教育部補助國內大學校院博士班研究生出席國際會議報告

2010 年 06 月 11 日

報告人姓名	林明儒	就讀學校系所及年級	中國文化大學體育學系運動教練研究所博士班一年級
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發表論文題目	(中文) 不同坡度跑對生理評估指標反應的影響 (英文) Effects of gradient variations on physiological responses to a 30-minute run		

一、前言

2010年第57屆美國運動醫學會 (American College of Sports Medicine, ACSM) 之年會，於美國馬里蘭州Baltimore Convention Center舉行，為期5天，自6月1日至6月5日。ACSM每年都在六月初舉行年會會議，它在目前的運動科學會議中之水準為數一數二的層級。此次的會議與歷屆不同之處，即是將Exercise is Medicine的觀念強調且融入其中，會議舉辦的前兩天皆以此為主軸。

此次的會議有來自全球世界各個不同國家的專家、學者及參與人員共6千多人 (總共有>3000 篇摘要通過大會審查並於會中進行口頭或海報式發表)，參加2010第57屆ACSM的會議，所以這是讓國際學術界知道臺灣運動科學發展的好機會。另外，本人亦要感謝教育部能給予此次出國學習與充電的機會之費用的補助，始能參加此一國際運動科學的會議。

二、重要活動內容與心得 (參加會議經過及與會心得建議)

(一) 六月一日

此次的會議是從 六月一日早上開始至六月五日止共5天。今年的ACSM會議與以往不同之處是將Exercise is Medicine的概念強調於會議中，而實際上此次會議是由兩個會議主軸融合在一起。第一天的上午10:00至10:50會議安排Exercise is Medicine Workshop，其主講者美國的Dr. E. Kraus，針對”Making the Scientific and Evidence Argument for Exercise Is Medicine”主題進行演講。另外，於下午的13:45至17:00安排諸多演講，其中有一主題為”Exercise, Why Does it Work!”演講者為丹麥的Dr. Bengt Saltin。尚有”International “Exercise is Medicine” Experiences: Past, Present and Future Perspective”等主題進行演講。其演講內容深入淺出，使本人在聽完之後收穫良多。

(二) 六月二日

上午08:00至09:15有一場獲大會邀請的演講，由美國的Dr. P. Koplan講演的”Physical Activity, Health, Health Care Reform and Lifestyle Reform Revisited”之專題，內容幽默有趣。09:30至11:30時段，本人參加了感興趣的演講 (包括Eccentric Contractions and Muscle Injury)，主持人為麻州大學的著名學者Dr. Clarkson，她在報告者的報告中皆能提出切要且精準的重點問題，真不愧是國際級的大師。其中與會報告者有天津體育學院的老師及日本研究生等亞洲人，雖然英文不是其官方語言或其母語，但他們都能表現得不錯，雖然在問答過程中有遲疑或聽不懂之處，但都能勇於嘗試，這是值得我們國內運動體育相關領域人員學習之處。另外，也參加了關於”Discussions on Hoe to Use NIRS to Evaluate Skeletal Muscle”的演講，獲得有關技術上的應用知識，尤其日本Dr. Takafumi Hamaoka淺顯易懂的講演，讓本人印象深刻。

今天也是本人的poster報告，報告時間為下午15:30至17:00，但必須於13:00張貼海報直至18:00才能將海報撤下。此一作為可供國內運動體育領域舉辦研討會時參考，因如此才能使與會者針對有興趣之主題海報有足夠時間可閱讀或發問問題。晚上20:30參加3rd Annual ACSM Student Bowel，此一活動是ACSM會議提供美國大學之學生相互競爭、贏得榮譽且可做為將來有利於升學或工作的一個資歷，潛在的作用實為ACSM會議有系統性及計畫性的培養下一代。此一模式可供國內運動體育領域做為學習仿效的作為。

(三) 六月三日

今天本人去參加有關 Blood Flow Restriction 的演講報告，主持人為 Dr. W. Sexton，報告的內容大多為阻力訓練對於血流的影響，不過主要是觀察

運動訓練過程中的變化。然而，若是能夠針對在運動訓練後的測驗，譬如：用於離心訓練引起肌肉損傷後的血流之影響，或許可能是個不錯的議題。聽完演講報告之後至大型會場觀看 poster，針對”Resistance Training”進行參覽及吸收新知。然而覺得美中不足之處，大會並無讓 poster 發表者有機會簡短介紹自己的研究內容 (例如可以以 3 至 5 分鐘簡要口頭發表)，這或許也可供國內運動體育領域舉辦會議時做為借鏡思考。

