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Effects of Arm Swing on Mechanical Parameters of Human Gait

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A B S T R A C T

The aim of this study was to investigate the influence of the upper limb swing on human gait. Measurements were performed on 52 subjects by using the Elite system with two cameras and a Kistler force platform. The recording of trajectories of characteristic body points on the subjects and the measurement of ground reaction forces have been performed at normal walking and at walking with emphasised rhythmic upper limb swing. The trajectory of the whole body mass centre, central dynamic moments of inertia and ground reaction forces have been calculated for every subject and mean curves of the entire group have been determined for walking with the natural and the emphasised upper limb swing. The determined mean values of normalised mechanical parameters have been compared and differences between the gait with the natural and the emphasised upper limb swing have been described.

Key words: *human walking, arm swing, trajectory of the whole body mass centre, ground reaction force, dynamic moments of inertia*

Introduction

Human walking is a result of a series of processes that take place in the neuromusculoskeletal system and has been extensively studied by many investigators from various disciplines. A great number of studies on human walking have been published. A lot of mathematical models of lower limb movements have been developed[1–5] but few reports have been written about the contribution of the upper limbs to the locomotion process. Some authors have even indicated that the arm movement is not a prerequisite for normal walking and have wondered why the upper limb movement has been retained during the evolutionary change[6].

Although the role of the upper limbs in walking must necessarily be secondary to that of the lower limbs, their movements are not purely passive. The reciprocal swinging of the arms plays an important role in gait. Elftman concluded that the arm swing is produced by a parallel action of muscular forces, gravity and passive elastic forces[7]. It is commonly thought that the swing of the upper limbs plays a counterbalancing role against the contralateral leg and the pelvic movement[7]. Some authors have suggested that a controlled upper limb movement is required to produce smooth, non-jerky locomotion[8,9].

This study was intended to reach a better understanding of the contribution of the upper limbs to the human gait. The purpose was to evaluate the influence of arm swing on some mechanical gait parameters. The main objective was to investigate the effect of the upper limb swing on the trajectory of the whole body mass centre, as well as on the changes of central body dynamic moments of inertia and ground reaction forces during human walking. The body mass centre represents a key factor in the analysis of human gait as it reflects the motion of the whole body. The knowledge of ground reaction forces and dynamic moments of inertia is a prerequisite for the analysis and simulation of human walking.

Subjects and Methods

A deeper insight into the role of arm swing in the gait could be obtained by adopting different arm swing patterns. Therefore, the measurement of ground reaction forces and the recording of trajectories of characteristic body points on the subjects were performed during walking at a normal speed (0.95 m/s $\leq v \leq 1.7$ m/s), with the

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natural and the emphasised upper limb swing. The emphasised upper limb swing meant a full reciprocal excursion of both arms. Measurements were carried out on 52 subjects (characteristics summarised in Table 1) with no apparent abnormalities of the locomotion system. The Elite system with two CCD cameras and a Kistler force platform were used for that purpose (Figure 1). A 9-m walkway, with the Kistler force platform located in the center, was used for the gait analysis. Ample space at both ends of the walkway was available to allow the subject to walk at approximately constant velocity.

To determine inertial characteristics, the human body segments could be modelled by geometric solids. Model that represented the body segments using a number of geometric solids was based upon simplifying assumptions[10], such as uniform density over a cross-section and along longitudinal axis of the segment. The nonrigidity of body segments was neglected and human body was considered as a system of rigid segments.

TABLE 1
PERSONAL PROFILE OF TEST SUBJECTS INCLUDED IN THE STUDY

Gender	No. of subjects	Age, years			Weight, N		
		$\bar{x}$	min.	max.	$\bar{x}$	min.	max.
Female	20	27.8	21	31	552	494	612
Male	32	30.5	22	26	829	710	1100

