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Full Length Article

Treadmill based reference running data for healthy subjects is dependent on speed and morphological parameters

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ABSTRACT

Objective: To obtain spatiotemporal and dynamic running parameters of healthy participants and to identify relationships between running parameters, speed, and physical characteristics.
Method: A dynamometric treadmill was used to collect running data among 417 asymptomatic subjects during speeds ranging from 10 to 24 km/h. Spatiotemporal and dynamic running parameters were calculated and measured.
Results: Results of the analyses showed that assessing running parameters is dependent on running speed. Body height correlated with stride length ($r = 0.5$), cadence ($r = -0.5$) and plantar forefoot force ($r = 0.6$). Body mass also had a strong relationship to plantar forefoot forces at 14 and 24 km/h and plantar midfoot forces at 14 and 24 km/h.
Conclusion: This reference data base can be used in the kinematic and kinetic evaluation of running under a wide range of speeds.

1. Introduction

Running requires a complex sequence of joint motions and produces a tremendous amount of force distributed throughout the body, which can often lead to injury (Daoud et al., 2012; Diebal, Gregory, Alitz, & Gerber, 2012). These kinematics and kinetics can be influenced by a variety of physical and biomechanical factors (Daoud et al., 2012; Heiderscheit, Chumanov, Michalski, Wille, & Ryan, 2011; Kernozek & Ricard, 1990). As such, the effective analysis of these characteristics may assist in improving running performance and a decreasing the risk of injury.

Previous research has investigated the various physical characteristics that may affect running biomechanics including age (Fukuchi, Stefanyshyn, Stirling, Duarte, & Ferber, 2014; Kline & Williams, 2015; Silvernail, Boyer, Rohr, Bruggemann, & Hamill, 2015), gender (Devita et al., 2016), muscle activity (Kyrolainen, Avela, & Komi, 2005; Nilsson, Thorstensson, & Halbertsma, 1985), and pelvic-trunk coordination (Seay, Van Emmerik, & Hamill, 2011), just to name a few. Aims of other studies identified gait asymmetries (Hoerzer, Federolf, Maurer, Baltich, & Nigg, 2015), fatigue-related changes (Brown, Zifchock, & Hillstrom, 2014) and running patterns in pathological populations (Creaby, Honeywill, Franettovich Smith, Schache, & Crossley, 2016; Kuhman, Paquette, Peel, & Melcher, 2016).

Running speed has also been identified as having a potential influence on running biomechanics (Fredericks et al., 2015;

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Table 1
Demographic and morphological characteristics of subjects (n = 417) categorized by running speeds and gender. All values are means (standard deviations).

Running speed (km/h)	Men/women	Age in years	Body mass in kg	Body height in m	BMI in kg/m^2
10	m (n = 246)	33.2 (± 11.5)	78.5 (± 10.1)	1.80 (± 0.07)	24.0 (± 2.40)
	w (n = 171)	30.3 (± 12.2)	63.6 (± 10.2)	1.69 (± 0.08)	22.2 (± 2.95)
12	m (n = 246)	33.2 (± 11.5)	78.5 (± 10.1)	1.80 (± 0.07)	24.0 (± 2.40)
	w (n = 170)	30.2 (± 12.0)	63.6 (± 10.3)	1.69 (± 0.08)	22.2 (± 2.96)
14	m (n = 244)	32.8 (± 10.8)	78.6 (± 10.2)	1.81 (± 0.07)	24.0 (± 2.41)
	w (n = 167)	29.7 (± 11.6)	63.7 (± 10.3)	1.69 (± 0.08)	22.2 (± 2.97)
16	m (n = 243)	32.9 (± 10.8)	78.7 (± 9.86)	1.81 (± 0.07)	24.0 (± 2.37)
	w (n = 152)	28.6 (± 10.5)	63.0 (± 8.54)	1.70 (± 0.08)	21.9 (± 2.21)
18	m (n = 238)	32.6 (± 10.6)	78.6 (± 9.90)	1.81 (± 0.07)	24.0 (± 2.38)
	w (n = 123)	27.9 (± 9.81)	62.9 (± 8.61)	1.70 (± 0.08)	21.7 (± 2.18)
20	m (n = 220)	32.0 (± 9.93)	78.5 (± 9.93)	1.81 (± 0.07)	23.9 (± 2.39)
	w (n = 82)	25.3 (± 8.10)	63.2 (± 8.55)	1.71 (± 0.08)	21.6 (± 2.06)
22	m (n = 186)	30.6 (± 8.88)	78.1 (± 10.1)	1.81 (± 0.08)	23.8 (± 2.43)
	w (n = 50)	24.0 (± 6.55)	62.6 (± 8.23)	1.71 (± 0.08)	21.2 (± 1.73)
24	m (n = 138)	29.1 (± 8.12)	77.9 (± 10.2)	1.81 (± 0.08)	23.8 (± 2.39)
	w (n = 28)	23.9 (± 8.17)	62.6 (± 7.53)	1.72 (± 0.07)	21.1 (± 1.94)

