EMG activity during positive-pressure treadmill running

Iain Hunter*, Matthew Kirk Seeley, Jon Ty Hopkins, Cameron Carr, Jared Judd Franson

Department of Exercise Sciences, Brigham Young University, Provo, UT, USA

A R T I C L E   I N F O

Article info
Received 19 September 2013
Received in revised form 28 January 2014
Accepted 29 January 2014
Available online xxxx

Keywords:
Locomotion
Jogging
Athletic Performance
Rehabilitation

A B S T R A C T

Success has been demonstrated in rehabilitation from certain injuries while using positive-pressure treadmills. However, certain injuries progress even with the lighter vertical loads. Our purpose was to investigate changes in muscle activation for various lower limb muscles while running on a positive-pressure treadmill at different amounts of body weight support. We hypothesized that some muscles would show decreases in activation with greater body weight support while others would not.

Eleven collegiate distance runners were recruited. EMG amplitude was measured over 12 lower limb muscles. After a short warm-up, subjects ran at 100%, 80%, 60%, and 40% of their body weight for two minutes each. EMG amplitudes were recorded during the final 30 s of each stage.

Most muscles demonstrated lower amplitudes as body weight was supported. For the hip adductors during the swing phase and the hamstrings during stance, no significant trend appeared.

Positive-pressure treadmills may be useful interventions for certain injuries. However, some injuries, such as hip adductor and hamstring tendonitis or strains may require alternative cross-training to relieve stress on those areas. Runners should be careful in determining how much body weight should be supported for various injuries to return to normal activity in the shortest possible time.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Lower-body positive pressure treadmills like the Alter-g treadmill shown in Fig. 1 create an upward force on the runner, due to a pressure difference between the lower- and upper-bodies. Many running related injuries are connected with ground reaction forces (Jacobs and Berson, 1986; Lysholm and Wiklander, 1987). These treadmills are a popular training method in rehabilitative settings, and may increase performance for collegiate and elite runners (Eastlack et al., 2005; Grabowski and Kram, 2008; Kurz et al., 2011; Pitetti et al., 1994; Soyupek et al., 2009). The aforementioned pressure difference reduces ground reaction forces during running (Cutuk et al., 2006) and may allow injured runners to recover from injuries while still performing their preferred mode of training.

It is difficult to unambiguously link EMG amplitude and musculoskeletal injury risk; however, researchers have indirectly associated EMG and injury risk, during running, in various ways. Several researchers reported that increased gastrocnemius activity at foot–ground impact during running, reflected by increased gastrocnemius EMG amplitude, likely increases Achilles tendon stress and strain (Giandolini et al., 2013; Nigg et al., 2003; Nigg and Wakeling, 2001). Kyrolainen et al. (2005) suggested that increased EMG amplitude during running increases muscle tendon stiffness for various major muscles of the lower-extremity. Furthermore, other researchers have demonstrated that increased hip muscle EMG during running is associated with knee injury (Souza and Powers, 2009). EMG has also been used to elucidate other injuries that are sometimes associated with running, including Achilles tendinopathy (Baur et al., 2012, 2011, Giandolini et al., 2013) and ankle sprains (Baur et al., 2011). Generally speaking, all of the studies mentioned in this paragraph imply that EMG amplitude increase may reflect an increase for running injury risk.

Some lower limb muscles involved in running utilize decreased intensity of activation due to the smaller ground reaction forces (Liebenberg et al., 2011). While reduced ground reaction force may decrease muscle activation for certain muscles during stance, reduced ground reaction force likely does not assist in hip flexion during the swing phase of running. Thus, some muscle activation patterns may not be altered while using positive-pressure treadmills (relative to a traditional treadmill). For example, the hip adductor muscles act during the swing phase to help maintain sagittal plane motion of the lower limb during swing (Gazendam and Hof, 2007). Also, the hamstrings are activated during knee flexion in early swing (Gazendam and Hof, 2007); because the pressure...
difference caused by positive-pressure treadmills is between the lower and upper-bodies, hamstrings activity during early swing may not decrease while running on positive-pressure treadmills (relative to traditional treadmill running). As ground reaction forces are decreased with positive-pressure treadmill running, we expect some muscles to require lower intensities of activation since metabolic cost is decreased (Grabowski, 2010; Grabowski and Kramer, 2008).

The purpose of this study was to determine muscle activity changes during positive-pressure treadmill running. We investigated muscle activation of 12 lower limb muscles throughout the entire gait cycle at 40%, 60%, 80%, and 100% of body weight. Relative to previous, similar research (Gazendam and Hof, 2007), this study focused on additional muscles and the entire gait cycle. We hypothesized that some muscles would show decreases in activation with each degree of body weight support while others, including the adductors, would not.