下午時段參與了”Differential Mechanisms Underlying Skeletal Muscle Injury versus Adaptation with Aging”以及”The Importance of Skeletal Muscle Transport Proteins During Exercise”主題的演講，獲益匪淺。

(四) 六月四日

早上參加了”Skeletal Muscle Injury and Repair: Cellular Mechanisms and Physiological Implications”的演講報告。其中當地馬里蘭大學 Richard M. Lovering 學者報告的主題”Contraction-Induced Skeletal Muscle Injury and Repair”，淺顯易懂，印象深刻。另外，密西根大學的 Dr. Brooks 報告的”Cellular and Molecular Mechanisms Underlying Protective”引起諸多回響，在場多位參與專家、學者共襄盛舉熱烈討論。

下午本人先去 poster 會場看 poster 發表，之後在參加幾場我感到興趣的演講 (包括 Oxidative Stress and Skeletal Muscle)。其中我發現有一些在國際上具有很不錯的學術地位的專家、學者，雖然沒有受到大會的邀請擔任專題演講或主持人，但和一般人一樣自行投稿來參加 ACSM 會議且是自己自費報名參加。這種現象在臺灣的運動體育學術界是不太可能會出現的 (這可能是我們無法進步的主要原因之一)，故我認為這是我們須要向西方人學習之處。

(五) 六月五日

今天為會議的最後一天，議程只有半天的時間。選擇了"The Biomechanics of Muscle Contraction"的主題，由來自加拿大的Dr. Walter Herzog進行專題演講。

最後，本人在參加此次第57屆5天的ACAM會議之後，先從Baltimore搭light train至BWI airport，搭機至達拉斯機場 (此機場極大之致，令人驚嘆！)，轉機至洛磯山機場，最後歷經13小時5分鐘後到達桃園機場。雖然整個行程很緊湊、很累，但是覺得很值得、很有收穫。特別在此，要再次感謝教育部的補助，讓本人此行得以圓滿完成。

三、結語

ACSM年會為目前國際上運動科學領域中之高水平的會議，在參加的過程中，參加者皆能有機會參加大部分大會所安排的活動 (例如專題演講)。另外，英文不是為非美系國家參加這個會議者的母語，故與會人員在討論或問題時都比較有耐心且願意多花一些時間與別人交流和切磋 (此指poster發表場次，oral發表場次則有時間限制)。另外，此會議的poster 發表的時間為每天全天候 (分上、下午場次)，可以讓有興趣者有充分時間進行參覽及發問問題，在poster發表此期間，尚有oral發表的場次以及專題演講的場次同時進行，讓會議參與人員依照自己的興趣領域有多樣化的選擇 (例如本人選擇Exercise training & Skeletal Muscle & Blood Flow的議題)。基此，本人認為此方式是一個不錯的發表方式，且在參加這次的ACSM會議之後，收獲及學習非常多。最後，要再次感謝教育部的補助，讓本人參加2010年ACSM會議得以順利圓滿完成。

四、攜回資料名稱及內容

1. Medicine & Science in Sports & Exercise (2010 Final Program, Baltimore, Maryland): Final Program.
2. Medicine & Science in Sports & Exercise (Volume 42, Number 5 Supplement to the May 2010): The abstract issue.
3. Medicine & Science in Sports & Exercise: Advance Program & Exhibit Guide.
4. ACSM 2010 Profiles in Sports Medicine and Exercise Science: A Professional Guide to Programs and Career Opportunities In Sports Medicine and Exercise Science.
5. Visit Baltimore: The Official Guide.
6. Baltimore Harbor Guide & Maps.
7. Maryland: Calendar of Events.
8.會議相關書面報告資料。

