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The Effect of Motorized vs Non-Motorized Treadmills on Exercise Economy during Acute Sub-maximal Bouts in Collegiate Cross-Country Female Athletes

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ABSTRACT

Background: Fitness equipment manufacturers have developed non-motorized treadmills (NMT) to better replicate overground running, a characteristic which motorized treadmills (MT) purportedly lack. Because NMTs are novel, limited empirical evidence exists regarding acute physiological and neuromuscular activity responses to its use. **Objectives:** The purpose of this investigation was to examine the effect of walking and running on an NMT and MT on exercise economy (EE), cardiometabolic responses, lower-body muscle activity, and rating of perceived exertion (RPE) in division II female cross-country athletes. **Methods:** Thirteen female cross-country athletes volunteered to complete a treadmill protocol that consisted of a warm-up walk, a 5-min walk, a 5-min run, and a 5-min cool-down walk on an NMT and MT on two separate occasions. During both treadmill conditions, VO_2, RER, neuromuscular activity, HR, and RPE were recorded and analyzed every minute. **Results:** VO_2 (NMT= 36.8 ± 10.0 ml/kg/min; MT= 27.4 ± 6.7 ml/kg/min), RER (NMT= 1.02 ± 0.14; MT= 0.89 ± 0.08), HR (NMT= 167 ± 18 bpm; MT= 142 ± 21 bpm), and RPE (NMT= 12 ± 2; MT= 9 ± 2) measures were significantly ($p<0.05$ for all) greater on the NMT than the MT in walking and running. **Conclusions:** The greater VO_2, RER, and HR experienced on the NMT indicates higher physical exertion, and the greater RPE on the NMT indicates the participants' perception of exertion correspond to the physiological responses. While cardiometabolic demand was greater on the NMT, thereby suggesting exercise economy was greater with the MT.

Key words: Aerobic, Running, Electromyography, Oxygen Uptake, Walking

INTRODUCTION

Practitioners have available to them a variety of training modes and protocols to enhance their clients' health or athletes' performance. Exercise on treadmills offers a consistent, accessible, and reliable form of aerobic training commonly used when outdoor areas are not accessible due to inclement weather or limited space availability. Fitness equipment manufacturers have introduced curved non-motorized treadmills (NMT) in general fitness, laboratory, and athletic settings. Compared to running on a motorized treadmill (MT), which allows an individual to run on a belt at different speeds determined by an external motor, NMTs have been shown to better mimic overground locomotion, allowing individuals to voluntarily manipulate speed, gait, and pace (De Witt, Lee, Wilson, & Hagan, 2009; Fullenkamp, Matthew Laurent, & Campbell, 2015; Stevens et al., 2015). Recent investigations have examined NMT exercise on anaerobic performance (Gonzalez et al., 2013; Highton, Lamb, Twist, & Nicholas, 2012; Mangine et al., 2014), maximal oxygen uptake (VO_{2max}) (Bacon, Carter, Ogle, & Joyner, 2013; Morgan, Laurent, & Fullenkamp, 2016), cardiometabolic demand (Edwards, Tofari, Cormack, & Whyte, 2017; Li, Xue, Hong, Song, & He, 2020; Schoenmakers, Crisell, & Reed, 2020), and muscular strength (Franks, Brown, Coburn, Kersey, & Bottaro, 2012). However, there is minimal research that understands exercise economy (EE) and neuromuscular activity while using an NMT.

During running, the human body experiences several physiological changes, including an increase in cardiac output and ventilation. This subsequently increases blood volume delivery throughout the body, increasing oxygen availability to the exercising skeletal muscle, thereby allowing an increase in oxygen uptake (VO_2). The capacity to convert oxygen to work is known as EE, which is normally expressed as pulmonary oxygen uptake for the mechanical work completed (Gaesser & Brooks, 1975). An increase in EE translates to greater oxidative phosphorylation of adenosine triphosphate (ATP) to fuel the muscle force generation required for a given external workload (Burton, Stokes, & Hall, 2004). Additionally, during a sustained exercise intensity, the body reaches a steady state; a concept implying that cardiovascular and respiratory gas responses are sufficient to meet the metabolic demand of the exercise stress (Ferretti, Fagoni, Taboni, Bruseghini, & Vinetti, 2017) leading to

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specific adaptations. For example, training at higher speeds, it has been shown to enhance running EE (Bacon et al., 2013; Skovgaard et al., 2014). While literature on the topic on NMT and EE is limited, one study reported running EE was greater on the MT compared to NMT trials (Edwards et al., 2017), additionally increasing cardiometabolic stress when NMT was used.

