# ABSTRACT

1. **Objective:** To determine if there are changes in temporal gait parameters with a focus on
2. pelvis when comparing overground and treadmill ambulation, and to assess the effect of
3. gender.
4. **Design:** An observational study employing motion analysis techniques to evaluate pelvic
5. movement during gait.
6. **Setting:** University biomechanics laboratory
7. **Participants:** Eight males (22.5 ± 3.0y) and six females (23.8 ± 4.1y).
8. **Interventions**: Not applicable
9. **Main Outcome Measures:** Cadence, stride time, stance phase % and pelvic tilt, obliquity
10. and rotation parameters throughout the gait cycle were assessed during overground and
11. treadmill walking. Kinematic data were recorded using a passive full body marker based
12. motion analysis system (Vicon, OMG, UK). Whilst an independent sample t –test was used
13. to determine if differences in walking speed were evident between genders, a two-way
14. repeated measures ANOVA was performed to examine the effect of walking mode and
15. gender on each dependent variable.
16. **Results:** Significant differences (p < .05) between overground and treadmill walking for the
17. temporal parameters analysed were evident for both genders. A lower pelvic obliquity motion
18. for treadmill walking when compared to overground was evident for both genders and the
19. pelvic rotation movement pattern showed the greatest difference between walking modes.
20. The majority of the significant differences between genders were of a magnitude greater than
21. the differences between overground and treadmill walking.
22. **Conclusions**: The differences in temporal and angular kinematics identified in the present
23. study should be considered when treadmills are used in a rehabilitation program.
24. **Key Words:** Overground; Treadmill; Pelvis; Kinematics

# INTRODUCTION

1. *Treadmill vs. Overground*

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1. Pathological gait relates to deviation from the normal patterns of movement. Abnormal gait
2. patterns could be the result of disorders of the brain, spinal cord, nerves, muscles, joints and
3. skeleton1. Gait analysis is an important aspect of assessment in clinical evaluation of gait
4. disturbances and in rehabilitation. Gait analysis protocol within a clinical setting commonly
5. employs a treadmill. The proposed benefits of using treadmills over overground walking
6. include: less space being required, control over speed and gradient, fewer cameras needed for
7. motion analysis, the capacity to use controlled protocol to assess ability to adapt to changes in
8. speed and surface slope, less data collection time, they allow the use of harnesses to support
9. body weight and simultaneous recording of other data such as an electromyogram and
10. metabolic costs.

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1. *Gait variability*
2. While it has been shown that when a treadmill’s belt speed is constant there is no mechanical
3. difference between treadmill and overground walking2, it may not be possible to maintain a
4. constant belt speed with variations in belt-speed found to be dependent on the power of the
5. treadmill and the mass of the participant3. Subsequently, Savelberg et al.3 found that these
6. differences in belt speed significantly affected kinematic parameters. Additionally, research
7. suggests that treadmill walking may result in less stride-to-stride variability4, 5 and an increase
8. in metabolic cost6, 7 when compared to overground walking.

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1. Many studies have compared the biomechanics of gait when walking overground and on a
2. treadmill, however, with inconsistent findings the relationship between the two modes is not
3. clear. Temporospatial parameters commonly used in gait analysis include walking speed,
4. stride time and length, step time and length and finally durations of stance and swing phase8.
5. Comparison of over ground and treadmill walking have previously shown that at identical
6. speeds, the stance period shortened, with increased cadence on the treadmill9-12. However,
7. Matsas et al.12 only found significant differences between the two modes of walking for the
8. first 4 minutes of data collection, at 6 minutes no significant differences were evident.
9. Additionally, Riley et al.13, 14 reported no differences in gait parameters. Conflicting findings
10. for differences in EMG recordings between overground and treadmill walking also exist
11. within the literature15-18.

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11 *Kinetics and Kinematics*

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1. The introduction of instrumented treadmill has allowed researchers to compare ground
2. reaction forces for treadmill and overground walking14, 15, 19. While Riley et al.14 found
3. significant differences in ground reaction force maxima, as these differences were
4. comparable to the variability in normal gait parameters, they concluded that the mechanics of
5. both modes were similar. Conversely, White et al.19 reported differences in force magnitude
6. between overground and treadmill walking during mid and late stance and Lee & Hidler15
7. reported differences in sagittal plane joint moments.

