this investigation, demonstrating that the groups were indeed well matched. In addition, the pack mass of both groups was also similar, and hence, differences in function and EIMD indices are unlikely attributable to discrepancies in pack mass or physical activity and conditioning. Furthermore, both groups were unaccustomed to mountain trekking activity, so differences in damage indices are likely the consequence of the intervention.

The timings for the ascent and descent were similar between groups, indicating that the walking speed was also similar. This is further supported by the nonsignificant differences in HR and suggests, metabolically, that the exercise intensity was comparable between groups. Despite the similar responses in HR between groups, RPE was lower in the TP group during the ascent. With regard to HR, previous research is conflicting; some studies (6,15) show an increase in HR with pole use compared with nonuse of poles. The increase in HR with poles use was suggested to be attributed to engaging additional muscle mass or increased load carriage from the poles; however, these studies were laboratory based and may not accurately reflect the ground–pole interaction seen in uneven mountain terrains (5). Conversely, our data are in agreement with others (14,15) who showed no change in the HR response between conditions (except for Jacobson and Wright (14), who showed a difference in the first 50 m) and lower RPE with pole use. Interestingly Jacobson and Wright (14) are the only other investigators who used trekking poles outside the laboratory environment (although on a graded slope rather than on mountainous terrain). The lower RPE scores shown consistently in the literature (14–17), and supported by this investigation, are likely attributable to the additional stability and reduced lower limb load provided by pole use on the ascending sections of the trek. It is possible that the TP participants assumed the poles afforded a benefit when ascending;

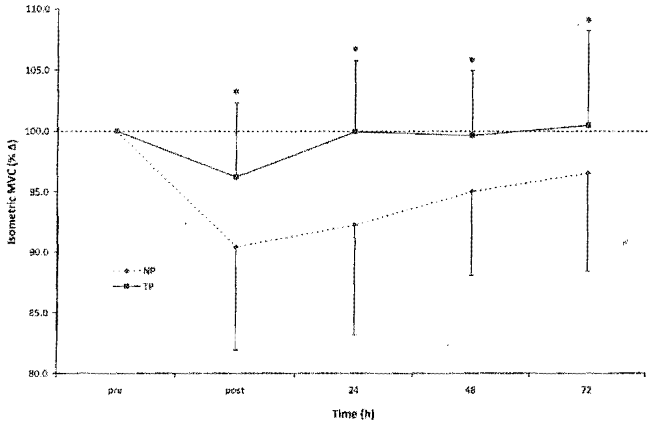

FIGURE 4—Isometric MVC after the ascent and descent of Mount Snowdon with the use of trekking poles (TP group) and without (NP group). Values are mean ± SD, $n = 37$. *Significantly greater isometric force in the TP group after the trek and at 24 and 48 h after the trek ($P < 0.05$).

however, no information was provided by the investigators before the trek and no participants had experience and presumably knowledge of trekking poles before the study.

The use of trekking poles has been previously demonstrated to reduce loading to the lower limb at the ankle, knee, and hip (2,15,27). On the basis of this strong evidence, we hypothesized that this would attenuate the extent of muscle damage sustained from mountain trekking. It is well documented that downhill ambulation contains a substantial eccentric component that causes appreciable damage (1,24) in comparison with uphill ambulation (21). Malm et al. (21) demonstrated that no increase in muscle damage indices (CK and DOMS) was evident in an uphill running group compared with that in a downhill group. Given the significant differences in muscle damage indices in our investigation, it seems likely that the trekking poles had the greatest effect in attenuating damage on the downhill sections.

Changes in damage indices as a result of eccentric muscle actions have been discussed extensively in the literature and are not discussed at length here; for a concise overview of the damage process, the reader is directed to Howatson and van Someren (12). DOMS peaked at 24 h in both groups and was significantly different at 24 and 48 h after the trek, demonstrating that pole use during mountain trekking reduced residual DOMS in the days after the trek. In addition, CK was also significantly elevated at 24 h in the NP group and remained close to baseline throughout the time course in the TP group, illustrating negligible damage in the TP group. Furthermore, MVC decrements were also negligible in the TP group in comparison to that in the NP group. Collectively, this presents strong evidence that trekking poles reduce the extent (almost to the point of complete attenuation) of muscle damage during a day's mountain trek.

