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Observational Study

Reference values of gait parameters in healthy Chinese university students: A cross-sectional observational study

Gait analysis

Abstract

BACKGROUND

Gait is influenced by race, age, and diseases type. Reference values for gait are closely related to numerous health outcomes. To gain a comprehensive understanding of gait patterns, particularly in relation to race-related pathologies and disorders, it is crucial to establish reference values for gait in daily life considering sex and age. Therefore, our objective was to present sex and age-based reference values for gait in daily life, providing a valuable foundation for further research and clinical applications.

AIM

To establish reference values for lower extremity joint kinematics and kinetics during gait in asymptomatic adult women and men.

METHODS

Spatiotemporal, kinematics and kinetics parameters were measured in 171 healthy adults (70 males and 101 females) using the computer-aided soft tissue (CAST) foot model. Full curve statistical parametric mapping was performed using independent and paired-samples t-tests.

RESULTS

Compared with females, males required more time (cycle time, double-limb support time, stance time, swing time, and stride time), and the differences were statistically significant. In addition, the step and stride lengths of males were longer. Compared to males, female cadence was faster, and statures-per-second and stride-per-minute were higher. There were no statistical differences in speed and stride width between the two groups. After adjusting for height, it was observed that women walked significantly faster than men, and they also had a higher cadence. However, in terms of step length, stride length, and stride width, both genders exhibited similarities.

CONCLUSION

We established reference values for gait speed and spatiotemporal gait parameters in Chinese university students. This contributes to a valuable database for gait assessment and evaluation of preventive or rehabilitative programs.

Key Words: Gait analysis; Gait; Reference values; spatiotemporal parameters; Kinematics; Chinese

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Core Tip: In this observational study, gait parameters of healthy Chinese university students were provided, and gender differences in gait as well as differences compared to other ethnicities were observed. These findings may contribute to localized clinical guidance and reference for the region.

INTRODUCTION

Gait is a fundamental characteristic of human walking, that can be influenced by factors such as race, age, and various diseases. Three-dimensional motion analysis systems are commonly employed for movement assessments in both clinical and research settings[1, 2]. This approach requires a normal reference derived from a healthy population to distinguish it from abnormal conditions. However, it should be noted that the reference values may not be universally applicable to every race or age group[3].

In China, approximately 22.7% of college students reported experiencing sports-related injuries in the past 12 mo[4]. Lower extremity injuries, including anterior cruciate ligament rupture, acute ankle sprain, and meniscal injury, account for nearly two-thirds of all reported injuries[5-8]. Numerous studies have examined gait changes in both African American and Caucasian populations[9, 10]. Gait studies on Asians primarily concentrate on individuals aged 60 and above[11, 12]. Currently, there is a lack of reference values for gait among college students, which often leads to overlooked early changes in gait and, an increased incidence of osteoarthritis. Three-dimensional motion analysis can serve as an early screening tool for knee osteoarthritis and a means of evaluating rehabilitation progress[13].

Due to variations in lower extremity kinematics and kinetics across different races, ages, and sexes, and the limited availability of data on Chinese adults other than the elderly population, this study aimed to investigate three-dimensional lower extremity kinematics and kinetics in healthy Chinese university students. The primary objective was to enhance our understanding of country-specific gait patterns and establish normative data as a reference for lower extremity movement in all dimensions. Additionally, these new reference values would be beneficial for identifying abnormal motion patterns related to conditions such as chronic ankle instability, deformities, and neuromuscular disorders.

MATERIALS AND METHODS

Study population and data collection

According to the World Health Organization's recommended normal weight range, this study included participants aged between 18 and 35 years with a BMI between 18.5 and 23.9 kg/m² to exclude underweight and overweight individuals. Research has indicated that gait patterns mature around the age of 7[14], and certain gait parameters, such as walking speed, tend to decline after the age of 40[12]. Therefore, this study primarily focuses on university students whose ages fall within the age range associated with a mature gait pattern. Written informed consent was obtained from all participants, who completed three health-screening questionnaires prior to participation. In addition, participants were required to engage in exercise for at least 20 minutes, at least three times per week. Individuals with pathological gait, serious cardiovascular and cerebrovascular diseases, mental and spiritual abnormalities, pregnant and lactating women, and those with contraindications to exercise due to other medical conditions were excluded. The inclusion and exclusion criteria are presented in Table 1.

