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A Comparison of Coordination Variability of Lower Extremity Segments in Men with Genu Varum and Healthy Men during Treadmill Running at Different Speeds: A Cross-Sectional Study

Mehdi Arabkhazaeli[1], Ali Abbasi[2], Mehdi Khaleghi-Tazji[2], Amir Letafatkar[3]

Original Article

Abstract

Introduction: The purpose of this research was to compare the coordination variability of lower extremity segments in men with genu varum and healthy men during treadmill running at different speeds.

Materials and Methods: Among sports and physical education students, 15 healthy men and 15 men with genu varum voluntarily participated in this research. Each participant ran on treadmill for 60 seconds at preferred speed and 25% faster and 25% slower than preferred speed. The kinematics data of lower extremities were collected by MyoMotion motion analysis system at 200 Hz sampling frequency. Coordination calculations were done by continuous relative phase (CRP) method for three segments coupling and compared between two groups.

Results: The results of repeated measures analysis of variance (ANOVA) between groups showed that coordination patterns of segments did not differ significantly between the groups during running at different speeds ($P > 0.05$). However, the change in running speed caused significant differences in coordination and coordination variability of segments in some phases of running in two groups ($P \leq 0.05$).

Conclusion: Coordination pattern of segments during running seems the same between genu varum and healthy groups; however, significant differences in these patterns and different running speeds were evident in both groups. On the other hand, coordination variability of segments was not different between groups, but the increase in running speed reduced the coordination variability during early and late swing and mid-stance phase of running in both groups. This finding may imply higher risk of overuse injuries at these phases.

Keywords: Coordination; Coordination variability; Genu varum; Running

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Introduction

Running is one of the most important sports activities to improve and maintain physical fitness in athletes of different sports. While running, the main task of bearing body weight is performed by the lower limbs, which in a repetitive pattern is responsible for absorbing the ground reaction force (GRF) and producing driving forces (1). The pattern of absorption and production of forces is carried out by the joints of the lower limbs, which act as a chain of motion and coordinate the movement of running. Among these, the knee joint, due to its position in the middle of this chain, plays a major role in maintaining balance and transferring forces to the upper structures of the chain (1,2). Therefore, any deviation or anomaly from the normal position of this joint can cause improper transfer of forces and damage to this structure (3).

Bow legs (or genu varum) is one of the main anomalies of the knee joint that is very common among normal people, especially athletes (4). In this

1- PhD Student, Department of Biomechanics and Sports Injuries, School of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran
2- Associate Professor, Department of Biomechanics and Sports Injuries, School of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran
3- Assistant Professor, Department of Biomechanics and Sports Injuries, School of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran
Corresponding Author: Ali Abbasi, Email: abbasi@khu.ac.ir

anomaly, the internal condyles of the femur are spaced apart, which can consequently affect the ankle and pelvic joints (5). The resulting abnormality can potentially lead to a change in the biomechanics of the knee joint and alter the function of the lower limb by altering the muscle tension line and altering the function of the mechanical receptors in the joint (6). This complication seems to cause the transfer of the knee axial forces from the center of the joint to the external compartment and can be applied to the external part up to 3.5 times the axial forces of the knee (7). Previous studies have suggested that a bow leg deformity can increase the risk of osteoarthritis of the knee joint as well as secondary injuries to the patellofemoral joint (8). Other studies have reported kinematic changes such as increased knee abduction angle, ankle eversion, and increased internal rotation of the knee while walking (9-11). Previous investigations on kinematics, however, have only been performed in terms of linear biomechanics analysis considering only the function of a joint or segment. On the other hand, the amount of joint angles in the natural direction of the body differs in the two sexes (12) and the aging process can affect it due to structural (13) and biomechanical changes such as osteoarthritis (14). Therefore, in order to prevent the confounding effect of gender and age, it is better to conduct studies by gender in the young age group that is more active in sports fields.

