International Journal of EXERCISE SCIENCE

Original Research

The Interaction of Treadmill Type and Incline Slope on Biomechanics and Muscle Activation During Human Locomotion

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ABSTRACT

International Journal of Exercise Science 17(1): 1478-1492, 2024. To investigate the effects of differing treadmills on impact acceleration and muscle activation. Methods: 15 males and 7 females (27.8 ± 7.7yrs), engaged in two sessions of high-incline walking (HIW), and low-incline jogging (LIJ) on different deck systems (cushioned) treadmills (TM1 and TM2). Sessions lasted 5-minutes, and participants maintained a self-selected pace matched for each session. EMG markers were placed over the Tibialis Anterior (TA), Soleus (SOL), Lateral Gastrocnemius (LG), Biceps Femoris (BF), Gluteus Maximus (GM), Anterior Deltoid (AD), Vastus Lateralis (VL), and the Erector Spinae (ES). Trident Inertial Measurement Units (IMU) were attached to the foot and sacrum. EMG activity, impact accelerations, heart rate, and RPE were collected at the 4-minute 30-seconds mark. Results: Peak EMG was higher for LG (p = 0.005), SOL (p = 0.010), and BF (p < 0.001) on TM1 compared to TM2, while AD exhibited lower peak activation during HIW compared to LIJ on TM2 (p = 0.010). The integral EMG activity increased for AD, ES, VL, SOL, LG, and GM only during HIW for both TM1 and TM2. However, only integral EMG activation of BF and LG differed between TM1 and TM2 during HIW. Foot and sacrum resultant acceleration was notably lower during HIW compared to LIJ on both TM1 and TM2. HR was significantly higher on TM1 (171.2 ± 24.8bpm) compared to TM2 (164.62 ± 23.7 bpm, p < .05) during HIW (p < .001), and RPE also differed between TM1 (13.96 ± 1.96) and TM2 (13.09 ± 1.97) during HIW (p < .05). Conclusion: At the same speed (correspond to an RPE of 11) and grade, treadmill design may impact peak and integral muscle EMG patterns, RPE, and HR responses.

KEY WORDS: Biomechanical outcomes, treadmill designs, electromyography (EMG), IMU acceleration

INTRODUCTION

Treadmills are widely utilized equipment in biomechanics research studies. They are often used to assess running kinematics (joint angles, trunk position, foot strike patterns) consistently and controlled, which can prove problematic on overground running/running outside. A treadmill provides an efficient way to perform exercise, allowing precise control over speed and grade. As per the IHRSA Health Club Consumer Report from 2018, treadmills were the most popular mode of exercise, with 43% of exercising individuals utilizing treadmills regularly (29). Therefore, over the past several years, fitness organizations have endorsed numerous treadmill advantages for health & well-being, such as inclined walking. Concomitantly, research has begun to explore the benefits of high-incline walking (HIW) and suggests that this type of activity may reduce impact forces and result in fewer injuries than (LIJ) flat surface activity (14,20,34). However, not all treadmills are built in the same way or have the same deck systems (cushioning). These differences between treadmills may influence biomechanical variables and therefore alter the reliability of research claims from inclined activity when the treadmill manufacturers differ from one another.

The biomechanical stresses experienced during treadmill running differ from those encountered during overground running. A possible explanation for this discrepancy could potentially be attributed to the mechanical characteristics of the treadmill and the presence of deck systems. For example, metal springs and rubber isolators underneath the treadmill deck help to reduce the noise as well as provide a vertical deformation effect (vertically suspension of treadmill deck) to the treadmill deck system. Colino et al. (6) performed an analysis examining the biomechanical responses by comparing 77 treadmills, 30 artificial turf pitches, and 30 athletics tracks. Results demonstrated that treadmills exhibited higher shock absorption compared to all other surfaces. The vertical deformation and energy restitution of treadmills were in between that of the vertical deformation, and energy restitution of athletic turf and tracks (6). Kerdok et al. (20) discovered an inverse relationship between treadmill stiffness and leg stiffness during level ground running. They observed a 29% increase in leg stiffness when participants performed activity on level ground, while treadmill stiffness changed from 945.7 kN/m to 75.4 kN/m. Similarly, Gidley et al. (14) demonstrated that running on a compliant (less stiff) deck treadmill resulted in significantly higher leg stiffness compared to a rigid deck treadmill when both were set at level ground. Researchers have highlighted the potential influence of biomechanical adaptations during running, such as adjusting muscle activity to increase or decrease knee, hip, and ankle joint mobility during the landing (impact absorption) phase, which leads to an increase in leg stiffness (10,17) and a decrease in vertical impact force peaks during running (25). Building on these insights into treadmill stiffness, it is important to further explore the impact of running surfaces on biomechanical adaptation during treadmill activity, specifically when it is performed at an incline.