發表論文全文：

EFFECT OF GRADIENT VARIATIONS ON PHYSIOLOGICAL RESPONSES TO A 30-MINUTE RUN

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ABSTRACT

This study investigated whether variations in gradient would affect the magnitude of physiological responses during a 30-minute run at an intensity of 70% of maximal oxygen capacity ($\dot{V}O_{2max}$). Forty untrained collegiate men were randomly assigned into 0%, -5%, -11%, and -16% groups (n=10 per group), and then performed a 30-minute run at gradients of 0%, -5%, -11%, and -16%, respectively, at the intensity of 70% of their pre-determined $\dot{V}O_{2max}$. Oxygen consumption ($\dot{V}O_2$), minute ventilation ($\dot{V}_E$), respiratory exchange ratio (RER), heart rate (HR), and rating of perceived exertion (RPE) were measured at 5, 10, 15, 20, 25 and 30 minutes, respectively, during each run. Blood lactate (LA) concentration was assessed by fingertip blood sample at 3 minutes after each run. The results showed that elevations of $\dot{V}O_2$, $\dot{V}_E$, RER, and HR during running for the -11% and -16% groups were significantly greater than for the -5% and 0% groups ($p<0.05$). However, the changes in these measures showed no significant difference ($p>0.05$) between the 0% and -5% groups, or the -11% and -16% groups. As for RPE and LA, no significant differences ($p>.05$) among the groups were observed. It is concluded that the steeper the gradient, the greater the increases in $\dot{V}O_2$, $\dot{V}_E$, RER, and HR. This may be due to the fact that at a steeper downhill gradient (-16%), the quadriceps femoris muscle lengthens to a greater extent than at lower (-5%, -11%) and level gradients.

Keywords: lengthening exercise, muscle damage, oxygen consumption, lactate, heart rate.

INTRODUCTION

The extent of change in oxygen consumption ($\dot{V}O_2$) can be used to evaluate how muscle groups in the human body respond to physical exercise (Dick & Cavanage 1987; Costill 1970). Recent studies (Saunders et al. 2004; Chen et al. 2007, 2008) have shown that in tests of physical exercise, analyzing physiological [maximal $\dot{V}O_2$ ($\dot{V}O_{2max}$), minute ventilation ($\dot{V}_E$), respiratory exchange ratio (RER), heart rate (HR), and blood lactate (LA)] and kinematic [stride length (SL), stride frequency (SF) of the lower-limb joints] parameters is an effective way to evaluate athletes' efficiency and performance. Chen et al. (2007) and Byrne et al. (2004) demonstrated that the extent of muscle damage suffered from performing a bout of downhill running (DHR) is somewhat similar to that suffered from running a marathon, suggesting that DHR can be used as a way of inducing muscle damage in laboratory experiments. The fact that DHR is an innate running form of the human body may explain why it has long been one of the most common methods used to induce damage in lower-limb muscle groups in studies of exercise-induced muscle damage (EIMD; Chen et al. 2007, 2008; Eston et al. 1995, 1996; Schwane et al. 1983).

To date, the only four previously studies have examined the effects of DHR, using under the intensity of 50%$\dot{V}O_{2max}$, on the upward drift in oxygen consumption (UDO; Klausen & Knuttgen 1971; Dick & Cavanagh 1987; Westerlind et al. 1992, 1994), and found that a significant increase in $\dot{V}O_2$ during a 30-45 min of lengthening exercise at 35%$\dot{V}O_{2max}$. In other studies (Byrnes et al. 1985; Pierrynowski et al. 1987; Smith et al. 1998; Eston et al. 1996, 2000; Braun & Dutto 2003; Chen et al. 2007, 2008) DHR is used merely as a means of inducing muscle damage in test subjects, while the actual topics of research (e.g. training, running economy) are explored from other angles. It should be noted that DHR protocol in these studies used at gradients of -10% to -15%, and required subjects to run at considerably higher intensities (70%$\dot{V}O_{2max}$ or 90%HR_{max}). Yet because none of these *later studies* measured the effects of DHR on UDO, it is still unknown what influence an intensity of or exceeding 50% of $\dot{V}O_{2max}$ will have on UDO. Furthermore, it is generally necessary to wait 1 to 3 days after DHR before *the* symptoms of muscle damage become apparent (Eston et al. 1995; Byrne et al. 2004; Chen et al. 2007, 2008). If we are able to observe significant changes in physiological parameters (e.g. $\dot{V}O_2$) during DHR at different gradients, rather than waiting for few days for muscle damage to occur, we will then be able to provide some evidence for the initial stages of EIMD.

Therefore, this study designed to test the hypothesis that when subjects engaged in DHR at different gradients, the extent of their physiological responses would be related to the gradient at which DHR takes place (-16%>-11%>-5%>0%).

