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Original Article

Gender differences between the three dimensional gait analysis data of young athletes

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Abstract

Aim: There are differences in skeletal structures between genders. These differences also have an impact on the gait patterns of individuals. The primary purpose of this study was to examine the differences between two genders with regard to gait parameters of young Turkish athletes. The secondary purpose was to form a representative gait sample of Turkish athletes.

Material and Methods: A total of 51 athletes; 29 females, 22 males (5-18 years, mean age: 11.7) who did not have any disease that might lead to gait pathology were included in the study. Three-dimensional gait analysis was performed on all participants with ViconBonita System (Oxford Metrics Ltd., Oxford, England). Temporo-spatial, kinematic, and kinetic variables were compared among the groups.

Results: Regarding the time-distance parameters; step distance (p=0.001) and stride length (p=0.002) were found to be greater in girls than in boys. The kinematic analysis showed that the maximum hip extension during the stance phase (H2, p=0.03) was greater in boys compared to the extension during the stance phase of the girls. The maximum hip flexion during the swing phase (H3, p=0.02), maximum hip adduction (H4, p=0.01) and maximum ankle plantar flexion (A3, p=0.04) were found to be higher in girls than in boys.

Conclusion: The gait analysis data had significant gender differences. Sport technology and biomechanics have been advancing rapidly. We suggest that normal data and biomechanical factors will be clearer as the gait analysis results of the athletes increase.

Keywords: 3-D gait analysis; gait; gender; gender recognition; gender differences

INTRODUCTION

There is an increasing body of studies that explore gait and gait differences. During gait analysis, body movements, posture and motion of muscles during gait are examined. Video camera systems and force recognition platform are used during three dimensional gait analyses. Kinetic, kinematic and force graphics are generated. Kinematic data shows that the angular changes on different planes (flexion-extension on sagittal plane, adduction-abduction on frontal plan and internal-external rotation on transverse plane) (1). The moment graphics were created with the kinetic data show the dominant muscle, while the amplitudes obtained through the power graphics show whether the muscles generate or absorb power (2-4).

Gait analysis is used not only to recognize the gait pattern but also in many areas such as medical diagnosis, rehabilitation and sport education to improve athletic performance (5-8). Through gait analysis, the compensatory modifications in the gait cycle can be detected. Moreover, gait abnormalities can be recognized and the physiological process or disease that causes the abnormal pattern can be detected. If the underlying pathology is detected accurately, energy consumption during gait can be reduced. Reduced energy consumption will result in longer distances of gait and functional independence. In the long run, the risk of secondary complications such as joint deformity, arthritis and overuse syndromes can be decreased (9).

It is generally acknowledged that there are differences in gait between female and male adults (10-14). We think that it is important to compare the gait analysis results of healthy individuals from different genders at the same age group during the assessments. There are a lot of studies in literature that analyse individuals at advanced age. However, there is a limited number of studies that analyse

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the differences between genders in the young age group. The purpose of our study was to compare the pelvis, hip, knee and ankle kinematic angles, kinetic parameters and time-distance parameters of female and male athletes aged between 5 and 18.

MATERIAL and METHODS

This retrospective study was approved by an institutional review board 13.02.2019 No: 12. Informed consent was obtained from the patients. The study was conducted as in a single centre study at our hospital, Gait Analysis Laboratory. The data was retrieved retrospectively from the computer through archive screening. The participants were divided into two groups: girls and boys. The athletes who did not have any diseases that would affect body balance and who could walk freely without sticks or mechanical assist devices were included in the study. All athletes did minimum one sportive activity at different levels 4-10 hours a week (Table 1). According to the exclusion criteria; those with a history of neurological disease, orthopaedic operation and acute /chronic pain were not included in the study. 51 female and male participants (5-18 years, mean age: 11.7) were analysed.

