Gait Asymmetry During a 5-Km Time Trial in Elite Runners: A Descriptive Study

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Abstract. The present study evaluated gait asymmetry in elite runners by quantifying the differences between ground contact times (GCTs) of the right and left foot and its continuous changes over the course of a 5-km time trial on a 400-m synthetic track. By means of the inertial sensor Axiamote, the GCT of every step was assessed. The results revealed an overall gait asymmetry of 2.6%, but no changes in gait asymmetry over the course of the 5-km time trial. On the bend, the GCTs of the left foot were significantly ($p < .001$) longer than the GCTs of the right foot, whereas no such differences were reported on the straight section. However, gait asymmetry remained the same for both the straight and bend Sects. (2.7 vs. 2.8%). Overall, no gender differences regarding gait asymmetry occurred. In conclusion, a low and consistent gait asymmetry between GCTs of both feet in male and female runners was observed.

Keywords: Change over time · Bend versus straight · Inertial measurement unit · Field condition · Temporal progress of fatigue

1 Introduction

There are an impressive number of studies conducted on mechanics in running. Parameters of interest are among others step length, step frequency, breaking time, aerial time, and ground contact time [1–3]. Knowledge of these parameters is relevant for athletes, coaches, and researchers. The athlete and the coach need objective information to improve running technique and performance, whereas researchers need those running parameters to gain new knowledge about key performance indicators and injury risk factors. One possible risk factor identified in the literature is asymmetry of the lower limbs, which has been shown to have an impact on the incidence of injuries and possibly affect athletic performance [4]. However, the threshold at which a deficit becomes problematic remains to be defined. Some overall gait asymmetry might be normal, as the running style is automatized over the years of training and/or due to difference in leg lengths [5, 6]. In term of changes over the course of 5-km time trials, previous research showed significant decreases in stride length and frequency, while ground contact time (GCT) and total stride duration progressively lengthened [1, 7]. However, no former study investigated changes concerning gait asymmetry over the

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course of a maximal long-distance run. Such information might provide insight into the onset and progression of the athlete's fatigue and potential adaptations in running style. Gait asymmetry might not be evident during the start phase of a race, but might arise with the development of muscular fatigue. Furthermore, when running on a standardized 400-m synthetic track, the bend may be a potential reason for a certain overall gait asymmetry [8, 9]. In the scientific literature, bend running has received very little attention compared with straight track running, despite the bend portion being a considerable part of the whole running distance on an athletic track.

It is difficult to determine the most relevant biomechanical parameters to assess gait symmetry and asymmetry, respectively, as running depends on a variety of parameters. However, it seems reasonable to consider the ground contact time (GCT), as this is the only moment during running to generate propulsive force. The ability to produce and transmit high amounts of muscular force to the ground over a short period of time is a major determinant of the performance in running [10]. It was reported that runners with shorter GCTs were not only faster but also more energy efficient than runners with longer GCTs [3, 10, 11]. The less economical runners have lower vertical leg stiffness, which leads to enhanced braking time, and therefore, a longer GCT [12]. Hence, measuring GCT may be of potential benefit to investigate the presence of gait asymmetry. Previous research showed 3.5% gait asymmetry regarding GCTs in male Australian Rules football players, while running on a treadmill at their individual 80% VO2max [13]. Similar, Kong and de Heer [14] reported an average of 3.6% gait asymmetry between the GCTs of both feet in male Kenyan distance runners when measured at five different submaximal speeds on a treadmill. However, there is a lack of data that is obtained at maximal speeds during long-distance runs. This lack of knowledge should be counteracted as it was shown that with increasing intensity, step variability increases [15]. Moreover, all the aforementioned studies targeting gait asymmetry assessed GCT on the treadmill. It is well known that running on a treadmill changes running patterns [16]. Therefore, in order to make conclusions about functional relevant changes in gait asymmetry, measurements should be applicable in field conditions and during entire trials.

So far, no study has evaluated the gait asymmetry during maximal long-distance time trials on a 400-m synthetic track. Furthermore, the influence of fatigue on gait asymmetry in healthy female and male subjects is not known. The aims of the present study were threefold: Firstly, to quantify the gait asymmetry between GCTs of the right and left foot in elite female and male runners during a 5-km time trial on an outdoor synthetic track; Secondly, to examine the changes in gait asymmetry over the course of this 5-km time trial; Lastly, to evaluate the influence of running the bend versus running the straight track on gait asymmetry.