Ground reaction forces (GRF) on level surfaces and low inclines (< 5%) have been studied extensively. However, little is known regarding GRF at high incline (> 15%). Gottschall & Kram studied running on treadmill at 5.2%, 10.5%, and 15.8% (15). They observed a lower impact GRF as the inclination increased. Specifically, they reported that at -5.2%, -10.5%, and -15.8% inclines, the normal impact forces were 18%, 32%, and 54%, respectively, while at +5.2% and +10.5% inclines, these forces were 13% and 22%, respectively. It should be noted that intensity was maintained as grades increased, leading to an increase in activity rate with each increase in grade. Swain et al. (33) suggest that loading forces are comparable between walking at 0% grade and 11% grade, and lower than level grade running.

While some studies have used force plates to compare ground reaction forces across various surfaces and inclines, others have estimated GRF using IMU accelerations and then correlated these estimates with force plate findings (16,26). Researchers have estimated the 3-D GRF (16) and peak vertical GRF (26) from impact accelerations during level-ground running using inertial sensors. Although not measuring GRF directly, inertial sensors are a viable option for monitoring impact forces or GRFs.

Regarding alterations in muscle activation during inclined walking, Lankford et al. (22) demonstrated that gait undergoes alterations beyond a 15% incline, transitioning from pendulum swing to walking lunge, which may exacerbate discrepancies in EMG activation patterns. This is supported by Swanson & Caldwell, (34) who conducted a running experiment on an incline treadmill at 30% and a constant speed. Their findings revealed an increase in average EMG muscle activation with incline, particularly in the gluteus maximus, gastrocnemius, vastus lateralis, rectus femoris, and soleus muscles, indicating a direct relationship between muscle activity and joint actions.

While numerous studies have explored the influence of surface inclines on various biomechanical factors, such as gait, impact forces, and muscle activation (16, 22, 26, 34), there remains a gap in research for treadmill activity at high inclines and the effects of different treadmill deck systems. Although one might assume that increasing the treadmill's incline leads to a decrease in the impact forces, it is essential to consider that a deck system of a treadmill may influence the impact forces. Additionally, the deck system of a treadmill may behave differently at a low incline than at a high incline. Consequently, the specific effects of treadmill design on biomechanical variables, particularly during high-incline activities, are less clear and warrant further investigation.

Therefore, the primary aim of this study is to investigate biomechanical responses at the same intensity (correspond to an RPE of 11) and grade on two different designed treadmills with different deck systems during high incline walking (HIW), and low incline walking (LIJ). Specifically, the study aims to investigate if similar biomechanical responses are elicited during both HIW and LIJ on these treadmills at same intensity. An essential question guiding the research is whether biomechanical data obtained from one brand treadmill deck system can be extrapolated to results on a different brand of treadmill deck system.

METHODS

Participants

No previous studies have compared the influence of varying treadmill design, incline walking, and their influence on EMG and resultant acceleration. Gidley et al. (14), compared the influence of treadmill design on kinematics variables and used a sample size of 11 participants and effect size ranging from -0.934 to 1.132. Therefore, no a priori power analysis was performed. However, G*Power 3.1.9.7 allows a validated power analysis based on parameters of tests performed (ANOVA), 2-tailed analysis, and effect size to determine an estimated sample for power (11,19). Power analysis using G*power established that the current study required 14 participants to achieve a power of 0.97, an effect size of 0.25, and $\alpha = 0.05$. Studies performed by Swanson et al. (34) and Alexander & Schwameder (1) analyzing EMG activity of the lower extremity during incline walking had sample sizes 12 and 10. The current study has a sample size that exceeded previous studies examining similar variables, albeit in different situations.

This study involved 22 participants (15 males and 7 females) with an average age of 27.8 ± 7.7 years (Table 1). All participants reported doing less than 150 minutes a week of moderate aerobic exercise or 75 minutes of vigorous exercise, and all reported having no known neuromuscular cardiovascular or orthopedic diseases in the 6 months prior to the study. Participant inclusion criteria were centered around representing consumers for the fitness company who are less physically active. All testing was conducted in the Biomechanics Lab at Cal Poly Humboldt. The study was approved by the Human Subjects Review Board at California State Polytechnic University, Humboldt, Institutional Review Board (#22-111) and executed in full accordance with the ethical standard of the International Journal of Exercise Science (24).

Table 1. Mean (SD) of Age, Height (m), and Weight (kg) of the participants involved in the study.

Gender	Age	Height (m)	Weight (kg)
Male	26.5±6.7	1.77±0.07	85.53±15.11
Female	30.0±9.3	1.61±0.06	72.70±13.83

Protocol

Each participant completed an informed consent, Physical Activity Readiness Questionnaire (PARQ+), and Exercise Questionnaire, and had their height and weight recorded. Surface EMG electrodes (Delsys Trigno, Natick, MA, USA) were positioned on the TA, SOL, LG, VL, BF, GM, AD, and ES as per SENIAM guidelines (18). Notably, only the right leg muscles were recorded, with symmetry assumed for comparison purposes (27). Inertial Measurement Units (IMU) (Vicon Blue Trident, Centennial, CO, USA) were placed on the dorsal aspect of the foot and sacrum (lower back), following a similar approach as in previous research (36). Participants were equipped with a Polar T31 heart rate monitor (Polar Electro OY, Kempele, Finland). Following this, all participants advanced to the MVC (Maximum Voluntary Contraction). During all the trails RPE and HR were also utilized at 4-minute 30-second mark.