Recently, the use of dynamic analysis methods has been emphasized in biomechanical research, by which the kinematic coordination or coupling of two or more joints and their coordination variability can be addressed simultaneously. The most important ones of these methods are continuous relative phase (CRP) analysis, vector coding, and discrete relative phase (DRP) analysis (15-20). In the CRP analysis method, using the angles and angular velocities of the segments, the relative motion of the two segments relative to each other is calculated in state space and the kinematic information of motion of the two segments relative to each other is extracted.

The coordination and control of human movement is the result of the natural dynamics of the musculoskeletal system in order to produce stable patterns and coordinated output (21,22). Coordination variability conceptually means the range of possible coordination patterns and the transfer of motion between patterns that a person shows while performing a movement. From the point of view of dynamic systems, a large reduction in variability leads to a rigid system; while its increase can create an unstable system (23,24). Various studies have examined the patterns of coordination and variability of coordination of joints and lower limb segments while running and walking with the aim of comparing running on a treadmill and ground (15,18), the effect of different running and walking speeds (17,25,26), and the effect of injury on the kinematics of running (27). However, no study was found to examine the effect of genu varum static abnormalities on coordination and lower extremity coordination variability during running. The question now is whether people with genu varum exhibit a different behavior in coordination and its variability while running compared to people with a normal knee angle. Therefore, the aim of the present study was to compare the coordination and coordination variability of the lower limb segments in men with genu varum and healthy knees while running on a treadmill at different speeds.

Materials and Methods

In this cross-sectional study, based on the call on the study, 15 healthy male volunteers and 15 male volunteers with genu varum anomalies ranging in age from 20 to 25 years were selected from among the students of the School of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran by the convenience sampling method and were purposively divided into two groups: healthy knee and genu varum. Physical education students are considered active athletes who have at least 5 training sessions per week in different sports, but are not necessarily professional athletes in a particular field. The type of sports activity was similar in all subjects and the similarity of the distribution of athletes in different fields in the two groups was not examined. The study was conducted in the period of February to March 2017 at the Sports Biomechanics Laboratory of Kharazmi University.

The subjects were selected based on the study of Abbasi et al. (15) using G*Power software (G*Power 3.1.9.7 freeware, University of Düsseldorf, Düsseldorf, Germany) at a significance level of $\alpha = 0.05$ and test power of 0.8. Based on the interview and evaluation by a physiotherapist, the healthy subjects had no lower extremity abnormalities, were in perfect musculoskeletal health, and had no history of injury in the past year. To detect genu varum, the subjects stood barefoot against the wall (with their muscles not contracted) and then the distance between the internal condyles of the two femurs at the most prominent point was measured in them by a digital caliper (Mitutoyo Corporation, Japan). The distance between the two condyles more than 3 cm was considered as genu varum (28). These subjects did not have any other abnormalities in the lower limbs and were in musculoskeletal health.

Before starting the study, the method was performed by the Institute of Sports Sciences and approved by the Research Ethics Committee (ethics code: IR.SSRI.REC.1399.995). First, all the steps of the test were explained to the subjects and all candidates, in case of willingness to participate in the test, completed the consent form and questionnaire. On the day of the test, the subjects attended the Sports Biomechanics Laboratory of Kharazmi University and after receiving explanations about the study method and getting acquainted with the information recording environment, they were evaluated. The subjects were familiar with how to run on a treadmill. Each subject ran on the treadmill at the preferred speed for 60 seconds, then 25% faster and 25% slower than their preferred speed were calculated, and they ran again for 60 seconds at each calculated speed on the treadmill. The order of running on the treadmill was the same for all subjects and the selection of the 25% lower and faster speed ratios was based on previous studies (15). Each test of running at any speed was performed only once for each subject and for data analysis, the information of ten intermediate running cycles (steps) was used for the next analysis in each test. The selection of different speeds based on the study by Abbasi et al. was aimed at determining the effect of speed on possible differences in coordination performance (15).