Table 1. Sports branch of athletes

Sports Branch	No. of athletes
Athletics	1
Ballet	2
Basketball	9
Fencing	1
Football	6
Taekwando	12
Volleyball	15
Swimming	5

Before the gait analysis, height, weight and lower limb length of each participant were measured. The gait analysis was conducted with Vicon Nexus Plug-in-GAİT (Oxford Metrics Ltd., Oxford, England) available in our laboratory. For the analysis, eight 100 Hz infrared cameras and two Bertec force platforms (Bertec Corp. Columbus, OH, USA) were used. 16 retroreflective markers were placed on certain anatomical points of the participants (modified Helen Hayes model) (Figure 1,2) (15-17).

Table 2. Variable descriptions

Kinematics	Moment variables (Nm/kg)	Power variables (W/kg)
HR1 Maximum rot. sagittal plane in stance	Hm1 Maximum hip extending moment	Hp1 First hip power generation peak
HR 2 Maximum rot. sagittal plane in swing	Hm2 Maximum hip flexing moment	Hp2 Hip power absorption
HR 3 Maximum rot. coronal plane in stance	Hm3 First hip abducting moment peak	Hp3 Second hip power generation peak
HR 4 Maximum rot. coronal plane in swing	Hm4 Second hip abducting moment peak	Kp1 First knee power absorption peak
HR 5 Maximum rot. transverse plane	Km1 First knee extending moment peak	Kp2 Knee power generation
H1 Maximum hip flexion in stance	Km2 Maximum knee flexing moment	Kp3 Second knee power absorption peak
H2 Maximum hip extension in stance	Km3 Second knee extending moment peak	Ap1 Ankle power absorption
H3 Maximum hip flexion in swing	Am1 Maximum ankle dorsiflexing moment	Ap2 Ankle power generation
H4 Maximum hip adduction	Am2 Maximum ankle plantar flexing moment	
H5 Maximum hip abduction		
H6 Maximum internal rot. in stance		
K1 Maximum knee flexion in stance		
K2 Maximum knee extension in stance		
K3 Maximum Knee flexion in swing		
K4 Maximum add. in stance phase		
A1 Ankle plantar flexion after heel contact		
A2 Maximum ankle dorsiflexion		
A3 Maximum ankle plantar flexion		

The participants were asked to walk freely, at a pace where they felt comfortable, on bare feet on the 9 m walking path that was the hidden force layer at a pace where they felt comfortable. All measurements were made by one researcher. The gait cycles when the individuals had full stance of each foot on the force platform were considered as the robust data. The participants were asked to walk repeatedly until the requirements were fulfilled. In this way, gait cycles of the right and left lower limbs were determined separately and 2-6 gait cycles were obtained.

The gait recordings were processed in Vicon Nexus version 2.8.1 (Vicon Motion Systems, Ltd., Oxford, UK). Then, kinematic and kinetic graphics were created with time-distance parameters using Polygon 4.3.3 software (Vicon Motion Systems, Ltd., Oxford, UK). This way, an average gait cycle was created for each individual and these cycles were subject to statistical analysis. Out of the time-distance variables; step width, stride length, cadence and walking speed of the participants in both groups were assessed. The kinematic and kinetic variables were selected for assessment according to the gait phases.