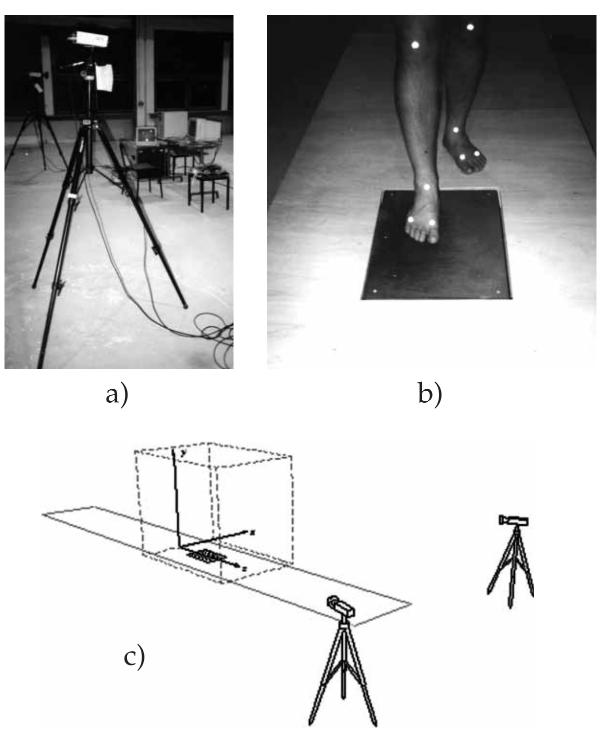

Fig. 1. a) Infrared cameras of measuring system ELITE. b) Contact of subject's foot with Kistler force plate. c) Calibrated volume with force plate and global coordinate system.

24 reflective markers were attached to palpable landmarks on the human body[11,12]. The landmarks allowed the definition of a 15-segment whole body model which included the foot, lower leg, thigh, upper trunk (thorax and abdomen), lower trunk (pelvis), head and neck, upper arm, forearm and hand segments[11,12]. The joint centres and centres of mass of segments were approximated using the data from literature[13–15]. The simplified approach was adapted that neglected markers movement due to skin displacements. 3D marker co-ordinates were the input data for the computer program which calculated orientations of segments, joint centres, trajectories of the whole body mass centre and central body dynamic moments of inertia during walking[10–12].

The subjects were walking barefoot and they were asked to walk successively at what they felt to be their normal speed. In a set of experiments carried out on each subject, the subject was instructed to walk 20 times: ten walks were natural walking and ten were walking with emphasised rhythmic upper limb swing.

Recorded data were processed and the walking trials without contact of the entire foot with the Kistler force plate were rejected. In order to be able to compare characteristics of walking, the determined characteristics of gait were normalised. The determined trajectories of the body centre of mass were normalised by the subject's height to give displacements of centre of mass in percentages of the body height. The original data of the body centre of mass displacement were averaged by normalising them to one hundred sample points per one walking cycle through cubic spline interpolation. The first and the last points marked the left heel contact. Ground reaction forces were normalised by body weight and shown as a function of the contact duration between the foot and the force platform. The total duration of contact represented 100% on the time axis. In order to be able to compare central dynamic moments of inertia, they were normalised by the body mass and radii of gyration were calculated as a square root of the quotient of the central dynamic moment of inertia and the body mass. One gait cycle was represented as 100% on the time axis. The origin (0%) and the end (100%) of the time axis marked the left heel contact.

From *individual patterns* of walking characteristics, a *typical pattern* for every subject was determined to describe the inter-subject variation.

Typical patterns of three components (vertical, fore-aft, medio-lateral) of ground reaction forces and *typical patterns* of displacements of the body mass centre in the lateral, vertical and fore-aft direction, as well as radii of gyration of the lateral, vertical and fore-aft axis during a gait cycle, were established for every subject. Fore-aft axis represented a longitudinal axis lying on the line of progression. *General patterns* and variation bandwidth of one standard deviation for a particular walking manner were determined from *typical patterns* of all subjects for the same manner of walking. A *general pattern* represented the mean curve of the entire group of subjects studied.

Results and Discussion

General patterns of displacements of the body centre of mass, for walking with the natural and the emphasised upper limb swing, are compared in Figure 2, and maximum displacements of the body centre of mass in the lateral, vertical and fore-aft directions are shown in Table 2.

Considering the walking at normal speed with the natural and the emphasised upper limb swing, the displacements of body centre of mass for the emphasised upper limb swing decreased in the lateral and the vertical directions and increased in the fore-aft direction.

Figure 3 represents a comparison of *general patterns* of three components of ground reaction forces during walking with the natural and the emphasised upper limb swing are shown in Fig. 3.

