Adaptation to Muscle Injury from Low Stimulus Non-Eccentrically Biased Acute Exercises

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ABSTRACT

Frimpong E, Antwi DA, Asare G, Antwi-Boasiako C, Dzudzor B. Adaptation to Muscle Injury from Low Stimulus Non-Eccentrically Biased Acute Exercises. JEPonline 2014;17:(3)1-11. The purpose of this study was to investigate whether low stimulus non-eccentrically biased acute aerobic exercises result in adequate adaptation in skeletal muscles. Thirty healthy subjects were randomized into three groups: (a) the low stimulus down-hill treadmill exercise group (LSDTEG); the low stimulus up-hill treadmill exercise group (LSUTEG); and the low stimulus level treadmill exercise group (LSLTEG). The three groups performed acute exercises (bout 1) and a repeated exercise (bout 2). In the acute exercises, all the groups exercised at 50% of heart rate reserve (HRR) for 30 min. Two weeks after the acute exercises, the subjects performed a repeated exercise bout at 80% of HRR for 45 min. Creatine kinase (CK), total white blood cells (TWBC), and perceived muscle soreness (SOR) before and 1, 24, and 48 hrs post-exercise were assessed as markers of muscle injury and adaption. The results showed that muscle injury was significantly higher in the LSDTEG than LSUTEG and LSLTEG in the acute exercises. However, there were no significant differences in mean CK, TWBC, and SOR among the groups in the repeated exercise. The extent of muscle adaptation was similar in all three exercise groups. Thus, acute exercises by sedentary individuals can be of low stimulus and non-eccentrically biased to reduce muscle injury while inducing adequate muscle adaptation.

Key Words: Aerobic Exercise, Heart Rate Reserve, Creatine Kinase, Perceived Muscle Soreness
INTRODUCTION

Normal human motion involves repeated cycles of eccentric and concentric muscle actions known as stretch shortening cycle (SSC) that conserves energy and decreases the metabolic cost of physical activity (18). Thus, during physical activity, limb muscles are involved in equivalent amounts of eccentric and concentric contractions (4). Studies (6,14,20,21,24,27) have shown that eccentrically biased acute exercise of high eccentric contraction component results in ultrastructural muscle injury. This type of muscle injury is best described as microtrauma that causes disruptions to the muscle architecture (1,3). The injury from the acute exercise induces adaptation in the muscle tissues that helps the muscle to be more resistant to subsequent strenuous or damaging exercises (10,13,15,19,22,23,28).

Research findings indicate that the muscle adaptation does not have to depend on serious or overt muscle injury from the acute exercise during a sedentary novel exercise performance (5,9,15,26). The reason is that, this protective effect against eccentric exercise-induced muscle injury is also produced when a smaller amount of eccentric actions are performed in the acute exercise (6,7,8,15).

Although, the mechanisms that cause exercise-induced muscle injury (EIMI) and adaptation are not fully elucidated, there is a close relationship between muscle injury and exercise with a large eccentric contraction component, which causes a greater magnitude of muscle damage in comparison with concentric or isometric muscle actions (25,30). Moreover, the question of whether low stimulus acute non-eccentrically biased aerobic exercise training in humans can protect muscle from eccentric contraction-induced injury must be well elucidated.

Koh and Brooks (17) reported that lengthening contractions and fiber degeneration and/or regeneration are not required to induce protection from lengthening contraction-induced injury. Clarkson et al. (11) found that a single bout of training with maximal voluntary isometric contractions protects muscle from muscle injury. In another study with animal models, Schwane and Armstrong (29) reported that previous exposure to level running that did not appear to produce injury in vastus intermedius and triceps brachii muscles protected the muscles from injury during downhill running in rats. We reported (15) in our previous study that both low and high stimulus of eccentric aerobic exercises induced similar muscle adaptation when similar eccentrically biased exercise of higher stimulus was performed in the repeated exercise. Studying the effects of low stimulus non-eccentrically biased acute exercises on muscle injury and adaptation may help attenuate EIMI and increase motivation to exercise.

The purpose of the study was to investigate whether low stimulus non-eccentrically biased acute aerobic exercises (Up-hill and Level Treadmill exercises) would induce adequate muscle adaptation. Thus, the specific objectives of this study were to: (a) assess the effects of up-hill and level treadmill running of acute aerobic exercises on muscle injury; (b) evaluate muscle adaptation developed from the acute exercises of up-hill and level treadmill running; and (c) compare muscle injury and adaptation resulting from up-hill and level treadmill with down-hill treadmill running.