MVC protocol: All EMG placements and MVC assessments were performed on the same day to ensure reliability. Participants were instructed to perform three trials of isometric maximum voluntary contractions (MVC) for each of the leg muscles monitored on their right leg (Table 2). Participants were provided with 1 practice trial to become familiar with the protocol. Each MVC trial involved maximally activating the specific muscle for 5-seconds to establish a value by which to normalize all subsequent activation levels during the experimental trials. Participants were provided with a minimum 2-minute rest period between each MVC trial.

Treadmill Testing: In this study, a randomized approach to treadmill selection was employed, utilizing two different design treadmills. Treadmill 1 (TM1), a Trackmaster TMX425 Medical Treadmill (Full Vision Inc., Newton, KS.) with a suspended deck system, and Treadmill 2 (TM2), a NordicTrack Commercial X22i treadmill (Icon Health & Fitness, Logan, UT) with a Reflex Cushioning was used to perform the LIJ and HIW trials at the same respective intensity and grade. As the same treadmill has been used throughout the study before testing, for both treadmills, the correct speed was verified by calculating the distance the belt traveled over 1-minute, and the incline was validated using an inclinometer only once.

Table 2. Explanation of the body posture and movement during maximum voluntary isometric contraction (MVIC).

Muscle	Position	Action	Resistance	Reference
Gluteus Maximus	Prone with knee flexed at 90°	Hip extension	Distal end of thigh	(38)
Biceps Femoris	Prone with knee flexed at 70°	Knee extension	Distal end of shank	(30)
Tibialis Anterior	Seated with knee flexed at 90° and ankle plantar flexed at 30°	Dorsiflexion	Dorsal aspect of forefoot	(7)
Soleus	Prone with knee flexed at 90°	Plantarflexion	Plantar aspect of forefoot	(38)
Lateral Gastrocnemius	Prone with knee flexed at 90°	Plantarflexion	Plantar aspect of forefoot	(38)
Vastus Lateralis	Seated with knee flexed at 90°	Knee extension	Distal end of tibia	(30)
Anterior Deltoid	Seated with shoulder and elbow flexed at 90°	Shoulder flexion	Distal end of upper arm	(2)
Erector Spinae	Prone	Back extension	Over shoulder	(37)

Rating of Perceived Exertion: Before data collection, participants were provided with standardized instructions to familiarize them with the Borg rating of perceived exertion scale's ranges, where 6 represents no exertion at all, and 20 indicates maximal exertion.

Speed Establishment Protocol: Following the MVC, participants were provided with approximately 5-minutes to determine self-selected sustainable jogging speed at a 1% incline and another 5-minutes to determine a self-selected sustainable walking speed at a 20% incline on the randomly assigned treadmill. Participants were instructed to use the Borg 6-20 RPE scale as a guideline to establish a self-selected speed utilized for subsequent testing. The purpose of incorporating the Borg scale was based on the concept that an RPE of 11 would produce a sustainable self-selected speed below the lactate threshold to avoid rapid fatigue during tests (31). Participants were also verbally informed that this speed should be sustainable for approximately 40-minutes. Once participants indicating their perceived exertion matched the desired rating of 11 on the scale within the given 5-minutes, the jogging and walking speeds were recorded. Those speeds were then utilized for each subsequent test as the self-selected speed for each respective participant. Subjects then took a brief 3-minute rest before commencing the treadmill protocol thereafter.

Treadmill Protocol: Every participant completed a LIJ session on both treadmills (TM1 and TM2) and a HIW session at a 20% incline on both treadmills (TM1 and TM2), using the jogging and walking speeds that were previously determined. The initial treadmill used was randomized, and each test commenced with LIJ. Participants performed a 5-minute session of LIJ on the first randomly assigned treadmill while maintaining the predetermined speed at 1% grade. At 4-minutes and 30-seconds, data on electromyography (EMG), inertial measurement unit (IMU), rating of perceived exertion (RPE), and heart rate (HR) were recorded. Subsequently, participants walked a short distance of approximately 20 feet to reach the second treadmill, where they initiated another 5-minute session of LIJ on the second treadmill at the same respective speed and grade. Similarly, data collection for EMG, IMU, RPE, and HR took place at the 4-minute 30-second mark. Following the LIJ testing, participants were asked to fully recover (~ 5-8-minutes), following which the treadmill protocol was repeated for the HIW tests. Participants completed two HIW protocols at the predetermined speed at 20% grade with the first treadmill being randomized and EMG, IMU, RPE, and HR being collected at the 4-minute 30-second mark. Participants then completed the final HIW tests on the second treadmill at the same respective speed and grade. Similarly, data collection for EMG, IMU, RPE, and HR took place at the 4-minute 30-second mark.

