Detailed kinematic evaluation of shoulder motion during normal gait in healthy young males

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Abstract. Complex kinematic analysis of human motion has become achievable through new technological developments. Several new studies have already taken advantage of the new kinematic approach for documentation and analysis of pathological motion, including palsy, paralyses, Parkinson's disease and others. However, physiological motion of gait and corresponding upper limb motion has seldom been studied. The aim of this study was to collect and analyse data of shoulder motion of 45 healthy young males during the gait cycle. Detailed dynamic kinematic measurements revealed that the arm remained constantly in an internal rotation position with changing and adapting angle along the gait cycle with maximal internal rotation at mid-stance and at mid-swing, and minimal internal rotation in the beginning and at the end of the cycle, as well as at mid-cycle. At the same time, the arm remained constantly in an adduction position, with maximal adduction by mid-cycle and minimal adduction in the beginning and at the end of the cycle. In parallel, the arm reached maximal extension around the beginning and the end of the cycle, with maximal flexion just before mid-cycle. During the gait cycle, there was regular and repetitive movements of the shoulder joint and the arm with constant range of movements, i.e. for the shoulder: 24.6°±3.4° for the flexion-extension movement, 6.44°±0.2° for the adduction-abduction movement and 4.57°±0.1° for the rotational movement. These data provide a first valuable base of the normal, physiological role of the arm for a stable and balanced gait in young adult males. From there, pathologies of the arm and shoulder may be dissected and their influence on the gait cycle investigated in the future. In addition, these data may also be used for the design and control of robotic arm prosthesis.

Keywords: human gait, kinematic parameters, shoulder joint, rehabilitation, three-dimensional video analysis, Vicon.

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1. INTRODUCTION

In the recent past, limited scientific observation methods restricted clinical evaluation of gait and corresponding body movements. In addition, data analysis was rather slow in a clinical setting. Only in the late 20th and early 21st century, substantial progress in informatics technology with new software and hardware, as well as new equipment for electromyography, has propelled the study of human motion to the next level. This new technology has significantly contributed to a better understanding of mechanisms of the normal and pathological gait. It also allows diagnosis of muscle-skeletal malfunction at an early stage before clinical symptoms appear, as well as objective evaluation and recording of recovery in the course of treatment and rehabilitation.

In orthopaedic medicine, abnormalities of gait have usually been associated with pathologies of the lower limb, the pelvis or the vertebral column. In neurological medicine, gait pathologies have generally been descriptive by using figurative terms like waddling gait or steppage gait. Most past studies covered usually only the bony, articular and ligament structures, and for the muscles mostly those of the lower limb, the pelvis and the vertebral column, mainly in the context of trauma. Only recently, new studies using modern kinematic technology and focussing on the upper limb in the context of gait have contributed to a more scientific approach of gait analysis, indicating that arm movements influence gait. Thus, it was shown that arm swinging influences gait through vertical shifting of the centre of gravity [1], changing gait stability [2] and influencing walking speed [3].

Movement patterns and specific models for the movement of the upper limb has been described for various diseases and pathologies, including parkinsonism, athetosis, multiple sclerosis, essential tremor, osteochondrosis of the thoracal column, osteochondropathy of the vertebral column, paralysis of peripheral nerves, etc. [4, 5]. In that respect, it has been shown that coordinated physiological arm swing substantially contributes to gait, as it helps with coordination of the leg muscles and increases energy efficiency by 8% [6], as well as with modifying lumbar spine load [7]. As gait and corresponding arm and leg motion patterns change over age, a recent study has documented age-dependent limb movements during gait [8]. However, the number of adult participants was rather small, pooling both males and females for the analysis. In addition, little is known about the coordinated movement of the upper limb during the gait cycle in normal healthy individuals. Therefore, we present here a detailed study and analysis of shoulder movements during normal gait for young adult males. This study investigated kinematic parameters of the shoulder in the context of normal gait and established a new data bank. These data may provide better understanding of the contribution of upper limb movements to normal and pathological gait. They may also help with the evaluation, diagnosis and treatment in the context of various diseases affecting gait, as well as with the development of robotic arm prosthesis and humanized robots.

2. METHODS

This study was done in the Centre of Biomechanics Research of Human Movement at the Astrakhan State University. Data acquisition and analysis of movements was done with help of Vicon equipment (Vicon, UK), including ten infrared digital cameras Vicon T40, a video camera Bonita 720, a Vicon Giganet Lab digital multiplex switch, Vicon Nexus and Polygon software, as well as a stabilometric force platform AMTI (AccuGaitACG, USA). Shoulder movement analysis was done according to our newly developed and recently published movement schemes.