METHODS

Subjects
This study consisted of 30 healthy University of Ghana students (18 males and 12 females) of the Korle Bu Campus. The mean age, weight, and height of the subjects were 21.2 ± 1.4 yrs, 60.1 ± 6.7 kg, and 1.7 ± 0.1 m, respectively. None of the subjects had participated in a structured exercise program for at least 6 months prior to the study, especially regarding eccentric exercises of the lower extremities such as down-hill running. They had no medical history for which the study’s exercises
were contraindicated. The research procedures and research design were approved by the Ethical and Protocol Review Committee of University of Ghana Medical School. All subjects gave written informed consent after having understood explanations of the experimental protocol and any potential risks that could be encountered.

**Procedures**

**Exercise Protocol**

After completing the Physical Activity Questionnaire (PAQ), the subjects were randomized into three groups. Subjects in each group performed two exercise bouts. Bout 1 consisted of the low stimulus acute exercise groups: Group 1, performed low stimulus level treadmill exercises (LSLTEG); Group 2, performed low stimulus up-hill treadmill exercise (LSUTEG); and Group 3, performed low stimulus down-hill treadmill exercise (LSDTEG), all at 50% of heart rate reserve (HRR) for 30 min. Two weeks later, the groups: LSLTEG, LSUTEG, and LSDTEG performed bout 2 exercises of eccentrically biased exercise at 80% of HRR for 45 min. The training stimulus in the second bout was necessary for assessing muscle tissue adaptation induced by the acute exercise of bout 1. The 2-wk time interval was allowed for recovery from bout 1. The intensity of the exercise for each group was to determine the target heart rate (THR) calculated as a percentage of the HRR. THR was calculated using the Karvonen method (16). This is given by the relation:

\[
\text{THR} = (\text{HR max} - \text{HR rest}) \times (\%\text{Intensity}) + \text{HR rest}
\]

Where maximal heart rate (HR max) = 220 – age, heart rate reserve (HRR) = HR max – HR rest, resting heart rate (HR rest) and percentage intensity (\%Intensity) calculated as a percentage of the HRR. The target heart rates were determined during the familiarization session 3 days before the level, up-hill, and down-hill treadmill running exercises.

Muscle injury was induced in the acute exercise bouts by the down-hill, up-hill, and level treadmill running. The Xenon treadmill (Okinawa, Japan) was declined at a gradient of 15° for down-hill exercise and inclined at 15° and at 0° for up-hill and level treadmill exercises, respectively. The down-hill slope was obtained by placing a wooden pallet under the rear of the treadmill. This was obtained from angle of declination and the length of the treadmill (12). Heart rate was monitored with a HR monitor, Polar Accurex Plus, Polar Electro Oy, (Kempele, Finland) to ensure that the subjects exercised within the set target HRs. As an adjunct to HR in monitoring exercise intensity, rating of perceived exertion was used (2). The speed of the treadmill was adjusted to the required target HRs. Blood pressure was measured using a standard mercury sphygmomanometer and stethoscope.

In order to minimize data variability, certain restrictions were placed on the subjects. Participants were told not to perform any exercise other than the physical activities associated with their activities of daily living. Furthermore participants were instructed to: (a) abstain from massaging, stretching, and any form of treatment to the lower limbs; and (b) refrain from taking any non-steroidal anti-inflammatory drugs (NSAIDs), nutritional supplements, alcohol, and caffeine before and during the experimental period.

**Blood Sample Collection**

Blood samples were collected before (baseline) and at 1, 24, and 48 hrs after exercise in both the acute and repeated bouts. Five milliliters (5 ml) of venous blood was drawn from the antecubital vein by venipuncture. Each blood sample drawn was divided into two tubes: (1) one-half was collected into EDTA tubes for full blood count (FBC) analysis; and (2) the other half into Serum Separator Tubes for
muscle injury markers. The time for blood sampling was fixed at 7:00 am after an overnight fast. Blood samples in Serum Separator Tubes were centrifuged at 3000 rev·min⁻¹ for 10 min and the serum aliquoted into labeled eppendorf tubes for CK analysis. Samples were stored at a temperature of −20°C until use.

**Biochemical and Physical Markers of Muscle Injury and Adaptation**

The serum CK activity was measured by the VITROS CK Slide method and the VITROS Chemistry Products Calibrator Kit 3 (UK). The serum circulating levels of TWBC were measured as inflammatory markers with Sysmex Autoanalyser (Kobe, Japan). Perceived muscle soreness (SOR) was used to assess pain of bilateral quadriceps by Visual Analog Scale (VAS).

**Statistical Analyses**

The data were analyzed using Statistical Package for Social Sciences (SPSS) version 16. Analysis of Variance (ANOVA) was used to compare mean differences among the three groups. Paired and unpaired t-tests were used to compare mean differences within and between two groups, respectively. A P-value of less than 0.05 (P<0.05) was considered significant. Data are presented as means ± standard deviation (mean ± SD).