The reduced muscle damage in the current investigation was almost certainly attributable to the lower forces to the lower limbs afforded by the use of poles that is evident from several biomechanical studies (2,17,27) especially during downhill ambulation (17,23). Intuitively, these forces are not lost, rather distributed over a larger area, namely, the upper body. We asked all participants if they experienced soreness in any other areas (other than the lower body); 16% ($n = 3$) of the TP group experienced modest soreness in *m. triceps brachii*. Conceivably, the overall damage response could be due to previous conditioning and susceptibility to the exercise insult; however, we reduced the potential variation by balancing groups according to sex and current physical activity level; there were no differences in subjects' characteristics or physical activity level, and so, it is seems an unlikely explanation.

Physical activity is extremely important in the maintenance of health, and walking in mountainous areas is a popular pastime. However, muscle damage can occur when there are downhill elements to negotiate, and this might affect the motivation of some to undertake such activity on a regular basis. It has been established that the negative effects of muscle damage can lead to reduced muscle function for many days after exercise where a high degree of force and reaction time may be required (9). These perturbations in function could precipitate injury (9) in the days after the initial insult, and therefore, the use of trekking poles may help to reduce the incidence of injury on the days after trekking. A recent article (18) examining the incidence of hill walkers and ankle injury found that 71% of ankle injuries were sustained by walkers not using poles (the majority of which were on the mountain descent) and, consequently, make strong recommendations for walkers to use poles in mountainous terrain. Although our investigation did not measure the prevalence of injury, the presence of muscle damage may increase the potential for injury, and hence, our investigation supports this recommendation. However, it is important to acknowledge that it seems likely that a combination of factors provided by the poles contribute to the beneficial effects, including greater stability, reduced loading on joints of the lower limbs, and reduced muscle damage.

In conclusion, this is the first investigation to examine the efficacy of trekking poles on indices of muscle damage; furthermore, to our knowledge, it is also the first documented study to use an ecologically valid environment to test this type of equipment. We have demonstrated that trekking poles reduce RPE in mountain ascent and reduce the extent of muscle damage after a day's mountain walking. These findings have strong application for exercisers wishing to engage in consecutive day's activity in mountainous terrains by maintaining greater muscle function, reducing soreness, and, hence, reducing the potential for the prevalence of injury.

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The results of the present study do not constitute endorsement by the American College of Sports Medicine.

REFERENCES

1. Ahmadi S, Sinclair PJ, Davis GM. Muscle oxygenation after downhill walking–induced muscle damage. *Clin Physiol Funct Imaging*. 2008;28(1):55–63.
2. Bohne M, Abendroth-Smith J. Effects of hiking downhill using trekking poles while carrying external loads. *Med Sci Sports Exerc*. 2007;39(1):177–83.
3. Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med*. 1970;2(2):92–8.
4. Butcher LR, Thomas A, Backx K, Roberts A, Webb R, Morris K. Low-intensity exercise exerts beneficial effects on plasma lipids via PPARgamma. *Med Sci Sports Exerc*. 2008;40(7):1263–70.