The study was approved by the Russian Ministry of Health represented by the Ethics Committee of the Astrakhan State Medical University on November 21, 2016 (No. 4).

45 healthy males aged between 18 and 25 years were recruited, with average height of 174±1.3cm and average weight of 68±1.8kg, with no asymmetry of arm movements during visual gait observation. However, arm movement asymmetry was expected to be possibly detected in some of these healthy individuals through this study. Thus, according to post-hoc detailed data analysis, only 10 out of the 45 had almost perfect symmetric movements.

The measurements were done for all participants at the same time of day, same light intensity, same noise intensity and ambient temperature. Everyone walked seven times a distance of 8 meters, along a straight line at the same speed. For data acquisition, the Plug-in Gait Full Body model with 40 markers (passive light reflecting) was used (Fig. 1). One complete gait cycle was extracted from the steady-state phase and used for statistical analysis for each of the seven walks per study subject. The following kinematic parameters of shoulder movements were analysed, including for the frontal axis: angle of flexion (positive digit) and extension (negative digit), for the sagittal axis: angle of adduction (positive digit) and abduction (negative digit), for the vertical axis: internal (positive value) and external rotation (negative digit). Acquisition of movement data was done with help of the software Vicon Nexus. Three-dimensional skeletal modelling and graphic representation of the data was done with help of the software Vicon Polygon. Of note, the movement extension measurements captured with the optoelectronic system clearly differs from the clinical approach. The main difference between the two approaches consists of measuring maximal extension of movements in the clinical setting, whereas the optoelectronic system acquires the time-dependent and dynamic extension of movements. For analysis of the shoulder movements, additionally to the three axis and corresponding movements of the shoulder joint mentioned above, also the basic body axis was considered.

The program MathCad was used for statistical data analysis. Assessment of normality was done with the Shapiro-Wilks test. Assessment of accuracy was done with the student-T Test (t=2, p=/<0.05).

3. RESULTS

Graphical analysis of movement of shoulder flexion and extension during the gait cycle (ipsilateral leg starting with the initial heel contact of the stance phase) revealed a sinusoidal curve characterized by a smaller arc-like line for shoulder flexion by mid-cycle (maximum: +7.05°±1.4°) and two more extended half-arc-like lines for shoulder extension in the beginning (maximum: -21.74°±2.7°) and towards the end of the cycle (maximum: -23°±4.4°) (Fig. 2). The arm reached in the flexion-extension movement the neutral position in the beginning of the single support phase (25 %), and then again in the beginning of the initial swing phase (75 %). Looking into the time-period of the gait cycle, one has to say that the forearm was 45% of the time in front and in 55% of time dorsal to the trunk. 10% of the time-period of the whole cycle is represented by no movement, but standstill for the change of direction, i.e. from flexion towards extension in the most anterior position, or from extension towards flexion in the most posterior position. When calculating maximal flexion and extension of the shoulder joint, extension was much bigger (19.9°±2.4°) in comparison with flexion (4.7°±0.7°), whereas the total range of the flexion-extension movement was of 24.6°±3.4° (Fig. 1).

