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Temporal characteristics of foot roll-over during barefoot jogging: reference data for young adults

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Abstract

The purpose of this study was to establish a representative reference dataset for temporal characteristics of foot roll-over during barefoot jogging, based on plantar pressure data collected from 220 healthy young adults. The subjects ran at 3.3 m s^{-1} over a 16.5 m long running track, having a built-in pressure platform mounted on a force platform. The initial contact, final contact, time to peak pressure and the duration of contact at the lateral and medial heel, metatarsal heads I to V and the hallux were measured. Temporal plantar pressure variables were found to be reliable (93% of ICC coefficients above 0.75) and both gender and asymmetry influences could be neglected. Foot roll-over during jogging started with heel contact followed by a latero-medial contact of the metatarsals and finally the hallux. After heel off, the forefoot started to push off at the lateral metatarsals, followed by a more central push off over the second metatarsal and finally over the hallux. Based on the plantar pressure data, the stance phase during running was divided into four distinct phases: initial contact (8.2%), forefoot contact (11.3%), foot flat (25.3%) and forefoot push off (55.1%). These findings provide a reliable and representative reference dataset for temporal characteristics of foot roll-over during jogging of young adults that may also be relevant in the evaluation of running patterns.

Keywords: Plantar pressure; Slow running; Biomechanics; Foot roll-over; Reference data

1. Introduction

Foot-to-ground contact during the stance phase in locomotion is difficult to analyse, due to the anatomical complexity of the foot segment [1]. Recent studies used multi-segmented foot models, to provide information about kinematics and kinetics of the rear foot, mid-foot and forefoot [2,3] and how they interact during gait. Pressure measurements also provide direct information on how the various foot structures and the ground interact [4,5]. Different sub-areas of the sole of the foot have been proposed for plantar pressure measurements [3,5–11]. For example, the sole of the foot has been considered as one area to interpret subtalar motion through plantar pressure measurements [12]. In a multi-segmented foot model, the sole might be better divided into various areas of interest [3]. Some studies reported the use of sensors, placed on the sole by palpation of the anatomical structures [1,4]. Limitations of this technique are the relative small size of sensors and an altered foot-to-floor contact due to the sensors under the foot [1]. More recent measuring devices applied as a plate or as in in-sole systems allow a pressure image of the entire sole. Sub-areas or masks are located on the pressure images, which are based on the anatomical structures of the foot, and can be derived from radiographic data [13,14]. However, collecting radiographic data is invasive and previous research has shown a good agreement of high-pressure areas with anatomical structures [1,14,15]. The most common sub-areas to analyse pressure distributions are the rear foot (often divided into medial, central and lateral heel areas), mid-foot and forefoot (metatarsal heads, hallux and lesser toes) [6–10].

Plantar pressure data obtained from those sub-areas provide peak and mean pressure values, and pressure–time integrals [6–9]. The timings of plantar pressure data also describe foot dynamics in stance [5,16] and could clarify the

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Table 1
Temporal parameters to describe foot roll-over during barefoot jogging

Variables related to the eight anatomical areas	
Initial contact of the area	% of TFC
Time to peak pressure of the area	% of TFC
Final contact of the area	% of TFC
Total duration of the area: time interval between initial contact and final contact of the area	% of TFC
Variables related to total foot contact	
Total foot contact (TFC): time interval between first contact and last contact of the foot on the plate	s
First foot contact (FFC)	% of TFC = 0%
First metatarsal contact (FMC): one of the metatarsal areas makes contact with the pressure plate	% of TFC
Forefoot flat (FFF): all metatarsal head areas make contact with the pressure plate	% of TFC
Heel off (HO): the two heel areas lose contact with the pressure plate	% of TFC
Last foot contact (LFC): last contact of the foot on the pressure plate	% of TFC = 100%
Phases of total foot contact	
Initial contact phase (ICP): from FFC (0%) to FMC	% of TFC
Forefoot contact phase (FFCP): from FMC to FFF	% of TFC
Foot flat phase (FFP): from FFF to HO	% of TFC
Forefoot push off phase (FFPOP): from HO to LFC (100%)	% of TFC

aetiology of overuse injuries in running, as the mechanism of unrolling the foot during stance in running seems to be important [17,18]. However, the reliability of temporal data depends mainly on the measuring rate and spatial resolution of the sensor grid [1,4,16]. Current technologies allow accurate plantar pressure measurements at sampling rates of 400 Hz or more and with high spatial resolution (>1 sensor per cm^2) in large surface pressure plates (>0.5 m^2), which permits analysis of foot-to-ground interaction during running. Running differs from walking by having larger impact and push off forces [19] and a shorter stance phase [16]. It could be hypothesized that the foot roll-over sequence during running is similar but occurs over a shorter period of time compared to walking, even if the foot is subject to greater forces.