Electromyography: During the study, muscle activation data was collected while participants jogged at a 1% incline and walked at a 20% incline. This data was obtained during the last 30 seconds of the treadmill exercises, precisely at 4-minutes and 30-seconds mark. The surface electromyography (EMG) signals were recorded following the standard procedures outlined by the International Society for Electrophysiology and Kinesiology (23). To ensure optimal signal quality, the skin was shaved, cleaned, and lightly abraded before placing bipolar surface electrodes (Ag/AgCl 10 mm IED, Trigno Delsys) on specific muscle sites of the right leg, including the Tibialis Anterior (TA), Soleus (Sol), Lateral Gastrocnemius (LG), Biceps Femoris (BF), Gluteus Maximus (GM), and Lumbar Erector Spinae (ES), following SENIAM guidelines (18). Electrode placement and signal quality were visually inspected before data collection. The EMG signals were collected at a rate of 1440 Hz and pre-amplified with a gain of 1700 (input impedance>100MΩ, standard mode rejection ratio>110 dB at 60 Hz). Electrode impedance remained below 5000 Ω, with negligible crosstalk between muscles. To determine muscle activation levels, participants performed three to four Maximum Voluntary Contraction (MVC) trials for each recorded muscle in the right leg. Researchers verbally encouraged participants to contract maximally and hold the contraction for approximately 3 seconds, with at least a 2-minute rest period between each MVC trial. Subsequently, EMG signals were subjected to band-pass filtering using a fourth-order Butterworth filter with a cut-off frequency of 20-400 Hz. The signals were then full wave rectified and smoothed using a root mean squared method with a 40ms moving window. MVC values were calculated by averaging the peak amplitude during each MVC trial for every muscle. For the analysis of EMG signals recorded during incline and level grade trials, normalization to peak MVC or integral of activation expressed as a percentage of MVC was carried out. The EMG analysis focused on the first 10 steps of the last 30 seconds during the stance phase in each jogging and walking trial and involved averaging the root mean squared (RMS) EMG values across these 10 strides. This approach is consistent with previous studies that measured 10 strides or less (32, 40).

Inertial Measurement Unit (IMU): The peak resultant mean acceleration was identified from raw unfiltered data collected by IMUs placed over the foot and sacrum. Acceleration data was gathered along the x, y, and z axes and then combined to calculate the resultant acceleration using the Pythagoras theorem: $ax^2 + ay^2 + az^2 = ar^2$, where ar represents the resultant acceleration, and ax, ay, and az represent accelerations in the respective x, y, and z directions (3).

Statistical Analysis
The effects of treadmill design on impact acceleration (foot and sacrum) and muscle activation (peak and integral) of the AD, ES, GM, VL, BF, SOL, TA, and LG were investigated by normalizing the EMG activity of the muscles to the maximum voluntary isometric contraction (MVIC). A two-way repeated measure ANOVA was used to determine the differences in impact acceleration and EMG (peak and integral) between TM1 and TM2 at LIJ and HIW. Bonferroni's post-analysis performed pairwise comparisons to examine specific comparisons within TM1 LIJ vs TM2 LIJ, TM1 HIW vs TM2 HIW, TM1 LIJ vs TM1 HIW, and TM2 LIJ vs TM2 HIW at the same intensity. The significance level of the analysis was set at $p < .05$. Statistical analyses were completed using JASP software (ver. 0.18.1, Amsterdam, The Netherlands).

RESULTS

In this current study, the effect sizes were calculated by using Cohen's d and partial eta squared. The interpretation of Cohen's d and partial eta squared are according to the guidelines proposed by Cohen (5), where values of 0.2, 0.5, and 0.8 represent small, medium, and large effect sizes for Cohen's d, and values of 0.01, 0.06, and 0.14 indicate small, medium, and large effect sizes respectively.

Physiological Response: All pairwise comparisons for HR and RPE between TM1 LIJ vs TM2 LIJ, TM1 HIW vs TM2 HIW, TM1 LIJ vs TM1 HIW, and TM2 LIJ vs TM2 HIW are found in Table 3. The ANOVA results for HR were significant between inclines (p = 0.003, η2 = 0.069) and between treadmills (p = 0.043, η2 = 0.138). The HR treadmill x incline interaction was significant (p = 0.002, η2 = 0.016). Pairwise comparisons for HR demonstrated a significant difference between TM1 HIW 171.2 ± 24.8bpm) and TM2 HIW (164.59 ± 23.7bpm, p < 0.001, d = 0.281). The ANOVA result for RPE was significant between inclines (p = 0.394) and between treadmills (p = 0.186). The RPE treadmill x incline interaction was significant (p < 0.001). Pairwise comparisons demonstrated significant differences between TM1 HIW (13.95 ± 1.96) and TM2 HIW (13.09 ± 1.97, p = 0.005, d = 0.493).

