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INVESTIGATING THE CHANGE IN 3-DIMENSIONAL KNEE AND PELVIC ANGLES DURING 30-MIN TREADMILL RUNNING IN RECREATIONAL RUNNERS: A PRELIMINARY STUDY

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ABSTRACT

This study aimed to investigate changes in knee and pelvic angles during 30-min treadmill running. Eight recreational runners ran on a treadmill at a speed equivalent to 70% of VO_{2peak} for 30 minutes while simultaneous 3-dimensional motion data of the lower extremities were collected using a lower limb and trunk marker model and 8 optoelectronic cameras. Knee and pelvic angles at initial contact (IC) and toe-off (TO) during the 1st and 30th min of 5 running gait cycles were analyzed and a paired samples *t*-test was used to evaluate differences between two-time points. The results showed no significant differences in 3-dimensional motion knee or pelvic (all P >0.05) angles between the first and last minute of running. There were also no differences in left and right leg step and stride length at IC and TO (all P >0.05). It is concluded that knee and pelvic angles do not change over the course of a 30-min treadmill run. For the pratical implication, the runners could maintain the running pattern consistency in lower limb kinematics when training 30-minutes run on treadmill.

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INTRODUCTION

Running is one of the most popular exercise as it is easy to access and not many equipment required. The important form of locomotion that is widely used to perform many recreational or competitive activities and sports (1). The running gait cycle begins when one foot comes in contact with the ground (beginning of the stance phase) and ends when the same foot contacts the ground again (2-3). The stance phase starts at initial contact and ends at toe off (4). In order to propel the centre of mass forwards during running, the pelvic and knee joints act as attachments for key locomotor muscles during the movement (5). Previous studies have reported the pelvis to possess an increased tilt dependent upon the step cadence to generate movement speed, with pelvic obliquity and rotation likely becoming more apparent when compared with walking (i.e., slower gait cycle/cadence) (6-7). This may increase the potential for adverse angular patterns and enhance injury risk. Indeed, the majority of biomechanical studies investigating running gait cycles have focussed on targeting interventions to enhance running performance and/or to reduce injury occurrence (8-10).

In long-distance runners, lower extremity training errors have been identified as a major injury risk factor for incidence of injury (11). Weak hip strength, particularly in the hip abductors and external rotators, is considered a risk factor for several running-related injuries (12). While it is documented that the knee is most likely to sustain an injury during prolonged running (1), it is possible that the changes in pelvic kinematics may also contribute to the increased potential for injury risk (13). For example, a change in pelvic motion is shown to be related with running distance, specifically pelvic tilt and rotation (14). This suggests that as running distance increases, excessive motion at the pelvis may lead to higher stress across pelvic structures, resulting in instability and the potential for sustaining a running injury (14). Also, recreational runners have a higher risk of lower limb running injuries than competitive runners (15-16).

Accordingly, the aim of this study was to investigate the change in the knee and pelvic angles during a 30-min treadmill run in recreational runners. We hypothesized that utilizing a relatively fast gait cycle over this duration would exhibit differences in knee and pelvic kinematics.

MATERIAL AND METHODS

Participants

Eight healthy recreational runners (5 males and 3 females) were studied (mean±SD: age, 38.75±6.82 yr, height 166.50±7.50 cm, mass 63.38±8.25 kg). Participants were familiarized with the experimental procedures, assessed risks of lower limb injury, and provided their voluntary written informed consent to participate. All participants regularly ran at least 25 kilometres per week and had completed at least 1 minimarathon. Participants were excluded from this study if they had: 1) pelvic and knee misalignment, 2) injury of the lower extremity, and/or 3) previous lower limb surgery in the past 6 months. The study conformed to the Declaration of Helsinki and was approved by the Institutional Ethics Committee (MU-CIRB 2019/132.0808).

Experimental Design

This study employed a quasi-experimental (pre-test and post-test) design. Each participant was asked to attend the laboratory on two separate visits. During the 1st visit, the participants performed an incremental treadmill protocol while simultaneous breath-by-breath (VO_2) measurements were recorded (Cortex METALYZER®3B, Leipzing, Germany). The participants were initially warmed-up on a treadmill (Treadmill (Valiant 2, CPET, Netherland) at a self-selected running speed for 5 minutes before starting an incremental exercise protocol beginning with 85% of the average speed calculated from the best 10 km time recorded then increasing 0.5 km/hr every 90 sec until reaching volitional exhaustion (VO_{2peak}). The treadmill speed at which point VO_{2peak} was attained was used to calculate each participants' speed at 70% of their individual VO_{2peak} (average VO_{2peak} running speed = 7.49±2.08 km/h).