The purpose of this study was to establish a reference dataset for temporal parameters describing the sequenced contact times of important anatomical plantar pressure sub-areas in the foot roll-over during barefoot jogging. Some conflicting views about gender effect [16,20] and asymmetry [16,21,22] in gait exist and therefore, the analysis of (a)symmetry, gender differences, and intra-individual variability were included in the study. Subsequently, the foot roll-over characteristics in running were compared with foot roll-over in walking, using data from the literature.

2. Method

The study was conducted on 220 physical education students who had given informed consent. Their characteristics are given in Table 2 and none had a history of lower limb pathology at the time of the study or in the preceding 6 months. The ethical committee of the local University Hospital approved the experimental protocol.

A plantar pressure plate (RsScan International, 2 m × 0.4 m × 0.02 m, 16,384 resistive sensors, 480 Hz and 2 sensors per cm^2) was mounted on top of an AMTI force platform (2 m × 0.4 m × 0.18 m, to ensure dynamic calibration of the pressure plate), flush and in the middle of a 16.5 m long running track. The track was covered with rubcor (5 mm) to prevent the subjects from adjusting their running style while aiming at the plate. The pressure plate identifies the initial contact as the instant when at least three sensors are activated at a resultant force level of above 5 N. This has no influence on temporal parameters, as total contact duration obtained from the pressure plate agreed well with that obtained from the AMTI force plate ($r = 0.959$; $P < 0.01$). An 8-bit A/D conversion was used and each sensor had an incremental sensitivity of 0.5 N and maximum measuring range of 127 N.

The participants were asked to run at a speed of 3.3 ms^{-1} (±0.17 ms^{-1}). Running speed was controlled by two pairs of infrared photo cells, interfaced with a digital clock, and located 3.3 m apart with the pressure plate in the middle. After familiarisation, a trial was considered as valid when the following criteria were met: (1) a heel-strike pattern, (2) a prescribed running speed and (3) no adjustment of gait pattern to contact the plate. A minimum of three valid trials from each side leg was analysed [23].

For each trial, eight anatomical pressure sub-areas were semi-automatically identified on the peak pressure footprint (Fig. 1). The sub-areas were medial heel (H_M), lateral heel (H_L), metatarsal joints I to V (M_1, M_2, M_3, M_4 and M_5) and the hallux (T_1) (heel areas: 2.1 cm length × 1.5 cm width; metatarsal areas and hallux: 1.4 cm length × 1.0 cm width).

Table 2
Subjects characteristics: mean and standard deviation of age, height and body mass

	Age (years)	Height (cm)	Body mass (kg)
Men (133)	18.3 ± 1.2	179.5 ± 5.9	69.0 ± 7.2
Women (87)	18.2 ± 0.7	166.9 ± 5.6	59.3 ± 7.1
Entire population (220)	18.3 ± 1.0	174.5 ± 8.4	65.1 ± 8.6

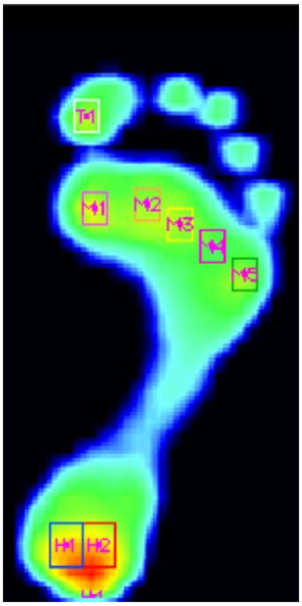

Fig. 1. The location of eight anatomical important sub-areas on the peak pressure footprint. (Footscan software 6.3.4mst, RsScan International.)