Table 3. Mean (SD) of average HR (bpm) and average rating of perceived exertion.

Variable	TM1 LIJ	TM1 HIW	TM2 LIJ	TM2 HIW
HR	162.7 ± 24.3	171.2 ± 24.8*	160.5 ± 21.75	164.6 ± 23.69*
RPE	13.09 ± 1.57	13.96 ± 1.96*	13.41 ± 1.44	13.09 ± 1.97*

Note: * = significant difference between TM1 HIW vs. TM2 HIW (P < 0.05).

Peak EMG activation: All pairwise comparisons for each muscle peak EMG activation between TM1 LIJ vs TM2 LIJ, TM1 HIW vs TM2 HIW, TM1 LIJ vs TM1 HIW, and TM2 LIJ vs TM2 HIW are found in Table 4. The ANOVA result for peak ES was not significant between treadmills (p = 0.086) and between inclines (p = 0.148). Similarly, treadmill x incline interaction for ES was not significant (p = 0.383). Pairwise comparisons for ES demonstrated no significant differences. The ANOVA result for peak AD between treadmills was not significant (p = 0.069) but was significant between inclines (p = 0.009, η2 = 0.176). The treadmill x incline interaction for AD was not significant (p = 0.080). Pairwise comparisons for AD demonstrated significant differences between TM1 LIJ (4.1 ± 2.3%) and TM1 HIW (2.6 ± 1.8%, p = 0.010, d = .812). The

ANOVA results for peak TA were significant between treadmills (p = 0.019, η2 = 0.053) and between inclines (p = 0.011, η2 = 0.175). The treadmill x incline interaction for TA was not significant (p = 0.883). Pairwise comparisons for TA demonstrated no significant differences. The ANOVA result for peak BF was significant between treadmills (p < 0.001, η2 = 0.047) and was not significant between inclines (p=0.182). The treadmill x incline interaction for BF was significant (p = 0.019, η2 = 0.017). Pairwise comparisons for BF demonstrated significant differences between TM1 HIW (39.1 ± 28.5%) and TM2 HIW (31.2 ± 21.1%, p < 0.001, d = .369). The ANOVA results for peak GM were not significant between treadmills (p = 0.732) and between inclines (p = 0.432). The treadmill x incline interaction for GM was not significant (p = 0.099). Pairwise comparisons for GM demonstrated no significant differences. The ANOVA result for peak LG between treadmills was significant (p = 0.048, η2 = 0.030) but not significant between inclines (p = 0.773). The LG treadmill x incline interaction was significant (p = 0.004). Pairwise comparisons for LG pairwise demonstrated significant differences between TM1 HIW (63.6 ± 27.0%) and TM2 HIW (55.7 ± 22.4%, p = 0.005, d = .335). The ANOVA results for peak VL were not significant between treadmills (p = 0.944) and between inclines (p = 0.674). The VL treadmill x incline interaction was not significant (p = 0.380). Pairwise comparisons for VL demonstrated no significant differences. The ANOVA results for peak SOL were not significant (p = 0.706). Peak SOL activation was significant between treadmills (p = 0.020, η2 = 0.035). The treadmill x incline interaction for SOL was also significant (p = 0.032, η2 = 0.016). Pairwise comparisons for SOL demonstrated significant differences between TM1 HIW (106.2 ± 72.3%) and TM2 HIW (94.5 ± 70.4%, p = 0.010, d = .184).

Table 4. Mean (SD) of peak EMG activity parameters (magnitude normalized in %).

Muscle	TM1 LIJ	TM1 HIW	TM2 LIJ	TM2 HIW
ES	36.0 ± 20.5	32.1 ± 17.1	35.2 ± 22.5	30.0 ± 15.3
TA	38.6 ± 14.1	32.8 ± 13.7	35.3 ± 13.8	29.9 ± 10.9
GM	32.6 ± 19.4	32.8 ± 14.4	39.6 ± 45.2	28.4 ± 11.6
VL	53.5 ± 20.0	52.6 ± 29.5	54.5 ± 24.4	51.8 ± 32.5
AD	3.2 ± 1.37	2.6 ± 1.3	4.1 ± 2.3#	2.6 ± 1.8#
BF	42.1 ± 17.6	39.1 ± 28.5*	40.1 ± 16.6	31.2 ± 21.1*
LG	60.3 ± 22.5	63.6 ± 27.0*	61.1 ± 21.3	55.7 ± 22.4*
SOL	98.7 ± 56.3	106.2 ± 72.3*	96.5 ± 51.9	94.5 ± 70.4*

Note: * = significant differences between TM1 HIW vs. TM2 HIW; # = significant differences between TM2 LIJ vs. TM2 HIW (P < .05).