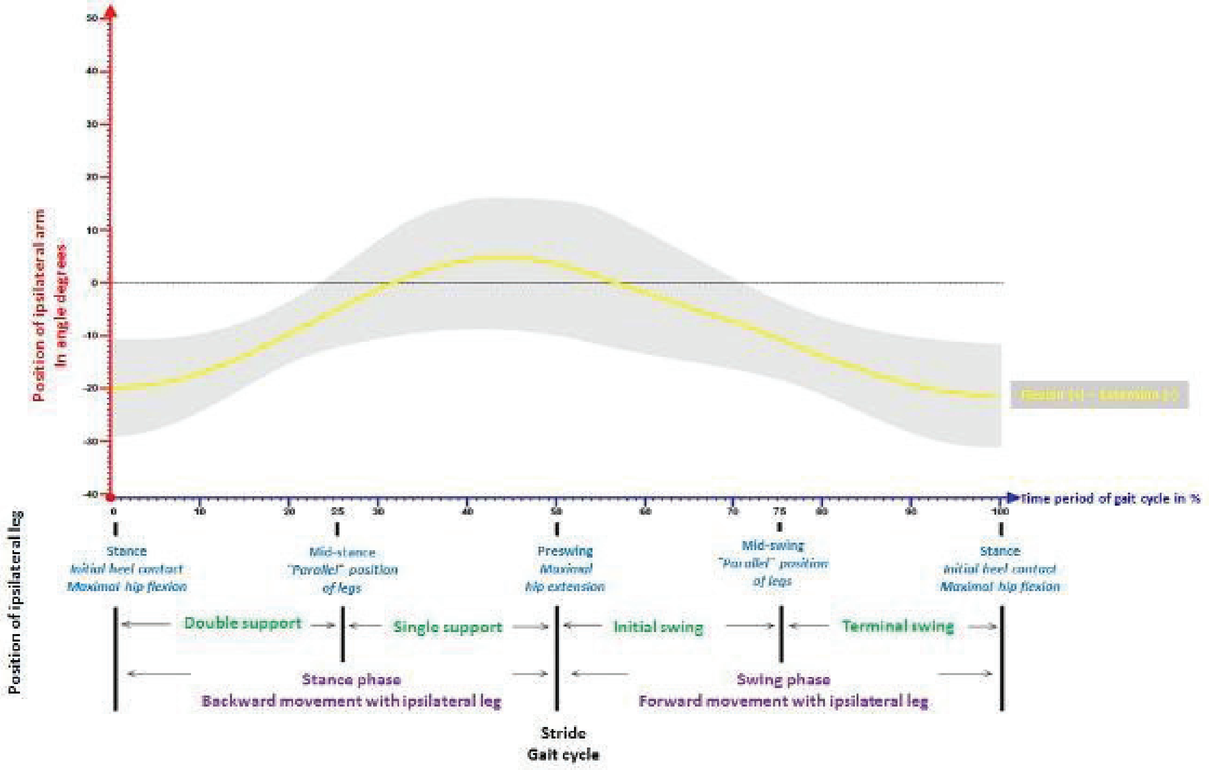

Figure 1. Shoulder flexion/extension joints during gait cycle.

The maximal extension of the shoulder joint was reached at the 1% time-point of the gait cycle, whereas the maximal flexion was reached at the 45% time-point of the gait cycle. Interestingly, the final and maximal anterior position of the hand was reached only at the 50% time-point of the gait cycle, due to additional flexion of the elbow (data not shown). The shoulder flexion position takes about 30% of the time of the gait cycle, in the middle of it, whereas the extension position takes about 70% of time.

The adduction - abduction movement of the arm during gait happens only in the shoulder joint, whereby the arm is consistently positioned in slight adduction. Considering the change of position of the hand, maximal adduction reached 25.1°±2.2° at the 44% time-point of the cycle, which takes place around the same time of maximal flexion in the shoulder joint (at 46.6% gait cycle time-point). The most lateral adduction point of 19.0°±1.3° happened at the very beginning, or very end of the gait cycle (time-point 0% and 100%). The maximal range of the adduction-abduction movement reached 6.44°±0.2°. This movement was perfectly synchronized with the flexion-extension movement of the shoulder (Fig. 2).

