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Influence of weighted cuffs on ground reaction forces in running of an elite unilateral upper extremity amputee athlete

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Abstract

Due to their opposing movement the swinging arms are considered not to have a major contribution to the overall motion of running. However, missing one upper extremity limb can lead to significant asymmetries. In the present study it was investigated what influence weighted cuffs, which are added to the missing limb, have on the ground reaction forces in running of an elite unilateral upper extremity amputee athlete. One elite athlete (PB 400m: 0:48.45, PB 800m:1:50.92) currently classified as T47 by the International Paralympic Committee due to missing his right forearm participated in this study. The subject had to perform several runs on a 100m Tartan track with a velocity of 8 m/s (high race speed) without and with wearing two differently weighted cuffs (0.5 kg and 1 kg) applied to the elbow of the impaired limb. Ground reaction forces (GRFs) were captured using four floor-level mounted Kistler force plates, mean vertical and horizontal GRFs were calculated over 100% of stance phase duration and statistical data was evaluated for maximum and minimum values. Patterns of vertical GRFs did not differ dramatically whereas the maximum vertical force revealed a highly significant and significant difference between left and right foot when running with heavy or no additional weight respectively. Overall results showed only singular differences for different weight conditions, but several statistically significant differences between left and right foot were found independent from weight conditions.

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Keywords: running, amputee, biomechanics, ground reaction forces, upper extremity function

1. Introduction

The function of the upper extremities during human locomotion has been of minor interest so far. In the late 1980ies two studies were published [1,2] investigating the arms contribution to running and found a small, but potentially important contribution with increasing importance with increasing running speed. Similar findings were observed by Lees and Barton[3] using a different calculation algorithm.

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Other than that, quite a number of studies exists that have been published with focus on the effect of arm swing restrictions on the human gait and during slow running, such as different changes in ground reaction forces (GRFs) [4–7].
According to Novacheck[8] kinetics most importantly the GRFs is one of three major fields of interest in walking and running biomechanics, besides kinematics and electromyography. To allow an intersubjective comparison GRFs are usually normalized to parameters such as body weight (BW), body weight times height (BWH) or body weight times leg length (BWL) [9].
Several studies have been carried out at different running and walking speeds, conclusively leading to a significant relationship between running speed and GRFs with the result that higher running speeds lead to higher peak forces and shorter force periods [10–13]. At a running speed of 4.5m/s Cavanagh and Lafortune[14] measured GRFs of 3 times BW in the vertical, 1 times BW in the anterior-posterior and 0.3 times BW in the medial-lateral direction with considerable differences between the subjects (N=17). Further Munro et al.[11] reported to have found physiological right-left asymmetries within individuals.
Based on the findings by Hinrichs[15] in 2010 the International Paralympic Committee (IPC) found impairments of the upper extremities between the wrist and the elbow (i.e. loss of a forearm) to lead to negligible limitations in middle- and long-distance running. Since after the Paralympic Games in London 2012 athletes affected by this have only been allowed to start in events up to 400m, which are started from a crouch position where a clear disadvantage is still given [16]. As long as the principles: safety, fairness, universality and physical prowess apply, it is allowed by IPC to use technology and equipment, such as sports specific prosthetic devices [17].
However, the lack of research in this area and the decisions presented by the IPC lead to the following research question (Q) and hypothesis (H):
Q: What influence does the use of weight cuffs additionally added to the impaired limb have on the horizontal and vertical GRFs of an elite unilateral upper extremity amputee athlete?
H: Weight added to the impaired limb can partly compensate the missing mass and therefore affects any asymmetries observable when running without additional weight cuff.

2. Methods and materials

One high-caliber male middle-distance runner (age: 26 years, height: 183 cm, weight: 67 kg, PB 400m [min:s]: 0:48.45, v_{mean} 400m: 8.3 m/s, PB 800m [min:s]: 1:50.92, v_{mean} 800m: 7.2 m/s)) currently classified as T47 by the IPC due to unilateral dysmelia (aplasia) of right forearm (including the hand) took part in the study. The subject was informed about the intended procedure and gave his oral consent prior to the measurements.
In order to create highly realistic conditions, four Kistler force plates (0.6m times 0.9m, 8 channel amplifier type 9865, Kistler Instrumente AG, Winterthur, SUI) were mounted on floor level and aligned consecutively along a 100m indoor Tartan track at the German Sports University Cologne. The subject was asked to perform several (at least four valid) runs on this track with a high running speed of approximately 8±0.5m/s based on his personal bests, while the force plates were sampling data at a rate of 1000Hz. The running speed was controlled via two double light barriers placed 0.5m before and 0.55m after the force plate section and resulted in an actual speed of 8.09±0.17m/s.
A trial was considered valid if at least one foot made ground contact fully on one of the four force plates without overstepping (Figure 1(a),(b)) and running speed was within the predefined range.
Three running conditions no, light and heavy were defined in regard to the weight added to the impaired limb using either no weight cuff or cuffs with 0.5kg or 1kg, respectively, on the right upper arm, proximal of the elbow (Figure 1(c),(d)).
Data processing was done with Matlab 7.04 (The Mathworks, Natick, USA). Horizontal (anterior-posterior (F_x) and medial-lateral (F_y)) and vertical ground reaction forces (F_z) of the stance phases for left and right foot were interpolated to 100% of the stance phase by detecting initial contact (IC) and toe-off (TO) on the force plate. Data were filtered with a zero-lag digital forward reverse moving average filter using a window width of 12ms and any offset value (mean value of 20 samples of the unloaded force plate) was subtracted from each channel. Additionally all values within a defined range of $-8N < x < +8N$ were set to zero to allow a clear discrimination between loaded and unloaded state. IC was then defined as the instance in time where the vertical GRF (F_z) exceeded the threshold used for the offset correction. TO on the other hand was calculated by finding the first instance in time after IC where