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Kinematic and dynamic patterns of human gait reference data for young women walking at low, preferred and high speeds

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Abstract

The purpose of this study was to presents reference data concerning gait speed for angular, kinematic and dynamic temporal and spatial parameters in patterns of groud reaction forces, knee joint moments of force and powers during a wide range of walking speeds of young womens. For the purpose of the study, comprehensive measurements and descriptive statistics were used to describe dynamic and kinematic variables at each walking speed tested. The tree walking velocities levels (low, preferred and high) were selected as the research objectives. The results showed that along with the increase in walking speed, the values of the analysed parameters also increase.

1. Introduction

The gait of a healthy human can be considered normal and can represent a reference for characterization of gait pathologies using the comparative method [1]. Gait speed has a significant effect on the kinematic and dynamic gait pattern [2,3]. The kinematic angular variables characterizing the knee and ankle joints have been found to be related to gait speed [4]. Therefore, three gait speed levels selected by the respondents were used in this study to provide valuable comparative data for the gait of healthy young women. The aim of the study was to develop a kinematic and dynamic gait pattern using the BTS Smart-E system.

2. Material and research methods

Anthropometric measurements were performed in a group of 15 women (age: 21.19±1.09 years, body height: 171.6±5.6 cm, body weight: 64.6±6.2 kg). The BTS Smart-E motion analysis system was used to measure kinematics and dynamics of motion during the examinations and to perform the subsequent analysis. The system features six optoelectronic IR cameras (operating at the frequency of 120Hz) allowing to track positions of passive markers present in the measuring space, placed in locations strictly defined by the basic Davis model. Two Kistler platforms and two Kistler amplifiers were employed to measure the kinetic gait parameters. The task of the participant was to walk a distance of about 6 meters with three different speeds (low, preferred and high) with three repetitions, which allowed to record 9 gait cycles for each examined gait speed. The kinematic and dynamic gait data obtained from the examination were used to calculate temporal and space variables and angular variables for both lower limbs. Descriptive analyses also included muscle torques and power developed in the joints and ground reaction forces (GRF). All respondents described their health status as good and gave their written consent to participate in the experiment. The research was also approved by the Senate’s Research Bioethics Commission at the University School of Physical Education in Wrocław, Poland.

3. Results

Table 1 presents the results for temporal and spatial variables, whereas Figs. 1 and 2 show angular kinematics for the low, preferred and high gait speeds for both sides and selected results of gait dynamics for the knee joint.

Tab. 1 Temporal gait variables for the low, preferred and high gait speeds and for both right and left lower limbs.

Gait speed	low	preferred	high
gait speed [m/s]	1.13±0.14*	1.41±0.08*	1.69±0.12
cadence [steps/sec]	1.68±0.14*	1.94±0.1*	2.14±0.1
stride length [m]	1.25±0.08	1.38±0.1	1.54±0.11
stride width [m]	0.16±0.02	0.15±0.04	0.15±0.06
stride time (cycle time) [s]	1.2±0.11	1.04±0.05*	0.93±0.04
Right lower limb			
mean speed of swing [m/s]	2.56±0.28*	3.11±0.29*	3.74±0.3
step length [m]	0.56±0.04*	0.61±0.08	0.65±0.14
relative stance duration [%]	64.5±1.2	62.9±1.7	62±1.6
relative swing duration [%]	35.5±1.2	36.6±2.1	38±1.7
relative double stance duration [%]	14.5±1.4	13±1.5	11.7±1.4
stance duration [s]	0.77±0.07	0.65±0.05	0.58±0.03
swing duration [s]	0.43±0.04*	0.38±0.03	0.35±0.02
double stance duration [s]	0.17±0.03*	0.13±0.02	0.11±0.02
Left lower limb			
mean speed of swing [m/s]	2.57±0.27*	3.14±0.3*	3.73±0.28
step length [m]	0.57±0.04*	0.61±0.08	0.66±0.13
relative stance duration [%]	64.8±1.3	63±1.1	61.8±1.3
relative swing duration [%]	35.2±1.3*	37±1.1	38.2±1.3
relative double stance duration [%]	14.6±1.2	13.3±2*	11.9±1.3
stance duration [s]	0.78±0.08*	0.65±0.04*	0.58±0.03
swing duration [s]	0.42±0.03*	0.38±0.02	0.36±0.02
double stance duration [s]	0.18±0.02*	0.14±0.03	0.11±0.01