Figure 1. An athlete is applying markers

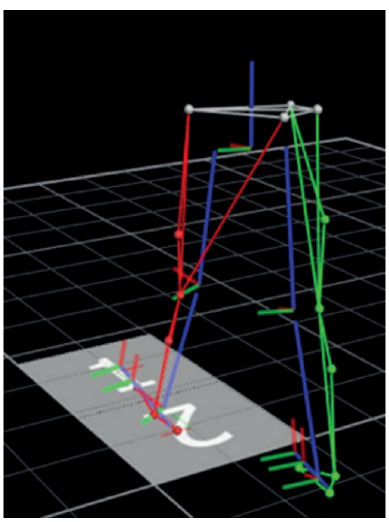

Figure 2. Display on computer screen during gait

Gait cycle is divided into 2: stance and swing phases. The duration of the stance and swing phases is the temporal measurement of the length of each phase in the gait cycle. Rancho Los Amigos (RLA) divided these phases into sub-groups according to specific functions, which have been adopted as the clinical standard. RLA divided the stance phase into 5 groups (initial contact, loading response, midstance, terminal stance, preswing) while dividing the swing phase (initial swing, midswing, terminal swing) into 3 groups. The anterior/posterior pelvic tilt, hip flexion/extension, hip abduction/adduction, knee flexion/extension, knee valgus/varus, ankle dorsi/plantar flexion values of all joints during the stance and swing phase were included in the study. The (dorsi) flexion and adduction values of the joints are positive, while the extension (plantar flexion) and abduction values are negative. 35 kinetic and kinematic variables were obtained from each participant that were (Table 2) (Figure 3).

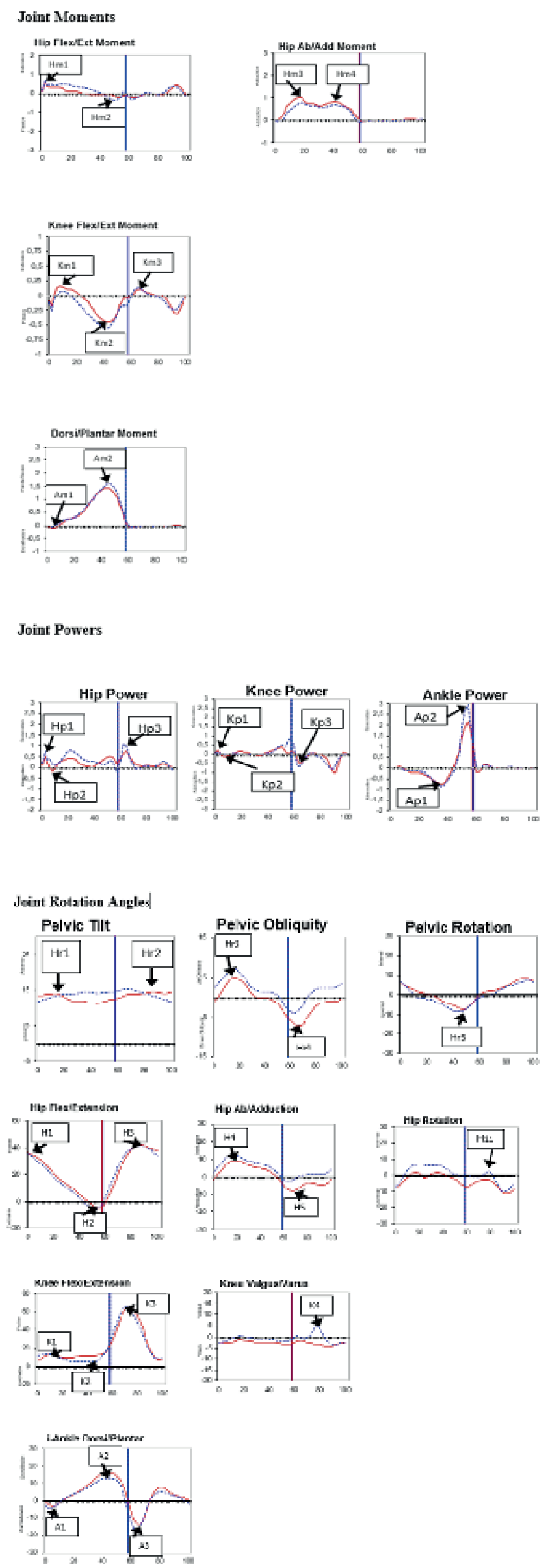

Figure 3. An example of parameter selection joint angles, moments and power on one individual's waveforms

Statistical analysis
Data were evaluated using SPSS for Windows 21.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were calculated as frequencies and percentages for categorical variables and as means, standard deviations (SDs), and medians for numerical variables. The distribution of the variables was evaluated using the Kolmogorov-Smirnov test. The differences between the groups were analysed with t test.

