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ORIGINAL ARTICLE

Shoe drop has opposite influence on running pattern when running overground or on a treadmill

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Abstract

Purpose Minimalist running shoes are designed to induce a foot strike made more with the forepart of the foot. The main changes made on minimalist shoe consist in decreasing the height difference between fore and rear parts of the sole (drop). Barefoot and shod running have been widely compared on overground or treadmill these last years, but the key characteristic effects of minimalist shoes have been yet little studied. The purpose of this study is to find whether the shoe drop has the same effect regardless of the task: overground or treadmill running.

Methods Twelve healthy male subjects ran with three shoes of different drops (0, 4, 8 mm) and barefoot on a treadmill and overground. Vertical ground reaction force (vGRF) (transient peak and loading rate) and lower limb kinematics (foot, ankle and knee joint flexion angles) were observed.

Results Opposite footwear effects on loading rate between the tasks were observed. Barefoot running induced higher loading rates during overground running than the highest drop condition, while it was the opposite during treadmill running. Ankle plantar flexion and knee flexion angles at touchdown were higher during treadmill than overground running for all conditions, except for barefoot which did not show any difference between the tasks.

Conclusions Shoe drop appears to be a key parameter influencing running pattern, but its effects on vGRF differ depending on the task (treadmill vs. overground running) and must be considered with caution. Unlike shod conditions, kinematics of barefoot condition was not altered by treadmill running explaining opposite conclusions between the tasks.

Keywords Footwear · Barefoot · Foot strike · Ground reaction force · Kinematics

Abbreviations

BF	Barefoot condition
BW	Body weight
D0	0 mm shoe drop condition
D4	4 mm shoe drop condition
D8	8 mm shoe drop condition
EU	European Union
EVA	Ethylene-vinyl acetate
GRF	Ground reaction force
vGRF	Vertical ground reaction force

Introduction

With the rising of the minimalist shoe trend, a large number of running shoe manufacturers have promoted a lower drop (height difference between the fore and rear parts of the inside of the shoe) of their shoes. Some brands claimed that a minimalist shoe with a flatter sole (lower drop) could cause biomechanical running pattern transition toward a barefoot running pattern.

Previous studies have showed plenty of kinematic differences between classical shod and barefoot running pattern while observing habitually shod runners. Indeed, habitually

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shod runners modify their running technique during barefoot running and exhibit a less dorsiflexed ankle at touchdown with a larger ankle joint range of flexion during the stance phase (Chambon et al. 2014; De Wit et al. 2000; Hamill et al. 2011; Bishop et al. 2006) and a more flexed knee joint with a lower knee joint range of flexion during the stance phase (Chambon et al. 2014; De Wit et al. 2000; Fukano et al. 2009). This altered segment configurations at touchdown leads to a midfoot strike in barefoot, i.e., a strike index between 34 and 67 % of total foot length (Cavanagh and Lafortune 1980) rather than a rearfoot strike while shod, i.e., a strike index between 0 and 33 % of total foot length (Hamill et al. 2011).

These kinematic differences between barefoot and shod running lead to a decrease of the first peak of vertical ground reaction force (transient peak) (Divert et al. 2005) and the associated loading rate (Hamill et al. 2011). However, studies have revealed a potential link between transient peak, loading rate and injuries. Indeed, on comparing the running biomechanics of control groups and runners with a history of plantar fasciitis (Pohl et al. 2009), tibial stress fracture (Milner et al. 2006) or various injuries (Hreljac et al. 2000), every author noted higher transient peak or loading rate for the injured group. Moreover, a retrospective study showed that in a population of competitive cross-country runners, rearfoot strikers habitually have significantly higher rates of repetitive stress injury than those who mostly forefoot strike (Daoud et al. 2012).