Integral Activation: All pairwise comparisons for each muscle integral EMG activation between TM1 LIJ vs TM2 LIJ, TM1 HIW vs TM2 HIW, TM1 LIJ vs TM1 HIW, and TM2 LIJ vs TM2 HIW are found in Table 5. The ANOVA results for integral AD were significant between treadmills (p = 0.030, η2 = 0.036) and between inclines (p = 0.002, η2 = 0.246). The integral AD treadmill x incline interaction was not significant (p = 0.814). Pairwise comparisons for AD demonstrated significant differences betweenTM1 LIJ (1.3 ± 0.6%) and TM1 HIW (1.9 ± 1.0%, p = 0.001, d = -0.850), and TM2 LIJ (1.5 ± 0.8%) and TM2 HIW (2.1 ± 1.4%, p = 0.042, d = -0.589). The ANOVA results for integral BF were significant between treadmills (p < 0.001, η2 = 0.021) and between inclines (p = 0.003, η2 = 0.312). The integral BF treadmill x incline interaction was significant (p = 0.012). Pairwise comparisons for BF demonstrated significant differences between TM1 LIJ

(13.3 ± 6.7%) and TM1 HIW (21.7 ± 14.4%, p = 0.004, d = -0.820), and TM1 HIW (21.7 ± 14.4%) and TM2 HIW (18.5 ± 11.3%, p < 0.001, d = 0.315). The ANOVA results for integral ES were significant between inclines (p < 0.001, η^2 = 0.569) but not significant between treadmills (p = 0.120). The integral ES treadmill x incline interaction was not significant (p = 0.388). Pairwise comparisons for ES demonstrated significant differences between TM1 LIJ (19.8±7.3%) and TM1 HIW (25.7 ± 12.7%, p = 0.040, d = -0.539), and TM2 LIJ (20.1 ± 9.1%) and TM2 HIW (26.0 ± 13.7%, p = 0.041, d = -0.538). The ANOVA results for integral VL were not significant between treadmills (p = 0.539) but were significant between inclines (p = 0.006, η^2 = 0.284). The integral VL treadmill x incline interaction was not significant (p = 0.994). Pairwise comparisons for VL demonstrated significant differences between TM1 LIJ (12.1 ± 8.1%) and TM1 HIW (20.3 ± 11.1%, p < 0.001, d = -0.857), and TM2 LIJ (11.9 ± 9.2%) and TM2 HIW (19.4 ± 9.9%, p < 0.001, d = -0.777). The ANOVA results for integral SOL were significant between inclines (p < 0.001) but not significant between treadmills (p = 0.063). The integral SOL treadmill x incline interaction was not significant (p = 0.122). Pairwise comparisons for SOL demonstrated significant differences between TM1 LIJ (39.5 ± 22.8%) and HIW (59.2 ± 38.8%, p = 0.002, d = -0.617), and TM2 LIJ (38.8 ± 21.3%) and TM2 HIW (55.0 ± 40.0%, p = 0.011, d = -0.507). The ANOVA results for integral LG were significant between inclines (p < 0.001, η^2 = 0.429) but not significant between treadmills (p = 0.050). The integral LG treadmill x incline interaction was significant (p = 0.006, η^2 = 0.022). Pairwise comparisons for LG demonstrated significant differences between TM1 LIJ (24.2 ± 9.4%) and TM1 HIW (33.6 ± 13.5%, p < 0.001, d = -0.860), and TM2 LIJ (24.6 ± 8.6%) and TM2 HIW (30.5 ± 11.5%, p = 0.014, d = -1.053), and TM1 HIW (33.6 ± 13.5%) and TM2 HIW (30.5 ± 11.5%, p = 0.006, d = 0.283). The ANOVA results for integral TA were not significant between treadmills (p = 0.102) but were significant between inclines (p = 0.041, η^2 = 0.116). The integral TA treadmill x incline interaction was not significant (p = 0.991). Pairwise comparisons for TA demonstrated no significant differences. The ANOVA results for integral GM were significant between inclines (p < 0.001, η^2 = 0.400) but not significant between treadmills (p = 0.781). The integral GM treadmill x incline interaction was not significant (p = 0.076). Pairwise comparisons for GM demonstrated significant differences between TM1 LIJ (11.7 ± 6.4%) and TM1 HIW (19.8 ± 8.5%, p < 0.001, d = -1.035), and TM2 LIJ (12.6 ± 8.7%) and TM2 HIW (18.5 ± 7.4%, p = 0.011, d = -0.753).