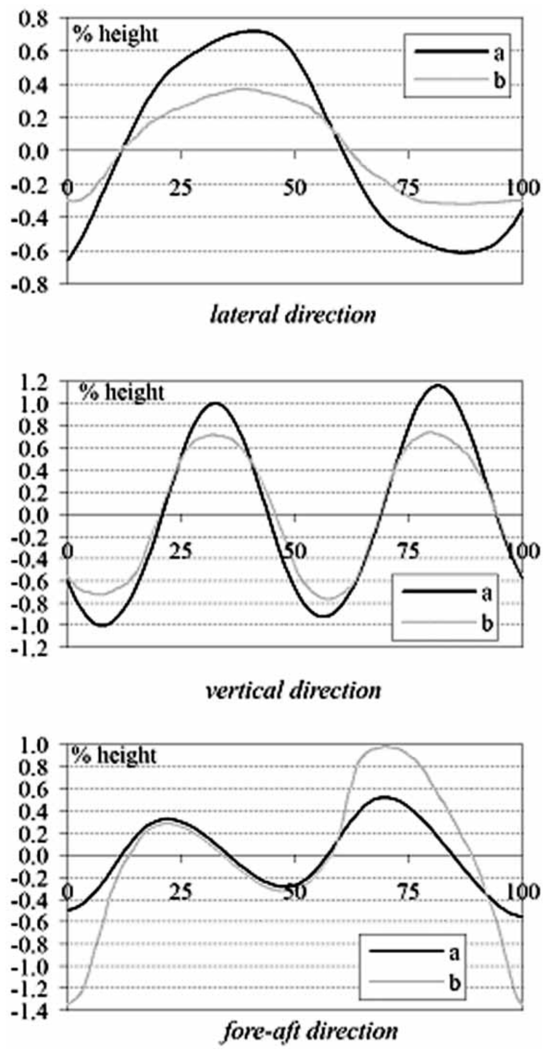

Fig. 2. Comparison of general patterns of displacements of the body centre of mass for walking with the natural (a) and the emphasised upper limb swing (b).

TABLE 2
MAXIMUM DISPLACEMENTS OF GENERAL PATTERNS OF BODY CENTRE OF MASS IN LATERAL, VERTICAL AND FORE-AFT DIRECTION

Direction	Maximum displacement in percentage of body height	
	Natural upper limb swing	Emphasised upper limb swing
Lateral	1.34	0.70
Vertical	2.16	1.50
Fore-aft	1.07	2.30