Given previously cited works, and despite the fact that no long-term prospective epidemiological study demonstrated the benefits or the dangers of running using minimal running shoes, it seems crucial to consider with interest low-drop shoes proposed by running shoes manufacturers. For habitually shod rearfoot strikers, the biomechanics of running in minimalist shoe has been shown to be closer to barefoot running than running in classical running shoe (Paquette et al. 2013). However, it is not clear whether the shoe weight, the upper, the sole stiffness, thickness, or the drop is the cause of the differences observed between minimalist and “classical” shod running. It has been shown that shoe mass (mass difference of 200 g) affects energy consumption and stride frequency during running (Divert et al. 2008). However, the study of Divert et al. (2008) did not show any effect for an added mass of 100 g. To our knowledge, no other study has shown the effect of added mass on kinematic pattern of running. To date, the main midsole characteristics altered by running shoe manufacturers are thickness and drop, to induce a change in foot strike pattern with reduced impact forces. Midsole thickness does not seem to be a key factor in triggering this change as varying midsole thickness from 0 to 12 mm did not modify running kinematic pattern and impact forces (Chambon et al. 2014). A recent study showed an alteration toward a midfoot pattern with lower-drop shoes during treadmill running (Horvais and Samozino 2013). While these authors reported alterations of the global running pattern, their study did not include loading rate and transient peak observation, thus making it impossible to infer about body loading and the potential injury risks. To date, no study has investigated the specific influence of shoe drop on vertical ground reaction force characteristics.

Besides, it can be noted that an important number of studies have compared barefoot and/or minimalist shoe and/or classical running shoe during treadmill running these last years (Cheung and Rainbow 2014; Divert et al. 2005; Hollander et al. 2014; Horvais and Samozino 2013; Lussiana et al. 2014; TenBroek et al. 2013; Squadrone and Galozzi 2009; Willy and Davis 2014; Shih et al. 2013). One can wonder whether the best way to test for shoe drop effects for habitually shod runners is to perform a treadmill running task. Indeed, Nigg et al. (1995) showed that treadmill running alters foot strike pattern with a foot strike pattern biased toward midfoot strike for treadmill relative to overground running. Moreover, Fellin et al. (2010) observed a 4.5 degrees decrease in foot dorsiflexion at foot strike during treadmill running. These observations may reveal a potential experimental bias with reference to overground running when testing for the drop effect during treadmill running. Indeed, it has been demonstrated that both treadmill and a lower shoe drop induce a decrease in foot/ground angle at touchdown. Although using a treadmill allows for a very low intra-individual variability, this task may not fairly represent overground running, especially when considering the shoe parameter (e.g., the shoe drop) which might affect footfall pattern.

This study aimed at determining whether two distinct experimentations using different tasks (treadmill vs. overground running) would have revealed the same conclusions regarding a drop effect on running pattern. It was hypothesized that shoe drop would affect running kinematics with a flatter foot position at touchdown (lower dorsiflexion angle) for low-drop conditions compared to high-drop conditions for the two tasks. These changes should affect vertical ground reaction force with a decrease of loading rate for low-drop conditions. As treadmill running has been shown to affect foot kinematics at touchdown with a flatter foot at impact, differences observed on kinematics and ground reaction forces between footwear conditions should be less pronounced during treadmill running.

Materials and methods

Participants

Twelve healthy male recreational runners (age: 21.8 ± 2.0 years, height: 182 ± 5 cm, body mass: 71.8 ± 5.9 kg, EU shoe size: 43) volunteered for participation in the experiments. All participants provided written informed consent prior to inclusion in this study, which was approved by the local ethical committee. Foot strike index (FSI) was calculated during overground trials for D8 condition according to Cavanagh and Lafortune (1980): 11 participants were rearfoot strikers (FSI < 33 % of foot length) and 1 was a midfoot striker (FSI > 33 and < 67 %) (mean value 24 ± 13 % of foot length). During the same experimental condition, 11 participants exhibited foot/ground angle greater than 8° [= rearfoot strike according to Altman and Davis (2012)] and 1 exhibited a foot/ground angle between −1.8° and 8° [= midfoot strike according to Altman and Davis (2012)] (mean value 20.3° ± 8.3°).

Experimental conditions

Three shod conditions and a barefoot condition were tested in randomized order. All shoes had identical lightweight upper, outsole thickness (3 mm of rubber), midsole hardness (EVA, 60 Asker C), and forefoot midsole thickness (2 mm). Shoe conditions only differed in rearfoot midsole thicknesses: 2, 6, and 10 mm and thus in drop (0, 4, and 8 mm respectively). Shoe mass was different for the three prototypes due to midsole differences, but this difference was negligible (196, 204, and 213 g for the three shoes from the lower-drop condition to the higher-drop condition). Each condition was first tested during treadmill running (7 min for familiarization to the new tested condition) before overground running.