The curved belt of the Woodway Curved NMT (Woodway Inc., Waukesha, WI) may offer advantages to runners due to its concave form, self-propelled belt, and ability to change acceleration freely. NMT may have some biomechanical advantages related to foot strike patterns, however it has been shown to have a detrimental effect on physiological stress for a given speed in acute bouts (Edwards et al., 2017; Morgan et al., 2016). Although individuals running on a MT executes a more natural running stride, the NMT encourages individuals to forefoot strike. This type of running technique requires an increase in muscle group activation compared to a overground running, where rearfoot striking is used more commonly (de Almeida, Saragiotto, Yamato, & Lopes, 2015; Gonzalez et al., 2013). Forefoot strike running gait indicates a reduction on the impact on joints by eliminating the ground reaction force of heel strike and allows proper running posture (Lorenz & Pontillo, 2012). Along with foot-strike patters, lower-body muscle activation can help indicate biomechanical markers on different locomotive surfaces. Previous research has indicated that during walking, jogging, and running conditions, there was an increase in muscle activity in rectus femoris, semitendinosus, and soleus in NMT when compared to MT and overground surfaces (Montgomery, Abt, Dobson, Smith, & Ditroilo, 2016).

While NMTs are increasingly available and marketed, the effect that curved NMTs have on exercise economy and neuromuscular activity during sub-maximal aerobic exercise bouts compared to traditional MTs is not well known. Due to the specific adaptations that occur with imposed demands, it is important to understand whether a difference in demands, and the body's responses to them, exist between exercise on NMTs and MT's. If different, the acute responses to each treadmill would have implications on long-term training effects, and thus this information would be important for exercise professionals to use when selecting equipment to meet their client's specific goals. The purpose of this study was to therefore, investigate the effect of walking and running on an NMT and MT on lower-body neuromuscular activity and exercise economy in NSCAA Division II female cross-country athletes.

METHOD

Experimental Approach

A cross-sectional randomized design was implemented to examine lower-body muscle activity, respiratory exchange ratio (RER), rating of perceived exertion (RPE), VO_2, and heart rate (HR) during sub-maximal steady-state walking and running bouts on an NMT and MT. To investigate these effects the study was conducted over three sessions. The first session served as a familiarization session while the two following testing sessions were randomized for treadmill type, non-motorized treadmill and motorized treadmill (independent variables). In both testing session the lower-body EMG, $VO_{2,}$ RER, HR, and RPE (dependent variables) were assessed every minute during 5 minute walking and running bouts.

Participant Characteristics

Thirteen female cross-country division II athletes (mean ± SD; age = 21 ± 3 y, height = 161.5 ± 4.9 cm, mass = 55.4 ± 6.4 kg) volunteered to participate in three testing sessions. A sample size calculation was not conducted as this was a convenience sample of female cross-country athletes on a single team. Participants were included in the study if they cleared all screening questionnaires, were currently on the women's cross-country team at the university, and were free from lower-body injuries. Participants were excluded from the study if they didn't clear the screening questionnaires, reported an injury in the last 6 months, or was not currently on the female cross-country team. The university's institutional review board (IRB) approved (#IRB-FY2017-57) this study and IRB approved informed consent was obtained where subjects were informed of the benefits and risks of the investigation. Prior to participation, individuals completed a health history questionnaire and a physical activity readiness questionnaire (PARQ). Both testing sessions were scheduled at least 24 hours between sessions and time with +/- 1 hour. For consistency, participants were instructed to maintain consistent diet and hydration habits over the course of this study and were asked to eat similar meal 24 hours prior to both testing sessions. Participants were also asked to refrain from any additional exercise outside of their normal scheduled practice and any supplementation/drug use throughout the duration of the study.

Procedures

Day 1 (Familiarization session)

The first session acted as a familiarization session for participants. Participants read and signed the IRB-approved informed consent document and completed the preliminary medical and PARQ. Height and weight were measured, and participants were familiarized verbally and physically with all testing procedures for the subsequent two testing days.