METHODS

Subjects and general procedures

Forty untrained male students participated in this study that had been approved by the Institutional Ethics Committee, and gave an informed consent document in conformity with the Declaration of Helsinki. Their mean (±SD) age, height, weight and $\dot{V}O_{2max}$ were 21.6 ± 1.7 yrs, 171.5 ± 5.4 cm, 66.5 ± 10.3 kg, and 51.1 ± 5.6 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. The $\dot{V}O_{2max}$ was determined by a graded maximal treadmill test using a motor-driven treadmill (Valiant, Lode B, V, Groningen, Netherlands) and an automated gas analysis system (Vmax29c, SensorMedics Corp., Yorba Linda, CA, USA) by the similar protocol described in the previous studies (Chen et al. 2007, 2008). Following a general stretching exercise for 10 minutes, the subjects ran until volitional exhaustion while the treadmill velocity was increased by 1 $mile \cdot hour^{-1}$ every two minutes from 3 $miles \cdot hour^{-1}$ without gradient.

The subjects were placed into one of four groups – 0%, -5%, -11%, and -16% – by matching the baseline $\dot{V}O_{2max}$ among the groups. The sample size was estimated using data from a previous study (Chen et al. 2008), in which subjects similar to those in this study performed similar bouts of DHR. It was shown that such a study would need at least nine subjects per group, based on the effect size of 1, alpha level of 0.05 and a power (1-beta) of 0.80. We recruited 10 subjects for each group. No significant differences ($P>0.05$) in age, height, weight or $\dot{V}O_{2max}$ were evident among the groups. None of the subjects had any resistance or endurance training in the year immediately preceding the study, and none performed any recreational activities (e.g., hill running, soccer, volleyball) that include large eccentric components. All subjects were requested not to perform any unaccustomed exercise or vigorous physical activity, and asked not to take any anti-inflammatory agents or nutritional supplements during the experimental period.

$\dot{V}O_{2max}$ was assessed approximately one week prior to DHR. All subjects were familiarized with the treadmill test to be used for measuring $\dot{V}O_{2max}$ two to three days prior to the actual $\dot{V}O_{2max}$ test.

Downhill running (DHR)

All subjects performed a 30-minute bout of DHR on the treadmill described earlier. The

DHR protocol was similar to that of previous studies (Chen et al. 2007, 2008). After 10 minutes of general stretching, subjects ran on the treadmill at a 0° gradient for five minutes using self-selected speeds, followed by DHR. The gradient of the treadmill for the 0%, -5%, -11% and -16% groups was set at 0%, -5%, -11% and -16%, respectively, and the velocity was adjusted in the first five minutes to obtain the pre-determined 70% $\dot{V}O_{2max}$ target for each subject. The velocity was not changed thereafter until completion of DHR, and the average speed of the treadmill for the 0%, -5%, -11%, and -16% groups was 6.2±0.7, 6.5±0.7, 7.5±0.8, and 7.8±1.0 miles·hour^{-1}, respectively.

Criterion measures

Dependent variables consisted of $\dot{V}O_2$, $\dot{V}_E$, RER, HR, rating of perceived exertion (RPE), and LA concentration. These measures, with the exception of LA, were assessed at 5, 10, 15, 20, 25, and 30 minutes during DHR for all groups. LA was measured before and at 3 minutes after each run.

During running, expired gas was continually collected using an automated gas analysis system (Vmax29c, SensorMedics Corp., Yorba Linda, CA, USA). The average values of the 60 seconds at each time point (i.e., 5, 10, 15, 20, 25 and 30 minutes) during each run were obtained for $\dot{V}O_2$, $\dot{V}_E$ and RER. HR was measured using an HR monitor (Polar S610, Kempele, Finland) at 5, 10, 15, 20, 25 and 30 minutes during each run, and the mean value of the average 60 seconds was used for further analysis. RPE was assessed during the last 20 seconds at each time point (i.e., 5, 10, 15, 20, 25 and 30 minutes) using the Borg scale (Chen et al. 2007, 2008). LA was measured using fingertip blood and a portable lactate analyzer (Lactate Pro^{TM}, Tester Meter, Arkray Inc., Kyoto, Japan) before the 30-minute run, and at three minutes thereafter.

Statistical Analysis

Changes in $\dot{V}O_2$, HR, $\dot{V}_E$, RER, RPE and LA over time were analyzed by a one-way repeated-measures analysis of variance (ANOVA). When a significant time effect was found, a Tukey *post-hoc* test was conducted to detect the location of significance from the baseline. Changes in $\dot{V}O_2$, HR, $\dot{V}_E$, RER, RPE and LA during the different gradients of DHR (0%, -5%, -11%, -16%) were compared by a two-way mixed-design ANOVA. When a significant interaction effect (gradient x time) was evident, a Scheffé's *post hoc* test was conducted. Statistical significance was accepted at $p < 0.05$.