For the next parts, "footwear factor" will refer to all the experimental conditions: drops of 0 mm (D0), 4 mm (D4), and 8 mm (D8) and barefoot (BF); "shod factor" will refer to the three shoe conditions (barefoot condition excluded); "task factor" will refer to treadmill and overground running.

Experimental task

First, the preferential running speed of each subject with their personal running shoes was determined on a stiff laboratory treadmill (®Tecmachine Medical Developpement S1200). Starting from 8 km/h, the speed was increased by 0.5 km/h every 15 s until the participant requested stabilization of the speed. At that moment, the participant could decide to decrease or increase the speed by 0.5 km/h several times until he felt he was running at his preferred speed. This speed was then used for all the remaining experimental trials of the participant.

For each experimental condition, the participants were asked to run on a stiff instrumented treadmill during 7 min, to stabilize their running pattern in their new footwear condition (Delattre et al. 2013). Analyses were done during the last 20 strides of the treadmill task. Then, participants had to run along a 15 m runway in which a force platform was mounted flush to the floor 10 m after the start of the run. Each subject had to perform seven valid running trials at his preferred speed (previously determined). Running speed was controlled by photocells apart from the force platform. All valid trials were performed with a right footfall on the force platform, within ±5 % of the prescribed speed.

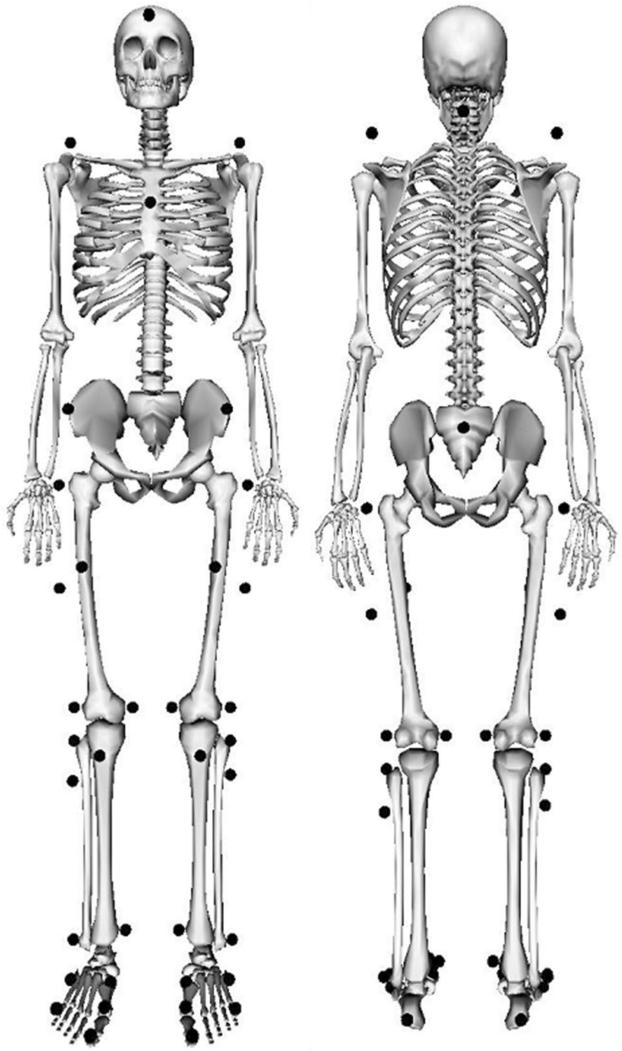

Fig. 1 Marker placement landmarks: forehead, seventh cervical vertebrae, middle of the sternum length, sacrum, right and left: acromiums, anterior superior iliac spines, greater trochanters, middle of the thigh on the lateral sides, middle of the thigh on front side, lateral and medial condyle of the knees, head of fibulas, tibial tuberosity, middle of the lateral side of the legs, lateral and medial malleolus, calcaneus tuberosity, proximal and distal extremities, of the first and fifth metatarsus, hallux extremity

Biomechanical measurements

Eight cameras of an optoelectronic motion capture system (®Vicon T40 and T20) tracked 40 reflective markers (Fig. 1). The marker set used was based on principles described in Kadaba et al. (1990) and used in Hamner et al. (2010). These markers were used to observe the 3D kinematics of the knee and ankle joints as well as foot/ground angle during the experimental tasks. Knee and ankle flexion angles were computed with OpenSim software (see description below). Positive values correspond to knee flexion and ankle dorsiflexion. For the knee, the neutral position corresponds to the extended position. For the ankle, the neutral position corresponds to an angle of 90° between the shank and foot segments. Foot ground angle was computed by taking the angle of the foot at foot strike in the sagittal plane (with hallux and calcaneus markers) and subtracting the neutral angle of the foot during standing. A positive angle indicated a hallux position higher than the calcaneus position.