2. Methods

Eleven National Collegiate Athletic Association Division I male cross-country runners (height = 1.81 ± 0.08 m, mass = 66.5 ± 5.1 kg, age = 21.2 ± 2.1 years) participated in the study after providing informed consent. This study was approved by the institutional review board and conformed with the ethical standards in sport and exercise science research (Harriss and Atkinson, 2011). All subjects were free of injury and had been consistently training for at least six months. After the skin surface was shaved, debrided, and cleaned, Delsys Trigno Wireless electrodes (manufacturer info) were placed over the following 12 muscles of the right lower limb: gluteus maximus, gluteus medius, medial hamstrings, lateral hamstring, vastus medialis, vastus lateralis, rectus femoris, hip adductors, gastrocnemius, soleus, peroneus longus, and tibialis anterior. Electrodes were placed at an estimated point midway between the muscle insertion and innervation zone, along the longitudinal axis of the muscle as described by Basmajian and DeLuca (1985). Placement was confirmed using manual muscle testing. Subjects then ran for two minutes at 100% body weight at a belt speed of 4.47 m/s (6:00 min/mi). This speed was chosen as it is a common speed of training for many of the long runs these subjects complete. EMG was recorded for twenty seconds beginning at 1:30 of each stage. This matches the time used in a previous treadmill running study for kinematics to stabilize (Riley et al., 2008). After the first two minutes of running, subjects continued at the same pace at 40%, 60%, 80% and 100% of body weight in random order for two more minutes at each body weight controlled by the researchers through the computer that controls the treadmill chamber’s pressure. Electromyography (EMG) data were collected (4000 Hz) for 20 s during each of the aforementioned body weight percents using the Trigno Wireless EMG System. The electrodes have a bipolar Ag/AgCl surface (Delsys Inc., Boston, MA, USA) with a fixed inter-electrode distance of 1 cm and are 10 x 1 mm. Gel was not required for these electrodes and were applied to subjects using double-sided tape. The common mode of rejection ratio that is greater than 80 dB. All electrode application procedures will follow previously recommended guidelines (Hermens et al., 2000).

Stance and swing phases were determined using the Trigno sensor’s ability to collect acceleration along with EMG (273 Hz), using the method described by Chapman (Chapman et al., 2012). Root mean square (RMS) amplitudes using a 50 ms window were calculated during four parts of the gait cycle: first half of stance, second half of stance, full stance, and full swing. The specific phase of interest for each muscle was determined as the phase that exhibited relatively high RMS amplitudes. If the amplitude remained relatively high throughout all of stance, the entire stance phase was included in the analysis. All EMG amplitudes were normalized to the 100% condition. This was done by dividing the average EMG amplitude of each condition by the average EMG amplitude of the 100% condition for each phase of interest.

A simple linear regression was completed for each muscle at the chosen phases of interest for that specific muscle with an alpha of 0.05. The normalized EMG average amplitude and percent of body weight were the dependent and independent variables respectively.

3. Results

Most muscles demonstrated lower amplitudes as more body weight was supported (Table 1 and Figs. 2 and 3). Generally, it appears that the muscles involved in support of the body used less activation as body weight was supported. However, for the hip adductors during the swing phase and the medial and lateral hamstrings during stance, a significant trend was not observed (p = 0.63, 0.22, and 0.44 respectively). Most of the muscles in this study have been investigated in the past with positive-pressure treadmill running, but we found two muscle groups that had no significant decrease in muscle activation throughout the body weight support conditions investigated here.

Table 1

<table>
<thead>
<tr>
<th>Muscle and phase</th>
<th>Standardized β</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip adductors swing</td>
<td>0.14</td>
<td>p = 0.63</td>
</tr>
<tr>
<td>Vastus lateralis stance</td>
<td>0.72</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Rectus femoris stance</td>
<td>0.64</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Vastus Medius Stance</td>
<td>0.70</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Gluteus medius stance</td>
<td>0.66</td>
<td>p = 0.02</td>
</tr>
<tr>
<td>Gluteus maximus stance</td>
<td>0.48</td>
<td>p = 0.07</td>
</tr>
<tr>
<td>Medial hamstring first half of stance</td>
<td>0.18</td>
<td>p = 0.22</td>
</tr>
<tr>
<td>Lateral hamstring first half of stance</td>
<td>0.39</td>
<td>p = 0.44</td>
</tr>
<tr>
<td>Peroneus Longus Stance</td>
<td>0.37</td>
<td>p = 0.01</td>
</tr>
<tr>
<td>Soleus Stance</td>
<td>0.46</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Tibialis anterior first half of stance</td>
<td>0.41</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Gastrocnemius Stance</td>
<td>0.47</td>
<td>p &lt; 0.01</td>
</tr>
</tbody>
</table>

*Significantly different at p < 0.05.
4. Discussion

Most muscles in this study showed decreases in activation as more body weight was supported. This shows part of the benefit of using positive-pressure treadmills in a rehabilitative setting. However, care should be taken when interpreting these results. A significant slope is encouraging, but some slopes were fairly small (Fig. 2). For example the peroneus longus activity had a statistically significant slope ($p = 0.01$) with body weight support, but did not decrease in activity as much as many other muscles. For the peroneus longus, this may be due to the different plane of motion leading to extra body weight support having less of an effect on activation.