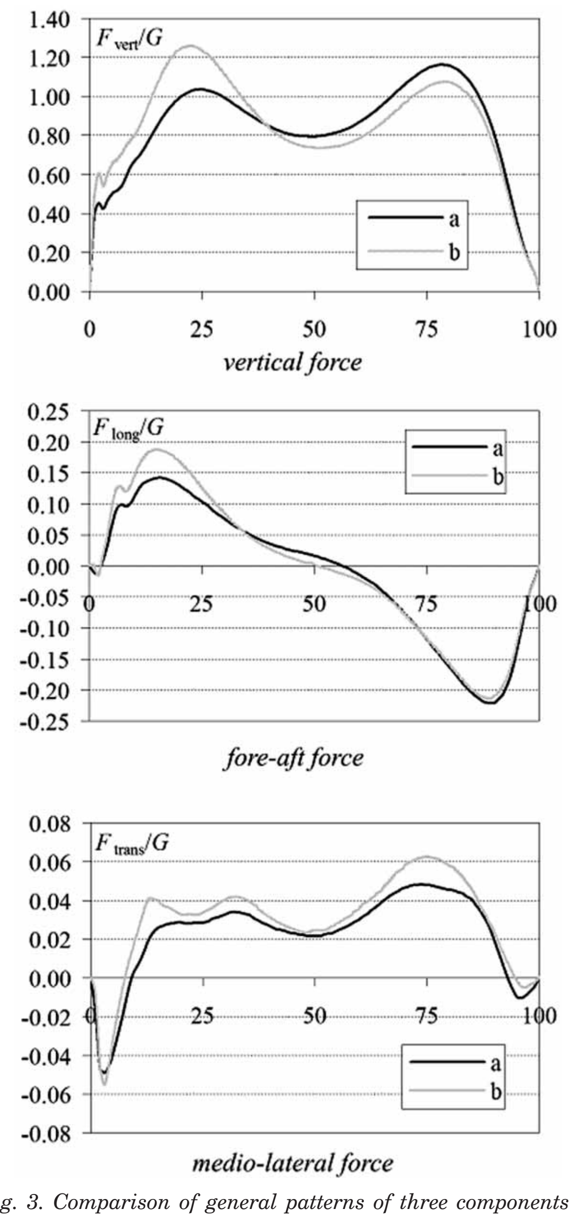

Fig. 3. Comparison of general patterns of three components of ground reaction forces for walking with the natural (a) and the emphasised upper limb swing (b). F_{vert}/G – vertical ground reaction force normalised by body weight, F_{long}/G – fore-aft ground reaction force normalised by body weight, F_{trans}/G – medio-lateral ground reaction force normalised by body weight.

swing. A typical feature of the vertical force component is its »dual hump« shape. During walking at normal speed with the natural upper limb swing, the second peak is higher when compared with the first one. During walking at normal speed with the emphasised upper limb swing, the first peak is higher. The maximum values of the first and the second peak of *general patterns* of vertical ground reaction forces are shown in Table 3.

TABLE 3
THE MAXIMUM VALUES OF THE FIRST AND THE SECOND PEAK OF GENERAL PATTERNS OF VERTICAL GROUND REACTION FORCES

	Natural upper limb swing	Emphasised upper limb swing
$(F_{vert}/G)_{max,I}$	1.0358	1.2583
$(F_{vert}/G)_{max,II}$	1.1627	1.0750

F_{vert}/G – vertical ground reaction force normalised by body weight

The *general pattern* of the fore-aft component of ground reaction force is nearly anti-symmetric with a larger fore and a smaller aft force. For walking with the emphasised upper limb swing, the fore-force was decreased and the aft-force was increased.

The *general pattern* of the medio-lateral component is asymmetric and the medial force is predominant. The medial force was increased in walking with the emphasised upper limb swing.

Figure 4 shows a comparison of *general patterns* of radii of gyration for the vertical, lateral and longitudinal axis. In the condition of emphasised upper limb swing, one can note that the emphasised upper limb swing increased the radii of gyration for the lateral and vertical axes, and decreased for the longitudinal axis.

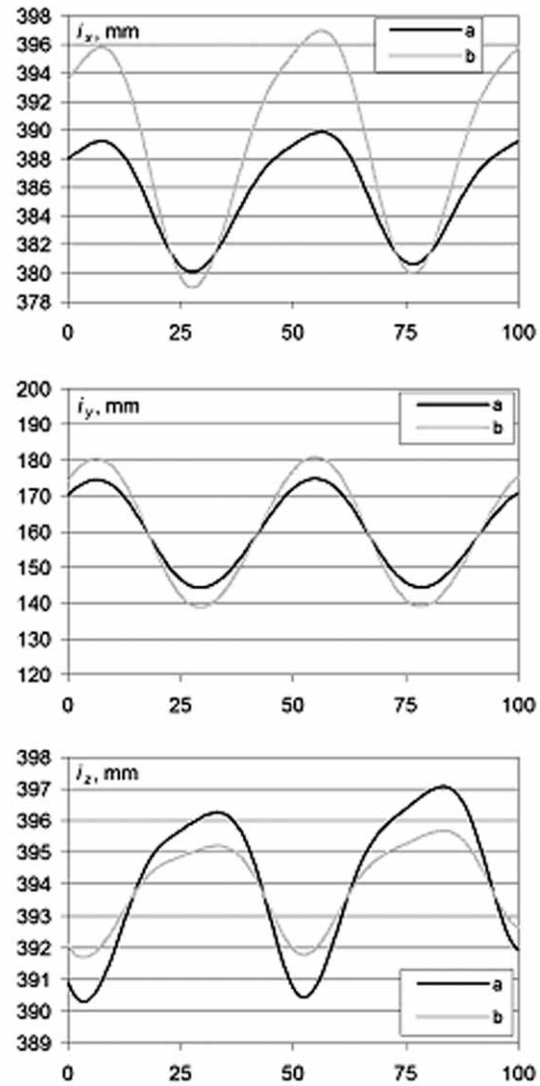

Fig. 4. Comparison of general patterns of radii of gyration for the vertical, lateral and longitudinal axis in the natural (a) and the emphasised upper limb swing (b) walking. i_x – radius of gyration for the lateral axis, i_y – radius of gyration for the vertical axis, i_z – radius of gyration for the longitudinal axis.