The test was performed for 60 seconds of running at any speed. Due to the short time, the test did not lead to fatigue in the subjects. However, to ensure that fatigue did not occur and to prevent its confounding effect on the study results, each subject rested for 5 minutes between each two running speeds. While running, lower limb kinematic information was recorded by the Myomotion Motion Analysis System (Noraxon USA. Inc.) at a sampling frequency of 200 Hz. For matching, all running tests were performed using Nike shoes that matched each subject's shoe size. In order to measure the kinematic information of the lower limb while running, the sensors of the motion analysis system were first placed on the segments of the feet, legs, thighs, and pelvis according to the manufacturer's instructions, and after calibration, the kinematic data were recorded while running. Data recorded in MATLAB software (Mathlab R2018a, MathWorks®, Natick, Massachusetts, United States) were analyzed. For analysis, the entire 100% running cycle was considered and analyzed. First, the running cycles were separated using the knee joint angle on the sagittal plane (15). The data were then filtered using a 4^{th} order Butterworth low-pass filter (LPF) with a cut-off frequency of 10 Hz, and the data for each running cycle were interpolated into 100 data.

The segments' coordination and coordinate variability were used to perform calculations. The coordination calculations were carried out using the CRP method for the segmental couplings of thigh flexion/ extension to shank flexion/extension, shank flexion/extension to shank plantar/dorsiflexion, and shank flexion/extension to shank internal/external rotation according to the laboratory global reference (absolute angles) and in accordance with previous studies (15,20,29), as previously raised in the occurrence of overuse injuries of the knee joint and introduced to investigate the risk of these injuries while running (15,23,27). The definition of movements was in accordance with the output of the system used; For example, the internal and external rotation of the leg was considered and defined as around the antero-posterior (AP) axis of the leg. The calculated number of 0 and 180 degrees in the CRP meant that the motion of the two oscillators was completely in-phase and completely anti-phase, respectively. The rest of the calculated numbers, which were between 0 and 180 degrees, were out of phase, where the two oscillators could be relatively in-phase (close to zero degrees) or relatively anti-phase (close to 180 degrees) (15,20,29). To calculate the coordination variability, the standard deviation of the CRP in each of the data in the running cycle was calculated and reported as a 100-number time series. The coordination and coordination variability data of the desired segments in all 100% of the running cycle were compared between the two groups in the three speeds. All statistical analyses were performed using Statistical Parametric Mapping (SPM) in MATLAB software. In order to compare the coordination and coordination variability of the segments, the inter-group repeated measures analysis of variance (ANOVA) test was employed at a significance level of $\alpha = 0.05$.

Results

15 healthy male volunteers and 15 male volunteers with genu varum deformities participated in the present study and passed all the steps correctly. Therefore, the participants' dropout rate was zero. The demographic information of the subjects is presented in table 1.

In studies accomplished on biomechanics of running and walking, the horizontal axis of the graphs denotes the percentage of gate or running cycles, which here represents the running cycle (from 0 to 40%: stance phase and from 40 to 100%: swing phase).

Table 1. Demographic characteristics of the participants

Variable	Healthy	Genu varum	Total	P
Number of participants	15	15	30	-
Age (year)	21.25 ± 2.46	21.83 ± 2.38	21.47 ± 2.40	0.845
Height (cm)	177.39 ± 6.78	175.83 ± 7.43	176.11 ± 7.26	0.649
Weight (kg)	75.35 ± 5.58	79.53 ± 7.62	77.43 ± 6.42	0.512
BMI (kg/m^2)	24.11 ± 2.64	23.57 ± 3.10	23.49 ± 3.86	0.743
Average training hours per week	42.14 ± 4.20	40.23 ± 3.18	41.57 ± 4.37	0.642

BMI: Body mass index
Data are reported as mean ± standard deviation (SD).

The results of the intra-group repeated measures ANOVA test by the SPM vector analysis revealed that for the couplings and the variability of the calculated couplings, there was no significant interaction between the group and the running speed (P > 0.050).

Additionally, the inter-group results did not show a significant difference in the couplings and the variability of the couplings between the two groups at different running speeds (P > 0.050) (Figures 1 to 6, sections A to C). However, the intragroup results reported differences in coordination and coordination variability between different speeds, as follows.