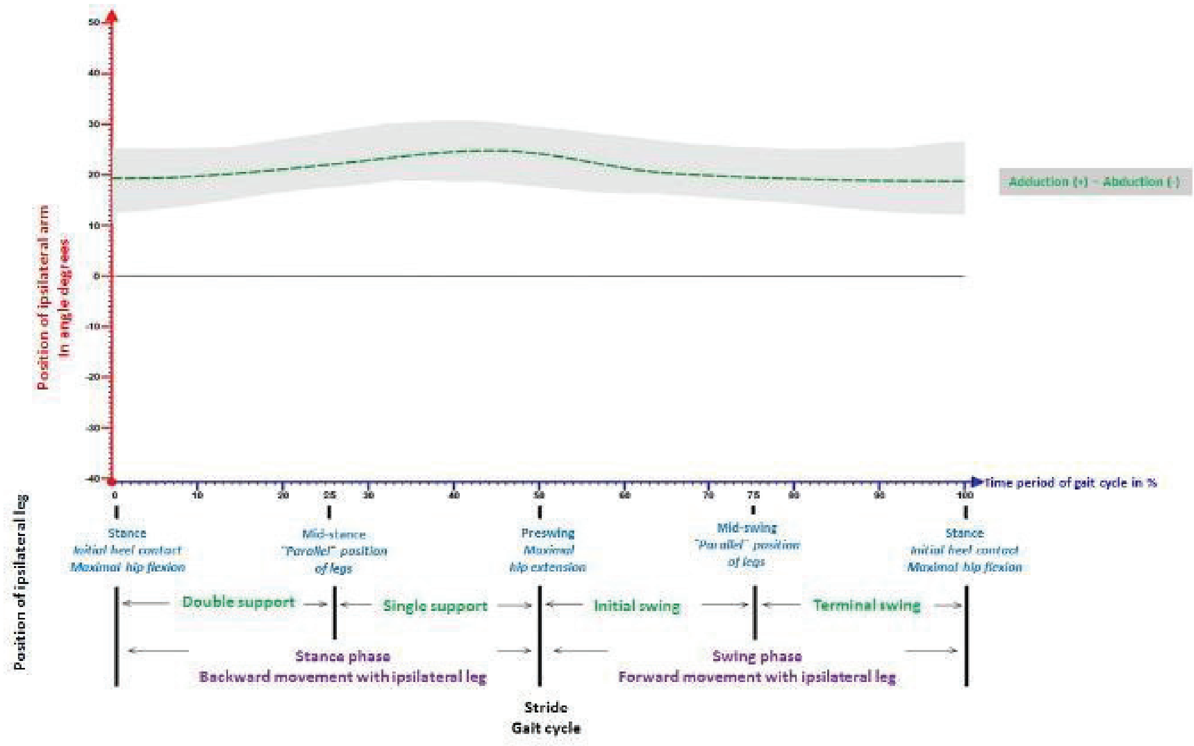

Figure 2. Shoulder adduction/abduction joints during gait cycle.

Usually, the arm is positioned in internal rotation during the whole gait cycle. Interestingly, there were two undulating rotational changes identified during the gait cycle, graphically represented in Fig. 2. The least internal rotation was measured in the very beginning and very end of the gait cycle (23.6°±2.4° at time-point 0%, and 25.5°±2.2° at time-point 100%), as well as by mid-cycle (25.5°±3.9° at time-point 50%). Maximal internal shoulder rotation was reached in mid-stance (28.9°±1.7° at time-point 27.5%) and mid-swing (29.3°±1.3° at time-point 72.5%) points of the gait cycle (Fig. 3). The maximal range of rotational movement in the shoulder was on average 4.57°±0.1°.

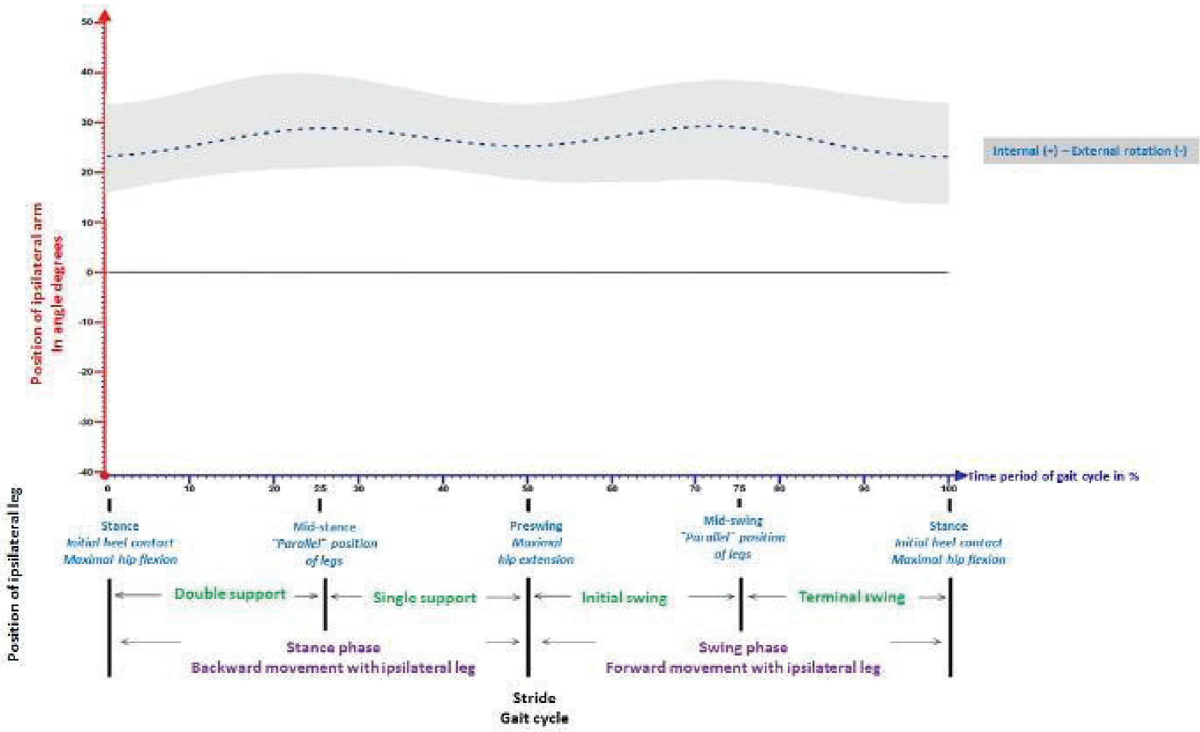

Figure 3. Shoulder rotation joints during gait cycle.