Ground reaction force (GRF) was measured by a force platform (®Kistler 9,281 CA) located on the floor and by force sensors of the treadmill. Data were recorded at 2,000 Hz (except for the kinematics recorded at 125 Hz) and synchronized using ®Nexus Software.

Prior to the dynamical captures and for each experimental condition, the position of the participant's markers was recorded during a static pose in the standard anatomical position.

Data analysis

Using OpenSim software, a generic model (Anderson and Pandy 1999) was scaled to match the subject's anthropometric measurements based on experimentally measured marker positions from the static pose. To reduce the measurement errors due to marker movements on the subject's skin, an inverse kinematic algorithm was used to solve the minimum difference between experimental and virtual markers (Delp et al. 2007). The outputs of this inverse kinematic step consisted of joint angles through time. Joint angle ranges of motion during the stance phase were computed between touchdown and maximal flexion angle during the stance phase.

Force data were filtered (a zero time lag Butterworth, 2nd order, low pass, net cutoff frequency of 50 Hz) before computation of the transient peak of the vGRF and loading rate. Loading rates were calculated between two end points describing 20 % and 80 % of the peak amplitudes, as in Duquette and Andrews (2010). When no distinct transient peak was detected on vGRF, the signal amplitude was measured using the average transient peak time as determined for each condition in trials where a transient peak was detected (Lieberman et al. 2010).

Statistical analysis

Standard statistical methods were used to compute means and standard deviation of the parameters studied for each participant and each condition. Two distinct repeated analysis of variance (®Statistica, Statsoft) with one factor (footwear) were used to test for the global effect of the footwear for each task to verify whether the conclusions on drop effect were similar, whatever the task (treadmill vs. overground).

All significant effects ($p < 0.05$) were followed by Tukey post hoc tests.

Results

Overground running task

Foot/ground angle ($F_{3,33} = 21.24$, $p < 0.01$) and ankle dorsiflexion angle ($F_{3,33} = 9.28$, $p < 0.01$) showed lower values at touchdown during barefoot running (9.3 ± 6.7° and 3.2 ± 7.1°) compared to shod running (averaged overall the shod conditions: 18.7 ± 8.4° and 10.0 ± 7.7°) (Table 1). D0 condition also induced significant lower foot/ground angle at touchdown than D8 condition (averaged: 16.1 ± 8.3° vs. 20.3 ± 8.3°). At touchdown, the knee joint exhibited higher flexion angle ($F_{3,33} = 10.84$, $p < 0.01$) during barefoot condition than during shod conditions (averaged: 16.7 ± 4.2° vs. 13.8 ± 5.1°).

During the stance phase, barefoot condition showed higher ankle joint range of flexion ($F_{3,33} = 14.80$, $p < 0.01$) than shod conditions (averaged: 28.0 ± 7.0° vs. 19.3 ± 6.4°) and lower knee joint range of flexion ($F_{3,33} = 26.73$, $p < 0.01$) than shod conditions (averaged: 30.8 ± 4.6° vs. 35.4 ± 5.0°) (Table 1).

Vertical ground reaction force exhibited higher loading rates ($F_{3,33} = 3.63$, $p = 0.02$) for barefoot running compared to D8 condition (141 ± 73BW/s vs. 96 ± 28BW/s) (Fig. 2a). Despite a similar trend, no significant difference was found for transient peak amplitudes (Fig. 2b).

Treadmill running task

Treadmill running task showed no effect of footwear factor on ankle angle at touchdown, but a significant effect on foot/ground angle at touchdown was highlighted ($F_{3,33} = 6.46$, $p < 0.01$) (Table 1). Indeed, barefoot (6.8 ± 6.4°) and D0 (5.2 ± 8.6°) conditions induced lower foot/ground angles than D8 condition (11.4 ± 5.5°). There was a significant effect of footwear factor on knee angles at touchdown ($F_{3,33} = 3.83$, $p = 0.02$) with higher knee flexion angle for barefoot (17.6 ± 3.7°) and D0 (17.4 ± 4.9°) conditions than for D8 (15.3 ± 4.2°) condition.