The thigh flexion/extension to shank flexion/extension of the foot flat phase and the initial-swing were different in three running speeds (Figure 1, sections D and E). Moreover, the shank flexion/extension to shank plantar/dorsiflexion coordination during the foot flat, late-stance, initial, and initial and late-swing phases differed in the three running speeds (Figure 2, sections D and E).

Discussion

The aim of the present study was to compare the coordination and coordination variability of lower extremity segments in people with genu varum and healthy knee while running on a treadmill at different speeds.

The findings suggested that the coordination of the desired segments did not differ between the subjects with genu varum and normal knees while running at three different speeds. The results of previous studies have reported kinematic differences including knee abduction angle, ankle eversion, knee internal rotation, and tibia internal rotation between the two groups of genu varum and normal knees while walking and running (9-11). Moreover, kinetic differences have been reported, including external adductor torques of the knee, GRF in the external direction, and external rotational torque while walking (9-11,30,31).

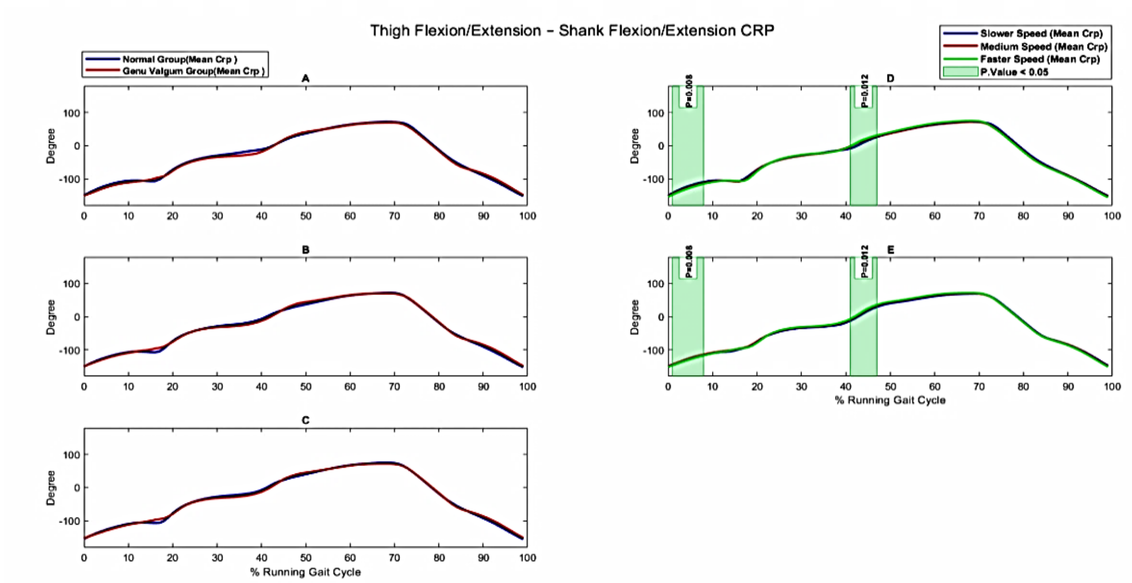

Figure 1. Results of intragroup (comparison among three running speeds) and intergroup (genu varum and normal knee group) thigh flexion/extension to shank flexion/extension coordination while running at three speeds on a treadmill in the genu varum and normal knee groups

