

Research article

Effects of motorized vs non-motorized treadmill training on hamstring/quadriceps strength ratios

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Abstract

Previous literature suggests that muscular involvement and biomechanical changes elicit different responses between overground and treadmill training. The objective of this study was to examine the effects of training on two different treadmill designs on the conventional (CR; concentric only) and functional (FR; eccentric to concentric) hamstring and quadriceps strength ratios. Fifteen men and sixteen women were randomly divided into three groups: motorized (MT), non-motorized (NMT) or control (C). Subjects completed pre and post-test isokinetic concentric and eccentric quadriceps and hamstring testing of both legs. Subjects completed 4 weeks of training on their respective treadmills with mileage increasing ½ mile each week, beginning with 2 miles. The C group did not participate in any training. The CR revealed a significant two way interaction of group x time with MT increasing (pre: 0.80 ± 0.09 to post: 0.84 ± 0.09), NMT decreasing (pre: 0.76 ± 0.13 to post: 0.74 ± 0.10), and C showing no change (pre: 0.79 ± 0.10 to post: 0.79 ± 0.09). The FR revealed a significant two way interaction of speed x sex with the FR increasing as speeds increased for men (60 degrees s⁻¹: 1.04 ± 0.11 ; 180 degrees s⁻¹: 1.66 ± 0.27 ; 300 degrees s⁻¹: 2.36 ± 0.45) and women (60 degrees s⁻¹: 1.05 ± 0.16 ; 180 degrees s⁻¹: 1.90 ± 0.26 ; 300 degrees s⁻¹: 2.75 ± 0.47) but women increased greater relative to men. Training mode elicited a specific change in concentric hamstring and quadriceps strength resulting in specific changes to the CR; however, neither training mode had an effect on eccentric hamstrings nor the FR. Special attention should be given to the mode of endurance training when the goal is to alter the hamstring/quadriceps CR.

Key words: Concentric, eccentric, conventional, functional, running, walking.

Introduction

Various modes of aerobic training have grown increasingly popular as recreational activities for many individuals. Running as well as walking involves a series of complex movements at multiple joints. Regardless of training mode, the body adapts and adjusts to the stresses placed on it. Often, recreational runners train outdoors and run overground when weather permits. However, there are instances when training indoors is necessary and a treadmill is the only readily available training mode. The treadmill is a sensible choice as an alternative to overground training due to its availability, as well as the ability to maintain a specific speed and slope (Schache et al., 1999). Previous literature suggests that body positioning, muscular involvement, and biomechanics change between overground and treadmill training (Schache et al., 1999).

Studies have investigated muscular activity in treadmill training compared to overground training (Prentice, 2006; Vogt et al., 2002). The results of these studies, however, are contradictory and inconsistent. Previous studies investigated a number of kinematic parameters involved in treadmill training as well as in overground training. These parameters include the knee in the sagittal plane, movements at the ankle joint, and kinematics of the lumbo-pelvic-hip complex (Baur et al., 2007; Bickham, 2000; McKenna and Riches, 2007; Riley et al., 2008; Riley et al., 2010; Schache et al., 1999; 2000; 2001; 2002; 2003; 2005; Vogt et al., 2002). Furthermore, few studies have investigated lower limb muscular involvement in overground and treadmill training as well as hamstring strength with various training modes (Croisier et al., 2007; Gajdosik et al., 1985; Koller et al., 2006).

A fundamental component of athletic activity is efficient movement. Improper or inefficient kinematics can cause individuals to alter muscle recruitment, therefore developing impairments, and leading to greater susceptibility to injury. Previous literature suggests if the pelvis is in an anteriorly rotated position, it may disrupt the length of a muscle's moment arm which in turn causes dysfunction to the ideal positions of the joint and the muscles surrounding it (Grossman et al., 1982; Janda, 1993). Therefore, an alteration to that particular muscle could adversely affect maximal force production. When alteration occurs, muscles in an altered length may undergo physiological changes (Grossman et al., 1982; Janda, 1993). Various training modes create a diverse training experience and force the body to engage different muscles to stabilize and move through the given range of motion. Few studies have investigated a change in muscle activation and strength between various aerobic training modes, including motorized and non-motorized treadmills.