During familiarization, participants were fitted with a portable metabolic measurement system and then underwent a process to self-select and practice a comfortable walking and running pace on the Woodway Curve 3.0 NMT (WOODWAY Inc. USA, Waukesha, WI). A self-selected pace was used for practical implications for varied running populations. In this process, participants were instructed to determine a comfortable speed as they performed the testing protocol. The speed for each phase was documented and replicated in for both testing days; NMT and MT conditions. Matching pace in both conditions assured that participants completed the same amount of work on the NMT and MT. Short durations of time were utilized to have participants reach steady state, since our main objective was to determine difference in NMT and MT in steady state. The testing protocol consisted of a 1) 5-min walking warm-up; 2) 5-min walking testing phase, 3) 5-min running testing phase, and 4) 5-min cool down. During familiarization, VO_2, RER, muscle activity, HR, and RPE were recorded every minute. Additionally, all participants were asked to record their diet on a diet log sheet for the preceding 24 h to each testing session to confirm consistency through the study.

Days 2-3 (Testing sessions)

During testing sessions two and three, participants were affixed with electromyography (EMG) electrodes and fitted with a portable metabolic measurement system. Participants then performed the exercise protocol described above either on the NMT or a standard MT (Precor, Woodinville, WA, USA) while HR, RPE, and VO_2 were collected every minute during the entire protocol. The order of trials was randomized for all participants. In both treadmill conditions, participants were instructed to match the walking and running paces that were previously determined during familiarization. EMG activity was recorded during the last 30s of the walking and running phases.

Measures

Lower-body muscle activity

Muscle activity was measured with the Delsys Trigno™ Wireless EMG System (Delsys Inc., Natick, MA, USA) throughout the last 30 s of the walking and running portion of the protocol. Each participant's right leg was prepared for EMG placement by checking the surface of the skin to be shaved and cleaned with an alcohol wipe at each of the following sites: medial gastrocnemius (MG), medial hamstring (MH), tibialis anterior (TA), and vastus lateralis (VL). To hold the sensor in place, double-sided tape was placed on the sensor, wrapped around with a nylon pre-wrap material, and secured with Coban stretch tape. Once securely applied, the participant then performed maximal voluntary isometric contraction (MVIC) for three sets of three seconds on each muscle group. Raw EMG data was filtered using a second order Butterworth band pass filter (100-400 Hz), and root mean square (RMS) was calculated for each trial of both MVICs and during the 30 s walk and run trials for all involved muscles. Peak RMS MVICs were calculated over the three trials and percent activation (%ACT) between MVICs and walking and running trails were calculated for each muscle (Dabbs, Black, & Garner, 2016).

Oxygen uptake, heart rate, and rating of perceived exertion

A heart rate monitor (Polar Electro, Inc., Lake Success, NY, USA) was affixed around the participants' chest to measure heart rate. Every minute, heart rate and RPE, using the Borg's RPE scale, was recorded throughout the protocol duration. The participants were fitted with a face mask and chest harness holding the COSMED K4 Portable Metabolic Measurement System (Cosmed USA Inc., Chicago, IL) to measure VO_2 and carbon dioxide production (VCO_2) (Edwards et al., 2017; Minahan, Poke, Morrison, & Bellinger, 2020). Steady-state values in the walking and running trials were used for analysis. Steady state was determined by averaging the minutes of each phase that were within 5 bpm for HR and within 2 ml/kg/min for VO_2 with corresponding RER.

Statistical Analysis

All statistical analyses were performed with SPSS software (IBM SPSS 24, Armonk, NY, USA). Paired sample t-tests were conducted to analyze the difference between NMT and MT during steady state walking and running in VO_2, RER, HR, RPE, and percent activation (%ACT) in lower-body muscle activity (MH, VL, TA, MG). An alpha level was set a priori at 0.05 to determine significant differences between treadmill types for all dependent variables. Cohen's d (cd) effect size and 95% confidence intervals (CI) were calculated and reported.

RESULTS AND DISCUSSION

Lower-body Muscle Activity

There was a significant difference between NMT and MT for %ACT in VL during walking (Table 1). There were no significant differences between NMT and MT for %ACT in MH, MG, and TA during walking (Table 1). There were no significant differences between NMT and MT for %ACT in VL, MH, MG, and TA during running (Table 1).

