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Short communication

# Joint kinematics and ground reaction forces in overground versus treadmill graded running

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ABSTRACT

*Background:* Treadmills are often used to assess running biomechanics, however the validity of applying results from treadmill graded running to overground graded running is currently unknown.
*Research question:* The purpose of this study was to investigate whether treadmill and overground graded running have comparable kinematics and ground reaction force parameters.
*Methods:* Eleven healthy male adults ran overground and on an instrumented treadmill as motion capture and force platform data were collected for the following conditions: downhill running at a slope of −8° at 10, 13 and 16 km·h$^{-1}$; level running at 10 and 13 km·h$^{-1}$; uphill running at a slope of +8° at 8, 10 and 13 km·h$^{-1}$. Sagittal joint angles at heel strike, mid-stance, and toe-off were computed for the ankle, knee and hip. Ground reaction force parameters including peak average and instantaneous normal loading rate, peak impact and active normal force, peak tangential (braking and propulsive) forces, and normal and tangential impulses were also calculated.
*Results:* Joint kinematics and ground reaction forces for level running were generally similar between overground and treadmill conditions. The following variables were significantly higher during overground uphill running (mean difference ± SD): average normal loading rate (14.4 ± 7.1 BW·s$^{-1}$), normal impulse (0.04 ± 0.02 BW·s), propulsive impulse (0.04 ± 0.02 BW·s), and vertical center of mass excursion (0.092 ± 0.031 m). The following variables were significantly higher during overground downhill running (mean difference ± SD): ankle plantarflexion at toe-off (−5.39 ± 6.19°) and vertical center of mass excursion (0.046 ± 0.039 m).
*Significance:* These findings suggest that subtle differences in kinematics and ground reaction forces exist between overground and treadmill graded running. These differences aside, we believe that overground kinematics and ground reaction forces in graded running are reasonably replicated on a treadmill.

## 1. Introduction

Treadmills have been used to investigate various biomechanical aspects of graded running [1–3]. Treadmills are advantageous as they offer the ability to collect data from many consecutive steps at different speeds and slopes [4]. Several studies comparing treadmill and overground level running have reported minor biomechanical differences; however, these studies generally concluded that treadmill-based analyses were generalizable to overground analyses [5,6]. With the rapid increase in trail running popularity, several studies have been performed on instrumented treadmills at different slopes to mimic overground uphill/downhill running [7,8]. However, since systematic biomechanical and neurophysiological differences have been observed between overground level and graded running [9], care must be taken to ensure that level treadmill running reflects graded treadmill running. The purpose of this study was to compare kinematics and ground reaction forces (GRFs) between graded treadmill and overground running to evaluate the validity of applying results from the former to the latter.

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**Table 1**
Kinetic and kinematic variables during uphill running [mean (SD)]. Overall mean differences across the conditions, together with the 95% confidence intervals ( ± 95% CIs) and the effect sizes for the differences [presented as partial eta squared ($\eta_p^2$)] are also shown.