*** statistically significant differences (Mann-Whitney U-test, P<0.05)**

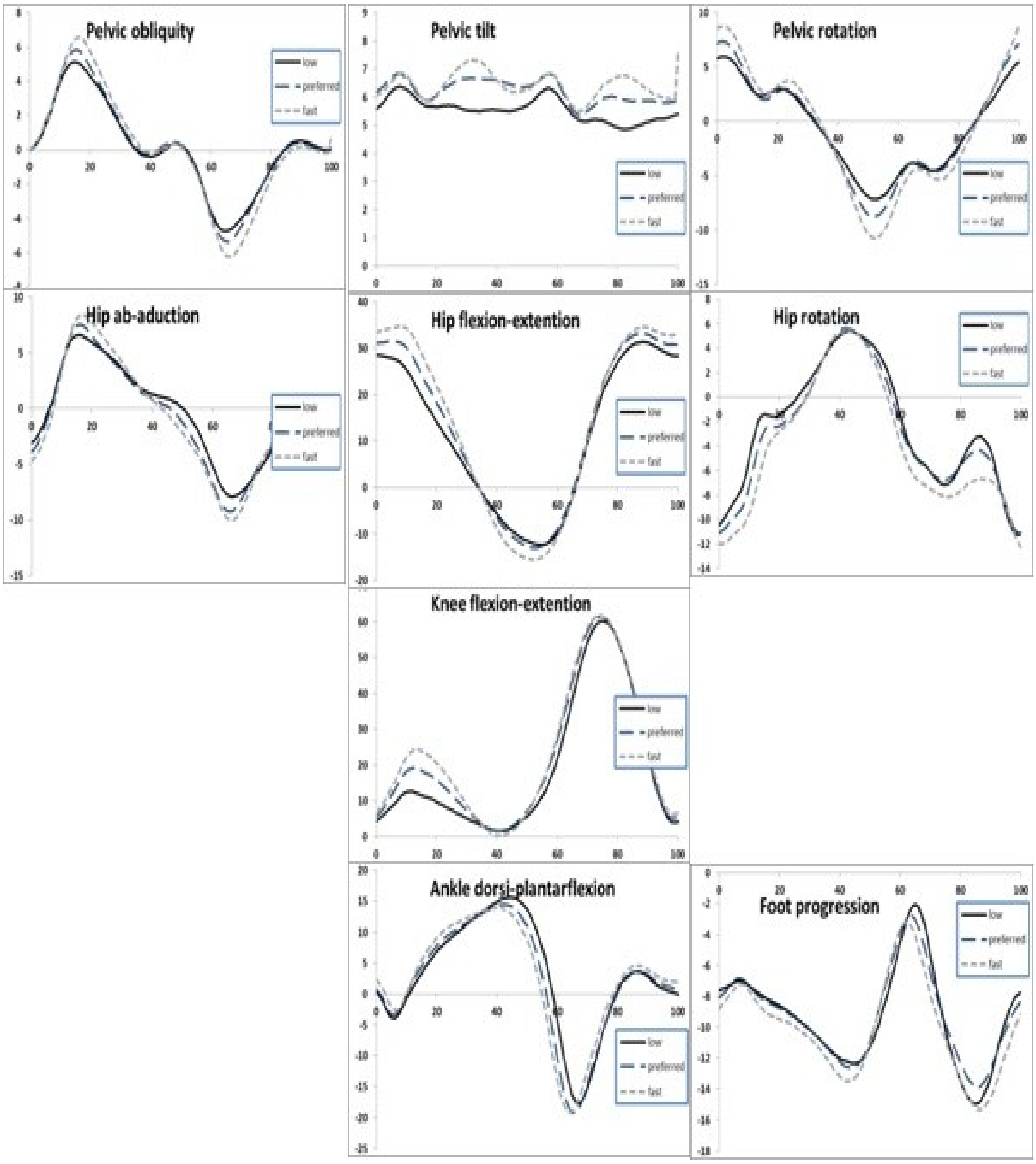

Figure 1. Angular kinematics for the low, preferred and high gait speeds for both sides.