**RESULTS**

The serum levels of CK, TWBC and SOR were compared between LSLTEG, LSUTEG and LSDTEG in the acute exercises as markers of muscle injury. The same markers were measured in the repeated bout exercises to assess muscle adaptation. Reductions in these markers in the repeated bout showed the extent of muscle adaptation developed from the acute exercise-induced injury. Table 1 shows the results of the characteristics of the subjects. There were no significant differences between LSLTEG, LSUTEG and LSDTEG among the variables: age, height, BMI, SBP, DBP, and HR (P>0.05).

**Table 1. Characteristics of the Subjects (LSLTEG, n = 10; LSUTEG, n = 10; LSDTEG, n = 10).**

<table>
<thead>
<tr>
<th>Variables</th>
<th>LSDTEG (Mean ± SD)</th>
<th>LSUTEG (Mean ± SD)</th>
<th>LSLTEG (Mean ± SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>21.7 ± 1.9</td>
<td>20.9 ± 1.1</td>
<td>21 ± 1.2</td>
<td>0.4848</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61.8 ± 6.5</td>
<td>58.5 ± 7.7</td>
<td>60.1 ± 5.9</td>
<td>0.4899</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.7 ± 0.1</td>
<td>1.7 ± 0.1</td>
<td>1.7 ± 0.1</td>
<td>0.7489</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>22.4 ± 2.3</td>
<td>20.7 ± 1.8</td>
<td>21.8 ± 2.0</td>
<td>0.2711</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>117.6 ± 4.2</td>
<td>118.6 ± 10.6</td>
<td>120.2 ± 4.0</td>
<td>0.5390</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>75.5 ± 6.2</td>
<td>75.3 ± 6.6</td>
<td>77.7 ± 2.7</td>
<td>0.5043</td>
</tr>
<tr>
<td>HR (beats·min⁻¹)</td>
<td>73.0 ± 8.3</td>
<td>74 ± 7.6</td>
<td>72.0 ± 4.8</td>
<td>0.6726</td>
</tr>
</tbody>
</table>

*LSDTEG - low stimulus down-hill treadmill exercise group, LSUTEG - low stimulus up-hill treadmill exercise group, LSLTEG - low stimulus level treadmill exercise group. Data are presented as mean ± SD. The mean differences in age, weight, height, BMI, SBP, DBP, and HR for LSDTEG, LSLTEG, and LSUTEG were not significant (P>0.05).*
Figure 1. Comparing Mean Serum Levels of CK between LSDTEG, LSUTED, and LSLTEG in the Acute and Repeated Exercises. There were no significant differences in means between LSDTEG, LSUTEG, and LSLTEG at baseline and 1 hr post-exercise in the acute exercises (P>0.05). **Indicates CK significantly higher in LSDTEG than LSUTEG and LSLTEG at 24 and 48 hrs post-exercise (P<0.0001; P<0.0001, respectively); but mean differences between LSUTEG and LSLTEG were not significant (P>0.05) in the acute exercises. There were no significant differences between LSDTEG, LSUTEG and LSLTEG at baseline and 1, 24, and 48 hrs post-exercise in the repeated exercises (P>0.05). ***Indicates significant drop in means within each group at 24 and 48 hrs post-exercise in the repeated exercises (P<0.05).
Figure 2. Comparing Mean TWBC between LSDTEG, LSUTEG, and LSLTEG in the Acute and Repeated Exercises. There were no significant differences (P>0.05) in mean TWBC between LSDTEG, LSUTEG, and LSLTEG at baseline and 1 hr post-exercise in the acute exercises. **Indicates TWBC significantly higher in LSDTEG than LSUTEG and LSLTEG at 24 and 48 hrs post-exercise (P<0.0001; P=0.0002, respectively), but mean differences between LSUTEG and LSLTEG were not significant (P>0.05) in the acute exercises. There were no significant differences between LSDTEG, LSUTEG, and LSLTEG at baseline and 1, 24, and 48 hrs post-exercise in the repeated exercises (P>0.05).
Figure 3. Comparing Mean SOR Score between LSDTEG, LSUTEG and LSLTEG in the Acute and Repeated Exercises. There were no significant differences in mean SOR between LSDTEG, LSUTEG and LSLTEG at baseline and 1 hr post-exercise (P>0.05) in the acute exercises. **Indicates SOR significantly higher in LSDTEG than LSUTEG and LSLTEG at 24 and 48 hrs post-exercise (P<0.0001; P<0.0001, respectively); but mean differences between LSUTEG and LSLTEG were not significant (P>0.05) in the acute exercises. There were no significant differences between LSDTEG, LSUTEG and LSLTEG at baseline and 1, 24, and 48 hrs post-exercise in the repeated exercises (P>0.05). ***Indicates significant drop in means within each group at 24 and 48 hrs post-exercise in the repeated exercises (P<0.05).