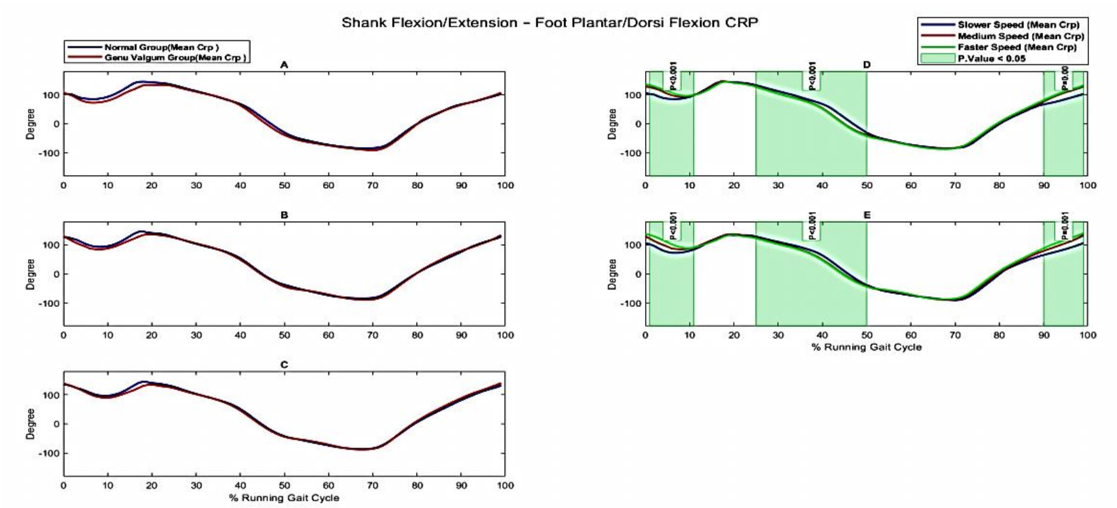

Figure 2. Results of intragroup (comparison among three running speeds) and intergroup (genu varum and normal knee group) thigh flexion/extension to shank plantar/dorsiflexion coordination while running at three speeds on a treadmill in the genu varum and normal knee groups

Although discrete comparison and linear analysis method were used in the aforementioned studies and these cases were not compared in the present study, the results of the present study were different from the results of those studies (9-11,30,31).

The lack of difference in segmental couplings between the two groups may be due to the similarity of the groups in terms of the amount of physical activity or the condition of their physical fitness or the type of exercise they perform. However, since in the present study only the coordination of the segments was examined, it is likely that the coordination of these segments on other movement planes, the coordination of other segments, or the coordination of the joints demonstrate a significant difference when running between the two groups, which needs future research in this area.

Given the results of the present study, running speed caused a significant difference in the thigh flexion/extension to shank flexion/extension coordination during the heel contact to foot flat (1 to 8% of the running cycle) and the initial-swing (41 to 47% of the running cycle) phases in both groups of genu varum and normal knee.

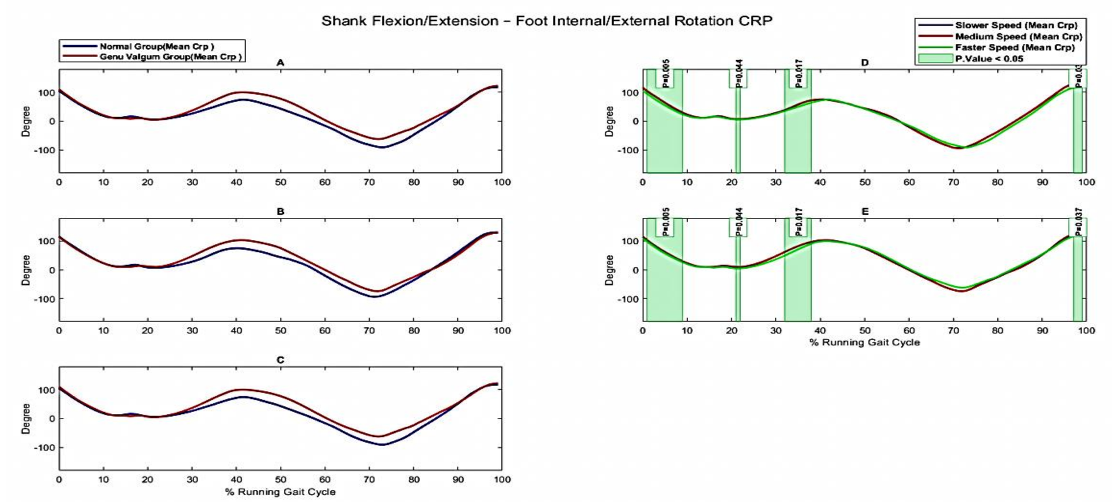

Figure 3. Results of intragroup (comparison among three running speeds) and intergroup (genu varum and normal knee group) shank flexion/extension to foot internal/external rotation coordination while running at three speeds on a treadmill in the genu varum and normal knee groups