During the stance phase, the ankle joint exhibited more flexion ($F_{3,33} = 5.32$, $p < 0.01$) for the barefoot (25.9 ± 5.2°) and D0 (26.8 ± 6.7°) conditions than for D8 (22.4 ± 4.1°) condition (Table 1). There was a significant effect of footwear on knee joint range of motion

Table 1 Mean values and standard deviations for all the experimental conditions

	Overground				Treadmill			
	BF	D0	D4	D8	BF	D0	D4	D8
Foot/ground ankle at touchdown (°)*	9.3 ± 6.7	16.1 ± 8.3	19.6 ± 8.9	20.3 ± 8.3	6.8 ± 6.4	5.2 ± 8.6	8.0 ± 8.3	11.4 ± 5.6
Ankle flexion angle at touchdown (°)*	3.2 ± 7.1	8.5 ± 7.9	11.1 ± 8.2	10.5 ± 7.4	3.8 ± 7.4	2.4 ± 8.3	4.0 ± 7.3	5.4 ± 5.4
Knee flexion angle at touchdown (°)*	16.7 ± 4.2	14.3 ± 5.6	13.4 ± 4.9	13.3 ± 5.3	17.6 ± 3.7	17.4 ± 4.9	16.6 ± 5.1	15.3 ± 4.2
Ankle dorsiflexion range of motion during the stance phase (°)*	28.0 ± 7.0	21.5 ± 6.5	18.4 ± 6.5	17.9 ± 6.1	25.9 ± 5.2	26.8 ± 6.7	24.4 ± 5.8	22.4 ± 4.1
Knee flexion range of motion during the stance phase (°)	30.8 ± 4.6	34.8 ± 4.6	35.4 ± 5.1	35.9 ± 5.5	25.9 ± 2.7	27.9 ± 3.3	28.8 ± 3.8	30.9 ± 3.0
Stance phase duration (ms)	273 ± 22	281 ± 20	284 ± 27	286 ± 22	287 ± 16	297 ± 17	293 ± 18	299 ± 16
Transient peak (BW)*	1.58 ± 0.37	1.47 ± 0.29	1.47 ± 0.25	1.42 ± 0.22	1.17 ± 0.21	1.23 ± 0.20	1.30 ± 0.28	1.33 ± 0.21
Loading rate (BW s^{-1})*	141 ± 73	121 ± 44	110 ± 36	96 ± 28	50 ± 22	53 ± 23	58 ± 22	66 ± 16

* Indicates a significant interaction between footwear and task factors (more details in the text). All significant effects were considered at $p < 0.05$. BF = Barefoot condition, D0 = 0 mm drop condition, D4 = 4 mm drop condition, D8 = 8 mm drop condition