Conclusion

The study has shown that the gait pattern is influenced by changes in arm swing. Deliberate changes of the arm movements during gait influence gait parameters and thus change the gait efficiency. An alternation in the normal motion of the upper limbs results in changes in the whole body kinematics and in dynamic stability.

The measurements have shown that components of ground reaction forces were influenced by changes in the upper limb swing during walking. The maximum magnitudes of vertical components of the ground reaction force, aft-force and medial force were increased for normal speed walking with the emphasised upper limb swing.

Considering the walking with the natural and emphasised upper limb swing, the displacements of the body centre of mass for the emphasised upper limb swing were decreased in the lateral and vertical directions and increased in the fore-aft direction. It can be concluded that the trajectory of the body centre of mass in walking with emphasised upper limb swing tends to exhibit decreased curvature and to come closer to a straight line.

The arms decreased the magnitude of vertical oscillations of the body centre of mass during walking and may reduce the energy expenditure.

The emphasised upper limb swing was found to change central dynamic moments of inertia of the whole body, thus influencing dynamical characteristics of gait.

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R E F E R E N C E S

1. PANDY MG, BERME N, J. Biomechanics, 21 (1988) 1043. — 2. PANDY MG, BERME N, J. Biomechanics, 21 (1988) 1053. — 3. KOOPMAN B, GROOTENBOER HJ, DE JONGH HJ, J. Biomechanics, 28 (1995) 1369. — 4. PERUMAL R, WEXLER AS, BINDLER-MACLEOD SA, J. Biomechanics, 39 (2006) 2826. — 5. REN L, JONES RK, HOWARD D, J. Biomechanics, 40 (2007) 1567. — 6. MURRAY MP, SEPIC SB, BERNARD EJ, J. Motor Behavior, 13 (1967) 226. — 7. ELFTMAN H, Human Biol., 11 (1939) 529. — 8. JACKSON KM, JOSEPH J, WYARD SJ, Electromyogr. Clin. Neurophysiol. 23 (1983) 425. — 9. JACKSON KM, JOSEPH J, WYARD SJ, J. Biomechanics, 11 (1978) 277. — 10. JURČEVIĆ T, MUFTIĆ O, Coll Antropol, 22 (1998) 585. — 11. JURČEVIĆ LULIĆ T, LULIĆ Z, MILČIĆ D, Upper limbs influence on the trajectory of the body mass centre during human walking. In: MIDDLETON J, JONES ML, SHRIVE NG, PANDE GN (Eds), Computer Methods in Biomechanics and Biomedical Engineering – 3 (Gordon and Breach Science Publishers, Amsterdam, 2001). — 12. JURČEVIĆ LULIĆ T, Dynamical Influence of Symmetrical Subsystems of Solids on the Motion of Entire System. PhD Thesis. In Croat (University of Zagreb, Zagreb, 1999). — 13. DONSKY DD, ZATSIORSKY VM; Biomehanika [in Russian] (Fizkultura i sport, 1979, Moskva). — 14. ENG JJ, WINTER DA, J. Biomechanics, 28 (1995) 1223. — 15. DE LEVA P, J. Biomechanics, 29 (1996) 1223.

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UTJECAJ NJIHANJA RUKU NA MEHANIČKE PARAMETRE LJUDSKOG HODA

S A Ž E T A K

Cilj ovog rada bio je istražiti utjecaj njihanja gornjih udova na ljudski hod. Mjerenja su provedena na 52 ispitanika pri čemu je korišten Elite sustav s dvije kamere i Kistlerova platforma za mjerenje sile. Snimanje trajektorija karakterističnih točaka na tijelu ispitanika te mjerenje reakcijskih sila podloge provedeno je za normalni hod te za hod s naglašenim ritmičkim njihanjem gornjih udova. Za svakog ispitanika su izračunate putanje središta mase cijelog tijela, središnji dinamički momenti tromosti i reakcijske sile podloge te su utvrđene srednje vrijednosti za sve ispitanike za hod s prirodnim i naglašenim njihanjem ruku. Utvrđene srednje vrijednosti normaliziranih mehaničkih značajki su uspoređene te su opisane razlike između hoda s prirodnim i naglašenim njihanjem ruku.