On the 2nd visit (experimental testing), the participants arrived at the laboratory at least 3 h postprandial having refrained from exercise, alcohol, tobacco, and caffeine during the previous 24 h. Upon arrival, the participants had lower limb and trunk markers affixed in accordance with Liverpool John Moores University (LJMU) model (Figure 1) (17), and were asked to put on their running shoes. After an initial warm-up, participants were asked to run on a treadmill (Walkerview, TecnoBody, Italy) at the speed calculated to be equivalent to 70% of their individual VO_{2peak} for a duration of 30 minutes.

3D kinematics data were simultaneously collected using 8 optoelectronic cameras (OptiTrack, NaturalPoint, USA) at 100 Hz. The kinematic data of last 5 running cycles were collected from the 0th to 1st and 29th to 30th minute at the sampling rate of 100 Hz. Pelvic and knee joint angles were collected when runners landed their each leg on the ground during IC and TO. Step length was calculated from the distance of calcaneus marker between IC and TO in each foot and stride length was forecasted from summation of left and right step lengths.

Data procressing

The 5 running gait cycles were time normalized to 100% during data processing. The Visual 3D software (C-motion, version 6) was used to analyze knee and pelvic kinematic variables. All marker trajectories were filtered at 9 Hz by a Butterworth low pass filter from the location of the three-dimensional coordinates of the markers placed on the body.

Figure 1. The lower limb and trunk retroreflective marker placement in accordance with the Liverpool John Moores University (LJMU) marker model (17).

Statistical Analysis

All data are presented as mean±SD. The distribution of the data was initially checked for normality by examining Q-Q plots and performing a Shapiro-Wilk test. According to data were considered to be normally distributed, a paired students *t*-test was used to evaluate differences between the first (pre: 1st min) and last (post: 30th min) minute of treadmill running for all 3D kinematic data (knee and pelvic angles at IC and TO, step and stride length). The Statistical Package for The Social Sciences (version 18; SPSS inc., Chicago, IL) was used for all statistical analyses. The alpha level of statistical significance was set at $P < 0.05$.

RESULTS

Treadmill speed and distance

The participants' average treadmill running speed at 70% of VO_{2peak} was = 7.49±2.08 km/hr, permitting an average distance of 3.44±0.87 km to be completed at the end of the 30-min run.

Pelvic angle at IC and TO

There was no significant change in pelvic angle in any of the 3-dimensions when measured in the final minute of the treadmill run (Table 1). Figure 2 illustrates the data of 1 participant's change in pelvic angle (tilt, obliquity, rotation) at IC and TO during the first and last minute of the 30-min run, respectively.

Table 1. 3-dimensional pelvic angles during the 1st and 30th minute of treadmill running (mean±SD).

Variables	1st min	30th min	*P*-value
Pelvic angle at initial contact			
Pelvic tilt (°) Anterior (-) / Posterior (+) tilt	1.01±2.14	0.70±2.65	0.751
Pelvic obliquity (°) abduction (-) /adduction (+)	-0.38±1.70	-1.10±2.07	0.209
Pelvic rotation (°) External (-) /Internal (+) rotation	1.52±2.05	-2.15±1.63	0.493
Pelvic angle at toe off			
Pelvic tilt (°) Anterior (-) / Posterior (+) tilt	0.26±2.92	-0.09±2.85	0.261
Pelvic obliquity (°) Abduction (-) / Adduction (+)	1.86±1.80	1.96±1.88	0.787
Pelvic rotation (°) External (-) / Internal (+) rotation	1.52±2.05	1.71±1.95	0.678