Resultant Acceleration: All pairwise comparisons for resultant acceleration for foot and sacrum between TM1 LIJ vs TM2 LIJ, TM1 HIW vs TM2 HIW, TM1 LIJ vs TM1 HIW, and TM2 LIJ vs TM2 HIW are found in Table 6. The ANOVA results for resultant foot acceleration were significant between inclines (p < 0.001, η^2 = 0.526) but not significant between treadmills (p = 0.616). The resultant foot acceleration treadmill x incline interaction was not significant (p = 0.192). Pairwise comparisons for resultant foot acceleration demonstrated significant differences between TM1 LIJ (25.31 ± 14.9m/s2) and TM1 HIW (12.17 ± 5.4m/s2, p < 0.001, d = 1.319), and TM2 LIJ (25.75 ± 11.3m/s2) and TM2 HIW (10.62 ± 4.3m/s2, p < 0.001, d = 1.519). The ANOVA results for resultant sacrum acceleration were significant between inclines (p < 0.001, η^2 = 0.718) but not significant between treadmills (p = 0.844). The resultant sacrum acceleration treadmill x incline interaction was not significant (p = 0.819). Pairwise comparisons for resultant sacrum acceleration demonstrated significant differences between TM1 LIJ (37.46 ± 14.6m/s2) and TM1 HIW (14.26 ± 2.3m/s2, p < 0.001, d = 2.407), and TM2 LIJ (37.50 ± 12.18m/s2) and TM2 HIW (13.76 ± 2.0m/s2, p < 0.001, d = 2.463).

Table 5. Mean (SD) of integral (area under curve) EMG activity parameters (magnitude normalized in %).

Muscle	TM1 LIJ	TM1 HIW	TM2 LIJ	TM2 HIW
AD	1.3 ± 0.6§	1.9 ± 1.0*§	1.5 ± 0.8	2.1 ± 1.4*
BF	13.3 ± 6.7	21.7 ± 14.4*	12.9 ± 6.3#	18.5 ± 11.3*#
ES	12.1 ± 8.1§	20.3 ± 11.1*§	11.9 ± 9.2	19.4 ± 9.9*
VL	19.8 ± 7.3§	25.7 ± 12.7*§	20.1 ± 9.1	26.0 ± 13.7*
SOL	39.5 ± 22.8§	59.2 ± 38.8*§	38.8 ± 21.3	55.0 ± 40.0*
LG	24.2 ± 9.4§	33.6 ± 13.5*§	24.6 ± 8.6#	30.5 ± 11.5*#
TA	12.2 ± 3.9	14.2 ± 4.6	11.2 ± 3.3	13.2 ± 4.5
GM	11.7 ± 6.4§	19.8 ± 8.5*§	12.6 ± 8.7	18.5 ± 7.4*

Note: * = significant differences between TM1 HIW vs. TM2 HIW; # = significant differences between TM2 LIJ vs. TM2 HIW; § = significant differences between TM1 LIJ vs. TM1 HIW ($p < 0.05$).

Table 6. Mean (SD) of resultant acceleration of foot and sacrum IMU sensor (m/s^2).

Segment	TM1 LIJ	TM1 HIW	TM2 LIJ	TM2 HIW
Foot	25.31 ± 14.89§	12.16 ± 5.43§	25.75 ± 11.29#	10.62 ± 4.28#
Sacrum	37.46 ± 14.61§	14.26 ± 2.27§	37.49 ± 12.18#	13.76 ± 2.04#

Note: § = significant differences between TM1 LIJ vs. TM1 HIW; # = significant differences between TM2 LIJ vs. TM2 HIW ($p < 0.05$).

DISCUSSION

Concerning the treadmill design, TM1 has the motor positioned near the rear rollers (responsible for moving the treadmill belt) with the front of the deck suspended giving the deck a "diving board" action. TM2 has a motor positioned near to front rollers and the deck is connected with the base on the front and back of both sides. Concerning the deck system, TM1 has 4 metal springs attached underneath the treadmill deck whereas TM2 utilizes 6 rubber isolators underneath the treadmill deck. The different locations of the motors, as well as the positioning of the attachments and differences in the deck, likely change the lever systems and therefore redistribute the weight and cushioning response between TM1 and TM2. These physical differences may help explain the differences in biomechanical and physiological variables observed between TM1 and TM2 during HIW at 20% grade.

Given that the treadmill speeds and grades were calibrated and verified before testing, both LIJ and HIW should, in theory, have elicited similar response (HR, RPE) between TM1 and TM2 if the treadmill designs produced a similar cushioning response. However HR and RPE were the same during LIJ, suggesting that the deck systems of the two treadmills represented a similar response during LIJ. Surprisingly, during HIW, HR and RPE were significantly higher on TM1 compared to TM2. This discrepancy suggests that the deck systems of the two treadmills may have elicited a different response at the same incline and intensity. This information supports the need for treadmill-specific claims. It should be noted that no participants' data were considered outliers for HR during HIW on either TM1 or TM2, therefore demonstrating a consistently observed increase in HR for TM1 during HIW.