So, someone with an ankle inversion injury or peroneus longus tendinitis should run with a relatively low body weight since body weight support has a smaller effect compared with some other muscles. However, someone with patella tendonitis may be safe running with only a small amount of body weight supported since the vastus medialis, vastus lateralis, and rectus femoris activities decrease dramatically as more body weight is supported.

There were also two muscles groups that showed no decrease in muscle activity during certain phases. During the swing phase, the hip adductors are relatively unchanged in activity as different amounts of body weight were supported. This is an important part of the running cycle where the adductors have a peak of activation likely to keep the swing leg moving in the forward direction (Gazendam and Hof, 2007). Since the effort of swinging the leg forward is not changed by the upwards force on the body, injuries related to the hip adductors will likely not be improved with this type of treadmill use.

During the first half of the stance phase, the medial and lateral hamstrings remained unchanged through the range of body weights. This was somewhat unexpected since this phase is connected with supporting body weight. Perhaps with extended training on a positive-pressure treadmill, runners would gradually alter their technique to the point that hamstring activity could be decreased as body weight is supported. However, for runners that are new to this type of training, the hamstrings seem to work equally during the first half of support. This is different than what Thomas et al. found with elderly women walking at 100% compared with 60% (Thomas et al., 2011). This is easy to explain since these activities and populations were very different. It seems that the hamstrings are less involved in body support than expected. They will still need high muscle activation to aid in producing the appropriate horizontal forces required in running which were not decreased enough by the positive-pressure treadmill. However, researchers and practitioners should realize our findings cannot be applied to all situations for positive-pressure treadmill use.

Another potential benefit of positive-pressure treadmill running is known as over-distance training. Some elite marathoners use positive-pressure treadmills to add to their weekly mileage without adding as much stress to their bodies. The results of this study show that, for most lower limb muscles, muscle activation decreases more body weight is supported. Thus, if there are concerns about the stress on a specific muscle or tendon, this study can be used to aid in selecting an appropriate amount of body weight that should be supported.

Runners maintain velocities with a lower metabolic cost when running with positive pressure treadmills due to the decreased vertical forces required (Grabowski and Kram, 2008). In order to maintain the metabolic cost, runners can increase treadmill speed according to the following equation derived from Grabowski’s work:

$$v_{new} = (6.11 + 2.29 \times \frac{\text{BW}}{\text{orig}} - 6.11 \times \frac{\text{BW}}{\text{orig}})/2.29$$

If someone plans on running with a greater treadmill speed to increase metabolic cost, they should realize certain muscles may require a greater load during certain phases of running. This could lead to greater stresses on certain muscles like the hip adductors and hamstrings. Thus, after considering the benefits of positive-pressure treadmill use, care should still be taken when determining the specifics of utilizing this type of training on an injured patient or athlete.

Underwater running also provides a cross-training method that decreases ground reaction forces (Masumoto et al., 2009; Masumoto and Mercer, 2008). However, running without the fluid resistance of water allows for a cross-training method without the increased effort required during the swing phase. This provides a running style more similar to over-ground running.

Positive-pressure treadmills provide some horizontal support. This may affect muscle activation differently than traditional treadmill running. While this makes comparing these results with...
traditional treadmill running difficult, the 100% condition has no vertical support, but similar horizontal support to the other compared conditions.

Any dynamic EMG study has issues with electrode movement over the skin. Fortunately in this study, we were comparing equal phases of the running stride, so electrodes should have been in the same location over the muscle for each time of measurement. However, there may still have been some drifting away from the specific muscles than were desired. There was also likely some crosstalk occurring over certain muscles. In these cases, we chose to name the muscles by groups instead a specific muscle. These included adductors and medial and lateral hamstrings. Some crosstalk also likely occurred with the quadriceps muscles. However, our best efforts were made to isolate those muscles as carefully as possible. There was very little trouble ensuring the correct muscles were sampled in certain locations, such as the hamstrings, soleus, and gastrocnemius.

Due to lower activation of certain muscles, positive-pressure treadmills may be a useful intervention for certain running related injuries. However, some injuries, such as hip adductor and hamstring tendonitis or strains may require alternative cross-training. These included adductors and medial and lateral hamstrings. Some crosstalk also likely occurred with the quadriceps muscles. However, our best efforts were made to isolate those muscles as carefully as possible. There was very little trouble ensuring the correct muscles were sampled in certain locations, such as the hamstrings, soleus, and gastrocnemius.

Conflict of Interest

There are no conflicts of interest related to this study.

Acknowledgements

No funding sources were used in this study.

References


Grabowski AM, Kram R. Effects of velocity and weight support on ground reaction forces and metabolic power during running. J Appl Biomech 2008;24:288–97.


Cameron Carr received his Bachelor of Science degree in Exercise Science from Brigham Young University in 2012. He is currently pursuing an M.D. degree at The University of Texas Southwestern Medical School. His research interests include optimization of track and field technique, running economy, and ischemia-reperfusion injury.

Jared Franson is an athletic trainer at Brigham Young University for their Track and Field/Cross Country teams. He has been there since 2010 where he started as a graduate student and completed his Masters degree in athletic training in 2012. He is now the head trainer for the Track and Field/Cross Country teams.