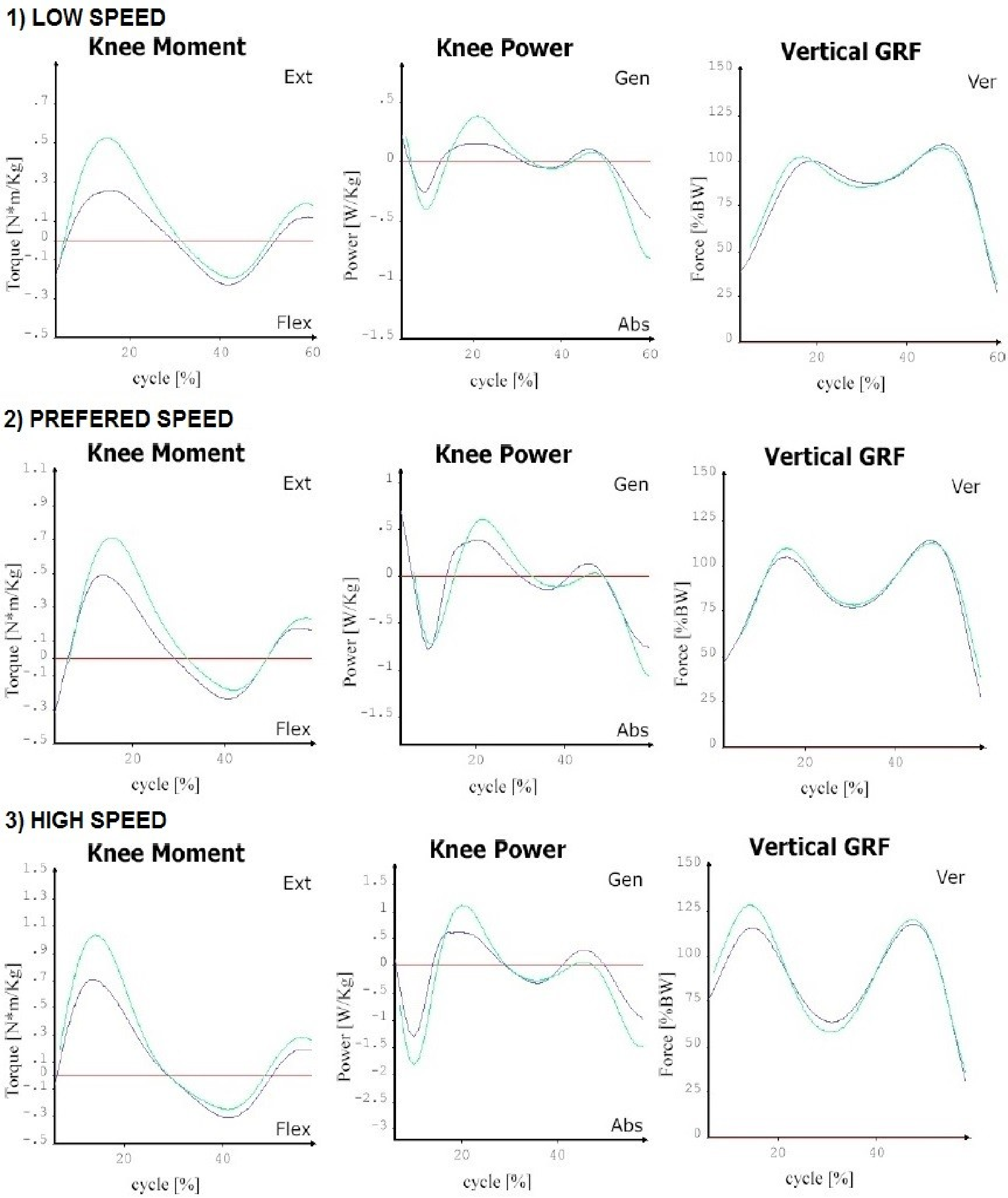

Figure 2. Diagrams showing the results of muscle torques and power for the knee and vertical GRF for the tested gait speeds for the right and left limbs.