Three independent observers had identified the eight areas (all 1.4 cm length × 1.0 cm width) in 20 trials before the study began. An inter-observer analysis of temporal parameters showed that single ICC coefficients were sufficient for the metatarsal and hallux areas, but not for the heel areas. Probably the small areas on the heel did not fully cover the area underneath the tuber calcaneus. A partial roll-over movement occurs at the heel during initial contact, as a rapid plantar flexion ensures a flat foot positioning [24,25]. Therefore, the pressure area underneath the tuber calcaneus is difficult to define within the small area and for the current study larger heel areas were used (2.1 cm length × 1.5 cm width).

All temporal variables, relative to the absolute total foot contact duration, are described in Table 1. Five events were used to divide stance phase into four time periods [16], but a different nomenclature was used to describe the functional behaviour of the foot during the respective phases (Fig. 2).

Descriptive statistics were calculated for all temporal variables. The trial-to-trial consistency Intra Class Correlations (average ICC) between three trials was calculated for both feet separately, for 80 participants that were randomly selected from the total population. Asymmetry and gender differences were analysed by a 2 × 2 repeated-measures ANOVA on the mean left and mean right stance phase of each participant of the entire population ($N = 220$). The effect size was estimated using a squared partial eta (η_p^2) if a gender effect, an asymmetry effect, or an interaction effect between both, was found. A squared partial eta value expresses the amount of variance, as a percentage of total variance that can be explained by a certain effect. The reference dataset was computed by first averaging all six trials of an individual and then averaging those results for all participants ($N = 220$). The distribution of roll-over patterns during running was studied from the roll-over pattern from initial to final contact of the sub-areas. A one-way ANOVA with post hoc Tukey tests was used to analyse significant differences in timings (initial contact, final contact and times

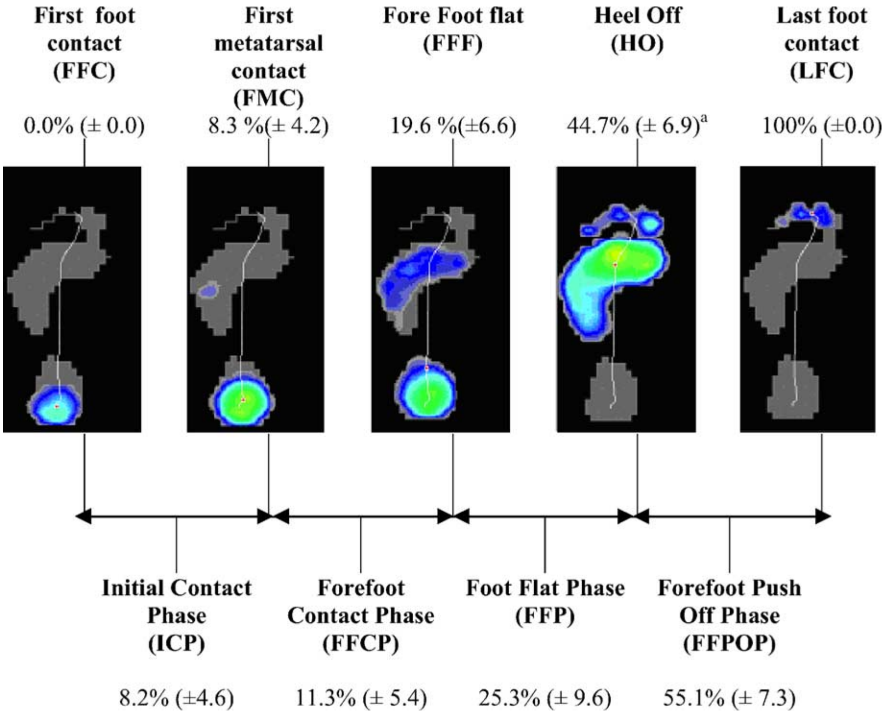

Fig. 2. Mean (±S.D.) timing of important time-events and phases relative to total foot contact (0.220 ± 0.019 ms). ([a]): Significant ($P < 0.05$) asymmetry, partial squared eta values (η_p^2) in Table 5.

to peak pressure) between the sub-areas. If no significant difference was found between two sub-areas, the areas were grouped for further analysis of the roll-over pattern. After grouping, the sequential roll-over pattern of initial contacts existed of six sub-areas (heel, $M_{5/4}$, M_3, M_2, M_1 and T_1), whereas the roll-over pattern of final contacts, existed of seven sub-areas (H_L, H_M, M_5, M_4, $M_{3/1}$, M_2 and T_1). The distribution of the most common roll-over sequence of initial and final contacts was derived from 220 mean roll-over patterns. All statistical tests were performed with the statistical program SPSS 11.0 and $P < 0.05$ was taken as a level of significance.