RESULTS

Regards to the time-distance variables, step and stride length was found to be longer in girls compared to the stride length of boys (Table 3).

Table 3. Demographics and spatio-temporal data

	Girls (n=29)	Boys (n=22)	p*
	Mean ± SD	Mean ± SD	
Age (years)	13 ± 3.7	10 ± 2.6	0.008
Height (cm)	159 ± 22.3	145 ± 15.8	0.008
Weight (Kg)	53 ± 18.3	40 ± 16.9	0.01
Stride Length (m)	1 ± 0.1	1 ± 0.09	0.002
Step Length(m)	0.57 ± 0.05	0.5 ± 0.05	0.001
Walking Speed(m/sec)	1 ± 0.14	1 ± 0.15	0.93

The results for kinematic and kinetic variables including the minimum, maximum and median values are shown in Table 4. The significant p value is p<0.05 and is indicated as bold in the table.

Pelvis: The anterior tilt angles during the stance and swing phases were found to be similar in both gender groups (HR 1 was 9.8° in girls, 7.8° in boys, HR 2 was 11.8° in girls, 10.2° in boys). The pelvic obliquity during the stance and swing phases was similar in both gender groups. Pelvic rotation angles were not different either (HR 5).

Hip: The athletes in both groups were observed to have the initial contact with similar hip extension [the maximum hip flexion angle during heel strike (H1) was 30.4° in girls and 27.3° in boys). After this phase, hip flexion decreased gradually and shifted to extension. The extensor moments that were created at that moment were observed to be similar [maximum hip extensor moment, Hm1= 0.5 Nm/kg]. Significant differences were not observed between the groups in the initial power generation on the hip (Hp1=0.3 W/kg). The net joint moment during the midstance shifted from flexion to extension in both groups [maximum hip flexor moment (Hm2) was -0.67 Nm/kg in girls and 0.78 Nm/kg in boys]. Exactly at that stage, a similar power absorption was observed (Hp2 was -0.21 W/kg in girls and -0.39 W/kg in boys). The maximum hip extension during the terminal stance (H2 was 5.7° in girls and 8.5° in boys) was greater in boys (p= 0.03). The active hip flexion during the swing phase was greater in girls compared to the boys (H3 was 35.4° in girls and 31.7° in boys with p=0.02).

Table 4. Statistical analysis of the kinetic and kinematic parameters

	Girls	Boys	p Value
	Mean ± SD	Mean ± SD	
HR 1	9.8 ± 4.4	7.8 ± 4.2	0.10
HR 2	11.8 ± 4.5	10.2 ± 4.6	0.26
HR 3	9.9 ± 4.3	8.5 ± 4.6	0.27
HR 4	11.7 ± 4.4	10.3 ± 4.6	0.24
HR 5	-4.5 ± 4.7	-5.4 ± 4.5	0.42
H1	30.4 ± 5.9	27.3 ± 6.2	0.13
H2	-5.7 ± 5	- 8.5 ± 4.5	0.03
H3	35.4 ± 5.8	31.7 ± 5.5	0.02
H4	7.3 ± 3.1	5 ± 3.06	0.01
H5	-6.6± 3.2	-6 ± 6.4	0.94
H6	1.2 ± 8.7	0.3 ± 10.7	0.82
K1	7.3 ± 5.8	6.6 ± 5.5	0.87
K2	4.9 ± 3.6	4.4 ± 4.7	0.58
K3	61.8 ± 5.3	58.7 ± 6.7	0.17
K4	0.25 ± 01	0.37 ± 0.86	0.17
A1	-3.6 ± 2.8	-3.4 ± 3.1	0.75
A2	16.3 ± 3.1	16.7 ± 3.7	0.31
A3	-12.6 ± 5.6	-9.04 ± 7.2	0.04
Hm1	0.54 ± 0.24	0.5 ± 0.25	0.76
Hm2	-0.67 ± 0.51	-0.78 ± 0.44	0.11
Hm3	0.59 ± 0.28	0.5 ± 0.24	0.09
Hm4	0.47 ± 0.23	0.43 ± 0.26	0.47
Km1	0.23 ± 0.23	0.34 ± 0.24	0.05
Km2	-0.09 ± 0.17	-0.09 ± 0.13	0.45
Km3	0.09 ± 0.1	0.11 ± 0.04	0.58
Am1	0.05 ± 0.34	-0.07 ± 0.07	0.07
Am2	1.1 ± 0.4	1.09 ± 0.2	0.20
Hp1	0.3 ± 0.37	0.3 ± 0.24	0.58
Hp2	-0.21 ± 0.47	-0.39 ± 0.39	0.10
Hp3	1 ± 0.45	0.88 ± 0.39	0.14
Kp1	0.33 ± 0.5	0.37 ± 0.4	0.46
Kp2	0.34 ± 0.47	0.31 ± 0.46	0.50
Kp3	-0.77 ± 0.37	-0.8 ± 0.53	0.81
Ap1	-0.58 ± 0.64	-0.64 ± 0.27	0.57
Ap2	2.62 ± 0.4	2.54 ± 0.43	0.50