5. Church TS, Earnest CP, Morss GM. Field testing of physiological responses associated with Nordic walking. *Res Q Exerc Sport.* 2002;73(3):296–300.
6. Ekblom B, Goldberg AN. The influence of training and other factors on the subjective rating of perceived exertion. *Acta Physiol Scand.* 1971;83(3):399–406.
7. Heggie TW. Paediatric and adolescent sport injury in the wilderness. *Br J Sports Med.* 2010;44(1):50–5.
8. Heggie TW, Heggie TM. Search and rescue trends associated with recreational travel in US National Parks. *J Travel Med.* 2009; 16(1):23–7.
9. Howatson G. The impact of damaging exercise on electromechanical delay in biceps brachii. *J Electromyogr Kinesiol.* 2010; 20(3):477–81.
10. Howatson G, Goodall S, van Someren KA. The influence of cold water immersions on adaptation following a single bout of damaging exercise. *Eur J Appl Physiol.* 2009;105(4):615–21.
11. Howatson G, McHugh MP, Hill J, et al. The effects of a tart cherry juice supplement on muscle damage, inflammation, oxidative stress and recovery following marathon running. *Scand J Med Sci Sports.* 2010;20(6):843–52.
12. Howatson G, van Someren KA. The prevention and treatment of exercise-induced muscle damage. *Sports Med.* 2008;38(6): 1–21.
13. Jacobson BH, Caldwell B, Kulling FA. Comparison of hiking stick use on lateral stability while balancing with and without a load. *Percept Mot Skills.* 1997;85(1):347–50.
14. Jacobson BH, Wright T. A field test comparison of hiking stick use on heart rate and rating of perceived exertion. *Percept Mot Skills.* 1998;87(2):435–8.
15. Jacobson BH, Wright T, Dugan B. Load carriage energy expenditure with and without hiking poles during inclined walking. *Int J Sports Med.* 2000;21(5):356–9.
16. Kirk J, Schneider DA. Physiological and perceptual responses to load-carrying in female subjects using internal and external frame backpacks. *Ergonomics.* 1992;35(4):445–55.
17. Knight CA, Caldwell GE. Muscular and metabolic costs of uphill backpacking: are hiking poles beneficial? *Med Sci Sports Exerc.* 2000;32(12):2093–101.
18. Kumar AJ, Gill DS, Fairweather C, Dykes L. The pattern of ankle fractures sustained by outdoor activities at the Snowdonia National Park, North Wales, United Kingdom. *Foot Ankle Surg.* 2009;15(3):144–5.
19. Laursen B, Ekner D, Simonsen EB, Voigt M, Sjøgaard G. Kinetics and energetics during uphill and downhill carrying of different weights. *Appl Ergon.* 2000;31(2):159–66.
20. Lee IM, Buchner DM. The importance of walking to public health. *Med Sci Sports Exerc.* 2008;40(7 suppl):S512–8.
21. Malm C, Sjödin TL, Sjöberg B, et al. Leukocytes, cytokines, growth factors and hormones in human skeletal muscle and blood after uphill or downhill running. *J Physiol.* 2004;1(556):983–1000.
22. Moir G, Button C, Glaister M, Stone MH. Influence of familiarization on the reliability of vertical jump and acceleration sprinting performance in physically active men. *J Strength Cond Res.* 2004; 18(2):276–80.
23. Neureuther G. The ski pole in summer [in German]. *MMW Munch Med Wochenschr.* 1981;123(13):513–4.
24. Nottle C, Nosaka K. The magnitude of muscle damage induced by downhill backward walking. *J Sci Med Sport.* 2005;8(3):264–73.
25. Paschalis V, Nikolaidis MG, Giakas G, Jamurtas AZ, Pappas A, Koutedakis Y. The effect of eccentric exercise on position sense and joint reaction angle of the lower limbs. *Muscle Nerve.* 2007; 35(4):496–503.
26. Reis JP, Macera CA, Ainsworth BE, Hipp DA. Prevalence of total daily walking among US adults, 2002–2003. *J Phys Act Health.* 2008;5(3):337–46.
27. Schwameder H, Roithner R, Muller E, Niessen W, Raschner C. Knee joint forces during downhill walking with hiking poles. *J Sports Sci.* 1999;17(12):969–78.
28. Siegal PZ. The epidemiology of walking for exercise: implications for promoting activity among sedentary groups. *Am J Public Health.* 1995;85(5):706–10.