All volunteers provided informed consent before undergoing the motion analysis. Gait analysis was performed using a 3D motion capture system (Qualisys Track Manager, Qualisys, Sweden), consisting of eight high-speed infrared cameras (Oqus700+, Qualisys, Sweden) at a sampling frequency of 1100Hz. Data were collected by synchronizing four Kistler force plates (9260AA; Kistler, Switzerland). Gait data were analyzed using modeling and simulation software (Visual 3D Professional V6, C-Motion Incorporation, USA). Lower limbs were analyzed using the Calibrated Anatomical System Technique (CAST) model[15]. A total of 32 reflective markers were attached to participants' bony landmarks and placed on the skin surface. Elastic bandages were used to secure the marker plates on the lateral upper two-thirds of the thigh and calf, with four reflective markers on each plate. Before commencing data collection, participants were ensured to be familiar with the walking procedure. This involved practicing walking at their preferred speed within a 2-meter range in front of and behind the Kistler force plate recording area. Participants completed three rounds of practice walking to minimize the potential impact of acceleration and deceleration on the results. After ensuring that the participants were familiar with the walking procedure and all reflective markers were detected, data from the three best gait cycles were averaged to calculate the joint angles for each participant. Gait speed (m/s), stride length (m), and stride width (m) were assessed, and kinematic and kinetic parameters were simultaneously recorded during the gait analysis.

Data on age, sex, weight (kg), height (cm), body mass index (BMI, kg/m^2), cadence, speed, cycle, stance, and swing times were collected. To ensure accuracy, we performed calibration and correction on the geodetic coordinate system and positions of the eight cameras. Subsequently, both static and dynamic data were collected. For the dynamic data, we selected eight consecutive gait cycles performed by the participants at their preferred walking speeds, starting from the beginning of each walking trial. Data from each gait cycle was processed to represent the 0–100% gait cycle. Finally, we averaged the values from the eight gait cycles to evaluate the kinematics and kinetics of the ankle, knee, and hip joints of each participant.

Statistical analysis

Because height affects certain gait parameters, we have normalized specific gait parameters based on height. Height-adjusted gait speed (gait speed/height)[16], height-adjusted step length (step length/height)[17], height-adjusted stride length (stride length /height), and height-adjusted stride width (stride width /height) have all been normalized to account for height, while height-adjusted cadence has been normalized using the square root of height (cadence x √height)[18].

All parameters are described using means and standard deviations, and the data were analyzed using SPSS 25.0. An independent samples t-test was employed for data conforming to a normal distribution, whereas the rank sum test was used for data that did not conforming to a normal distribution. Statistical parametric mapping (SPM) was conducted to visualize the complete time series of the angle, moment, and power assessment. Two-tailed paired t-tests was usd to compare kinematics and kinetics. The SPM analysis were performed in MATLAB (R2020b, The MathWorks Inc) using open-source code (M.0.4.8, www.spm1d.org). The significance level was set at P = 0.05.

RESULTS

A total of 171 volunteers participated in this study, with an average age of 24.63±2.19 years. Of these, 101 (59%) were female. The mean height was 1.68 ± 0.08 cm, and the mean weight was 58.59 ± 10.06 kg. The average body mass index (BMI) was 20.60 ± 2.15 kg/m^2. The demographic data are presented in Table 2.

spatiotemporal parameters

The spatiotemporal parameters of the participants are listed in Table 3. Compared to females, males required more time in terms of cycle time, double limb support time, stance time, swing time, and stride time, with statistically significant differences. In addition, males exhibited longer steps and stride lengths. On the other hand, females demonstrated faster cadence, higher steps per second, and more strides per minute than males. There were no statistically significant differences in speed or stride width between the sexes. However, after adjusting for height, it was observed that women walked faster than men, with a significant difference between them (0.06 m/s, $p < 0.05$) (Table 3). Additionally, even after height adjustment, women maintained a significantly higher cadence than men ($p < 0.05$), while the significant differences in step length and stride length between men and women disappeared. There were no significant differences in stride width observed between men and women.

Kinematic and kinetic parameters

As depicted in Figure 1, we have gathered motion parameters for the hip, knee, and ankle joints in various planes. Significant differences were observed in the joint kinematics and kinetics at the ankle, knee, and hip among all participants. The detailed kinematics and kinetics of the ankle, knee, and hip are shown in Figure 2, 3, and 4, respectively.

Hip joint

Regarding the hip joint, sex differences were significant in sagittal hip flexion from 0 to 13% and from 75 to 100% of the gait cycle (P = 0.030 and P = 0.007, respectively). Significant differences were also observed in the frontal plane of the hip joint during the 4%–21% (P = 0.015), 57%–66% (P = 0.034), and 86%–91% (P = 0.043) gait cycles. In the transverse planes of motion, significant differences were identified between the groups from 78 to 100% of the gait cycle (*P* = 0.009).