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1. Previous research on gait kinematics has also found conflicting results, with some reporting
2. differences9, 14, 16, 20 and others not7, 12, 15, 17. While some researchers have found significant
3. differences in joint angles they considered these irrelevant in their reports due to their
4. magnitude (< 3°)14, 20. On the contrary, Watt et al.21 reported reductions in the majority of
5. joint angles during treadmill walking; however of the twelve parameters where significant
6. differences were evident only two were of a magnitude greater than 3°. These conflicting
7. interpretations of results among researchers make it difficult to conclude whether differences
8. between the two modes are present or not.

4

5 *Other factors*

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1. Another confounding factor which may affect the identification of differences between
2. treadmill and overground walking is the age of study participants. While Riley et al.14 found
3. no differences between the conditions for young participants, Wass et al.22 found that older
4. people were unsuccessful in familiarising themselves to treadmill walking after 15 minutes.
5. In addition, Greig et al.13 reported higher heart rates in older adults when they walked on
6. treadmills than overground, even after they had undertaken familiarisation sessions, and no
7. difference in young people.

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15 *Gap in knowledge*

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1. While there are a number of studies which have examined differences in joint kinematics
2. between overground and treadmill walking the majority of these have focused on the ankle,
3. hip and knee joints with few assessing the role of the pelvis14, 21, 23, 24 which plays an
4. important role in walking. The movement pattern of the pelvis can be affected by conditions
5. such as leg length inequality, increased lumbar lordosis and trunk bending (lateral, anterior
6. and posterior)25-28. The pelvis is an important element in human locomotion which not only
7. influences the pathomechanics of the low back and the hip but also contributes to postural
8. stability29. Furthermore the pelvis plays an important role in the control of walking velocity.
9. Whilst it is beyond the scope of this manuscript to describe the fundamental pelvic movement
10. during gait and it is described elsewhere1, a previous study examined the effects of a lumbar
11. corset on pelvic kinematics using a treadmill with results indicating significant differences in
12. the frontal plane29.

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1. Of the limited research to date which have examined pelvic movement none have examined if
2. gender has an effect on pelvic movement, even though pelvic range of motion have shown to
3. be affected by gender30, 31, 31. Additionally, as Alton et al.9 found that gender had an effect on
4. hip and knee kinematics during treadmill and overground walking, it warrants a need to
5. quantify if differences occur at the pelvis.

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1. While looking at the gender differences in the variability of gait parameters at 4 different
2. speeds, a previous study indicated that there are no differences in basic gait parameters such
3. as the stride length and stride time. In general, the women exhibited lower variability than
4. their male counterparts for various joint rotations. This was more evident in higher gait speed.
5. However, the authors suggest that the gender differences in variability may not be consistent
6. across different levels of the motor system32. Therefore the purpose of the present preliminary
7. study was to determine if differences in temporal values and angular parameters in the pelvic
8. complex occur, when comparing overground and treadmill ambulation. 'This information
9. will provide data that can be used in designing protocols for clinical intervention, as well as
10. base line normative data for future research. Additionally this study will also investigate if
11. gender differences are evident in basic temporal gait parameters and/or in pelvic complex
12. parameters.

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1. It was hypothesised that there would be differences in angular parameters between male and
2. female participants in the two modes of walking, but that there would be no differences in
3. temporal measures.

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5 **METHODS**

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# 7 Participants

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1. A convenient sample consisting of 8 males and 6 females were recruited from a group of
2. University students (participant demographics shown in Table 1). Ethical approval was
3. sought and received from the University Ethics committee. All participants signed an
4. informed consent form before participating in the study. All participants were familiar with
5. treadmill walking and reported no known musculo skeletal pathologies. Each participant
6. wore their own trainers and appropriate clothing to allow for marker placements on
7. anatomical landmarks.

16

17 **Equipment**

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1. The study was conducted in a gait laboratory with a walkway of nine meters. Timing gates
2. were used to establish over ground walking speed, with this speed then used to set the speed
3. for the treadmill (model T9700HRT, Vision Fitness, Wisconsin, USA). Kinematics were
4. recorded using a motion analysis system (Vicon, OMG, UK) with 8 cameras with a viewing
5. 4.0\*4.0\*1.8m, operating at a sampling rate of 200Hz.