The differences in the measured kinematic and dynamic parameters were observed for gait at high, preferred and low speeds. Increase in walking speed (1.13±0.14m/s for low speed, 1.41±0.08m/s for preferred speed and 1.69±0.12m/s for high speed) led to a reduction in the duration of the swing from 0.43±0.04s for low speed to 0.35±0.02 s for high speed and double support time from 0.17±0.03s for low speed to 0.11±0.02s for high speed (similar results were observed for the right and left limb). This was associated with the change in the angular range of motion in the sagittal plane of the hip joint by 42.0º, 45.8º and 53.3º for low, preferred and high speed, respectively. Similar relationships were observed in the knee joint, with the range of joint motion increasing with the speed (56.1º for low speed, 57.8º for preferred speed and 60.7º for high speed). There were no significant differences between the range of motion and speed in the ankle joint.

4. Discussion

Walking is the basic form of human locomotion and the most comfortable and economic way of moving over short distances [5]. This form of human locomotion is usually characterized by low speeds and cyclic movements, which can be recorded using cinematographic methods in laboratory settings [6,7]

Analysis of gait parameters can be helpful in the determination of the effectiveness of rehabilitation, conservative treatment, and surgical interventions, and provides important information on the functional status of patients and their disabilities. Furthermore, the gait of a healthy human can be considered normal and can represent a reference for characterization of gait pathology using the comparative method [1]. A great deal of reference data can be found in the literature. However, many researchers have argued [10] that each laboratory, due to its specificity, should use norms adjusted to its measurement conditions. Furthermore, few studies have evaluated variability of kinematic measurements for the research group selected in this study.

Growney et al. [11] studied kinematic and kinetic profiles of the lower limbs in the hip, knee and ankle joints in all planes and found that they were quite reproducible in people walking at their natural or preferred gait speeds. A similar conclusion was drawn by Kadaba et al. [12], who examined gait variables for kinematic, kinetic and electromyographic data and temporal parameters of forty healthy people. Several projects have been also devoted to the gait analysis in different age groups. Macwilliams et al. [13] collected kinematic and kinetic databases for normal gait for joint angles, muscle torques and power during adolescent gait. Stansfield et al. [14] studied 26 healthy seven-year-old children to verify the importance of age or speed to characterization of common angles, muscle torques and power. Chester et al. identified age-related differences in kinematic and kinetic gait parameters in children aged 3-13 years [15] and adults [16] and indicated the importance of using age-matched normative data.

The BTS Smart-E gait analyser provides quantitative measurements of kinematic gait parameters. These variables can be used in the study in different ways. We chose to present a few spatio-temporal and joint angle parameters that can be easily defined during the gait cycle. No statistically significant differences in these parameters were observed between the right and left lower limbs. The gait cadence was 1.68±0.14 steps/sec for the low speed, 1.94±0.1 steps/sec for the preferred gait and 2.14±0.1 steps/sec for the high speed. The stride length was 1.25±0.08 m for the low speed, 1.38±0.1 m for the preferred speed and 2.14±0.1 steps/sec for the high speed. We also found that joint angles increased with increasing gait speed. The increase was statistically significant ($p > 0.05$) for all angle parameters. Knee swing angle increased from about 56.1 deg to 60.7 deg, whereas hip flexion-extension angle increased from 42.0 deg to 53.3 deg.

5. Summary and conclusion

This paper presents reference data concerning gait speed for angular, kinematic and dynamic temporal and spatial parameters of natural gait of healthy young women. Changes in these parameters occurred with increasing gait speed. The reference data were developed in the specialized Biomechanical Analysis Laboratory of the University School of Physical Education in Wrocław, with procedures based on the Quality Management System ISO 9001:2009.

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