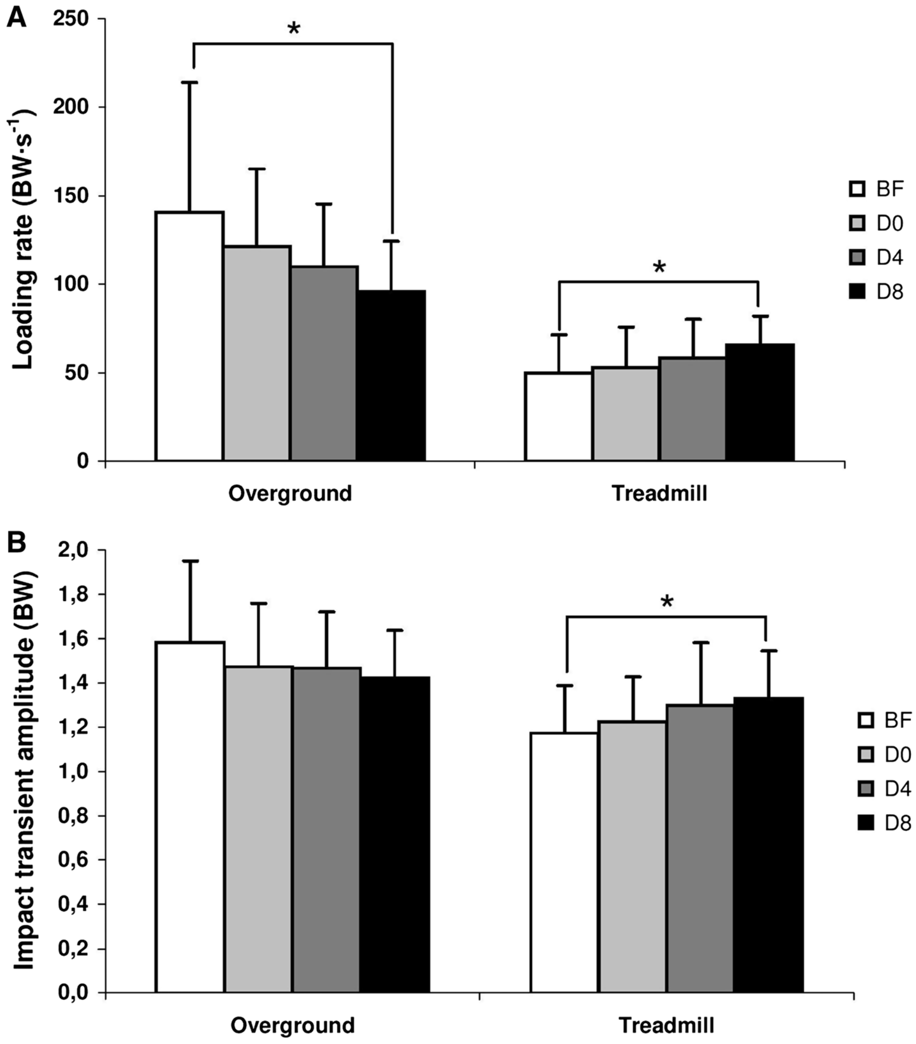

Fig. 2 Impact transient loading rate of vertical ground reaction forces in BW s^{-1} **a** and impact transient amplitude in BW **b** for the four footwear conditions (mean ± standard deviation) as a function of task condition. Asterisk indicates a significant difference ($p<0.05$) between two footwear conditions. Note the opposite influence of footwear conditions on both variables depending on whether the participants ran overground or over a treadmill

($F_{3,33} = 52.34$, $p < 0.01$). Indeed, barefoot (25.9 ± 2.7°) condition induced lower range of flexion than D4 (28.8 ± 3.8) and D8 (30.9 ± 3.0) conditions.

Transient peak ($F_{3,33} = 2.97$, $p = 0.04$) and loading rate ($F_{3,33} = 3.55$, $p = 0.03$) of vertical ground reaction force were both lower for barefoot condition than for D8 condition (1.17 ± 0.21BW vs. 1.33 ± 0.21BW for transient peak and 50 ± 22BW s^{-1} vs. 66 ± 16BW s^{-1} for loading rate) (Fig. 2).

Discussion

The primary purpose of this study was to determine whether the findings related to the effects of shoe drop on running pattern were the same for overground and treadmill running.

Surprisingly, the influence of the drop factor on vertical ground reaction force was opposite between overground and treadmill running (Fig. 2). Indeed, compared to the barefoot condition, the highest shoe drop condition induced the lowest loading rates during overground running, while it induced the highest loading rates during treadmill running. These observations may have important implications for the understanding of the influence of the shoe features on the running pattern. To explain these results, a repeated analysis of variance with two factors "*footwear and task*" was used to analyse the possible interactions between task and footwear on kinematic variables. This would indicate whether each footwear condition revealed the same kinematic differences between the two tasks. Statistical analysis showed a significant task/footwear interaction concerning foot/ground angle ($F_{3,33} = 10.57$, $p < 0.01$) (Fig. 3a), ankle joint angle ($F_{3,33} = 7.63$ $p < 0.01$) (Fig. 3b), and knee joint angle ($F_{3,33} = 3.16$, $p < 0.04$) (Fig. 3c) at touchdown. While barefoot condition did not show any difference between overground and treadmill running in foot/ground angle, ankle and knee joint angles at touchdown, every shod condition showed significant modifications of these three variables. Foot/ground angle at touchdown showed higher values during overground running than during treadmill running for D0, D4, and D8 conditions (16.1 ± 8.3, 19.6 ± 8.9 and 20.3 ± 8.3 vs. 5.2 ± 8.6, 8.0 ± 8.3 and 11.4 ± 5.5, respectively) (Fig. 3a) denoting a flatter foot/ground angle in treadmill running. Ankle angle at touchdown exhibited higher dorsiflexion angle during overground running than during treadmill running for D0, D4, and D8 conditions (8.5 ± 7.9, 11.1 ± 8.2 and 10.5 ± 7.4 vs. 2.4 ± 8.3, 4.0 ± 7.3 and 5.4 ± 5.4) (Fig. 3b). Knee angle at touchdown showed lower angle during overground than during treadmill task for shod conditions (14.3 ± 5.6, 13.4 ± 4.9 and 13.3 ± 5.3 vs. 17.4 ± 4.9, 16.6 ± 5.1 and 15.3 ± 4.2 for D0, D4 and D8, respectively) (Fig. 3c).