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# 25 Data collection

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1. Anthropometric data were recorded for each participant and reflective markers were
2. positioned by the same researcher, using a whole body marker set (Plug-in gait, Vicon, OMG,
3. UK). Calibration was undertaken for each participant using a static trial. A walkway 9m long
4. with the 4m – 8m section used for data collection was set up overground with participants
5. instructed to walk with normal cadence. Timing gates **(**Brower Timing Systems, USA) were
6. used to record the participant’s preferred walking speed and were subsequently used to
7. control for speed between trials. Kinematics were recorded over three seconds to allow for
8. capture of one full gait cycle and ten trials for each participant were recorded. Each
9. participant performed overground then treadmill walking on the same day to avoid
10. reapplication of markers. The treadmill was positioned in the same direction as the walkway.
11. For each participant the treadmill was set to their personal average speed calculated from the
12. overground walking. The participants walked for a minimum of a minute before each trial
13. and ten trials of three seconds duration were captured for analysis. For the purpose of clarity,
14. the following terminology was employed: forward or the backward tilting of the pelvis is
15. described as pelvic tilt, the lateral tilting of the pelvis is described as pelvic obliquity and the
16. turning of the pelvis is described as rotation.

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# 19 Data Processing and Analysis

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1. Gait parameters for heel strike and toe off were identified for both left and right feet by frame
2. analysis. When identifying foot contacts the downward velocity of the heel marker and the
3. footwear and skeletal loading were taken into account23. Similarly toe off was identified by
4. analysis of the vertical displacement of the toe marker. Mean values for cadence, stride time,
5. foot off and various pelvic angles (Table 2 lists the angular parameters) were calculated for
6. all the participants in both overground and treadmill conditions. The angular parameters used
7. were adapted from previous related studies23, 33.

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1. Data were entered into SPSS version 17.0 for statistical analysis. An independent samples t-
2. test was used to determine if walking speed was affected by gender. A two-way ANOVA was
3. performed to examine the effect of walking mode (overground and treadmill) and gender on
4. each dependent variable (gait and angular parameters).

8

9 **RESULTS**

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1. Table 3 provides values and statistical results for the temporal parameters and Table 4 details
2. the results of pelvic angle differences. Figures 1 - 3 represent the movement of the pelvis in
3. the three planes for female and male overground and treadmill walking. Any gender
4. differences in temporal and kinematic parameters were not affected by the participants self
5. selected walking speed as No significant difference between genders for walking speed was

16 evident (t(12) = 1,12, p = 0.285).

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# 18 Temporal parameters

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1. A significant difference (p < .05) was evident between genders for stride time only with
2. females exhibiting a shorter stride time when compared to males. When comparing
3. overground to treadmill walking significant differences were identified for the mean temporal
4. parameters conditions with a lower cadence and longer stride time and stance phase..
5. Additionally, the interaction between gender and walking mode for stance phase reached
6. significance with females spending a smaller proportion of the gait cycle in stance phase
7. when compared to males for the overground condition and a higher proportion for the
8. treadmill condition.

3

# 4 Pelvic angle parameters

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1. Females generated a significantly greater pelvic tilt angle at toe off than males. The
2. interaction between gender and walking mode for this parameter also reached significance
3. with females reducing this angle when treadmill walking and males increasing this angle.
4. Furthermore an interaction effect for pelvic angle at initial contact was evident with the same
5. findings as toe off (i.e. females reduced this angle when treadmill walking whereas males
6. increased it'). While the general movement pattern for pelvic tilt did not appear to change a
7. great deal for females between walking modes, for males, while the magnitude of the range
8. of movement remained constant, there was an increase in anterior tilt of approximately 2°
9. throughout the gait cycle for treadmill walking (Figure 1).

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1. Significant differences (p < .05) were evident between genders for three of the four pelvic
2. obliquity angles, with females generating greater pelvic obliquity motion. When walking
3. mode was compared significantly lower maximum upward and downward obliquity were
4. evident when participants walked on a treadmill. A significant interaction effect for the
5. second maximum downward angle indicated that gender had a greater effect on overground
6. walking than walking on a treadmill. Additionally, males were found to have their pelvis in a
7. slightly upward pelvic obliquity position at initial contact for treadmill walking but a slightly
8. downward pelvic obliquity position for overground walking (Figure 2).