Oxygen Uptake, Heart Rate, and Rating of Perceived Exertion

Oxygen uptake was significantly greater on the NMT than the MT during both walking ($p< 0.01$, cd=-2.78, CI=-10.45/-6.72) and running ($p<0.01$, cd=-1.62, CI= -12.85/-5.87) phases. Correspondingly, RER was greater on the NMT

Table 1. Percent muscle activation (mean ± SD) for lower-body muscles in MT and NMT during walking and running

Muscle	Condition	MT	NMT	p-value
VL	Walk	74.3 ± 18.3	89.4 ± 4.0	*0.028
	Run	45.5 ± 27.0	55.7 ± 18.6	0.348
MH	Walk	88.5 ± 4.0	81.2 ± 15.1	0.136
	Run	78.0 ± 11.8	66.6 ± 32.5	0.159
MG	Walk	75.5 ± 7.6	71.0 ± 10.6	0.065
	Run	64.9 ± 12.7	63.7 ± 12.3	0.695
TA	Walk	74.6 ± 11.7	76.9 ± 16.7	0.638
	Run	77.0 ± 12.1	73.5 ± 23.1	0.526

MT = Motorized Treadmill; NMT = Non-motorized Treadmill; VL = Vastus Lateralis; MH = Medial Hamstring; MG = Medial Gastrocnemius; TA = Tibialis Anterior; SD = Standard Deviation; *Significant ($p<0.05$) differences between run and walk than MT during walking and running. Steady-state HR was significantly higher on the NMT than the MT during walking ($p<0.01$, cd= 2.63, CI= 18.12/28.90) and running ($p<0.01$) phases. Subjective responses reflected the physiological HR responses in that RPE was also significantly higher on the NMT than on the MT as well in both walking ($p=0.3$, cd= 0,67, CI= 0.11/1.88) and running ($p<0.01$, cd=1.89, CI= 1.86/3.61) phases. All means, standard deviations, and p-values are reported in Table 2.

Discussion

This study aimed to investigate the cardiometabolic (VO_2, RER, HR), perceptual (RPE), and neuromuscular (lower-body muscle activity) responses during walking and running on the NMT and MT in division II female cross-country athletes. The main findings were that significant differences exist between the NMT and MT for VO_2, RER, HR, and RPE in both walking and running conditions, in which NMT values were greater than MT values. However, the muscle activity showed no significant differences in either condition, except for VL activity during the walking phase of the protocol.

The greater VO_2 and HR experienced on the NMT serves as a physiological indication of higher intensity exertion, while the higher RPE suggests that the participants likewise subjectively perceived a higher intensity on the NMT as opposed to the MT. The VO_2 and RER results parallel previous studies that have shown that NMT requires greater metabolic demand when compared to the MT (De Witt et al., 2009; Edwards et al., 2017; S. M. C. Lee, Dewitt, & Smith, 2008; Morgan et al., 2016) while walking and running, despite the athletes performing at the same absolute workload on both treadmills. During MT use, a person lifts their own body weight to maintain a position above a moving belt (Kram, 2000) whereas on an NMT a person applies ground reaction forces to overcome the inertia of the otherwise stationary belt. Perhaps this additional physical demand on the NMT causes the extra metabolic demand as evidenced in this study by the higher observed VO_2 resulting in a decrease in EE compared to the MT in both walking and running. It should also be noted

Table 2. VO_2, RER, HR, and RPE in MT and NMT during walking and running (mean ± SD)

Variable	Condition	MT mean	NMT mean	p-value
VO_2 (ml/kg/min)	Walk	14.1 ± 1.95	22.7 ± 3.4	*< 0.001
	Run	27.4 ± 6.7	36.8 ± 10	*< 0.001
RER	Walk	0.85 ± 0.08	0.90 ± 0.10	*0.020
	Run	0.89 ± 0.08	1.02 ± 0.14	*0.000
HR (bpm)	Walk	103 ± 16	126 ± 19	*< 0.001
	Run	142 ± 21	167 ± 18	*< 0.001
RPE	Walk	7 ± 1	8 ± 1	*0.031
	Run	9 ± 2	12 ± 2	*< 0.001

MT = motorized treadmill; NMT = non-motorized treadmill; SD = standard deviation; VO_2 = oxygen uptake; RER = respiratory exchange ratio; HR=heart rate; RPE= rate of perceived excursion; *Significant ($p<0.05$) differences between run and walk

that due to the lack on consistent inertial loading on the NMT, an individual that is lighter in mass may be at a disadvantage (decrease EE) compared to a heavier individual due to the greater relative increase in force and power to overcome the belts resistance at a given speed, as demonstrated in previous research (Edwards et al., 2017; Lakomy, 1987). Additionally, several different biomechanical and physiological factors interact to affect running exercise economy. Distance runners—such as the cross-country athletes in the current study—train to optimize fatty acid oxidation during high work rates whilst sparing glycogen, which is impactful in longer endurance events such as marathons or triathlons (Saunders, Pyne, Telford, & Hawley, 2004). The trained runners of the current study responded to an acute sub-maximal bout of exercise on the NMT with a lower exercise economy (i.e., higher oxygen uptake for the same given absolute workload experienced on the MT). Participants' higher VO_2 and RER suggests they are less economical during this acute bout of exercise on the NMT. Perhaps consistent training on this device might elicit physiological adaptations and biomechanical adjustments to enhance exercise economy after chronic use.