RESULTS

It was found that after five minutes of running (at gradients of 0%, -5%, -11% and -16%, respectively), subjects in the 0%, -5%, -11% and -16% groups all showed a $\dot{V}O_2$ of around 35.6±2.0 ml·kg^{-1}·min^{-1}, a $\dot{V}_E$ of around 58.8±4.2 L·min^{-1}, an RER of around 0.92±0.01, an HR of around 156.9±5.8 beat·min^{-1} and an RPE of around 10.2±0.3. In addition, the LA values of all subjects prior to beginning their runs were found to be within a normal range (around 0.9±0.1ug·L^{-1}). In order to facilitate direct comparison of these four different gradients, the present study reported the normalized data of each variable instead of raw data (Figures 1-4).

As shown in Figure 1, the elevation of $\dot{V}O_2$ during a 30-minute run was significantly greater for subjects in the -16% and -11% groups than for those in the -5% and 0% groups ($p<0.05$). However, no significant difference ($p>0.05$) was seen between the -11% and -16% groups, and the 0% and -5% groups. For the 0% group, $\dot{V}O_2$ was found to be 4% greater at the 30th minute of level running than at the 5th minute, but this was not considered a significant difference ($p>0.05$). For the other three groups, by contrast, $\dot{V}O_2$ was significantly higher (i.e., -16% group: 17%; -11% group: 12%; -5% group: 7%; $p<0.05$) at the 30th minute of DHR than at the 5th minute.

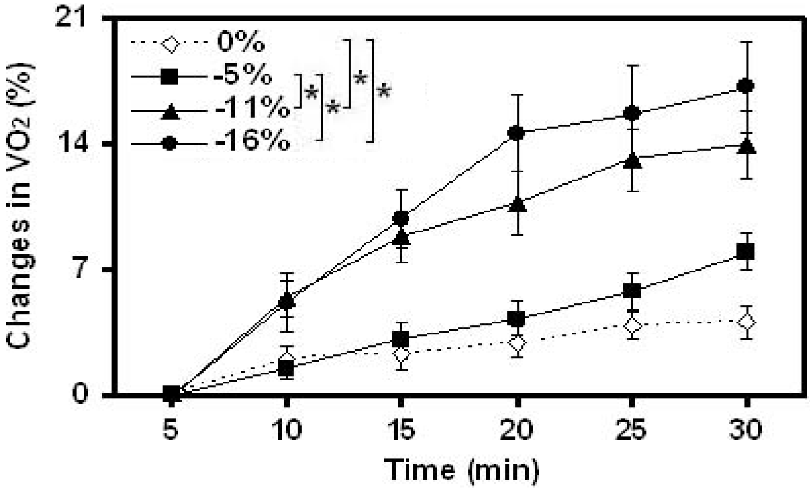

Figure 1: Normalized changes in oxygen consumption ($\dot{V}O_2$; means ± SD) at 5, 10, 15, 20, 25, and 30 minute during the different gradients of running (0%, -5%, 11%, and -16%). *Indicates a significant difference ($p<0.05$) between groups.

Similar results were found for $\dot{V}_E$, RER, and HR (Figures 2-4). From data in Figures 2-3, we can see that during the 30-minute run, subjects in the -16% and -11% groups showed a significantly greater ($p<0.05$) increase in both $\dot{V}_E$ and RER than did those in the -5% and 0%

groups. However, there was no significant difference ($p>0.05$) between the -11% and -16% groups, and the 0% and -5% groups. HR data from Figure 4 show that during the 30-minute run, the increase in HR was greater ($p<0.05$) for the -16% and -11% groups than for the -5% and 0% groups. HR increase was greater for the -5% group than for the 0% group ($p<0.05$), but no significant difference ($p>0.05$) was found between the -11% and -16% groups.

Furthermore, the present study found that while running at each gradient leads to a significant increase (about 46~56%; $p<0.05$) in RPE, no significant difference ($p>0.05$) in RPE values was seen among these four groups. Similar results were also noted for the degree of change in LA (about 13~14 μg/L), when this criterion was measured at 3 minutes after the subjects had finished running. Therefore, the results of these two variables are not shown in the text.