2 Methods

2.1 Subjects

A total of 10 female and 15 male (24.5 ± 3.4 years old, 174.8 ± 9.0 cm, 63.0 ± 8.1 kg) orienteers, competing at the international level, were recruited to

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participate in the study. All athletes were part of the Swiss Orienteering National Team and trained on average 14.1 ± 3.2 h per week. The local ethics committee approved the study and all participants provided written informed consent before testing. A medical questionnaire was administered to exclude athletes with any known lower limb injury in the past six months.

2.2 Procedure

The measurements took place during running a competitive 5-km time trial of the Swiss Orienteering Team. The time trial was one of the selection criteria for the participation in the upcoming world championships. After an individual warm-up session the runs were carried out on the 1st lane of a 400-m outdoor synthetic track with a radius of the curvature of 36.5-m [17]. The female and male runners started in two gender-segregated groups, and thereafter the gender groups were again split in half to avoid too many runners on the track at the same time. The athletes were free to choose their own pace in order to achieve the shortest time possible over the 5-km. Split times were provided every 200-m, including verbal encouragement. The time trials were performed in sunny weather, with no wind and air temperature constant at 24 °C. Running shoes were not predetermined; four athletes wore spikes and the other 21 wore minimal shoes. However, analyses for different shoe types were beyond the scope of this study.

2.3 Data Collection

Before testing, two Axiamote measurement units (Axiamo GmbH, Nidau, Switzerland) were attached, by means of customized elastics, to the shoe laces of the left and right foot of each subject. The Axiamote sensor (size: 3.8 × 3.7 × 0.8 cm; weight: 13 g) consists of a 9-axis MotionTracking™ device MPU-9150 (InvenSense, Inc., San Jose, USA) that combines a 3-axial accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer. Accelerometer data was recorded with a full-scale range of ±16 g and a sampling rate of 1,000 Hz. Sensor operation and data transmission was established via Bluetooth, and data processing took place by the proprietary software. Good validity and reliability of the sensor in terms of GCT was recently demonstrated [18]. In order to assess split times per 200-m for every athlete, two video cameras (Handycam HDR-CX700VE, Sony Corporation, Tokyo, Japan) were placed alongside the track, one on the 200-m line and one on the finishing line.

2.4 Data Analysis

Running velocity and GCTs were averaged for each of the 25 segments of 200-m. Gait asymmetry between GCTs of both feet was computed as in Eq. 1 [19, 20].

$$\frac{|\text{GCT right} - \text{GCT left}|}{0.5 \cdot (\text{GCT right} + \text{GCT left})} \times 100 = \text{gait asymmetry } [\%] \quad (1)$$

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Only a subset of steps out of each 200-m segment was evaluated in order to differentiate between gait asymmetry on the bend and straight track sections. To ensure that GCTs from purely the bend and purely the straight track were included in the analyses of the respective section, the fifth to fourteenth step and the last fourteen to five steps of each foot per 200-m segment, respectively, were computed. Consequently, ten gait cycles each section were evaluated for running the bend and straight track section, respectively.

2.5 Statistical Analysis

Statistical analyses were performed by using SPSS Statistics 22 (Inc., Chicago, IL, USA) and the level of significance was set at $p \leq .05$. Data were expressed as overall means ± standard deviation and illustrated by means of boxplots. Gait asymmetry between GCTs of the left and right foot, straight and bend track section, and gender differences were calculated using paired and independent samples *t*-tests, respectively. The effect of running distance on gait asymmetry was evaluated by a repeated measures ANOVA on the 25 segments of 200-m and time*gender interactions. Furthermore, for comparison between straight and bend sections, also repeated measures ANOVA was applied.

3 Results

Mean 5-km performance time for both gender was 17 min 06 s ± 1 min 39 s (ranging from 14 min 43 s to 20 min 21 s), resulting in an average speed of 4.92 ± 0.48 ms^{-1} (Table 1). Men were running significantly ($p < .001$) faster than women and had significantly ($p < .001$) shorter GCTs. The measured gait asymmetry between GCTs of the left and right foot was 2.6 ± 2.1% without gender differences. Figure 1 illustrates the changes in gait asymmetry over the course of the 5-km time trial. The applied repeated measures ANOVA with a Greenhouse-Geisser correction revealed no significant changes over the 25 segments of 200-m ($F_{6,114} = 1.194$, $p = .317$) and no time*gender effects ($F_{6,114} = 2.194$, $p = .106$).

Table 1. Subjects' performance presented as means ± standard deviation.

	Overall	Women	Men
5-km time [min:ss]	17:06 ± 01:39	18:54 ± 00:56	15:55* ± 00:35
Speed [ms^{-1}]	4.92 ± 0.48	4.42 ± 0.26	5.24* ± 0.26
CV speed [%]	3.4 (1.9-6.1)	3.4 (1.9–5.0)	3.4 (1.9–6.1)
GCT [ms]	193.7 ± 14.3	199.3 ± 13.9	190.0* ± 13.3
Gait asymmetry [%]	2.57 ± 2.14	2.47 ± 1.79	2.65 ± 2.34

Note: CV = coefficient of variation in running speed per 200-m segment presented as mean (range); GCT = ground contact time; $^{*}p < .001$ between gender.