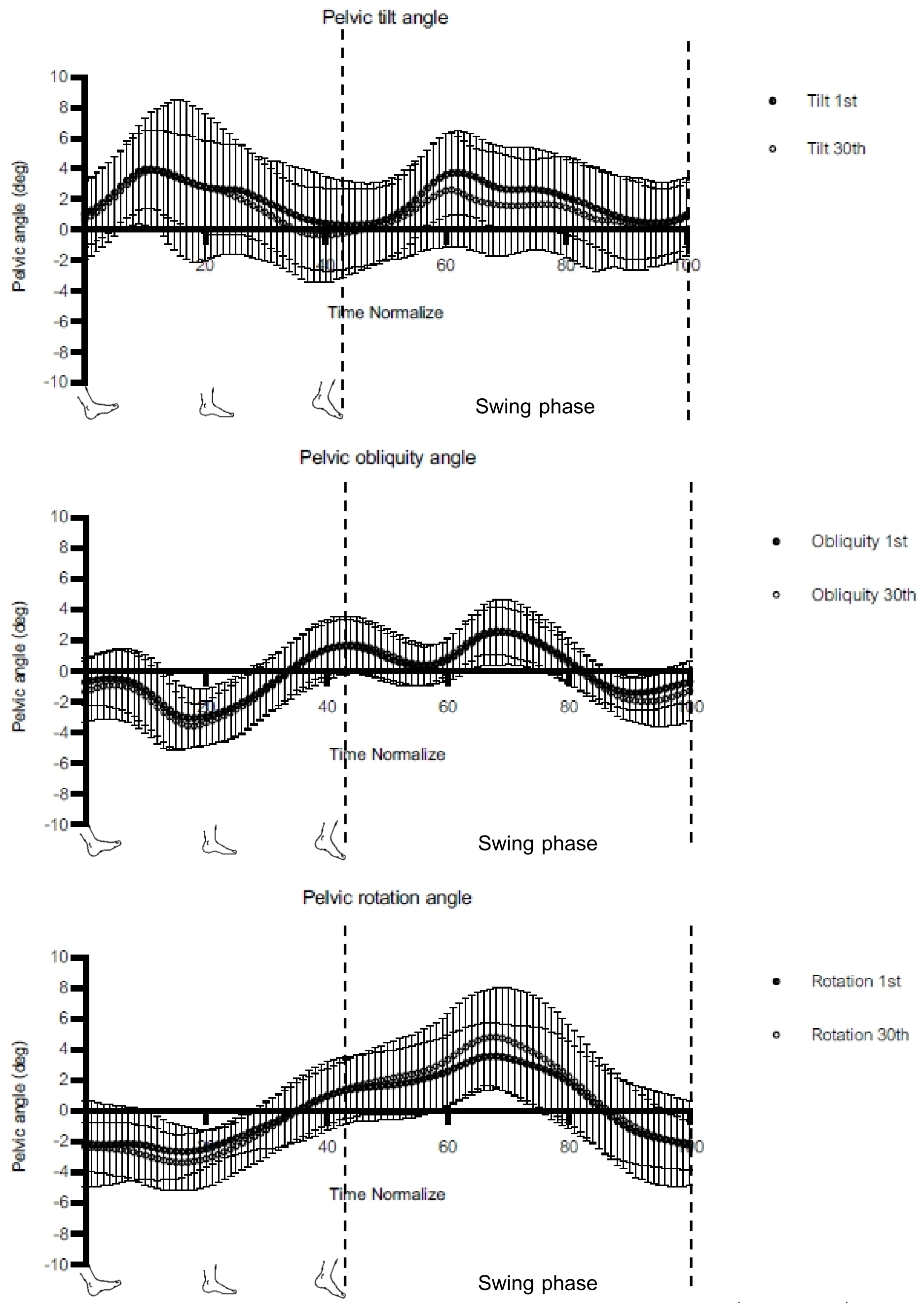

Figure 2. The average and standard diviation change in participant's pelvic tilt (top panel), obliquity (middle panel), rotation (bottom panel) angle at IC and TO during the 1st and 30th minute of treadmill running.

Knee angle at IC and TO

There was also no significant change in left or right knee angles in any of the 3 dimensions in the final minute of the treadmill run (Table 2). Figure 3 illustrates the change in one participant's knee angles (flexion: extension; abduction: adduction; internal rotation: external rotation) in the left and right leg at IC and TO during the first and last minute of the treadmill run, respectively.

Table 2. The 3-dimensional knee angles during the 1st and 30th minute of treadmill running (mean±SD).