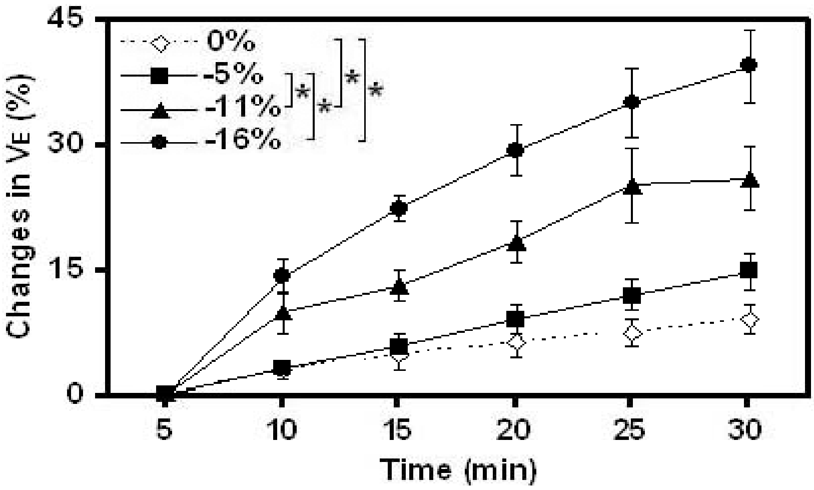

Figure 2: Normalized changes in minute ventilation ($\dot{V}_E$; means ± SD) at 5, 10, 15, 20, 25, and 30 minute during the different gradients of running (0%, -5%, 11%, and -16%). *Indicates a significant difference ($p<0.05$) between groups.

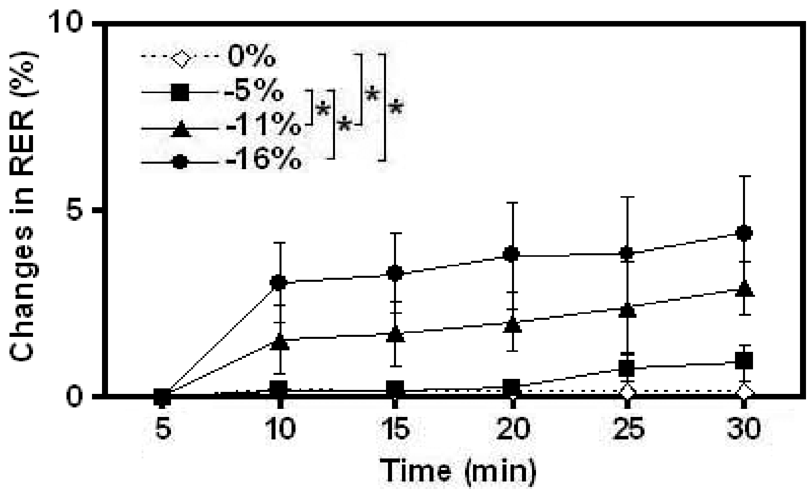

Figure 3: Normalized changes in respiratory exchange ratio (RER; means ± SD) at 5, 10, 15, 20, 25, and 30 minute during the different gradients of running (0%, -5%, 11%, and -16%). *Indicates a significant difference ($p<0.05$) between groups.

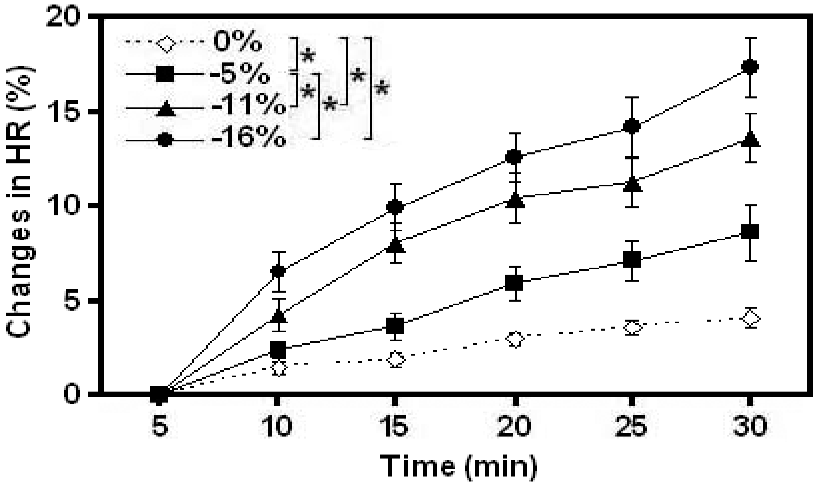

Figure 4: Normalized changes in heart rate (HR; means ± SD) at 5, 10, 15, 20, 25, and 30 minute during the different gradients of running (0%, -5%, 11%, and -16%) or during a 30 minute run at the gradients of 0%, -5%, 11%, and -16%. *Indicates a significant difference ($p<0.05$) between groups.