3. Results

Mean and standard deviation (S.D.) of temporal characteristics of the foot roll-over during barefoot jogging are given in Table 3. A normal distribution was found for all the variables studied. ICC coefficients are given in Table 4 and show that, except for the time to peak pressure underneath the heel areas, 93% of all variables had ICC coefficients above 0.75 and 18% above 0.90.

Repeated-measures ANOVA showed an interaction effect of asymmetry and gender for time to peak pressure of M_4 ($F = 4.201$; $P = 0.042$) and for final contact of H_L ($F = 7.136$; $P = 0.01$). For several other variables (Table 5), a gender and/or asymmetry effect was found. Squared partial eta values (η_p^2) for the interaction effects and for gender and asymmetry influences are given in Table 5. All eta values were below 0.09, meaning that only 9% of the overall variance could be explained by gender, asymmetry, or an interaction between the two. All descriptive data for the temporal characteristics of foot roll-over during barefoot jogging normalized to mean foot contact duration are given in Table 3.

A one-way ANOVA (d.f. = 7) and post hoc Tukey tests showed no significant differences between initial contact of H_M and H_L ($P = 1.0$), between initial contact of M_5 and M_4

Table 3
Reference data of the temporal foot roll-over during barefoot jogging (3.3 ms^{-1}) relative to total foot contact (0.220 ± 0.019 s) (lateral heel (H_L), medial heel (H_M), five metatarsal heads (M_1–M_5) and hallux (T_1), $N = 220$)

	Initial contact (% contact time)		Final contact (% contact time)		Duration of contact (% contact time)		Time to peak pressure (% contact time)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
H_L	0.0	0.0	41.4^{*}	7.7	41.4	7.7	3.7	1.0
H_M	0.0	0.0	$44.5^{**,***}$	6.9	44.5	6.9	4.3	2.1
M_5	9.3	5.5	75.1	5.0	65.8	7.3	46.0	10.3
M_4	10.5	5.3	84.5	5.1	74.0	7.9	54.2^{*}	7.0
M_3	12.7^{**}	4.5	$91.9^{**,***}$	4.2	79.3	6.3	58.7	5.8
M_2	15.1	4.3	$94.4^{**,***}$	3.5	79.3	5.3	62.4^{**}	6.0
M_1	18.5^{**}	5.8	$90.8^{**,***}$	3.7	72.3	6.7	55.4^{**}	5.3
T_1	32.1^{**}	9.1	98.4^{***}	2.6	66.3	9.4	78.3	9.9

* Significant ($P < 0.05$) interaction gender—asymmetry, partial squared eta values (η_p^2) in Table 5.

** Significant ($P < 0.05$) asymmetry, partial squared eta values (η_p^2) in Table 5.

*** Significant ($P < 0.05$) gender influence, partial squared eta values (η_p^2) in Table 5.

Table 4
ICC values of initial contact, final contact, duration of contact and time to peak pressure of the eight anatomical sub-areas (lateral heel (H_L), medial heel (H_M), five metatarsal heads (M_1–M_5) and hallux (T_1)) and of the five important time events during total foot contact (first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF), heel off (HO), last foot contact (LFC), $N = 80$)

	Left				Right			
	Initial contact	Final contact	Duration of contact	Time to peak pressure	Initial contact	Final contact	Duration of contact	Time to peak pressure
H_L	–	0.91	0.90	0.67	–	0.88	0.82	0.60
H_M	–	0.91	0.88	0.63	–	0.86	0.79	0.61
M_5	0.88	0.91	0.90	0.83	0.88	0.86	0.87	0.79
M_4	0.86	0.89	0.89	0.76	0.80	0.78	0.77	0.72
M_3	0.84	0.91	0.91	0.82	0.83	0.89	0.86	0.78
M_2	0.84	0.93	0.91	0.82	0.84	0.91	0.87	0.84
M_1	0.88	0.91	0.89	0.82	0.87	0.91	0.87	0.85
T_1	0.84	0.92	0.80	0.89	0.88	0.69	0.86	0.73
FFC	–				–			
FMC	0.86				0.88			
FFF	0.89				0.85			
HO	0.91				0.88			
LFC	–				–			

