Gait & Posture 46 (2016) 135–141

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

In-shoe plantar pressure distribution and lower extremity muscle activity patterns of backward compared to forward running on a treadmill

Thorsten Sterzing [a,c], Clivia Frommhold [b,c], Dieter Rosenbaum [d,*]

[a] *Li Ning Sports Science Research Centre, Beijing, China*
[b] *Department Medical Affairs, Bauerfeind AG, Zeulenroda, Germany*
[c] *Department of Human Locomotion, Chemnitz University of Technology, Chemnitz, Germany*
[d] *Movement Analysis Lab, Institute for Experimental Musculoskeletal Medicine, University Hospital Münster, Münster, Germany*

ARTICLE INFO

Article history:
Received 23 September 2015
Received in revised form 3 March 2016
Accepted 9 March 2016

Keywords:
Backward locomotion
Plantar pressure patterns
Gait line
Pedobarography
Electromyography

ABSTRACT

Objective: Backward locomotion in humans occurs during leisure, rehabilitation, and competitive sports. Little is known about its general biomechanical characteristics and how it affects lower extremity loading as well as muscle coordination. Thus, the purpose of this research was to analyze in-shoe plantar pressure patterns and lower extremity muscle activity patterns for backward compared to forward running.

Methods: On a treadmill, nineteen runners performed forward running at their individually preferred speed, followed by backward running at 70% of their self-selected forward speed. In-shoe plantar pressures of nine foot regions and muscular activity of nine lower extremity muscles were recorded simultaneously over a one-minute interval. Backward and forward running variables were averaged over the accumulated steps and compared with Wilcoxon-signed rank tests ($p < .05$).

Results: For backward compared to forward running, in-shoe plantar pressure distribution showed a load increase under metatarsal heads I and II, as well as under the medial midfoot. This was indicated by higher maximum forces and peak pressures, and by longer contact times. Muscle activity showed significantly higher mean amplitudes during backward running in the semitendinosus, rectus femoris, vastus lateralis, and gluteus medius during stance, and in the rectus femoris during swing phase, while significantly lower mean amplitudes were observed in the tibialis anterior during swing phase.

Conclusion: Observations indicate plantar foot loading and muscle activity characteristics that are specific for the running direction. Thus, backward running may be used on purpose for certain rehabilitation tasks, aiming to strengthen respective lower extremity muscles. Furthermore, the findings are relevant for sport specific backward locomotion training. Finally, results provide an initial baseline for innovative athletic footwear development aiming to increase comfort and performance during backward running.

1. Introduction

Forward locomotion of humans has evolved as the most effective strategy, due to the orientation of anatomical structures and vision. Initial biomechanical research revealed that backward running is characterized by smaller knee and hip joint ranges of motion, reflecting the restricted human anatomy regarding backward running [1]. These findings correspond to observations of shorter ground contact time and a shorter step length observed in backward running and sprinting [2,3]. Further biomechanical and neurophysiological differences were shown for backward compared to forward locomotion, among others addressing, the vertical ground reaction force component, lower extremity joint moments, barefoot plantar pressures, neuromuscular control strategies, and also trunk and head stabilization aspects [2,4–7]. Regarding biomechanical loading, a softer landing and harder take-off was reported for backward running, combined with a lower efficiency of the stretch-shortening cycle of the involved muscle tendon units [8]. Due to the reversed nature of the touchdown and push-off characteristics compared to the normal heel–toe forward running style [9,10], the backward running impulse is directed more vertically during push-off than during the breaking phase of

---

[*] Corresponding author. Tel.: +49 251 835 2970; fax: +49 251 835 2993.
E-mail address: diro@uni-muenster.de (D. Rosenbaum).

http://dx.doi.org/10.1016/j.gaitpost.2016.03.009
0966-6362/© 2016 Elsevier B.V. All rights reserved.

ground contact [11]. Electromyography (EMG) measurements have illustrated differences in the lower extremity muscle activity between backward and forward running during stance and swing phase [12].

Backward locomotion is less cost-effective regarding human's metabolic energy consumption than forward locomotion [13]. Various researchers examined preferred and energetically optimal transition speeds from backward walking to backward running [14,15], and compared transmission efficiency between backward and forward walking [16]. Regarding cardiovascular and metabolic aspects, backward walking and running require higher oxygen uptake and provoke higher heart rates compared to forward locomotion at the same absolute workload [13,17–19]. In general, backward running provokes an about 30% increased energy expenditure compared to forward running [17,19].

Backward locomotion is used in rehabilitation [2,20]. In clinical settings, backward oriented exercises are prescribed to improve coordination skills of patients, or when medical circumstances do not allow exposure to repetitive high loading of forward locomotion [20–22]. For instance, patellofemoral joint compression forces were reduced in backward compared to forward running [23].