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1. For both pelvic rotation parameters, there was a significant effect for walking mode but no
2. effect for gender. At initial contact the internal rotation was lower during treadmill walking
3. when compared to overground, with the females approaching a more neutral rotation position
4. and the males a slight externally rotated position. Furthermore, a lower external rotation at
5. toe off during treadmill walking was evident. The general pelvic rotation movement pattern
6. employed by both genders for overground walking appears to be considerably different than
7. the movement pattern for treadmill walking (Figure 3). After initial contact the pelvis
8. remained in internal rotation for a greater percentage of the gait cycle in treadmill walking,
9. and the maximum external rotation angle also occured later in the gait cycle.

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11 **DISCUSSION**

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1. With the overall objective of determining the differences in temporal and angular parameters
2. in the pelvic complex, when comparing overground and treadmill ambulation, this study also
3. examined the temporal gait parameters between male and female participants. The reported
4. results provide normative data to inform further studies in this area and will help in designing
5. protocols for clinical intervention.

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# 19 Temporal parameters

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1. While previous research has found gender differences in temporal gait parameters34, 35, with
2. women tending to have a higher cadence than men, in the present study gender differences
3. were only evident for stride time. Treadmill cadence was found to be less (12% for females
4. and 16% for males) than the cadence performed overground; this is in conflict with previous
5. research where the cadence values were found to increase while walking on the treadmill9, 10,
6. however, no change in cadence between these walking modes has also been reported14. A
7. possible reason for these conflicting reports could be the ability of treadmills to maintain a
8. constant belt velocity, as body mass has been found to affect belt velocity3. Stride time was
9. found to increase (15% for females and 19% for males) during treadmill walking in
10. comparison to overground, with both within the normal range previously reported36. For
11. stance phase treadmill values were significantly greater (11% for females and 8% for males)
12. than overground. This finding in the present study adds to the inconsistent results for stance
13. phase in the literature with some researchers reporting no difference in stance phase between
14. treadmill and overground walking16 and others reporting a decrease in stance phase with
15. treadmill walking9, 10. However, the values reported within the current study concurs with a
16. previous study which recorded stance phase as being 69% of the gait cycle for an age range
17. of 20 – 29 years for a female and male participant group during treadmill walking37.
18. Moreover the stance phase percentage values reported in the present study follow other
19. research evaluating running on a treadmill, where treadmill running is associated with an
20. increased stance period23. The variation in the temporal values could possibly be attributed to
21. differences in heel contact and toe off identification. The current study looked at the
22. displacement of the heel and toe markers using frame-by-frame analysis to identify stance
23. phase. Although this was performed by the same experienced researcher, this may have been
24. a source of error. However, previous research has found the reliability of visual identification
25. when compared to footswitches and force plates to be high38.

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1. The results also demonstrate that the stance phase component of the overall gait cycle in
2. female participants is lower when compared to males for the over ground condition. On the
3. contrary it is shown to be higher while walking on the treadmill. When compared to previous
4. research32 which indicated no significant differences in treadmill locomotion between the
5. genders, the current study shows differences, which warrant further detailed investigation.
6. This will be particularly relevant while planning treadmill based treatment intervention.

3

# 4 Pelvic angle parameters

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1. Gender comparisons highlighted that female anterior pelvic tilt angle was greater during toe
2. off than males. Examination of the pelvic tilt movement pattern during gait (Figure 1)
3. indicated the diverse adaptation to the modes of walking undertaken by males and females.
4. Similarly the toe off pelvic downward obliquity angle was greater in females than males.
5. These differences in the pelvic movement during toe off phase have not been reported
6. previously. The maximum upward and downward obliquity of the pelvis during gait was
7. significantly reduced during treadmill walking, which is in accordance with previous
8. research24. Clinically, excessive pelvic obliquity is caused by leg length inequality among
9. other things39. The reported reduction in obliquity might favour the use of treadmill in
10. treatments interventions in which reduced obliquity is desirable.

16

1. The female pelvic rotation maximum upward and second maximum downward angle were
2. significantly less than the males. While the values reported in this present study for pelvic
3. range of motion are similar to those presented by Crosbie et al.31 they reported no significant
4. difference between genders at self selected walking speed. A possible reason for this
5. difference is the age range of the study participants, as age has been shown to affect pelvic
6. movement40. Crosbie et al.31 used a much wider age range of participants (20 – 50 years) than
7. the present study (18 – 28 years).