Motorized treadmills have a flat running surface with a motor that propels a continuous moving belt in which the runner attempts to match the speed through stride length and stride rate. Non-motorized treadmills have a curved surface without a motor which requires the runner to stride on the surface and propel the belt with each stride. Past studies have concluded when running on a motorized treadmill there is a more pronounced forward leaning of the upper torso (Baur et al., 2007; Tong et al., 2001). With this forward leaning posture, muscles of the erector spinae as well as paraspinals are placed on stretch and hip flexors are in a more shortened position. Strength and range of motion of the muscles involved in hip and knee flexion and extension, specifically eccentric and

concentric hamstring strength, are vital components for runners of all levels.

With motorized treadmill training, the pelvis is placed in a more anteriorly rotated position, forcing the hip flexors to be further shortened and causing a decrease in hip flexion range of motion. At this time, there is a lack of research regarding the role of motorized vs. non-motorized treadmill training and their effect on hamstring and quadriceps strength. Therefore, the purpose of this study was to examine the effects of motorized vs. non-motorized treadmill training on the hamstring/quadriceps strength ratios.

Methods

Participants

Fifteen men (age: 22.67 ± 2.16 years; height 1.78 ± 0.09 m; mass 83.00 ± 14.22 kg) and sixteen women (age: 22.31 ± 1.62 years; height 1.65 ± 0.06 m; mass 73.33 ± 15.69 kg) were counterbalanced into three groups: motorized treadmill (MT; 5 women, 5 men), non-motorized treadmill (NMT; 6 women, 5 men), and control (C; 5 women, 5 men). Approval for this study was obtained from the University Institutional Review Board. Participants were non-runners and stated they did not regularly participate in running activities within the last six months. Subjects were free of chronic as well as acute musculoskeletal or neurological injuries within the last six months. Written informed consent was obtained from each subject prior to the start of testing. All subjects restricted additional fitness activity during the training and testing period and were limited to the study training protocol. No subjects missed more than two non-consecutive training days.

Procedures

Each subject completed a pre-test and post-test measurement of isokinetic concentric and eccentric hamstring/quadriceps strength at three angular velocities: 60, 180 and 300 degrees \cdot s $^{-1}$. The conventional ratio (CR) was calculated as the ratio of concentric hamstrings (CH) to concentric quadriceps (CQ). In addition, we calculated the functional ratio (FR) which is defined as the ratio of eccentric hamstring (EH) to CQ moments (Aagaard et al., 1998).

Strength testing

The testing protocol began with a five-minute general warm-up on a cycle ergometer at 50 watts with a self-selected cadence. Bilateral isokinetic testing was conducted using a Biodex System 3 dynamometer (Biodex Medical Systems, Shirley, NY). Subjects were seated on the dynamometer with their body stabilized by straps over the thighs, waist and chest. Once seated and strapped, range of motion was set at 10 degrees to 90 degrees of flexion (0 degrees at full extension). Prior to testing, subjects completed a familiarization and specific warm-up of 5 repetitions at 120 degrees \cdot s $^{-1}$. Order of testing was from slow to fast: 60, 180 and 300 degrees \cdot s $^{-1}$. Subjects performed five repetitions at each velocity and muscle action. Peak torque was recorded as the maximum torque

during any repetition. Rest intervals between speeds were two minutes and five minutes between muscle actions. Subjects did not receive any visual feedback, but were verbally encouraged throughout the duration of testing.

Motorized treadmill training

Subjects performed all training sessions on a Quinton treadmill (Quinton Fitness Equipment, Clubtrack, Fontana, CA). Subjects completed a familiarization session of ten minutes on the motorized treadmill prior to the first session. They completed 4 weeks of training with three sessions per week. The treadmill was set at no incline for the duration of the training period. Each training session began with a five-minute warm-up on the treadmill at 45% of heart rate reserve (HRR, Karvonen method). After five minutes, effort increased to 65% of the subjects' HRR. We measured heart rate using POLAR heart rate monitors (HR, Polar Electro Inc., FS1 and TS1, Woodbury, NY). Mileage increased ½ mile per week. The first week, subjects completed two miles per visit, the second week 2.5 miles per visit, the third week three miles per visit and the fourth week 3.5 miles per visit.