DISCUSSION

The main findings of the present study showed that when subjects ran for 30 minutes at an intensity of 70% of $\dot{V}O_{2max}$, the extent of increase of $\dot{V}O_2$, $\dot{V}_E$, RER and HR was significantly greater for the -11% and -16% groups than for the -5% and 0% groups (Figures 1-4). However, no significant difference was seen between the -11% and -16% groups, and the 0% and -5% groups (Figures 1-4). As for the extents of increase of RPE and LA, moreover, these were found to be unaffected by the gradient on which subjects ran. These results suggest that the greater the downhill slope, the more obvious the increase in physiological parameters.

The present study found that when the 0% group ran for 30 minutes on level ground at an intensity of 70% of $\dot{V}O_{2max}$, subjects' $\dot{V}O_2$ levels showed no significant increase (Figure 1). This was similar to the findings of several previous studies (Byrnes et al. 1985; Dick & Cavanagh 1987; Westerlind et al. 1992, 1994). This may be related to the intensity of level running due to Gleeson et al. (1995) found that the human body reaches its anaerobic threshold at an exercise intensity of around 80% of $\dot{V}O_{2max}$. If this is the case, the intensity of 70% of $\dot{V}O_{2max}$ used in the present study may be too low to cause a significant increase in the

$\dot{V}O_2$ levels of subjects in the 0% group.

The present study found that the $\dot{V}O_2$ levels of subjects in the -16% (17%), -11% (12%) and -5% (6%) groups were all significantly higher at the 30th minute of DHR than they were at the 5th minute (Figure 1). Similar results were also found for $\dot{V}_E$, RER, and HR (Figures 2-4). These findings support the contention of previous studies (Byrnes et al. 1985; Dick & Cavanagh 1987; Westerlind et al. 1992, 1994): performing one 30-45-minute bout of DHR can lead to a significant increase in $\dot{V}O_2$, $\dot{V}_E$, RER, and HR. Of these, Byrnes et al. (1985) asked subjects perform a 30-minute DHR (-10°) at an intensity of 157 beats/min, and showed that both $\dot{V}O_2$ and HR were around 6% higher at the 30th minute of DHR than at the 10th minute. Dick & Cavanagh (1987) had subjects perform a 40-minute DHR (-10%) at an intensity of 44%$\dot{V}O_{2max}$, and found that $\dot{V}O_2$ (10%), $\dot{V}_E$ (6%) and integrated EMG (IEMG; 23%) were all significantly higher at the 40th minute of DHR than at the 10th minute. Westerlind et al. (1992) made subjects perform a 30-minute DHR (-10%) at an intensity of 40%$\dot{V}O_{2max}$, with the result that HR (13%), $\dot{V}O_2$ (16%) and $\dot{V}_E$ (21%) were significantly higher at the 30th minute of DHR than at the 1st minute. In addition, DHR was found to have caused significant muscle damage in the subjects. Westerlind et al. (1994) found that when subjects performed a 45-minute DHR (-10%) at an intensity of 50%$\dot{V}O_{2max}$, both $\dot{V}O_2$ (5%) and HR (11%) increased significantly. From the results of the aforementioned and present studies, thus we can see that the level to which physiological parameters change following a bout of DHR seems to be influenced chiefly by both the gradient and the intensity at which subjects run.

Previous studies (Costill 1970; Westerlind et al. 1992) reported that physiological parameters ($\dot{V}_E$, RER, and HR) could be the main factors behind the UDO that occurs when subjects perform concentric exercise at an intensity greater than 60%. The present study found that subjects in the -5% (12%), -11% (14%) and -16% (17%) groups that performed DHR, using 70%$\dot{V}O_{2max}$, all experienced a significantly greater increase in HR from the 5th minute to the 30th minute of exercise than did subjects in the 0% group (4%; Figure 4). Moreover, Westerlind et al. (1992) postulated that HR, or the amount of work done by the heart, may be related to the degree of change in $\dot{V}O_2$ during DHR. Because $\dot{V}O_2$, $\dot{V}_E$ and RER show the similar trend as HR when subjects engage in DHR (Figures 1-4), these results might indicate that when testing the effects of running at different gradients, these four physiological parameters can all serve as effective indices to evaluate exercise intensity and physiological response.