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1. Pelvic rotation angles were most affected by the walking condition with the greatest
2. difference in both movement magnitude and pattern. Pelvic rotation at initial contact was
3. significantly less while walking on the treadmill when compared to overground for both
4. genders, with this decrease being of the greatest magnitude of all the significant differences
5. (4.7° for males and 4.1° for females). In addition, a lower pelvic rotation was evident at toe
6. off for male participants. There was a large decrease (46% for males and 48% for females) in
7. the pelvic rotation range of motion during gait for overground (8.9° for males and 10.1° for
8. females) and treadmill (4.8° for males and 5.3° for females) walking, which is again
9. consistent with research carried out by Vogt et al.24. Vogt et al.24 suggested that this reduction
10. in pelvic movement during treadmill walking may be attributed to stiffness in the kinematic
11. chain.

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1. In a group of low back pain patients, a previous study41 looking at lumbopelvic rotation in a
2. static condition, demonstrated that the rotation in the early part of hip lateral rotation is higher
3. in male participants when compared to women. Based on this the authors postulated that this
4. difference might make men more vulnerable to low back pain associated with hip lateral
5. rotation. Although the current study didn’t look at a patient population and it reports results
6. from a dynamic upright postural condition, the results could be compared to other previously
7. published studies and the overall results contribute to further understanding of pelvic motion.
8. This understanding will contribute to designing exercise interventions in patients with
9. conditions such as low back pain. Furthermore, the results highlight the need for further
10. scientific research into new running based exercise programs such as C*hi running* or *Barefoot*
11. *running.*

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1. In summary, wherever significant differences were evident in the results, the magnitude of
2. the difference between genders was generally greater than the difference between overground
3. and treadmill, apart from pelvic rotation angles. The magnitudes of all the significant
4. differences were small (1 – 4.7°). On one hand, these differences could be viewed as being
5. too small to be clinically significant when measurement error is considered, while on the
6. other, given the limited range of motion that occurs at the pelvis these changes may indicate a
7. change in the gait pattern.

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# 9 Study Limitations

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1. Although there is no available data to support the thought that an alteration in pelvic
2. movement is directly related to the resonant frequency of the combined system or its
3. individual components (the participant and the treadmill), this is an area of further
4. investigation.

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1. One of the limitations involved in the study was the manual identification of gait events
2. discussed. However, this would have had little effect on the kinematic pattern or the peak
3. magnitudes. The other limitation could be from the footwear which has an influence on
4. movement. All participants wore their own trainers which had varying designs and material
5. properties.

21

22 **Conclusion**

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1. The present study identified differences in temporal and angular kinematics when comparing
2. overground and treadmill locomotion and between genders. The use of treadmill for
3. rehabilitation is becoming increasingly popular, because it is a convenient and controlled
4. piece of equipment. However this study has presented differences the treadmill produces
5. when compared to overground walking. Therefore when treadmills are used in assessment
6. and rehabilitation these differences should be considered.

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**Table 1**

Table 1. Participant demographics

|  |  |  |
| --- | --- | --- |
|  | Male (n = 8) | Female (n = 6) |
| Age (years) | 22.5 ± 3.0 | 23.8 ± 4.1 |
| Mass (kg) | 75.0 ± 6.0 | 59.2 ± 4.4 |
| Height (cm) | 183.7 ± 6.9 | 168.0 ± 5.7 |

**Table 2**

Table 2. Angular parameters measured.

# Pelvic movement Parameter (degrees)

Tilt Initial contact angle

Toe off angle

Obliquity Initial contact angle

First maximum upward angle Toe off angle

Second maximum downward angle

Rotation Initial contact angle Toe off angle

**Table 3**

Table 3. Temporal parameter values (means ± SD) and results for statistical comparisons.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Group** | **Overground** | **Treadmill** | Male vs. Female | **Comparison (P value)**  Overground vs. Treadmill | Gender \* Walking mode |
| Cadence (steps/min) | Female | 115.82 ± 5.88 | 101.74 ± 5.65 | 0.081 | <0.001\* | 0.100 |
|  | Male | 114.24 ± 5.82 | 96.42 ± 5.63 |  |  |  |
| Stride time (s) | Female | 1.03 ± 0.05 | 1.18 ± 0.07 | 0.037\* | <0.001\* | 0.115 |
|  | Male | 1.05 ± 0.05 | 1.25 ± 0.08 |  |  |  |
| Stance phase (% of gait cycle) | Female | 62.17 ± 1.2 | 68.81 ± 1.28 | 0.833 | <0.001\* | 0.020\* |
|  | Male | 62.94 ± 2.0 | 67.85 ± 0.92 |  |  |  |

* + Significant difference (p < .05)

**Table 4**

Table 4. Pelvic angle parameter values (means ± SD) and results for statistical comparisons.