Table 5
Partial squared eta values (η_p^2) for significant ($P < 0.05$) asymmetry, gender influence or for significant interaction effect of asymmetry and gender for the temporal variables during foot contact of barefoot jogging

	Asymmetry	Gender influence	Interaction
Total contact duration	0.023	0.048	–
Initial contact			
M_3	0.024	–	–
M_1	0.023	–	–
T_1	0.032	–	–
Time to peak pressure			
M_4	–	–	0.020
M_2	0.057	–	–
M_1	0.045	–	–
Final contact			
H_1	0.081	0.022	–
H_2	–	–	0.021
M_3	0.029	0.037	–
M_2	0.057	0.059	–
M_1	0.044	0.084	–
T_1	–	0.035	–
HO	0.063	–	–

($P = 0.208$), between final contact of M_1 and M_3 ($P = 0.289$), between time to peak pressure of H_M and H_L ($P = 0.976$), and between time to peak pressure of M_1 and M_4 ($P = 0.513$).

Start, end, and duration of the four phases of foot contact are expressed in Fig. 2, relative to total foot contact duration. Initial contact phase (ICP) starts with forefoot contact (FC) (0%) and ends after 8.2% at first metatarsal contact (FMC), which is the start of the forefoot contact phase (FFCP) and accounts for the following 11.3% of stance phase. During these first two phases, the foot makes contact with the ground until forefoot flat (FFF) is reached at 19.6%. In the following 25.3% of total foot contact (TFC) duration, the foot has a flat position throughout the foot flat phase (FFP). After heel off (HO) (44.7%), the remaining part of total foot contact duration, the forefoot push off phase, lasted for 55.1%.

Table 6 presents the frequency of the most common sequential orders for the onsets of the six plantar pressure sub-areas. In total, 17 different contact patterns were detected. The most common was H $M_{5/4}$ M_3 M_2 M_1 T_1 and accounted for 74.1% of all foot contact patterns. The three most common patterns for making contact (Table 6) represented 87.2% of all roll-over patterns. The remaining 12.8% was equally distributed over the other 14 patterns, all with a very low frequency (<4%). In total, 13 different patterns for final contact were found. Here, the most common pattern was H_L H_M M_5 M_4 $M_{3/1}$ M_2 T_1, which occurred in 80.9% of all cases. The three most common patterns for final contact (Table 7) represented a total of 89.5% of all roll-over patterns.

Table 6
Most common patterns for making contact of the plantar pressure areas during barefoot jogging ($N = 220$)

Pattern	N	Percent
H $M_{5/4}$ M_3 M_2 M_1 T_1	163	74.1
H $M_{5/4}$ M_3 M_1 M_2 T_1	19	8.6
H M_3 M_2 $M_{5/4}$ M_1 T_1	10	4.5
Total		87.2

Table 7
Most common patterns for plantar pressure area push off during barefoot jogging ($N = 220$)

Pattern	N	Percent
H_L H_M M_5 M_4 $M_{3/1}$ M_2 T_1	178	80.9
H_L H_M M_5 M_4 $M_{3/1}$ T_1 M_2	13	5.9
H_M H_L M_5 M_4 $M_{3/1}$ T_1 M_2	6	2.7
Total		89.5

4. Discussion

A reliable and representative reference dataset for temporal characteristics of foot roll-over during slow barefoot running has been created which will assist in distinguishing between normal and abnormal running patterns. Several reference datasets exist for mean pressure, peak pressure or pressure–time integrals in walking conditions [6,7,11], but a temporal dataset based on plantar pressure measurements for walking and running has not been reported previously. The dataset in this study is unique since it was based on a large population of 220 healthy young adults without foot pathologies. They provided a ‘stable’ running pattern at sub-maximal jogging speed on an indoor runway.

Good (93% > 0.75) and very good (18% > 0.90) [23] ICCs between trials were found in almost all temporal characteristics of the foot roll-over, except for the heel sub-areas. During the initial contact phase, the initial impact force peak occurs, which is a reflection of the fast deceleration of the distal segments of the support leg along with the slower deceleration of the head, arms and trunk [26]. A minor change in timing of the acceleration of one of the segments during initial contact can change the timing of total impact force peak ($t_i = 14 \pm 5$ ms) [27] occurring during initial contact phase. This could cause the greater intra-subject variability of time to peak pressure underneath the heel. Another possible explanation for this increased variability is based on the location and magnitude of the heel areas. It is still difficult to include the calcaneus and its movement within the enlarged areas used in the current study (2.1 cm in length, 1.5 cm in width) and therefore a larger mask for the heel area should be used as in other studies [6,11].