There were no significant differences between the groups regarding the secondary power generation in the hip during the active hip flexion (Hp3). The initial hip abduction peak moments (Hm3) were found to be similar. The maximum hip adduction was found to be significantly different in girls than in boys (H4 was 7.3° in girls and de 5° in boys) (p=0.01). There were no significant differences between the groups with regard to the maximum abduction

(H5 was 6.6° in girls and and 6° in boys). The secondary hip abductor moments (Hm4) were not significantly different between the groups. The maximum internal rotation during the stance phase (H6) was similar.

Knee: The knee flexion at initial contact (maximum knee flexion during heel strike (K1)) was 7.3° in girls and 6.6° in boys with which they started walking. Following the load response, knee flexion increased slightly. At that stage, the initial power absorption in the knee (Kp1) was similar in both groups. During the load response phase, the extensor moments preventing the collapse of the knee at flexion were also found to be similar (Km1 was 0.23 Nm/kg in girls and, 0. 34 Nm/kg in boys). At the midstance phase, the knee was observed to shift to extension (K2 was 4.9° in girls and 4.4° in boys). There were no significant differences between the groups regarding the maximum knee flexor moment (Km2) and power generation of the knee (Kp2). The peak knee flexion angle during the initial swing phase (K3) was 61.8° in girls and 58.7° in boys. At the same phase, there were no statistically significant differences between the groups regarding the secondary knee extensor moment (Km3) and secondary power absorption of the knee (Kp3).

There weren't any differences in the maximum knee abduction moments, either. (K4)

Ankle: There weren't any statistically significant differences between the groups regarding the plantar flexion during the initial ankle roll (A1 was 3.6° in girls and 3.4° in boys). There were no differences regarding the maximum ankle dorsiflexor moment (Am1) and power (Ap1). No difference was found in the maximum ankle dorsiflexion (A2), plantar flexor moment (Am2) and power generation (Ap2) at the terminal stance phase. The maximum ankle plantar flexion during the preswing phase was greater in girls (A3 was 12.6° in girls and 9.04° in boys) (p= 0.04).

DISCUSSION

This is the first report on normative gait patterns of typically developed Turkish athletes. Our results are strengthening findings of specific hip, and ankle kinematic differences. People learn how to walk instinctively by testing their bodies until they find an individual way of walking starting from the early years of their lives. Despite the individual nature of this process, there is a characteristic way of walking for all people (18-20). A healthy child is expected to have a gait pattern until four years of age, whereas there may be some changes in gait due to the developing body structure in the following years (21). The lower limbs continue developing for 13.2 years in girls and 15.6 years in boys (22). It is very difficult to determine the normal gait pattern in this age group because it is highly variable during the development stage.