**Pelvic Parameter (degrees) Group Overground Treadmill Comparison (P value)**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **movement** |  |  |  |  | Male vs. Female | Overground vs. Treadmill | Gender \* Walking mode |
| Tilt | Initial contact angle | Female | 10.73 ± 4.65 | 9.62 ± 5.06 | 0.194 | 0.767 | 0.006\* |
|  |  | Male | 7.5 ± 3.53 | 8.85 ± 3.30 |  |  |  |
|  | Toe off angle | Female | 9.67 ± 4.41 | 8.65 ± 5.10 | 0.046\* | 0.629 | 0.025\* |
|  |  | Male | 5.88 ± 2.83 | 6.55 ± 2.90 |  |  |  |
| Obliquity | Initial contact angle | Female | 0.80 ± 1.63 | 0.06 ± 1.67 | 0.893 | 0.097 | 0.087 |
|  |  | Male | -0.49 ± 1.88 | 0.46 ± 1.77 |  |  |  |
|  | First maximum upward angle | Female | 6.84 ± 2.28 | 4.35 ± 2.09 | 0.001\* | <0.001\* | 0.236 |
|  |  | Male | 3.64 ± 1.75 | 1.99 ± 2.13 |  |  |  |
|  | Toe off angle | Female | -4.58 ± 2.57 | -4.29 ± 2.04 | 0.004\* | 0.858 | 0.521 |
|  |  | Male | -2.14 ± 1.83 | -2.30 ± 1.80 |  |  |  |
|  | Second maximum downward angle | Female | -6.58 ± 2.15 | -4.35 ± 2.06 | 0.001\* | <0.001\* | 0.027\* |
|  |  | Male | -3.49 ± 1.80 | -2.56 ± 1.78 |  |  |  |
| Rotation | Initial contact angle | Female | 5.01 ± 2.38 | 0.91 ± 2.81 | 0.138 | <0.001\* | 0.548 |
|  |  | Male | 4.05 ± 2.36 | -0.66 ± 2.57 |  |  |  |
|  | Toe off angle | Female | -2.89 ± 1.89 | -2.32 ± 1.88 | 0.783 | 0.010\* | 0.175 |
|  |  | Male | -3.27 ± 1.98 | -1.55 ± 2.57 |  |  |  |

* + Significant difference (p < .05)

**Figure 1 - Legend**

Figure 1. Gait cycle pattern for male and female pelvic tilt when walking overground and on a treadmill for left (a) and right (b) side.

**Figure 1**

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**Angle (degrees)**

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0% **Gait cycle (%)**

100%

Female - overground - left pelvic tilt Female - treadmill - left pelvic tilt Male - overground - left pelvic tilt Male - treadmill - left pelvic tilt

(a)

13

11

**Angle (degrees)**

9

7

5

3

0% **Gait cycle (%)**

100%

Female - overground - right pelvic tilt Female - treadmill - right pelvic tilt Male - overground - right pelvic tilt Male - treadmill - right pelvic tilt

(b)

**Figure 2 - Legend**

Figure 2. Gait cycle pattern for male and female pelvic obliquity when walking overground and on a treadmill for left (a) and right (b) side.

**Figure 2**

-8

8

6

4

2

0

-2

-4

-6

0%

100%

**Angle (degrees)**

**Gait cycle (%)**

Female - overground - left pelvic obliquity Female - treadmill - left pelvic obliquity Male - overground - left pelvic obliquity Male - treadmill - left pelvic obliquity

(a)

**Angle (degrees)**

-8

8

6

4

2

0

-2

-4

-6

0%

100%

**Gait cycle (%)**

Female - overground - right pelvic obliquity Female - treadmill - right pelvic obliquity Male - overground - right pelvic obliquity Male - treadmill - right obliquity

(b)

**Figure 3 - Legend**

Figure 3. Gait cycle pattern for male and female pelvic rotation when walking overground and on a treadmill for left (a) and right (b) side.