Gait is commonly assumed to be symmetrical [21], and in previous studies symmetry has been found for stride, swing and stance durations during gait at a self-selected speed [5,19]. In the current study, some differences between left and right feet were found for temporal aspects in foot unroll.

In this large population, the partial squared eta values revealed that only a very low percentage of the variance could be explained by asymmetry analysis of the foot roll-over. However, for the individual the analysis should always include the left and right foot separately [22].

Gender influences in gait were found by Blanc et al. [16] for stride, stance and swing duration, for cadence and for all variables linked to stance. In the current study, gender influences were found for some temporal parameters in running, but again, partial squared eta values were very low. Thus, the influences of gender and asymmetry were negligible in this large dataset.

Another purpose of the current study was to describe the characteristics of the foot roll-over in running. Previous research [16,28], described foot roll-over patterns based on the on- and off-switching of four sub-areas underneath the foot (heel, M_5, M_1, hallux). In both studies, the most common pattern that was found was heel–M_5–M_1–hallux, both for initial contacts and final contacts. The present study used more sub-areas of the sole of the foot and some of the areas could be grouped together, as there was no discrimination in timing between initial or final contact during foot roll-over. In the pattern of initial contacts, H_L and H_M and also M_5 and M_4 were grouped. The latero-medial roll-over for initial contact, described by Blanc et al. [16], was also found in the more detailed sequencing in $H_{L/M}$ $M_{5/4}$ M_3 M_2 M_1 T_1 in the present study. No differences in timing were found between M_3 and M_1 when push off occurred and the forefoot areas reached the end of contact with the ground. A common roll-over pattern for final contacts of the sub-areas, H_L H_M M_5 M_4 $M_{3/1}$ M_2 T_1 was found for almost 81% of the entire population. Another 8.5% of the roll-over patterns revealed a more central final push off over M_2.

Running is characterized by a single support phase and the division of stance into the phases described in the current study was based on studies by Winter [29] and Blanc et al. [16] and refer to the evolution of the pressure distribution underneath the foot during roll-over. Initial contact phase starts with first foot contact and ends at FMC. During ICP, the peak pressure underneath the two heel areas occurs at approximately 4% of total foot contact (TFC), reflecting the impact. This impact peak timing concurs with timing of the first force peak in the vertical ground reaction force in barefoot running [26]. In the current study, no differences were found between the initial contacts of H_L and H_M, although some studies have indicated that foot contact in walking and running starts with a more lateral loading of the heel, followed by medial loading [4,30]. The present results revealed that H_L and H_M could be considered as one single area making contact with the ground. Moreover, no differences were found between the two heel areas with regard the time to peak pressure. However, the absence of differences in timing between the two heel sub-areas for initial contact and for time to peak pressure should be treated with caution because of the limitations regarding the limited size of the heel areas, as described above.

The forefoot contact phase starts with FMC and ends when all metatarsal heads make contact with the ground. According to previous research [10,18], first forefoot contact was made by M_5, but a one-way ANOVA revealed no significant differences between first contact of the sub-areas under M_5 and M_4. These two metatarsals could be grouped as one lateral area representing first forefoot contact during running. Further forefoot contact occurred in a lateral to medial direction and the forefoot was flat at 19.6% of TFC. During ICP and FFCP the pressure distribution was likely to reflect a rapid ankle plantar flexion, followed by a fast initial pronation [7,31,32]. From the time of flat forefoot position (19.6%) to HO (at 44.7%), the heel and all metatarsal areas were in contact with the ground, defined as the foot flat phase. While the foot is in this flat position, dorsiflexion, subtalar eversion and foot abduction have been observed in previous kinematic studies [31,32]. The time to HO in this study was comparable to the time of maximal pronation (41%) reported previously [33]. A later final contact of the medial heel area in comparison to the lateral area, in the current study, could indicate a pronated position of the rear foot at HO [7]. During flat forefoot position, a fast forward load shift occurred, as the heel leaves the ground.