While there is little need for backward oriented locomotion in daily life, it is more frequent in sports and leisure. In team sports like basketball, handball or soccer, backward oriented actions occur during defence movements to allow focussing on game-related circumstances. Racket sports like badminton or tennis require players to perform backward oriented steps and jumps. Thus, backward oriented acceleration, running and jumping mark important sport-specific requirements, and contribute to athletes' performance [15]. Additionally, track-and-field backward sprinting and running are regarded as independent disciplines, with international competitions increasingly held and race distances ranging from 100 m to marathons. Backward locomotion appears very sensitive to training [3]. Already moderate training efforts resulted in improved acceleration, sprinting and running performance. Training effects were more pronounced with longer distances and predominantly achieved by an increased step length. It was further shown that locomotion speed is to a large extent specific for the individual, as faster forward runners were also faster backward runners.

Despite the increasing relevance of backward oriented locomotion in leisure, rehabilitation and competitive sports, quantitative data on its specific biomechanical characteristics are scarce. For instance, general plantar pressure distribution and foot areas prone to high loading have not yet been described, even though foot loading analyses were shown to be of value for clinical [24,25], athletic [10], and footwear [26] aspects. The claim that backward running is effective for strengthening specific lower extremity muscles is only weakly supported. Therefore, the purpose of this research was to analyze in-shoe plantar pressures and muscle activity patterns of the lower extremity during backward compared to forward running. It was hypothesized that whole and regional plantar foot loading differ considerably in their magnitudes and roll-over characteristics between locomotion types. Further, it was hypothesized that backward running requires distinct EMG activity patterns of lower extremity muscles compared to forward running, reflecting its altered kinematic characteristics.

2. Methods

2.1. Participants

Nineteen participants (eleven males, eight females; Mean (SD) age: 27.7 (7.5) years, height: 173.7 (11.6) cm, mass: 68.4 (14.2) kg, BMI: 22.3 (2.1) kg/m^2, shoe size: 41.6 ± 3.0 EUR) were recruited for this laboratory study. They were volunteers from local running and triathlon clubs and provided written informed consent prior to participation in this research. Procedures of this research were approved by the local ethics committee prior to commencement. Participants were recreational or sub-elite heel–toe style runners when running forward, reflecting the predominant running style [9,10], and injury-free when tested. They did not have specific experience in backward running.

2.2. Instrumentation

Backward and forward running was performed on a motor-driven treadmill (Woodway GmbH, Weil am Rhein, Germany). Data collection comprised in-shoe plantar pressure distribution and muscle activity measurements of the lower extremity as characterized by EMG. In-shoe pressures of the left and right foot was measured by an in-sole system featuring 99 sensors per insole at a measurement frequency of 100 Hz (Pedar X, Novel, Munich, Germany). Recordings of in-shoe plantar pressures and EMG signals were synchronized to determine stance and swing phase intervals. EMG signals were collected by a surface electrode system at 2000 Hz (Noraxon Myosystem, Noraxon, Scottsdale, AZ, USA). Nine muscles of the right or left leg, randomized between participants, were measured: tibialis anterior, peroneus longus, soleus, lateral gastrocnemius, semitendinosus, biceps femoris, rectus femoris, vastus lateralis, gluteus medius. The SENIAM guidelines for bipolar surface EMG recordings were applied [27].

2.3. Procedures

Running was performed in participants' own running shoes to avoid confounding factors due to shoe adaptation. Participants had sufficient time to familiarize with the forward and backward running tasks, which also served as warm-up. They performed forward running at individually preferred speed, and backward running at 70% of their self-selected forward speed, as backward running requires higher metabolic energy consumption than forward running [13]. Following the mounting of EMG instrumentation, participants' individual referential amplitudes of maximum voluntary isometric contraction (MViC) of the selected muscles were taken [27,28]. Testing was performed by an experienced clinical technician for three to five seconds for each muscle. The treadmill was operated in the same direction during all testing, while runners switched their running orientation to perform the backward running task. All participants performed forward running first, followed by backward running, to avoid potential carry-over effects from unfamiliar backward running to familiar forward running. There was sufficient rest between the running tasks to avoid fatigue effects potentially caused by the forward running task. Duration of the forward and backward running task was 5 min each, with the fifth minute used for data collection. Hence, there was a 4 min adjustment period for participants to adopt a rhythmic running style.

2.4. Data processing and statistics

The plantar aspect of the foot was divided into nine anatomical regions, using a modified version of the PRC mask [29]: medial rearfoot, lateral rearfoot, medial midfoot, lateral midfoot, metatarsal head I, metatarsal head II, metatarsal heads III–V, hallux, toes II–V. Contact area, contact time, maximum force, and peak pressures were analysed for each mask. Additionally, contact area, force-time integral, and pressure-time integral were analysed for the whole foot. For data processing of in-shoe pressures, the left or right foot of participants was randomly selected.