No significant differences were observed in the peak hip extensor moment during the early stance. However, significant differences were observed between 67% and 77% of the gait cycle (P < 0.001). Significant differences in hip power were observed during 68%–77% of the gait cycle (P < 0.001). No significant differences were observed in the hip abductor moment.

Knee joint

At the knee joint, a significant sex difference was observed in sagittal knee flexion from 0 to 100% of the gait cycle (P < 0.001), indicating differences in the range of knee movements during walking. However, no significant differences were observed in frontal knee adduction. In the transverse planes of motion, particularly during 90%–97% of the gait cycle, there was high variability among the participants (*P* = 0.028).

Regarding knee kinetics, no statistically significant differences were detected in the knee extensor moment or knee power. However, differences were observed in the knee valgus moment between the two smaller intervals (*P* = 0.018 and *P* = 0.046, respectively).

Ankle joint

At the ankle joint, no significant sex-related differences were observed in ankle plantarflexion, dorsiflexion, inversion, or eversion. However, significant sex differences were found in the ankle eversion moment at initial contact (P < 0.001) and from 58%–62% of the gait cycle (*P* = 0.013). No significant differences were detected in the ankle plantarflexor moment or ankle power.

DISCUSSION

Spatiotemporal parameters

In this study, we established inclusion and exclusion criteria based on previous research on gait reference values[11, 12]. Furthermore, we utilized three assessment tools to evaluate the physical activity functionality of participants. These tools include the Foot and Ankle Ability Measure (FAAM), designed to assess the muscular and musculoskeletal function of the lower extremities, feet, and ankle joints[19]; the Lysholm knee score, employed to evaluate general knee joint conditions and functionality[20, 21]; and the Harris Hip Score, utilized for assessing hip pathology and health-related quality of life in daily activities[22, 23]. All three assessment tools have been validated as responsive, reliable, and effective evaluation instruments, thus supporting the definition of a healthy population and a mature gait pattern. Building upon this foundation, we investigated the spatiotemporal parameters, kinematics, and kinetics of the gait of Chinese college students. We observed that women had significantly faster cadence, higher statures-per-second, and strides-per-minute, accompanied by longer step lengths. However, women exhibited significantly shorter stride, step, cycle, double-limb support, stance, swing, and stride times than men. No significant sex differences were observed in speed or stride width. After adjusting for height, it became evident that women walked significantly faster than men (0.06 m/s, $p < 0.05$) (Table 3). Importantly, even when height differences were taken into account, women still exhibited a significantly higher cadence than men ($p < 0.05$). Interestingly, the previously observed significant differences in step length and stride length between males and females disappeared. As for stride width, no significant differences were found between men and women. These findings regarding sex differences in cadence, gait speed, and cycle time were consistent with previous studies conducted in laboratory settings, which reported that women had a faster cadence and shorter cycle time than men[24]. Compared to individuals from the Southeast Asian region, our study found that Chinese participants had slightly faster walking speeds (men:1.14 m/s for Southeast Asians, 1.24 m/s for Chinese; women:1.13 m/s for Southeast Asians, 1.22 m/s for Chinese)[12]. However, sex differences in stride width tended to be similar to those observed in Southeast Asian population. Additionally, the Chinese participants in our study exhibited longer step lengths and shorter double-limb support times than the Southeast Asian population. Furthermore, they have a faster cadence than Southeast Asian and Korean populations[25]. A faster cadence can lead to increased wear of the knee joint, which may contribute to the incidence and risk factors of symptomatic knee osteoarthritis in Chinese women[26].

Kinematic and kinetic data

Furthermore, our findings demonstrated significant sex differences in the kinematic and kinetic gait features of the three major lower-limb joints. These differences were primarily observed in the hip and knee joints rather than the ankle joint, indicating overall pattern differences throughout the gait cycle. Compared to previous studies, our results also showed variations in gait patterns. Previous studies have consistently shown that females exhibit lower overall transverse plane hip internal rotation angles[27], and smaller ankle plantarflexor moments throughout most stance phases[25]. In contrast, our findings revealed that females had higher overall transverse plane hip internal rotation angles, and no significant differences were observed in ankle plantarflexor moments. These discrepancies may be attributed to the variations in the gait speed of the participants. Although there are differences between men and women in many gait features, the effect size of some of these differences is relatively small, and therefore individual features may not fully explain the significant differences between the sexes. However, when these small differences are considered, an overall difference in the gait cycle between healthy males and females becomes evident. Our findings are in agreement with previous studies investigating sex differences in gait kinematics among older adults[28-30]. Specifically, in our study, healthy females exhibited significantly greater hip adduction during the stance phase of gait than healthy males. Our results are similar to the majority of previous studies that have reported differences in sagittal, frontal, and transverse plane hip joint angles between younger healthy males and females during walking[31, 32]. In contrast to investigations involving middle-aged and older healthy adults[25, 33], our study found no significant differences in knee adduction angles, or ankle plantarflexion and inversion angles between healthy younger males and females. These contradictory findings may be attributed to subtle changes in gait associated with biological aging[34]. The mean age of the subjects in the current study was 24.92 ± 2.25 years, while the subjects in the aforementioned studies were in their forties or sixties. Therefore, sex-specific gait kinematic differences in healthy younger adults are dissimilar from those previously found in healthy older adults.