Kyrolainen et al., 2005; Nilsson et al., 1985; Santos-Concejero et al., 2016). The influence of running speed on kinematic and kinetic parameters is believed to be an important factor in determining runner's performance, running economy, and strain diagnosis (Moore, 2016). Unfortunately, the previous research investigating the role running speed plays in kinematic and kinetic parameters has used a variety of sample sizes, speeds, and participant demographics, thereby creating a dichotomy in results and adding to the confusion surrounding the interpretation of these findings. Therefore, further investigation is needed in this area using a large sample size and running at a wide variety of speeds in order to generate speed-related reference values which enable differentiated derivatives. Therefore, the primary aim of this study was to determine spatiotemporal and kinetic running parameters at speeds ranging from 10 km/h to 24 km/h in a large cohort of participants. A secondary aim was to identify relationships between running parameters and morphological characteristics.

2. Method

2.1. Participants

417 asymptomatic recreational runners (246 men, 171 women) aged 13–76 years volunteered to participate in this study (Table 1). Participants were included if there was no history of musculoskeletal or neurological disease, gait disorders or any painful condition that could have affected their running performance. Exclusion criteria included the presence of an apparent marked pelvic asymmetry, scoliosis, or the ingestion of medication that could have interfered with their running mechanics.

2.2. Procedures

All testing was conducted in a university sports medicine laboratory within a department of orthopedic and trauma surgery. The study was approved by the local ethics committee and all participants or parents of minors, respectively, gave their informed consent. In advance of the investigation all subjects completed a questionnaire regarding sport activity and orthopedic medical history.

Running trials were performed on a dynamometric treadmill with fall protector (h/p/cosmos/quasar, FDM-THQ-3i, zebris medical GmbH). This instrumented treadmill contains a pressure based measurement unit (sensor area: 135.5 × 54.1 cm) with a resolution of 1.4 sensors per cm^2 (total number of sensors: 10.240). The sampling rate for the force plate was 300 Hz. Furthermore, two mobile camera modules (Logitech HD Pro C920) were set behind and beside the treadmill to confirm correct foot placement on the treadmill. Prior to data collection, the force plate was set to zero in order to calibrate the entire measurement system.

Following a two-minute warm-up various running speeds were completed with a maximum of eight different speeds (10, 12, 14, 16, 18, 20, 22, 24 km/h). The duration of each speed was 30 s and each trial was followed by a total recovery period to avoid fatigue across trials. Subjects ran in their personal running shoes. Running speeds were not randomized because we speculated that not all participants would be able to run at some of the faster speeds. This sequence of running speeds also allowed participants to ramp up their effort with a progressive increase in speed.

After finishing data collection, spatiotemporal parameters (e.g., stride length, cadence, foot progression angle and gait line length) and pressure-based ground reaction forces were analyzed by means of software information. Gait line length was defined as the length of the center of pressure trace along the sole of the foot. The FDM software provides the ability to mark the foot into three regions representing heel, midfoot and forefoot (metatarsal first to fifth, hallux, and the lesser toes). This function was then used to determine maximum pressure distribution across the three foot areas.