Variables	1st min	30th min	*P*-value
Knee angle at initial contact			
Left knee flex/ext (°) Extension (+) / Flexion (-)	-14.28±1.92	-13.78±3.29	0.567
Left knee ab/ad (°) Abduction (-) / Adduction (+)	0.02±2.88	0.41±2.95	0.152
Left knee int/ext rot (°) External (+) / Internal (-) rotation	-9.54±8.16	-11.76±5.54	0.412
Right knee flex/ext (°) Extension (+) / Flexion (-)	-14.70±3.19	-14.77±5.01	0.962
Right knee ab/ad (°) Abduction (-) / Adduction (+)	0.36±2.26	0.21±2.36	0.780
Right knee int/ext rot (°) External (+) / Internal (-) rotation	-17.32±6.47	-20.42±4.42	0.749
Knee angle at toe off			
Left knee flex/ext (°) Extension (+) / Flexion (-)	-17.91±6.01	-18.47±6.17	0.587
Left knee ab/ad (°) Abduction (-) / Adduction (+)	-1.01±3.8	-1.27±3.91	0.374
Left knee int/ext rot (°) External (+) / Internal (-) rotation	-9.54±8.16	-10.84±8.56	0.447
Right knee flex/ext (°) Extension (+) / Flexion (-)	-22.14±4.3	-21.38±6.63	0.225
Right knee ab/ad (°) Abduction (-) / Adduction (+)	-0.6±1.95	-1.01±2.18	0.494
Right knee int/ext rot (°) External (+) / Internal (-) rotation	-17.32±6.47	-18.55±6.64	0.082

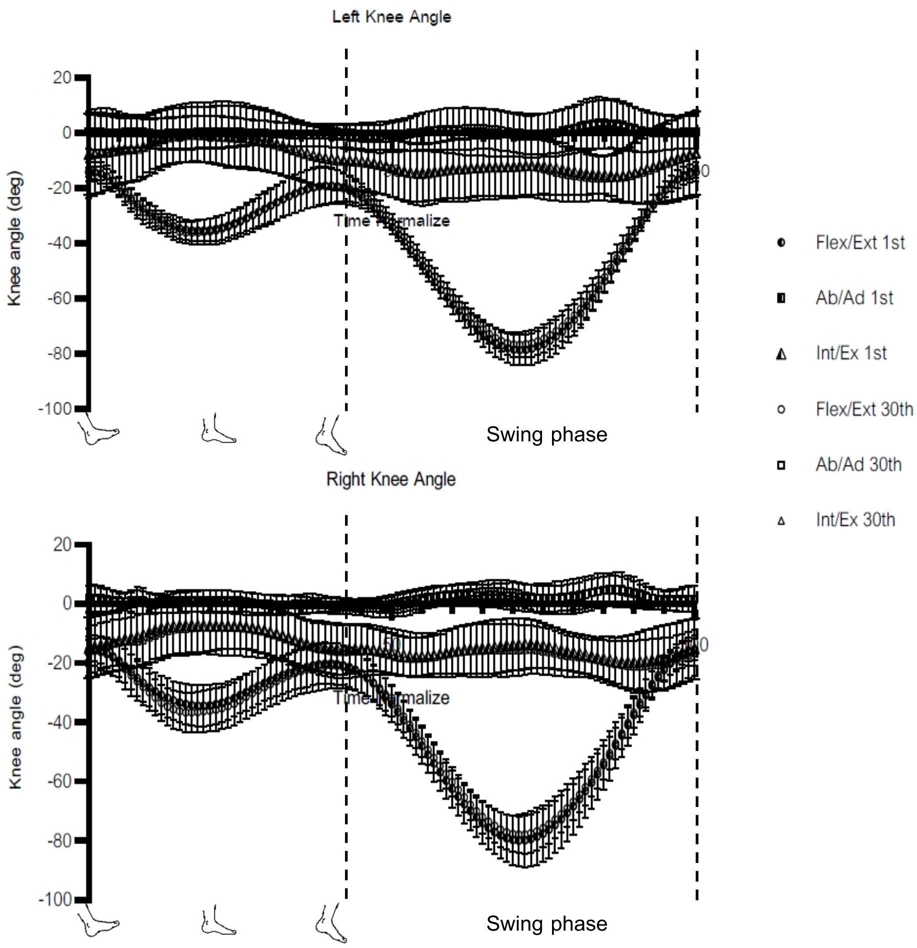

Figure 3. The average and standard diviation change in participant's left (top panel) and right (bottom panel) knee angle at IC and TO during the 1st and 30th minute of treadmill running.

Step and stride length

Step length was not significantly different between the first and last minute of treadmill running (Table 3), with both the left and right limbs having a similar stride length, respectively (Table 3).

Table 3. Step and stride length during the 1st and 30th minute of treadmill running (mean±SD).