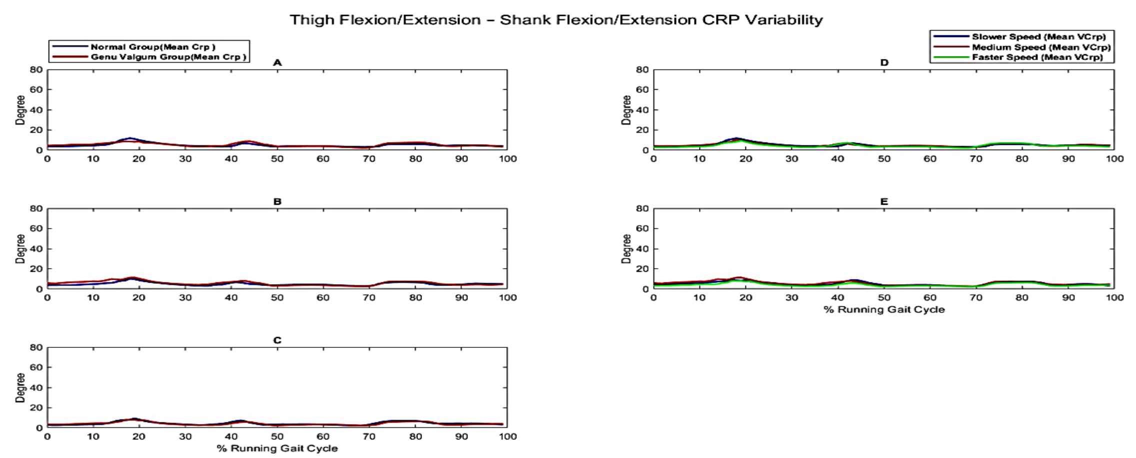

Figure 4. Results of intragroup (comparison among three running speeds) and intergroup (genu varum and normal knee group) thigh flexion/extension to shank flexion/extension coordination variability while running at three speeds on a treadmill in the genu varum and normal knee groups

Additionally, the shank flexion/extension to the foot plantar/dorsiflexion coordination pattern during the heel contact to foot flat (1 to 8% of the running cycle), late-stance and initial swing (25 to 50% of the running cycle), and late-swing (90 to 99% of the running cycle) and the shank flexion/extension to the foot internal/external rotation coordination pattern during the heel-contact to foot flat (1 to 8% of running cycle), mid-stance (21 to 23% of running cycle), late-stance (32 to 38% of running cycle), and late-swing (97 to 99% of running cycle) were different at different speeds while running, but this difference was not significant between the two groups.

The results regarding the differences in the pattern of coordination of the segments were consistent with the findings of previous studies reporting differences in the coordination pattern of the lower limb segments while running at different speeds (15,17,25,26). Given the results, it seems that more change in running speed causes a difference in the coordination pattern of the lower limb segments during the change of running phase (from stance to swing and vice versa) and this indicates the use of different segment coordination strategies during the change of phases of movement that change with the change of the running speed. These results can be used for exercise coaches as well as patient rehabilitation to design a specific exercise program by identifying the segmental coordination patterns while running at different speeds.