In the current study, participants were instructed to choose their own speeds that would make them feel like they were exerting at level 11 on a scale of perceived exertion during both LIJ and HIW. However, it's important to note that the participants in the study were not currently physically active. The reason for this intentional recruitment process was to target a population that is typically marketed to by fitness companies. It's possible that the lack of physical activity among the participants made it challenging for them to choose an activity intensity that would correspond to an RPE of 11, especially during HIW. This is supported by the fact that after 4 minutes and 30 seconds, the participants reported an RPE of over 13 for both LIJ and HIW trials, despite being advised to select a speed that would correspond to an RPE of 11. Normally, exercising at an RPE of 11 should be below the lactate threshold and should not result in an RPE of 13 within 5 minutes.(31). This information leads to the idea that individuals unaccustomed to such activity levels, specifically during incline, may have difficulty producing consistent RPE values. It seems like the main difference in the trials was seen in TM1's rating of perceived exertion (RPE) between the high-intensity workout (HIW) and low-intensity jog (LIJ) trials. Despite the RPE being generally consistent between the trials, TM1 reported a higher RPE during the HIW (13.96 ± 1.96) compared to the LIJ (13.09 ± 1.57). On the other hand, TM2 reported similar RPE values between LIJ (13.41 ± 1.44) and HIW (13.09 ± 1.97). It's possible that the treadmill system used by TM1 during the HIW might have contributed to unfamiliar movements, leading to changes in RPE as the workout progressed. A limitation of the study was that the pre-established activity response at an RPE of 11 was determined only on either TM1 or TM2 for each participant. Therefore, any discrepancies in activity response due to a particular manufacturer's treadmill design respective to the other treadmill would not have been identified in the pre-testing speed establishment protocol. This limitation also proved to validate that speed and grade are not the only factors contributing to such activity response on a treadmill system and that variables such as the deck systems may alter activity response and therefore biomechanical and physiological variables. The current study did not collect metabolic data. Future, studies may wish to incorporate a measure of oxygen uptake to further verify activity performed.

It is important to recognize that peak EMG and integral EMG represent different responses of the muscle. Previous research has largely looked at both peak and integral muscle activation during activity. These studies demonstrate a consistent increase in peak EMG in SOL, BF, LG, and AD (12,21,34). These changes in peak EMG can be attributed to either a change in grade, a change in intensity, or both. It should be noted that the speed is typically maintained in these studies, while grade increases. In the current study, the speed was decreased as the grade increased in an attempt to produce a similar activity rate. Our results showed TM1 alone produced significant increases in peak EMG in the LG, SOL, and BG as grade increased whereas there were no differences for activity response on TM2 between LIJ and HIW. However, TM2 produced a significant decrease in peak EMG in the AD as grade increased. These results suggest that the peak EMG of the muscles responded differently to the treadmill design or deck systems as speed and grade were matched between TM1 and TM2.

Researchers have demonstrated that incline walking introduces a distinct gait pattern. Studies demonstrate incline walking results in a change from a pendulum walking pattern to a walking lunge, requiring additional muscle activation to lift the limbs (13,22). Researchers suggest a prolonged activation of lower extremity muscles during incline walking due to an increased stance phase duration during inclined walking compared to low-incline walking (35,39). Especially Tokuhiro et al. (35) observed increased integrated EMG activity in lower limbs (hamstrings and gluteus maximus) as the incline rose from 3° to 12° at a constant walking speed. Similar results were reported by Wall-Scheffler et al. (39), who observed increased duration of lower extremity muscle activation as the incline increased from 0% to 20%. Correspondingly, in our study integral EMG of the AD, BF, ES, LG, SOL, VL, and GM saw patterns of increased activation. However, the increase was inconsistent between TM1 and TM2, suggesting an increase in incline from LIJ to HIW appears to influence specific muscle activation patterns.

Although many studies have used force plates to assess loading rates, there have been studies that demonstrate a moderate correlation in estimating loading rates using accelerometers (4,28). Similar to Gottschall and Kram (15) and Ehlen et al. (9) our results indicate a decrease in loading rates as seen in the foot and sacrum IMU as the incline increases. These findings likely represent a reduction in loading rates during HIW resulting in changes in foot-striking patterns (15), changes in gait patterns as the incline increases further than 15% (13,22), as well as the increased flexion angle of the knee at foot strike (8) during HIW. Given that HIW on TM1 and TM2 resulted in similar IMU impact acceleration responses, the deck systems of TM1 and TM2 may have worked comparably on the vertical deformation of the treadmill surfaces.

Conclusion: Our investigation revealed that at the same intensity and grade, treadmill design may impact the peak and integral muscle EMG patterns, RPE, and HR responses during HIW. Regardless of the treadmill design, impact accelerations of the foot and sacrum decreased as the grade increased from 1% to 20%, highlighting the effect of jogging vs walking. These results suggest that caution should be taken when extrapolating biomechanical and physiological results from one treadmill to another.

ACKNOWLEDGEMENTS

We gratefully acknowledge Dr. Tim Coffee for his assistance in writing.

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