Variables	1st min	30th min	*P*-value
Left step length (m)	0.50±0.10	0.50±0.10	0.763
Right step length (m)	0.51±0.12	0.52±0.11	0.390
Stride length (m)	1.00±0.22	1.01±0.20	0.442

DISCUSSION

The main findings in this study showed that treadmill running for a duration of 30-min did not lead to a significant change in 3-dimensional knee or pelvic angles at IC or TO. Moreover, we observed step and stride lengths to remain unchanged at the end of a 30-min treadmill run.

In the present study, the 3-dimensional analysis showed that pelvic angle changed by less than 3 degrees during the stance phase (Table 1). Our current findings are in agreement with previous work, which demonstrated novice and competitive runners' pelvic angles to change minimally during the stance phase (<3 degrees) during a running task to exhaustion (18). It may be speculated that the ability to restrict large changes in pelvic angle ROM allows for stabilization of the body and the effective transfer of force generation to the lower body when running (19). Sagittal plane movements (i.e., flexion or extension of the limbs) are essential to propel the body forward during running (5). In this study, we did not observe any marked difference in knee angles during running at the end of the 30-min run, albeit knee flexion/extension angle at IC and TO changed slightly (less than 1 degree) in both legs (Table 2). A comparable change in knee angle at IC (1.2 degrees) has previously been reported over a similar treadmill run duration (20 min) (20). However, our work contrasts with Derrick TR, et al. (2002), who reported decreasing 4.4 degrees in knee angle at the end of an exhaustive run (8). The discrepancy in our findings is likely related to participants running to exhaustion. Clansey and colleagues' study (2012) reported greater ROM displacement more probable after fatiguing exercise (more compensation) (20). Willwacher and colleagues (2020) stated that the fatigue-related to the change of hip and knee joint kinematics needs to be considered when addressing risk factors for running-related injuries. Therefore, future work may attempt to address kinematic alterations in knee and pelvic joint during exhaustive treadmill running, rather than over running durations which do not elicit excessive fatigue. This will help elucidate how altered joint kinematics may increase phase-related loading absorption during the stance phase and potential for increased risk of sustaining an injury (21).

In addition to not finding marked changes in knee angle in the sagittal plane, we did not observe any alteration in knee angle in the frontal or transverse planes (in either leg). The participants' knee angle at IC and TO changing by less than 1 and 3 degrees in the frontal and transverse planes, respectively. In line with these findings, Tian (2020) also reported knee angle at IC to not significantly change in these planes of movement after long-distance running; knee angle decreasing by less than 2 degrees over the duration of the run (22). Similarly, Dierks et al. (2010) reported knee angle to change by less than 2 degrees in both the frontal and transverse planes during high intensity running (more than 85% of maximum heart rate) over a duration of 30 to 60 minutes (23). Furthermore, we also did not record any marked changes in knee abduction or knee internal rotation at the end of the 30-min treadmill run, which have been associated with risk of overuse injury at knee joint. For example, knee varus angle has been shown to be strongly associated with the progression of knee osteoarthritis (OA) (24). Consequently, it appears that running over similar durations on a treadmill may not expose the runner to risk of injury associated with this type of movement. Step and stride lengths are spatio-temporal running parameters representing running gait speed. In the present study, no difference was observed in either variable (in either leg) over the duration of the treadmill run as the intensity (running speed) that has been set in this study may not heavy enough to influence the fatigue effect.

This study had several limitations; thus, caution is warranted when interpreting the data. Firstly, we used a relatively small sample size (8 runners), thus increasing the likelihood of making a type 2 error (i.e., false negative; accepting a false null hypothesis). Secondly, foot strike patterns should be investigated according to the lower limb kinematics changes. Finally, the EMG activities and ground reaction forces have not been measured in this work. Therefore, future work should attempt to examine foot strike pattern, muscle EMG activity, and ground reaction forces to extend our understanding of important biomechanical changes related to injury risk during prolonged running.

CONCLUSION

The 3-dimensional motion of knee and pelvic angles had no significant changes between the first and last minute of running at IC and TO. Also, there were no differences in left and right leg step and stride length at IC and TO. Therefore, when observing the running kinematics the findings from this work could suggest that running on treadmill over a similar duration and relative intensity may require further research into changes in knee and pelvic kinematics in recreational runners. For the pratical implication, the runners could maintain the running pattern consistency in lower limb kinematics when training 30-minutes run on treadmill.

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