The forefoot push off phase (FFPOP) started with HO at 44.7% of stance phase and ended with LFC. Peak pressures for the metatarsal sub-areas occurred during this FFPOP. This may indicate, (1) a preparation of the foot to provide a rigid lever at the push off, and (2) a plantar flexion in the ankle joint [31,32]. The rise to peak pressures started laterally (M_5 at 46%), followed by a synchronous push off pattern of M_4, M_3 and M_1. Finally, the second metatarsal area reached maximal pressure at 62.4% of TFC. Near the end of FFPOP, the metatarsals left the ground in jogging, in agreement with the findings of Blanc et al. [16] for walking, and there was no obvious latero-medial sequence. In addition, there were no temporal differences between the final contacts of M_3 and M_1. A more central forefoot push off occurred, with M_2 being the last metatarsal to reach its peak pressure and being the last metatarsal to leave the ground. However, this did not mean that only M_2 was acting during push off, as the first and second metatarsal heads bore an almost equal amount of load during push off [34,35]. The limited range of motion of M_2 at the tarsometarsal joint, compared to the more flexible first ray, may explain the longer contact of the second metatarsal area. FFPOP continued over the hallux until LFC.

After the first impact during ICP, a latero-medial contact of plantar pressure sites under the metatarsals occurred. This probably indicates pronation during FFCP and FFP, which is necessary to provide an adaptive structure to the foot. This was followed by peak pressures occurring underneath the lateral part of the foot (M_5), which is likely to indicate a resupination occurring during FFPOP. This resupination is necessary to make a rigid and propulsive structure of the foot for push off [11,30]. Later in the FFPOP, a more central push

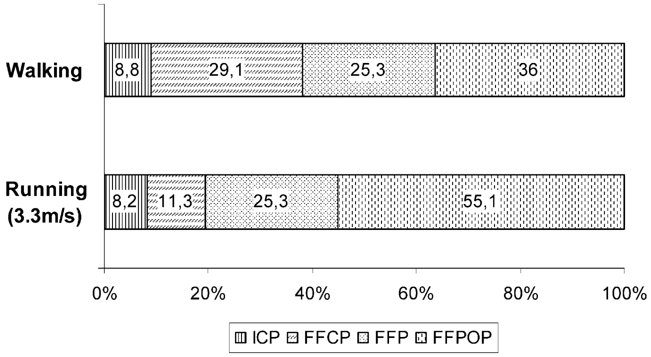

Fig. 3. The duration of the sub-phases of the stance phase for walking (Blanc et al. [26]) and running (current study results), relative to total foot contact (walking t_{cont} = 670 ms, running t_{cont} = 220 ms).

off pattern, first over M_4, M_3 and M_1 and finally over M_2 occurred with a final push off over the hallux.

Comparing the current findings in jogging (Fig. 3) with literature about the foot roll-over in walking revealed distinct differences, thus rejecting the hypothesis that a similar relative timing of key events of the foot roll-over occurs in both gait types. Jogging differs from walking in that it has an earlier HO (44.9% of TFC in jogging against 64% in walking [16]). This indicates a relatively faster weight transfer from rear foot to forefoot. During jogging and walking, the ICP and the FFP have almost the same relative duration, respectively 8 and 25% of TFC. This means that during jogging the duration of FFCP is shorter (11.3% of TFC in jogging against 29% in walking [16]) and latero-medial metatarsal contact occurs faster. In the present study, an earlier rear foot–forefoot weight transfer occurred during running, as well as a faster latero-medial weight shift [16]. Increased peak pressures occur underneath the medial part of the forefoot as walking speed increased [9]. An earlier shift of the pressure towards the medial forefoot, together with greater peak pressures on the medial forefoot as speed increases, would be expected to indicate a greater load on the medial forefoot during running compared to walking.

The aim of this study was to establish a reference dataset describing the temporal characteristics of foot roll-over during slow running. Four functional phases were proposed and were indirectly linked to functional foot movements. However, it seems obvious that plantar pressure measurements should be combined with other biomechanical evaluation tools, such as, 3D-kinematics and functional measurements from podiatry. Besides temporal aspects, also individual pressure amplitudes of sub-areas may provide important information about the functional behaviour of the foot. Multi-segmented kinematic data of the foot and – according to Jacob [35] – information about the force loading of different parts of the foot, combined with plantar pressure measurements, could provide a complete image of foot biomechanics during running. However, the mean temporal foot roll-over as described in the present study can help in the evaluation of individual roll-over patterns.

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