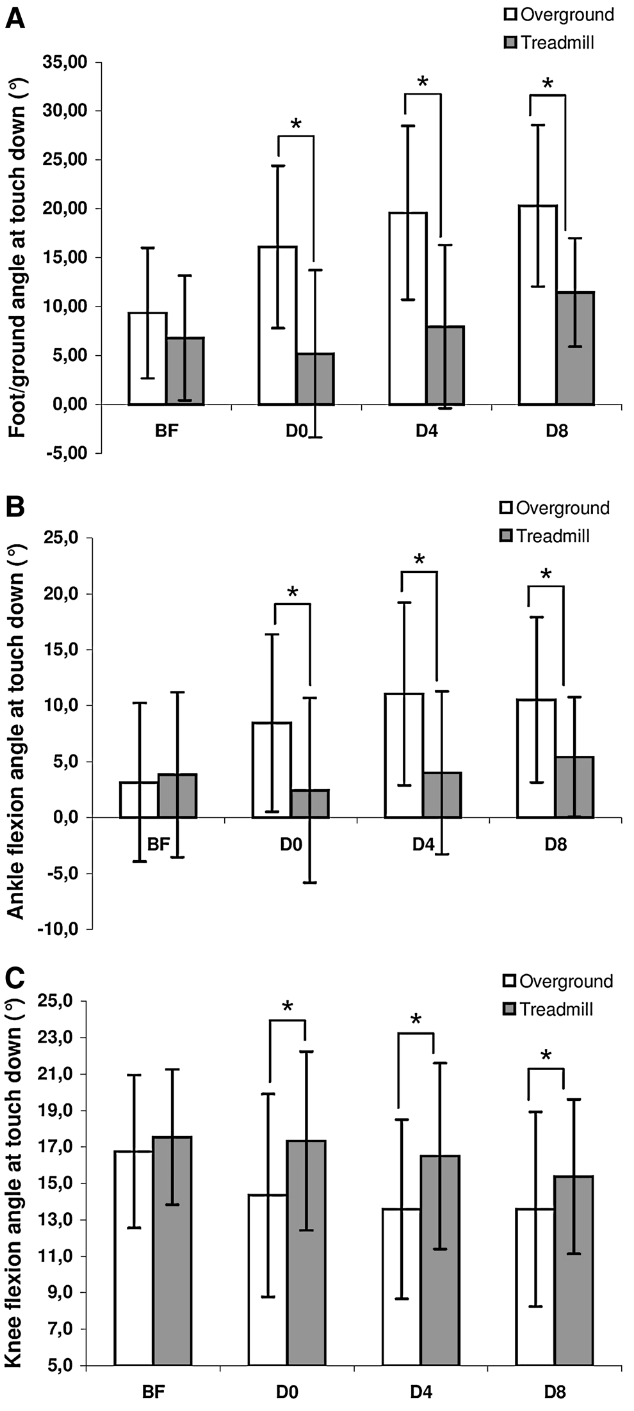

Fig. 3 Foot/ground angle at touch down in ° **a** ankle dorsiflexion angle at touch down in ° **b** and knee flexion angle at touch down in ° **c** for the two task conditions (mean ± standard deviation) as a function of footwear. Asterisk indicates a significant difference ($p<0.05$) between two task conditions. Note the systematic absence of effect for barefoot condition between overground and treadmill running and the systematic differences as soon as a shoe is present

Vertical ground reaction forces showed important differences in loading rates between overground and treadmill running (Fig. 2a). Indeed, overground running induced loading rate values 51 % higher than treadmill running. These may be explained by the mechanical properties of the interface between the ground and the foot at touchdown. Although stiffness of the instrumented treadmill was higher than the stiffness of commercially available fitness treadmills, it is likely that treadmill stiffness was lower than ground stiffness.