Gait analysis has been conducted for children since 1980s (23). Studies have shown that the kinematic angles during gait vary depending on the age of the participants. Nonetheless, there is a very low number of studies that have included healthy individuals at younger age. Unfortunately, the findings of the studies are controversial (10-14). We think that these controversies are due to the different age groups compared and the use of different analysis systems in the studies .

Moreno et al. (24) argued that race might lead to differences between genders in terms of gait parameters although there were no significant differences between children aged 6-13 years regarding the time-distance parameters. Zakaria et al. (25) found that the mean weight, height and step time were greater while cadence was lower in girls. This was associated with the fact that girls had a bigger physical structure compared to boys. Smith et al. (26) reported that there wasn't any difference between girls and boys aged 6-10 years regard to the time and distance parameters. In our study, step and stride lengths were found to be significantly higher in girls than in boys. We think that the step length was greater in girls because their mean height was higher.

During a normal gait, the knee is expected to be in full extension or flexion of 5° at the initial contact (2-4). Full extension of the knee during the initial contact is an indication that the individual can lock the knee, which shows that s/he has a stable gait pattern. In the age group in our study; the knee flexion at initial contact was 7.3° in girls and 6.6° in boys. We may suggest that a stable gait pattern still could not develop in this age group.

Zakaria et al. (27) reported that the maximum hip (H1) and knee (K1) flexion was statistically higher in boys compared to girls. Moreover, they argued that the differences in the kinematic results might be due to the physical factors affecting the groups. Boys were lighter and had a longer step time; therefore, they tended to have greater flexion. They found that hip abduction, knee abduction and ankle eversion was greater in boys while knee adduction was greater in girls. The stride length was greater in boys while it was lower in girls. They found that the hips and knees of boys were more internal. In our study, the hip flexion (H3) and adduction (H4) were significantly in girls. Moreover, girls had a greater ankle plantar flexion (A3) compared to boys. Boys, however, had a greater hip extension (H2) than that of girls. Although the hips of the female athletes in our study were in adduction, other joints did not change position. Although the boys were lighter and shorter, their hips were in extension.

In recent years, gait analysis has been frequently used for athletes. In particular, this has raised awareness about injuries that are affected by biomechanical differences. Training programs are designed to prevent injuries. The anterior cruciate ligament injuries that are the most common ones are four to six times more frequent in female athletes compared to these of male athletes (28,29). Valgus increase in the knees is greater in female athletes during descent. Hip adduction is greater in female athletes doing strength sports (for example football) compared to male athletes (30). Other studies show that the knees descend at valgus due to the hip abduction asymmetry.

Insufficient hip abduction power leads to femoral adduction, hip internal rotation and lower limb with knee valgus in female athletes (31-33). Femoral internal rotation in the hip increases starting from the beginning of loading to the load response. A wide pelvis and increased femoral are considered to be associated with the mechanism of injury among runners and athletes. Similarly, female athletes with small feet are considered to increase the plantar flexion angle to protect the knee kinematic (34). Hip flexion (H3) and adduction (H4) among the athletes in our study were markedly greater in girls. However, we did not find any differences between the gender groups regarding the power generation and absorption in these joints. We think that we can identify the etiological factors more clearly if the gait analysis is used more frequently during the assessments made before the injuries occur.

There were some limitations in our study. As the participants were assessed in the laboratory, they might pose different gait patterns and speeds compared to their daily routine gait patterns, which might have a negative impact on the objective evaluation of the results and small number of patients. The upper limb data and EMG findings were missing.

CONCLUSION

Conclusion; generally, the three dimensional gait analysis data were similar for the two genders. We think that the advancements in the gait analysis technology and its wider use in the clinical practice will help collecting objective results in evidence-based treatments. We also suggest that gait analysis will also be useful for athletes with the rapid increase in the sports technology.

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