| | 8 $km \cdot h^{-1}$ | | 10 $km \cdot h^{-1}$ | | 13 $km \cdot h^{-1}$ | | Condition Effect (*p*-value) | Overall mean difference | ± 95% CIs for difference | $\eta_p^2$ for difference |
|---|---|---|---|---|---|---|---|---|---|---|
| | Instrumented Treadmill | Overground | Instrumented Treadmill | Overground | Instrumented Treadmill | Overground | | | | |
| ALR ($BW \cdot s^{-1}$) | 24.0 (8.7) | 36.9 (21.3) | 33.6 (11.3) | 46.2 (20.2) | 41.8 (19.2) | 59.5 (19.0) | **0.04** | 14.4 | 13.8 | 0.22 |
| ILR ($BW \cdot s^{-1}$) | 40.1 (13.1) | 53.5 (28.4) | 53.3 (21.2) | 64.1 (25.7) | 73.9 (28.8) | 80.8 (23.1) | 0.29 | 10.6 | 20.5 | 0.07 |
| Impact peak (%)[a] | 23.6 (34.4) | 47.3 (38.2) | 36.4 (41.8) | 65.5 (43.0) | 40.0 (48.1) | 65.5 (48.2) | 0.14 | 0.3 | 0.4 | 0.13 |
| PAF (BW) | 2.2 (0.1) | 2.2 (0.2) | 2.3 (0.2) | 2.3 (0.1) | 2.4 (0.2) | 2.5 (0.2) | 0.74 | 0.02 | 0.1 | 0.01 |
| $I_{norm}$ ($BW \cdot s$) | 0.37 (0.02) | 0.40 (0.04) | 0.35 (0.02) | 0.39 (0.04) | 0.32 (0.02) | 0.36 (0.03) | **0.01** | 0.04 | 0.02 | 0.51 |
| PBF (BW) | −0.06 (0.04) | −0.10 (0.05) | −0.09 (0.04) | −0.15 (0.05) | −0.12 (0.04) | −0.19 (0.05) | **0.01** | 0.05 | 0.04 | 0.39 |
| PPF (BW) | 0.34 (0.04) | 0.37 (0.02) | 0.38 (0.04) | 0.41 (0.04) | 0.45 (0.05) | 0.49 (0.06) | 0.06 | 0.03 | 0.03 | 0.21 |
| $I_{prop}$ ($BW \cdot s$) | 0.047 (0.003) | 0.052 (0.008) | 0.044 (0.004) | 0.048 (0.007) | 0.042 (0.004) | 0.046 (0.007) | **0.04** | 0.004 | 0.005 | 0.23 |
| Ankle angle at HS (°) | 13.4 (7.5) | 17.1 (6.3) | 13.2 (7.8) | 16.1 (6.8) | 11.8 (8.9) | 16.2 (6.8) | 0.28 | 3.8 | 7.2 | 0.07 |
| Knee angle at HS (°) | −30.6 (5.1) | −28.9 (5.5) | −32.2 (9.2) | −27.7 (4.9) | −33.5 (5.3) | −29.8 (6.0) | 0.28 | 3.1 | 5.8 | 0.07 |
| Hip angle at HS (°) | 32.3 (5.8) | 32.9 (5.0) | 35.1 (6.1) | 34.8 (5.5) | 38.6 (5.7) | 37.6 (6.1) | 0.98 | 0.1 | 5.0 | 0.00 |
| Ankle angle at mid-stance (°) | 28.7 (6.3) | 31.3 (3.9) | 28.6 (5.8) | 30.9 (3.8) | 27.4 (6.2) | 30.2 (4.2) | 0.23 | 2.9 | 4.9 | 0.09 |
| Knee angle at mid-stance (°) | −41.2 (8.9) | −42.9 (5.0) | −42.2 (8.0) | −44.3 (4.3) | −41.8 (5.1) | −44.4 (3.8) | 0.38 | −2.4 | 5.7 | 0.05 |
| Hip angle at mid-stance (°) | 14.1 (5.0) | 15.8 (5.5) | 15.5 (5.1) | 17.5 (5.3) | 16.6 (3.1) | 18.5 (4.3) | 0.36 | 1.9 | 4.3 | 0.05 |
| Ankle angle at TO (°) | −11.7 (6.1) | −14.4 (5.5) | −13.2 (6.4) | −14.8 (5.0) | −14.3 (7.4) | −14.9 (4.5) | 0.53 | 1.7 | 5.7 | 0.02 |
| Knee angle at TO (°) | −16.4 (8.6) | −16.5 (7.0) | −14.8 (9.7) | −13.4 (5.6) | −9.9 (5.4) | −12.0 (5.8) | 0.84 | 0.6 | 6.0 | 0.00 |
| Hip angle at TO (°) | −9.0 (4.9) | −8.3 (5.6) | −10.7 (6.3) | −10.4 (5.7) | −15.4 (4.8) | −13.2 (5.8) | 0.62 | 1.2 | 4.9 | 0.01 |
| Vertical Excursion (m) | 0.094 (0.013) | 0.166 (0.028) | 0.090 (0.014) | 0.187 (0.011) | 0.072 (0.015) | 0.179 (0.056) | < **0.01** | 0.092 | 0.016 | 0.90 |
| Running Speed ($km \cdot h^{-1}$) | 8.0 | 7.7 (0.8) | 10.0 | 9.4 (0.5) | 13.0 | 11.8 (0.8) | | | | |

[a] Percentage of trials that contained an impact peak (100% = impact, 0% = transient/no impact). Negative angles correspond to ankle plantarflexion, knee flexion, and hip extension. ALR = average loading rate, ILR = instantaneous loading rate, PAF = peak active force, $I_{norm}$ = normal impulse, PBF = peak braking force, PPF = peak propulsive force, $I_{prop}$ = propulsive impulse. HS = heel strike, TO = toe-off.

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