Non-motorized treadmill training

Subjects performed all training sessions on a CURVE treadmill (Woodway, Waukesha, WI). Subjects completed a familiarization session of ten minutes on the non-motorized treadmill prior to the first session. They completed four weeks of training with three sessions per week. Each training session began with a five-minute warm-up on the treadmill at 45% of heart rate reserve (HRR, Karvonen method). After five minutes, effort increased to 65% of the subjects' HRR. We measured heart rate using POLAR heart rate monitors (HR, Polar Electro Inc., FS1 and TS1, Woodbury, NY). Mileage increased ½ mile per week. The first week, subjects completed 2 miles per visit, the second week 2.5 miles per visit, the third week 3 miles per visit and the fourth week 3.5 miles per visit. Subjects assigned to the control group participated in the pre and post isokinetic testing but did not participate in any treadmill activity for the duration of the study.

Statistical analyses

Statistical analyses were performed using SPSS for Windows (version 19.0; Chicago, IL). The level of significance was set a-priori at $p < 0.05$. Two $2 \times 3 \times 2 \times 2 \times 3$ (time \times group \times sex \times leg \times speed) mixed factor ANOVA's analyzed CR and FR.

Results

The CR ANOVA revealed a significant ($p < 0.05$) two way interaction of group \times time. The CR for the Motorized (MT) group increased, the non-motorized (NMT) decreased, and control (C) did not change from pre to posttest (Figure 1). These ratios are explained by the values in Table 1 where the MT group showed a greater increase in CH relative to CQ, the NMT group showed a greater increase in CQ relative to CH and the C group showed similar increases in CH and CQ.

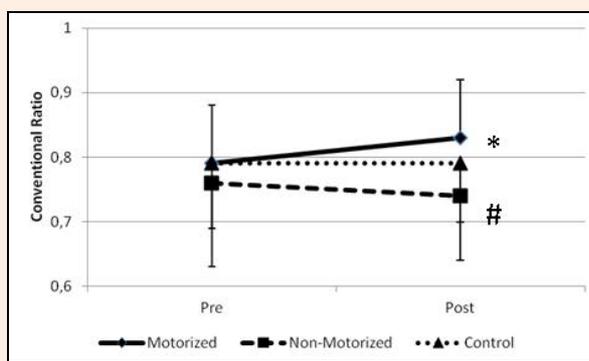
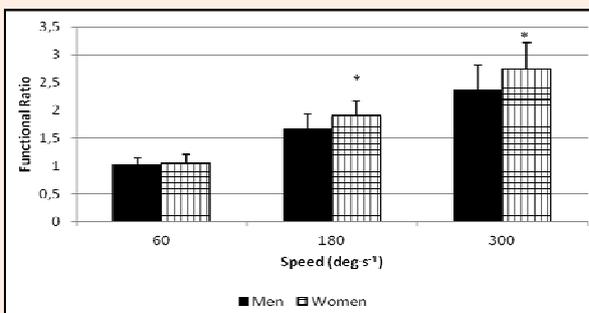
The FR ANOVA demonstrated no significant ($p >$

Table 1. Pre and post concentric hamstring (CH) and concentric quadriceps (CQ) peak torque ($\text{N}\cdot\text{m}^{-1}$) by group collapsed across sex, speed and leg. Data are means (\pm SD).

	Motorized		Non-Motorized		Control	
	CH	CQ	CH	CQ	CH	CQ
Pre	95.2 (18.4)	126.3 (24.6)	91.8 (29.2)	127.7 (37.9)	100.1 (26.7)	135.5 (41.7)
Post	100.8 (31.0)*	125.1 (36.5)	94.4 (26.6)	133.5 (34.1)*	105.2 (26.3)*	139.1 (44.8)*

* Significantly greater than Pre.

0.05) interactions involving time and group but there was a significant ($p < 0.05$) two way interaction of speed \times sex. The FR increased for both men and women as speed increased but increased greater in women relative to men (Figure 2). These ratios are explained by the values in Table 2 where EH increased at a similar rate across speeds for each sex but CQ decreased greater for women relative to men (Table 2).

**Figure 1.** Pre and post conventional ratios (mean \pm SD) by group collapsed across sex, speed and leg. * significantly greater than Pre, # significantly less than Pre.**Figure 2.** Functional ratios by sex and speed (mean \pm SD) collapsed across group, time and leg. * significantly greater than men.

Discussion

The purpose of this study was to examine the effects of motorized vs. non-motorized treadmill training on the hamstring/quadriceps CR and FR. The main finding was that the different types of treadmills elicited dissimilar

outcomes when comparing quadriceps and hamstring strength. The motorized treadmill had greater effect on the hamstrings resulting in a CR increase while the non-motorized treadmill affected the quadriceps to a greater extent resulting in a CR decrease. Neither form affected the FR.