The intensity increase on the NMT might be attributed to the user working harder to propel the belt instead of matching the belt speed of a standard treadmill. It is speculated that the curved shape of the running platform on NMT forces users to intentionally shift the foot strike anteriorly to maintain upright posture and balance, however patterns of foot strike were not investigated. As these athletes run with a more forward foot strike compared to their accustomed running pattern, they are activating more muscles of the leg that are normally not as engaged and improving running form by influencing their stride angle (Hatchett, Armstrong, Parr, Crews, & Tant, 2018). The user can generate more power to propel the belt, causing them to work harder for the same task on the NMT in comparison to the MT. When exercising on a NMT or MT, different gait patterns occur even at the same given speed, creating different tasks in movement (S. M. C. Lee et al., 2008), while changes of speed and gait have been shown to effect muscle activation (Cappellini, Ivanenko, Poppele, & Lacquaniti, 2006). Recent studies have found correlations between a greater hip-knee-ankle (HKA) angle and an increase in medial muscle activation (Kim, Bae, Lee, & Lee, 2016; N. Lee, 2018), however in our study there was a significant difference only in the VL during the walking condition. These findings could be associated with variances in participant's gait patterns, leading to an HKA angle not large enough to make a significant difference in the other muscles. These differences may be due to training status of runners; however, the previous research participants did not specify the training level, therefore not allowing us to make accurate comparisons. In contrast to our findings, previous research has seen an increase in lower-body muscle activity during walking and running conditions in NMT compared to MT and overground surfaces (Montgomery et al., 2016).

Strengths and Practical Implication

Practitioners should consider utilizing NMT for their athletes for short distance training bouts instead of long distance if running exercise economy isn't a concern. However, it likely that long-term adaptions may occur after training on the NMT. Athletes may even benefit from a cardiovascular training protocol incorporating the NMT, allowing them to train closer to their maximum, promoting maximal overall performance. Short-term and long-term training goals needs to be considered prior to deciding to utilize NMT in cardiovascular training in regards to exercise economy. Although long-term effects were not investigated in the current study, short-term steady state was assessed in running and walking where exercise economy was hindered when using the NMT in athletes not accustomed to using this type of treadmill.

Some limitations of the study are that only two intensities (walking and running) were used, a self-selected pace was used instead of a percentage of peak VO_2, and the duration of walking and running was short for the trained runners. Similarly, a further limitation to the study was that the population used was cross-country athletes who adhere to a specific set of training protocols to maximize distance running. Testing other athletes from different types of run-training, and even active general population, could be considered for future research. Another potential limitation could be cross-talk between the muscles altering the activation signals during the EMG measures. Additionally, this study was limited by no measures of basic blood indicators to verify cardiometabolic outcomes. More research is needed in long term training effects on a NMT and its influence on physiological, perceptual, and biomechanical measures. Future research using NMTs could investigate chronic use of the NMT and assess training adaptations. It would be interesting to investigate a NMT and graded exercise testing and how different populations respond both physiologically and biomechanically.

CONCLUSIONS

Running on the NMT can elicit different cardiometabolic, perceptual, and lower-body muscle activity responses compared to an MT, which would potentially affect a practitioner's choice of equipment for training their clients. Distance runners effectively rely on training to improve their running economy; not hinder it. Therefore, these results indicated that the NMT is a better consideration for short distance training bouts instead of long distance if running exercise economy isn't a concern, however long-term adaptions may occur but were not investigated. Since it is shown that VO_2, RER, HR, RPE are more beneficial on non-motorized treadmills in acute settings, appropriate athletes may benefit from a cardiovascular training protocol incorporating the NMT, allowing them to train closer to their maximum, promoting maximal overall performance. Future research should investigate adaptations when performing aerobic exercise on a NMT longer bouts and over time.

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