The absence of kinematic difference between overground and treadmill running for barefoot condition (opposite to footwear conditions) is yet to be explained. It can be supposed that barefoot running is less prone to perturbation induced by treadmill, because sensitive feedbacks and proprioception features are strongly increased in this situation (Squadrone and Galozzi 2011). This absence of difference may partially explain the opposite results for loading rates between barefoot and highest shoe drop condition in overground and treadmill tasks. This assumption is supported by a previous study of Gerritsen et al. (1995) based on a two-dimensional musculoskeletal model to simulate the impact phase in running. By varying body configurations at touchdown, these authors investigated the influence of initial foot placement and knee joint angle on impact force and loading rate. Similar to our results on overground running, the loading rate increased when the initial foot angle decreased, corresponding to a flatter foot. Gerritsen et al.'s study also showed that knee angle at touchdown had small to no effect on impact transient and no effect on loading rate. From our results, the changes occurring for the knee joint angle at touchdown are not likely to explain the difference of results concerning loading rates between overground and treadmill running. But it is interesting to note that knee angle was not influenced by treadmill during barefoot running, unlike for shod conditions.

The decrease in foot ground angle at impact observed during treadmill running for shod condition is consistent with the studies of Nigg et al. (1995) and Fellin et al. (2010). However, the origin of the differences in kinematics between overground and treadmill running are not explained in the literature. Nigg et al. assumed that the subjects adapted their landing style to provide a touchdown during treadmill running that may be perceived as more stable by the runners. This strategy required less time for the foot to be flat on the surface. More generally, Dingwell et al. (2001) hypothesized that locomotor control during treadmill locomotion may be significantly affected by changes in visual and vestibular perceptual information. These perturbations could also explain the global differences in running pattern observed between overground and treadmill running.

Opposed to overground running, treadmill running highlighted more subtle significant differences between shod conditions due to a shoe drop modification. The treadmill running task appears to be the easiest task to be accomplished by the participants. This can be explained by the high reproducibility of treadmill running compared to the overground running task. Indeed intra-individual variability was higher during overground running than during treadmill running. This higher variability in overground running can be explained by the higher requirement to perform the task. During overground running trials, participants had to land on the force plate with their right foot fully positioned over the surface of the force plate, while they had to run at a specific speed (controlled by photocell sensors) with an accuracy of ±5 %. While the high reproducibility is the rationale for performing the experimental tests on treadmill rather than overground, some serious misunderstandings may arise from this choice. Indeed, non-negligible differences between overground and treadmill running have been highlighted in the present study and others (Nigg et al. 1995; Fellin et al. 2010). Treadmill running could thus highlight a specific running pattern far from the one shown by the participants when running overground.

One limitation of this study could be the non-randomization of task conditions. However, similar kinematic results were observed by Nigg et al. (1995) and Fellin et al. (2010) who compared shod running overground and on a treadmill when controlling for the randomization of the tasks. These authors also observed smaller foot/ground angle during treadmill running compared to overground running. It can thus be supposed that for our study, the order effect is negligible. Given the results of the present study, the kinematics of barefoot running appears to be less affected by the task (overground vs. treadmill running) than shod running. Treadmill would affect kinematic running patterns only during shod running. Previous treadmill results should be interpreted carefully for inference of overground running, and future studies focusing on footwear designed for overground running should preferentially be done overground.

Future studies should incorporate long-term analysis to observe the modifications of the overground running pattern after a training period in low-drop shoes.

Conclusions

To conclude, shoe drop has a significant effect on running pattern and vertical ground reaction forces. Even if barefoot condition is clearly different from every shod condition, the zero shoe drop condition was the closest to barefoot concerning kinematics and ground reaction variables observed in this study. Moreover, overground and treadmill running lead to opposite conclusions regarding the effects of shoe drop on vertical ground reaction forces. This could be due to kinematic alteration at touchdown between the two tasks, especially on shod conditions.

Conflict of interest All authors disclose that there is no conflict of interest regarding this study.

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