The fact that subjects in this study who engaged in DHR experienced different degrees of changes in physiological parameters ($\dot{V}O_2$, $\dot{V}_E$, RER and HR) is likely related chiefly to the different gradients (-5%, -11% and -16%) at which they ran. One limitation of the present study was the absence of treadmills equipped with force plates and high-speed video cameras, which would have enabled us to evaluate subjects' impact force, as well as the joint angle variations of the lower limbs during running. However, Gottschall & Kram (2005) showed a relationship between the gradient at which subjects ran and impact force as measured by a force plate on a treadmill. For example, the normal impact peaks of the -16%, -11% and -5% groups were found to be greater than that of the 0% group by 54%, 32% and 18%, respectively. Moreover, Buczek & Cavangh (1990) found that when the subjects engaged in DHR at a gradient of -10%, the variation of the knee joint angle (35.1°) was significantly greater than that of the subjects who ran on level ground (27.2°). More recently, Chen et al. (2007) postulated that when subjects engage in DHR, the quadriceps femoris muscle should extend and contract to a greater degree than when they run on level ground. This would cause the subjects to experience a gradual increase in both $\dot{V}O_2$ and $\dot{V}_E$ as they engage in DHR for longer periods of time. The above hypotheses would seem to suggest that the steeper the downhill slope at which subjects run, the greater the range of lengthening contraction of the knee extensor, and thus, the greater the extent of muscle damage.

Hreljac et al. (2000) reported that the primary biomechanical parameter distinguishing injured from never-injured runners is impact peak force extent. The extent of the vertical impact peak for the injury group was 13% larger than that of the non-injury group, a difference equivalent to DHR at -5% in the Gottschall and Kram (2005) study. Other studies have also shown that high impact forces are related to an increase in the occurrence of injury (Grimston et al. 1994). These impact forces can be moderated by increasing the knee flexion angle at foot strike and decreasing stride length during downhill and level running, but such modifications are metabolically expensive (Derrick et al. 1998). In light of these findings, we do not rule out the possibility that the above hypotheses may help to explain why DHR at different gradients caused the physiological parameters of subjects in the present study to increase by different degrees.

The fact that DHR causes a significant increase in physiological parameters (Figures 1-4) might also be partly related to neurological factors and muscle stiffness. Eston et al. (1995) postulated that when humans engage in DHR, the knee extensors, anterior tibial muscles and hip extensors all perform lengthening contractions, in order to help the body resist gravity. These contractions, in turn, lead to muscle damage. Dick and Canavagh (1987) and Westerlind et al. (1992) also suggested that the UDO occurring during DHR may be related to muscle damage. This could be due to the fact that DHR requires the use of more muscle groups than level running, leading to an increase in $\dot{V}O_2$. Klein et al. (1997) suggested that $\dot{V}O_2$ and $\dot{V}_E$ do not increase significantly until the latter stages of running, as the muscle damage that occurs during these stages causes a gradual increase in nerve activity. Dutto & Braun (2004) and Barry & Cole (1990) found that when DHR leads to muscle damage, significant muscle stiffness occurs. This stiffness then inhibits the body's ability to convert elastic energy into mechanical work, leading to a marked increase in $\dot{V}O_2$. Thus, subjects who engage in DHR at different gradients might experience different levels of muscle damage and muscle stiffness in the latter stages of running. This stiffness inhibits the body's ability to convert elastic energy into mechanical work, and in response, the body likely recruits more muscle fibers to assist with DHR. These hypotheses might be able to indirectly explain why subjects in this study who participated in the -5%, -11% and -16% groups experienced a significant increase in physiological parameters ($\dot{V}O_2$, $\dot{V}_E$, RER and HR) during the latter stages of DHR. Future studies are needed to test these issues.

CONCLUSION

The results of this study show that when the subjects engage in DHR at a fixed intensity of 70% of $\dot{V}O_{2max}$, the range of the lengthening contractions of the quadriceps femoris muscles seems to increase as the gradient becomes steeper. This in turn leads to muscle damage and stiffness, which may, as subjects continue running, cause the body to recruit more muscle fibers to assist with DHR. In the end, this causes a marked decrease in running efficiency ($\dot{V}O_2$, $\dot{V}_E$, RER and HR). Therefore, these findings may provide a preliminary explanation for the different extents of muscle damage induced by DHR.

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