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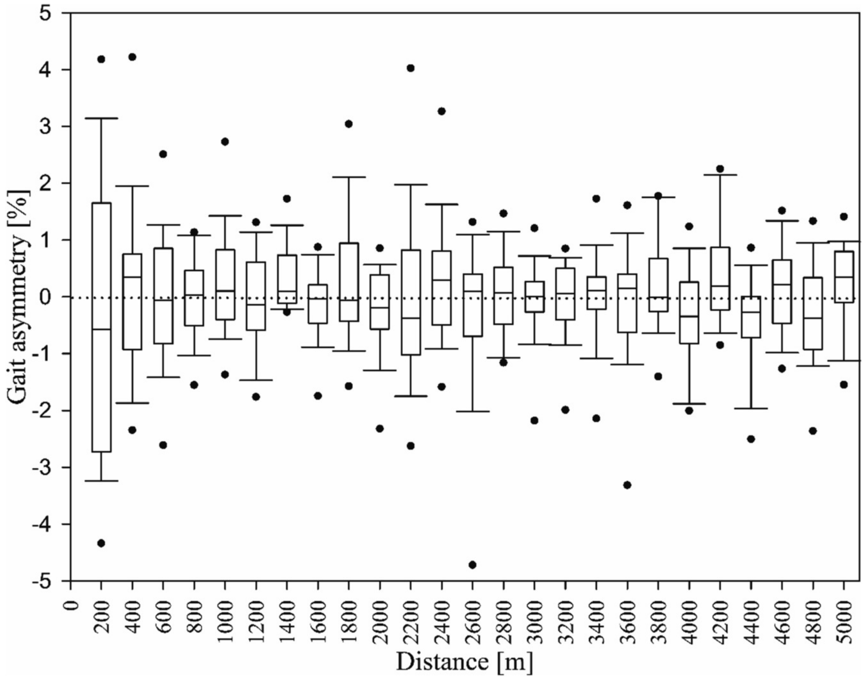

Fig. 1. Relative differences in ground contact times between both feet at each 200-m segment during the 5-km time trial. No significant gait asymmetry changes over the course occurred. For each boxplot the middle line represents the median value, the lower and upper limits represent the interquartile range, the error bars indicate the range and the dots denote the 5th and 95th percentiles.

Regarding differences in gait asymmetry between the straight and bend track section, GCTs on the bend were significantly longer compared to the GCTs on the straight track section (193.7 vs. 192.9 ms, $p < .001$; Table 2). Moreover, the GCTs of the left foot were significantly longer than the GCTs of the right foot on the bend (194.5 vs. 192.8, $p < .001$), whereas no difference in GCTs between both feet was shown on the straight section (193.0 vs. 192.9, $p = .876$). However, the relative gait asymmetry remained the same on the straight track section compared to the bend section with 2.7 and 2.8%, respectively. Repeated measures ANOVA did not reveal differences in gait asymmetry between the straight and bend track sections ($F_{1,291} = 8.602$, $p = .093$).

4 Discussion

The present study sought to examine gait asymmetry during running and its changes over a 5-km time trial. Furthermore, data were separately evaluated for straight and bend track sections of the 400-m synthetic track. Gait asymmetry was quantified by the

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Table 2. Data on ground contact times (GCTs) of both feet separated by the straight and bend track section.

N = 625	GCTs both feet [ms]	GCTs left [ms]	GCTs right [ms]	Δ left-right [*t*-value; *p*-value]	Gait asymmetry [%]
Straight	192.9 ± 14.5	193.0 ± 15.3	192.9 ± 14.5	0.16; .876	2.7 ± 2.2
Bend	193.7 ± 14.5	194.5 ± 15.0	192.8 ± 14.7	6.10; .000	2.8 ± 2.3
Δ bend-straight [*t*-value; *p*-value]	3.81; .000	7.06; .000	−0.41; .680		0.238; .812

difference between the GCTs of the left and right foot. Overall, gait asymmetry in all elite orienteering athletes was 2.6%. This was less when compared to Brughelli et al. [13] and Kong and de Heer [14], who reported 3.5% and 3.6% asymmetry between GCTs of both feet, respectively. However, it is difficult to make direct comparisons between studies as the applied methodologies differed. The cited studies obtained data of male subjects on a treadmill at submaximal speeds. Moreover, subjects were Australian Rules football players demonstrating a different running style compared to athletic running specialists [13]. Lastly, data were measured during six step cycles only, which was reported to be very little, and therefore less reliable [14, 15]. The current 5-km time trial was executed under field conditions that automatically led to greater variability in pacing. This in turn might impact gait asymmetry even more. However, it appeared that the present elite athletes had smaller gait asymmetry despite running at maximal velocity over approximately 17 min.