Few studies have examined the role of treadmill training and its specific role in muscular adaptations (McKenna and Riches, 2007; Riley et al., 2008; Schache et al., 1999; Schache et al., 2001). Additionally, these studies have focused on kinematic changes rather than changes in strength. We examined both the CR and FR due to the inconsistent findings of previous literature on the validity of one or both ratios as a tool to assess the risk of injury (Aagaard et al., 1998; Ahmad et al., 2006; Delestrat et al., 2010; Holcomb et al., 2007; Hole et al., 2000; Mjolsnes et al., 2004; Rosene et al., 2001). It has been suggested that body positioning, muscular involvement, and biomechanics are different between overground vs. treadmill training (McKenna and Riches, 2007; Riley et al., 2008; Schache et al., 1999; Schache et al., 2001). Prior research has shown significant differences in hip flexion and hip extension differences between overground and treadmill training (Schache et al., 1999). McKenna and Riches (2007) reported that the hip extension angle at toe-off was significantly less on a motorized treadmill when compared to overground. Furthermore, knee extension, knee abduction and ankle plantar flexion significantly increased for overground vs. treadmill training (Riley et al., 2008). A NMT is most similar to overground locomotion in that the leg must actively pull through on each step since the belt is not motorized. In addition, the MT has a flat surface while the specific NMT used in this study has an incline curve at both ends. This incline curve might place the body in a more forward leaning position during locomotion. Our results suggest that MT training elicited greater hamstring involvement and less quadriceps, resulting in a decrease in CQ strength. In contrast, NMT training increased both the CH and CQ but elicited greater quadriceps involvement relative to hamstrings. This may be due to the incline curve at the front of the NMT, requiring greater hip flexion at foot strike and greater hip extension during toe-off. Although we did not measure hip musculature, it has been suggested that reliance on different muscles and joint positions can affect muscle recruitment (Prentice, 2006). While it seems logical that training on the NMT, with the need to pull

Table 2. Eccentric hamstring (EH) and concentric quadriceps (CQ) peak torque (N/m ; mean \pm SD) by sex and speed collapsed across group, leg, and time.

	60 $\text{deg}\cdot\text{s}^{-1}$		180 $\text{deg}\cdot\text{s}^{-1}$		300 $\text{deg}\cdot\text{s}^{-1}$	
	EH	CQ	EH	CQ	EH	CQ
Men	222.4 (61.6)	213.4 (42.7)	254.2 (67.7)	153.3 (23.1)*	256.4 (48.8)	112.2 (23.2) *#
Women	152.4 (40.4)	145.9 (27.3)	186.9 (52.2)	99.2 (17.8) *	186.9 (46.5)	68.7 (12.4) *#

* Significantly less than 60; # significantly less than 180.

through on each step, would elicit greater hamstring involvement than the MT, this is not supported by our results. This could be due to greater use of the hip extensors on the NMT and the greater force they generate relative to the hamstrings. Moreover, the MT may have elicited less quadriceps involvement because the belt carried the leg through each stride with a constant belt speed, which is in contrast with the variable self-propelled belt speed occurring with each stride on the NMT.

Conventional ratio

Several studies have investigated factors influencing the CR (Aagaard et al., 1995; 1998; Ahmad et al., 2006; Holcomb et al., 2007; Hole et al., 2000; Rosene et al., 2001). However, very few have investigated the effect of training mode on that ratio. Rosene et al. (2001) conducted a study investigating the differences in the CR for a collegiate athletic population. Various sports included in their study were men's and women's volleyball, men's and women's soccer, women's basketball and women's softball. Similar to the results of our study, they also found no significant differences between legs. This may be due to the fact that the sports they investigated and treadmill training both engage right and left limbs similarly.

Zakas et al. (1995) examined CR ratios between different levels of basketball and soccer players and reported no significant differences. Contrary to these results, Read and Bellamy (1990) reported significant differences between tennis, squash, and track athletes. The authors attributed these differences to training adaptations, strength, flexibility, and level of competition. While both studies compared ratios between sports, results may have been different because of the varying demands of the sports that were investigated. While there are differences in sport demands between basketball and soccer, greater differences are seen between tennis, squash, and track. This illustrates the need to understand the specific training adaptations associated with different modes of training, which was a focus of our study.