DISCUSSION

An important factor in inducing adaptation in skeletal muscles is the stimulus and type of acute exercise (15). The limb muscles perform different amounts of eccentric or concentric contractions depending on the surface over which the physical activity is carried out. Since EIMI is inevitable with acute exercise of a novel exercise performer, it is useful to find ways of reducing EIMI while developing adequate muscle adaptation. One such strategy is to explore muscle injury and adaptation that could result from a low stimulus non-eccentrically biased exercise compared with low stimulus eccentric acute exercise.
The question of whether low stimulus acute non-eccentrically biased aerobic exercises elicit similar muscle adaptation as low stimulus eccentric exercise did in our previous study has not been addressed. The primary finding of this study was that the low stimulus down-hill (eccentric) aerobic exercise resulted in higher muscle injury than the low stimulus up-hill and level treadmill (non-eccentric) exercises. However, the muscle tissue adaptation was similar in the repeated exercise bouts in the three exercise groups.

Although the findings of this study show that all three exercise groups (LSDTEG, LSUTEG, and LSLTEG) demonstrated evidence of high muscle injury in the acute exercises, the injury was highest in the LSDTEG compared to both LSUTEG and LSLTEG. Furthermore, evidence of muscle injury was reduced in the three exercise groups in the repeated exercises. The results of this study are consistent with previous studies where there was increased evidence of muscle injury in the acute exercise bouts, but dramatic reduction in markers of muscle injury in the repeated exercises that were eccentrically biased (10,13,17,19,22,23,28). The extent of muscle injury is highly correlated with the amount of eccentric component of muscle contractions. Thus, the higher the amount of muscle contractions, the higher the injury induced (15). The LSDTEG which is eccentric in nature resulted in higher muscle injury. On the contrary, the LSUTEG and LSLTEG with low eccentric contractions components showed evidence of lower and similar muscle injuries in both the acute and repeated exercises.

The attenuations in markers of muscle injury in the repeated exercises depict muscle adaptation and protective mechanism against potentially damaging exercises in all the exercise groups. Interestingly, the LSUTEG and LSLTEG developed similar muscle adaptation like the eccentrically biased LSDTEG, which is known to induce adequate muscle adaptation (6,9,15). The present study appears to answer the question as to whether or not the acute exercise bout has to involve eccentrically biased muscle contractions to elicit serious symptoms of muscle injury in order to develop protection associated with muscle adaptation. This is because LSDTEG and the non-eccentrically biased LSUTEG and LSLTEG developed similar muscle adaptation. The LSUTEG and LSLTEG were afforded similar protection induced by the few eccentric contractions of the acute exercises against a higher amount of eccentric muscle actions 2 wks later in the repeated bout exercises.

The present study supports the findings of Paddon-Jones and Abernethy (26). These authors found that acute adaptation to low volume eccentric exercise could occur in the absence of significant muscle damage and that exposure to a small number of non-damaging eccentric contractions can significantly improve recovery after a subsequent damaging eccentric exercise bout. Koh and Brooks (17) reported that eccentric or lengthening contractions and muscle fiber degeneration are not required to induce adaptation against eccentric-induced muscle injury. Even though LSDTEG, LSUTEG, and LSLTEG were subjected to different exercises at the same stimulus in the acute exercises, similar muscle adaptations were developed.

This study demonstrates that an acute non-eccentrically biased exercise of a low stimulus can induce adequate adaptation against subsequent injurious eccentric exercises. Thus, acute exercises of non-eccentrically biased or having the same amounts of eccentric and concentric effects can be performed to stimulate adaptation process in the skeletal muscles. This finding makes the stimulus of these non-eccentrically biased exercises appropriate given that less muscle soreness was reported in the repeated exercise. Thus, the repeated bout effect can be produced with non-injurious and low stimulus acute exercises. This approach will reduce muscle soreness and, perhaps, as well motivate a sedentary person starting any exercise program to improve physical fitness.
CONCLUSIONS

This study showed that low stimulus eccentric and non-eccentric exercises induced similar muscle adaptation. However, muscle injury was higher in the eccentric exercise group in the acute exercises. Low stimulus acute exercises of non-eccentrically biased muscle work can induce adequate muscle adaptation. Therefore, acute exercises by sedentary individuals should not be eccentrically biased in order to develop muscle adaptation against damaging exercises. Thus, low stimulus acute exercises on up-hill and level treadmills can induce adequate muscle adaptation.

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