Interestingly, the athletes in the present study kept gait asymmetry constant over the entire course of 5-km, because no 200-m segment could be detected as being particularly different from the others (Fig. 1). Related literature is lacking, as either gait asymmetry was not investigated or only over short sprint distances [1, 7, 21]. In previous research on sprint running it was recommended that data of distances longer than 30-m be obtained, because gait asymmetry might differ during different phases and/or at steady state running [21]. However, in the current study this assumption could not be confirmed, as no progression in gait asymmetry over time was observed. The elite athletes in the present study were able to consistently deal with the emerging fatigue and neither gender showed potential physical limitations by uneconomical and imbalanced behavior, which in turn could have increased injury risk or affected performance. Previously, it was stated that fatigue does not necessarily result in marked changes in kinematics during submaximal distance running [22]. Our findings support and extend this observation in that gait asymmetry was evaluated over the course of a maximal long-distance time trial. However, it has to be emphasized that the data were obtained in healthy runners. It might be assumed that athletes with previous or chronic injuries of the lower limbs are differently affected by fatigue and may show increases in gait asymmetry over the course of a race.

Throughout the time trial, the GCTs were significantly longer on the bend than on the straight track sections. More specifically, on the bend, the GCTs of the foot on the inside lane of the track (= left foot), were significantly longer than the GCTs of the

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right foot, whereas this difference did not exist on the straight section. However, the present study also highlights that the reported overall gait asymmetry cannot be explained by the bends of the circular 400-m track alone, because relative gait asymmetry remained the same on the straight compared to the bend track section with 2.7 and 2.8%, respectively. In previous studies investigating 200-m sprinting, asymmetries in kinematic movement patterns between left and right steps were larger on the bend than on the straight track [8, 9]. Moreover, Churchill et al. [8] demonstrated a decrease in sprinting performance on the bend due to reduced step frequency and increased GCT of the left step compared to the straight section. However, it was not known whether the bend had the same influence on gait asymmetry during sprinting and during long-distance running. Considering the significantly longer GCTs of the left than the right foot, the present results indicate that the bend has a similar influence on gait asymmetry during running at approximately 5 ms^{-1} as at 10 ms^{-1}, which was reported in the previous sprint study [8]. Nevertheless, in our study no mechanical explanations of force production can be provided, as the applied methodology was highly practical for field measurements in an entire group, yet, it has some limitations. Also, whether running performance differ between straight and bend track sections in long-distance runs needs to be examined in further research.

Individual gait asymmetry is masked when data is averaged for a whole sample, as in the present study. For example, depending on the athletes' individual running patterns, i.e., whether they tend to have a right or left foot imbalance, relative gait asymmetry decreases or increases when performing long-distance runs on an athletic track due to the bend. Furthermore, theoretically, some athletes could show higher gait asymmetry at the beginning and reduce this over the course of the race, while others may adapt in the other direction. Therefore, in high performance settings, data should be individualized so that personal strengths and weaknesses can be obtained for diagnostic and prognostic purposes. In case of gait asymmetry, targeted training interventions may be defined. In this respect, frequent measurements could be valuable, as classifying one's deficits after an injury is difficult when individual baseline data are lacking. For instance, having long-term data at hand would be useful for athletes, coaches, and medical staff to monitor rehabilitation progress or even to define a return to competition after rehabilitation.

The Axiamote sensor is a device with high practical application for enabling regular monitoring and evaluation of gait asymmetry in running. The small size and light weight allows data acquisition not only during training sessions but also during competitions. Additionally, data can be evaluated in real time even for a group of athletes.

5 Conclusions

The present study showed low and consistent asymmetry between GCTs of the left and right foot in healthy elite orienteers over a 5-km running time trial on a 400-m synthetic track. The athletes appeared to have the ability to deal with the emerging fatigue, as no alteration in gait asymmetry occurred over time. Furthermore, the GCTs of the left leg were significantly longer compared to the contacts of the right foot. Yet this alone does

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not explain the overall gait asymmetry, because relative gait asymmetry remained the same for both the bend and straight track section. Care should be taken when interpreting averaged data over a whole sample, and therefore, individual evaluation of gait asymmetry is recommended. The specified technology can obtain individual and long-term data to monitor gait asymmetry over single training sessions or entire training periods.

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