Holcomb et al. (2007) investigated the effect of hamstring-emphasized resistance training on CR strength ratios using collegiate women soccer players. Subjects participated in a six-week strength training program and were tested pre and post. Contrary to our results, their study revealed no significant difference for the CR ratio. The authors believed they would see a significant increase in the ratio following training because prior literature suggests that soccer players have a decreased CR due to stronger quadriceps. However, their subjects had pre ratios higher than average, which probably masked any CR changes.

Functional ratio

The FR may be an important aspect for measuring muscular strength relationships because knee joint movement involves eccentric hamstring muscle actions simultaneously with concentric quadriceps actions during extension and vice versa during flexion (Aagaard et al., 1995; 1998). It has been suggested that specified training, such as eccentric and Nordic hamstring exercises may alter EH strength (Holcomb et al., 2007; Hole et al., 2000). In a

concentric study, Mjolsnes et al. (2004) found no significant increases in EH strength following a ten-week progressive program of CH exercises. Their findings are consistent with ours, as we did not see significant increases in EH strength following either MT or NMT training.

In contrast to our findings, Holcomb et al. (2007) showed a significant increase in the FR following six weeks of hamstring-emphasized resistance training. Their results demonstrated that FRs increased above 1.0 (i.e. EH and CQ are equal), which is meaningful due to evidence suggesting a FR greater than 1.0 may aid in the prevention of ACL injuries (Aagaard et al., 1998). Differences between our results and those of Holcomb may be due to study design. Holcomb focused on resistance training of the hamstrings while our study focused on endurance training utilizing both quadriceps and hamstrings. Furthermore, their resistance training program lasted six weeks while we investigated changes across four weeks only. Since the NMT training required participants to pull their legs through for propulsion, this may have required greater quadriceps involvement; resulting in greater quadriceps strength changes. As mentioned earlier, this may be explained by the inclined, curved design of the treadmill and the more forward position in which the body is placed to maintain stride length. Due to the forward body position, adaptations occur in a specific manner relative to the stride and pull-through demands for propulsion.

In a clinical study, Hole et al. (2000) examined both the CR and FR in men and women with ACL ruptures awaiting surgical reconstruction. Interestingly enough, they did not find any differences between injured and normal sides for either ratio. The authors attributed this to the fact that most subjects sustained their injury a year prior to the study. Dvir et al. (1989) suggested that over longer periods of time following injury, full return of hamstring strength is achievable. Hole et al. (2000) found significant strength decreases in EH and CQ when comparing normal and injured sides. While we tested pre and post training and examined men and women, our results were not consistent with their findings, as our study showed no changes in EH and a decrease in CQ for the MT group. This may be explained as a function of the subject population as we used healthy recreationally trained subjects while Hole used injured subjects who were ACL deficient and they also saw no ratio changes. Therefore, the validity of the CR and FR as an evaluation tool for ligament laxity and dynamic stability of the knee may be called into question (Ahmad et al., 2006).

A study conducted by Delextrat et al. (2010) investigated the use of the CR and FR as tools to assess fatigue in soccer players. Their results revealed significant decreases in both ratios following soccer specific field tests. They suggested that the FR is a more valid measurement of fatigue brought on by soccer specific activities when compared to the CR. They also speculated that high velocity eccentric strength training may be necessary for injury prevention in soccer players. While our training did not include sprinting or specific high velocity, eccentric movements, it did involve brisk walking, jogging or running. Therefore, the MT training may have forced the

hamstrings to adapt to faster movements rather than slow, easy walking, leading to an increase in the CR.

Conclusion

The main findings of this study are that training mode elicited a specific change in CH and CQ strength resulting in specific changes to the CR; however, neither training mode had an effect on EH or the FR. Our results may indicate that MT training might be the proper aerobic training tool for an individual whose goal is to increase their CR. In contrast, NMT training might be the choice for an individual whose goal is to decrease their CR. Furthermore, we were able to see changes in the CR in only four weeks of training while other studies have used six to ten weeks (Hole et al., 2000; Koller et al., 2006; Prentice, 2006). Depending on the particular population and the demands of their sport, special attention should be given to the mode of endurance training when the goal is to alter either the CR or FR.

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Key points

- Specificity of treadmill training had different effects on concentric strength.
- Specificity of treadmill training had little or no effect on eccentric strength.
- Conventional and functional strength ratios may give different results based on training mode.
- Four weeks is long enough for strength results to be apparent in untrained people.

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