In this study, spatiotemporal gait parameters, as well as kinetic and kinematic parameters, were analyzed to assess sex differences and movement patterns. Future studies should investigate the impact of age on gait parameters using a comprehensive curve analysis to identify group differences. Additionally, these analytical methods should be employed to investigate dynamic motion and its association with various conditions such as changes in orientation and gait patterns during single- and double-leg landing, running, and knee osteoarthritis (KOA). Examining movement patterns across different activities can provide a better understanding of potential disparities between men and women. This could be particularly relevant for patients with KOA because women have a higher incidence of this condition.

This study had several limitations. First, the small sample size prevented us from conducting an intragroup analysis based on sex. Future studies with larger sample sizes are needed to investigate potential sex differences within each group more comprehensively. Secondly, this study only captured gait information during a single period. Future studies should consider collecting gait data from the same individuals in different age groups to examine how gait individuals across different age ranges. Finally, our study did not report the specific muscle work during walking. Future equipment improvements will allow for a more comprehensive analysis of lower limb muscle work and other related parameters.

CONCLUSION

This study aimed to investigate the motion parameters of the hip, knee, and ankle joints in Chinese adults aged 18-35 years. The findings highlight the importance of considering sex-based differences in gait biomechanics in future studies. Our results indicate significant differences between men and women in the range of motion of the knee joint in the sagittal plane, whereas smaller differences were observed in the range of motion of the hip joint. No significant differences were observed in the range of motion of the ankle joint between males and females, suggesting potentially distinct gait pattern for each sex. While our study focused on Chinese college students, further population-based research is recommended to explore gait parameters across different age groups.

ARTICLE HIGHLIGHTS

Research background

Gait refers to the movement patterns and rhythm of various body parts when an individual walks, making it a crucial indicator of human movement function and overall health. Currently, there is a relatively limited body of research on gait characteristics in Chinese male and female populations. To address this research gap and provide more precise reference values for the region, we aim to collect gait data from healthy Chinese university students and conduct a comprehensive analysis of gender differences.

Research motivation

Through this study, we hope to reveal the commonalities and disparities in gait among Chinese men and women, thereby providing more accurate foundations and references for future clinical diagnosis and treatment. This research could have a positive impact on improving the diagnosis and rehabilitation measures for relevant conditions, as well as optimizing sports training and exercise rehabilitation programs.

Research objectives

We aim to collect gait data from healthy male university students in China and conduct a detailed analysis of their gait characteristics, including stride length, step frequency, and gait cycle. Through this research, we will gain a deeper understanding of the gait characteristics of male and female individuals in China, providing valuable data and guidance for medical and rehabilitation practices in the region. Additionally, these findings hold the potential to optimize sports training and exercise rehabilitation programs, promoting overall health and physical performance.

Research methods

A total of 171 volunteers participated in this study, with an average age of 24.63±2.19 years. Baseline data of the participants were collected, including gender, age, height, weight, body mass index (BMI), Foot and Ankle Ability Measure (FAAM), Lysholm knee score, and Harris hip score. Gait data were captured using the Qualisys 3D motion capture system. Data analysis was conducted using SPSS 25.0 and MATLAB (R2020b, The MathWorks Inc).

Research results

In this study, significant differences were observed between males and females in the range of motion of the knee joint in the sagittal plane, while smaller differences were observed in the range of motion of the hip joint. No significant differences were found in the range of motion of the ankle joint between males and females, suggesting the existence of potentially distinct gait patterns for each sex.

This study provides more accurate evidence for future clinical diagnosis and treatment.

In future research, we will increase the sample size and collect gait data from the same participants in different age groups to study the changes in gait across various age ranges.

Research conclusions

This study utilized statistical parameter mapping to analyze the gait characteristics of males and females throughout the gait cycle, providing motion parameters of the hip, knee, and ankle joints. The findings highlight the importance of considering sex-based differences in gait biomechanics in future research.

Research perspectives

When guiding treatment plans, healthcare providers should be vigilant about the varying expectations of different gender and racial/ethnic groups. Taking these expectations into consideration is crucial to enhance patient compliance and treatment outcomes.

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