ABSTRACT

Title: The effect of upper limbs' movement on the dynamic balance of the adult human body.

Introduction: The vast majority of scientific research on gait analysis and stability in humans focuses on the importance of the lower limbs during movement, often neglecting the movement of the upper limbs. A significant difficulty in parameterizing the movement of the upper limbs is its high variability and high complexity. Moreover, the method of conducting research and analyzes is not unified, which means that there are sharp differences in the research practice used in laboratories of human movement analysis around the world. Currently, there are no standards to distinguish normal arm swing from that which is associated with the action of an external disturbance on the human body and the resulting process of control and recovery of balance. There are also no standards that would allow distinguishing between healthy people and those suffering from diseases of the musculoskeletal system. An analysis of stability in humans that does not take into account upper limb movement is therefore incomplete. The literature cited in this work confirms that active arm swing helps regain balance when it is lost and is an important element of locomotion.

Research objective: The main aim of the study was to develop a method for quantitative assessment of upper limb movement and to identify upper limb movement patterns associated with high dynamic stability in humans. The following specific objectives were also distinguished:

1) Verification of existing and development of own parameters for assessing the stability of the human body in dynamic conditions, taking into account the movement of upper limbs
2) Determining the reference values for parameters describing the movement of upper limbs, which will reflect high dynamic stability
3) Assessing the influence of inter-limb coordination on the stability of the human body
4) Defining the conditions for maintaining a stable posture and resistance to destabilizing factors while walking in various conditions.

Methods: Laboratory tests included the analysis of the movement of the human body during various types of gait. This movement was recorded using the Vicon optoelectronic motion analysis system and dynamometric platforms. The research involved 19 adults who did not suffer from neurological diseases or any other disorders that could affect postural stability. 37 reflective markers were glued to the subjects' bodies, and then the Plug-in-Gait biomechanical model of the entire body was implemented in the Vicon Nexus software. Using research equipment, parameters such as walking speed, step length, marker trajectories in 3D space, ground reaction force vectors, as well as the point of application of this force (COP) were measured.

Subsequent data processing and analysis were performed in Mokka and Matlab software. Information about the center of mass of the body was obtained based on kinetic modeling from the operations window available in the Vicon software.

To quantitatively assess the movement of the upper limbs, the AS_{IA} parameter was formulated, reflecting the amplitude of the arm swing. Based on the literature, the following parameters were calculated: the distance between the center of body mass projected on the ground and the COP point as well as the distance between the line of action of the ground reaction force and the center of body mass in 3D space. All three parameters were normalized in time in relation to the % of the gait cycle and in relation to the body height of the examined person, and their values were determined separately for the right and left sides of the body. To examine the symmetry of movement for the upper and lower limbs, Pearson's correlation coefficients were calculated for all 3 parameters between the right and left limbs.

Results: Due to differences in results, the subjects were divided into 2 groups. The first group is the reference group, within which the subjects are characterized by high symmetry of movement of the upper limbs. In normal walking the following values of the Pearson correlation coefficient for the AS_{IA} parameter were obtained: 0.872 ± 0.091. The second group includes subjects with significantly lower symmetry of upper limb movement. Under normal walking conditions, the Pearson correlation coefficient for this group was: 0.304 ± 0.201. Correlation values for the AS_{IA} parameter of approximately 0.5 or less were considered as low symmetry of upper limb movement based on previous research results. The nature of the movement of the upper limbs, its symmetry, and swing amplitude significantly depended on the type of motor activity performed. Relatively difficult tasks to perform were backward walking and tandem walking. While performing these tasks, several subjects experienced a temporary loss of balance, which resulted in rapid and high fluctuations in selected parameters. The subjects from the first group obtained lower values of the Pearson correlation coefficient when walking backward (equal to 0.410 ± 0.355) compared to normal walking. In the case of the second group, the average value of the Pearson correlation coefficient for backward walking (equal to 0.330 ± 0.949) is similar to that for normal walking for this group, but the variability of the analyzed values is much higher. Backward walking was characterized by the greatest variability in the value of the Pearson correlation coefficient for the AS_{IA} parameter, taking into account all motor tasks and both groups. Low symmetry of upper limb movement is also characteristic of tandem walking, where the Pearson correlation coefficient for the AS_{IA} parameter was 0.451 ± 0.278 in the first group and 0.219 ± 0.170 in the second group, respectively. For both groups, in backward walking and in tandem walking, the values of the Pearson correlation coefficient for the COP-COM parameter remain high and are characterized by low inter-individual variability, similar to walking at three different speeds.

High variability between subjects was observed for the H parameter when walking over an obstacle, especially among subjects from the second group. Crossing an obstacle engages the right and left sides of the body differently, which is reflected in significant differences in the values of all analyzed parameters between the right and left limbs. In the first group, when the obstacle is placed in front of the force platform, the symmetry of the upper limb movement is the lowest among all movement tasks, where the average value of the Pearson correlation coefficient for the AS_{IA} parameter is 0.263 ± 0.238. Also in the second group, notably low values of the Pearson correlation coefficient were obtained, equal to 0.090 ± 0.461, when performing this task. Taking into account both groups and all motor tasks, overcoming an obstacle with an obstacle placed in front of the platform is also characterized by the lowest Pearson correlation coefficient for the COP-COM parameter, which indicates worse symmetry of lower limb movement than in other motor tasks. In both groups, the Pearson correlation coefficient for the H parameter during obstacle walking with an obstacle placed in front of the platform is lower than in the case of walking on a straight track performed at 3 different speeds or tandem walking. In the second configuration, when the obstacle is placed behind the force platform, low symmetry of the movement of the upper limbs was also noted. In the first group, the average value of the Pearson correlation coefficient for the AS_{IA} parameter was: 0.414 ± 0.266, while in the second group: -0.030 ± 1.077. Additionally, in both groups for this motor task, the lowest value of Pearson's correlation coefficient for the H parameter was obtained, taking into account all motor tasks. In the first group, this value is: 0.552 ± 0.263, and in the second group: 0.641 ± 0.355.

Conclusions: The obtained results confirm that there is no single correct pattern that would describe the movement of the upper limbs during walking and ensure high dynamic stability. Significant differences were noticed among the subjects in the way they moved their upper limbs. In 7 study participants belonging to the second group, low symmetry of upper limb movement was noted, which resulted from a smaller swing amplitude for the right upper limb compared to the left limb. Despite the low symmetry of movement of the upper limbs, the subjects from the second group did not experience problems with balance while performing motor tasks, and their gait remained stable.

Stable gait is associated with a specific nature of the curve for the AS_{IA} parameter in both study groups, where these characteristics depend on the % of the gait cycle and the kinematics of the lower limbs, which is related to the inter-limb coordination between the upper and lower limbs. The greatest amplitude of arm swing during normal and fast walking occurs near the heel strike. For participants from the first group, this occurs around 50% of the gait cycle for both the right and left upper limbs. However, for the second group, only the left upper limb reaches the maximum swing amplitude near 50% of the gait cycle, while for the right upper limb, the maximum value of the AS_{IA} parameter occurs at 6% of the gait cycle. Nevertheless, the occurrence of the maximum amplitude of arm swing near the moment of heel strike has a statistical tendency in both groups, creating a characteristic stereotype of upper limb movement, which suggests that good inter-limb coordination has a significant impact on the stability of the human body during walking.