4. DISCUSSION AND CONCLUSION

The influence of the arm movement on the gait cycle has become increasingly the focus of research in sport science and clinical medicine [5, 9-11]. Previously published work has already emphasized on the importance of arm movement on the gait cycle by using various approaches [1-3, 6]. In addition, few studies looking into arm swing during the gait cycle indicate that in healthy individuals its extend and symmetry varies depending on age (toddler, child, adolescent, adult), as well as depending on speed of walking or running [8, 12-15]. To our knowledge, no study has been published looking into gender differences, to date. However, our study provides a very objective description of the shoulder and arm movement in the context of the normal gait cycle in healthy, normal adult males with symmetric motion by using a very detailed kinematic approach.

The role of the arm has been attributed to a stable and balanced gait, as well as for economizing energy expenditure by about 8% by coordinating with the cyclic movements of vertebral column, the pelvis and the legs, which indicates the importance of the shoulder joint for the gait [6, 7, 16, 17]. In addition to passive motion elements, various mechanisms controlling muscle actions of the upper limb during the gait cycle have also been reported [18, 19]. The control of the active component in arm swinging during gait has also been studied by various groups, but still lacks detailed understanding. Thereby, a cerebral and brain stem component, as well as circuits of the spinal cord have been identified, connecting the upper and lower limb, as well as influencing each other [6].

Our data, collected from detailed, dynamic kinematic measurements with multiple parameters, and corresponding evaluation highlight the range of motion in the shoulder joint that are coordinated with the gait cycle. Interestingly, the arm remains constantly in an internal rotation position with changing and adapting angle along the gait cycle with maximal internal rotation at mid-stance and at mid-swing, and minimal internal rotation in the beginning and at the end of the cycle, as well as at mid-cycle. At the same time, the arm remains constantly in an adduction position, with maximal adduction by mid-cycle and minimal adduction in the beginning and at the end of the cycle. In parallel, the arm reaches maximal extension around the beginning and the end of the cycle, with maximal flexion just before mid-cycle. During the gait cycle, there are regular and repetitive movements of the shoulder joint and the arm with constant range of movements, i.e. for the shoulder: 24.6°±3.4° for the flexion-extension movement, 6.44°±0.2° for the adduction-abduction movement and 4.57°±0.1° for the rotational movement.

In the beginning of the gait cycle (stance phase with initial heel contact), the position of the arm in the shoulder joint is characterized by its maximal extension position (-21.74°±2.7°), which does not correspond to the maximal possible extension position. At the same time in the beginning of the cycle, the arm stays at its minimal adduction position (19.0°±1.3°), as well as its minimal internal rotation position (23.6°±2.4°). Around mid-cycle, the arm is in its maximal flexion position (7.05°±1.4°) and maximal adduction position (25.1°±2.2°), but back towards a clearly decreased internal rotation (25.5°±3.9°). The arm reaches neutral position in the shoulder joint at time-points 25% and 75% of the gait cycle when maximal internal rotation has been achieved (28.9°±1.7° at 25%, 29.3°±1.3° at 75%).

The flexion-extension movement of the shoulder along the gait cycle is almost, but not completely symmetric when considering the shoulder joint with its maximal flexion at time-period 45% to 50%. However, the hand reaches its most ventral position exactly at mid-cycle indicating that the movement of the arm during the gait cycle is more complex than just that of the isolated shoulder motion. Although the shoulder movement covers most of it, additional movements of the elbow, including flexion-extension and pronation-supination, may also have to be considered for a more complete understanding of the role of the arm during gait [8, 13].

To our knowledge, this is the most extended kinematic investigation of the shoulder joint movement during the gait cycle for healthy, young adult males. These data provide a first valuable base of the normal, physiological role of the arm for a stable and balanced gait. From there, pathologies of the arm and shoulder may be dissected and their influence on the gait cycle investigated in the future. In addition, these data may also be used for the design and control of robotic arm prosthesis.

AUTHORS' CONTRIBUTIONS

O. Vorontcova and L. Udochkina developed the idea and the theory of the article. I. Mazin and E. Fedyulina carried out the experiment and performed the computations. All authors discussed the results and created the final manuscript.

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