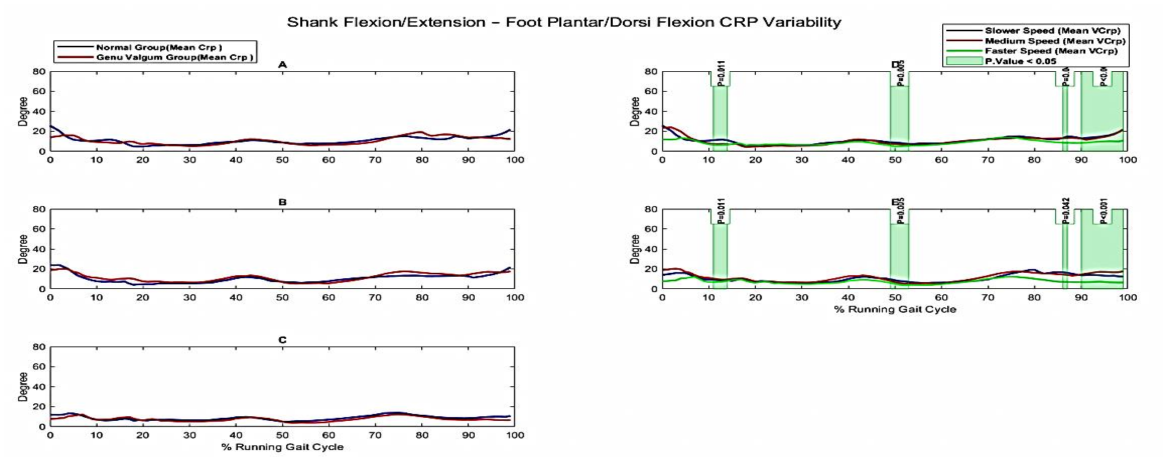

Figure 5. Results of intragroup (comparison among three running speeds) and intergroup (genu varum and normal knee group) shank flexion/extension to shank plantar/dorsiflexion coordination variability while running at three speeds on a treadmill in the genu varum and normal knee groups

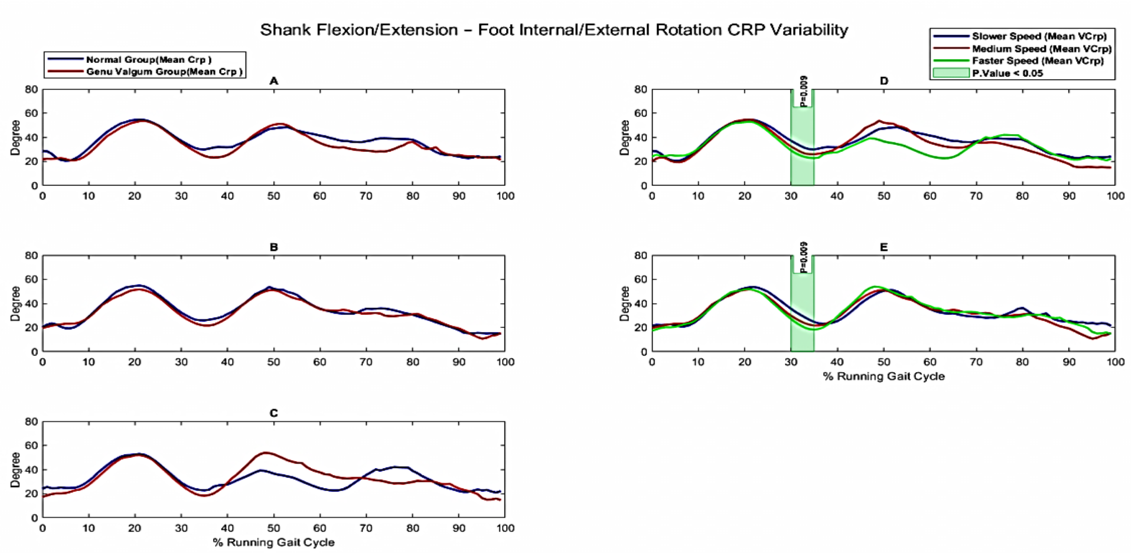

Figure 6. Results of intragroup (comparison among three running speeds) and intergroup (genu varum and normal knee group) shank flexion/extension to foot internal/external rotation coordination variability while running at three speeds on a treadmill in the genu varum and normal knee groups

The findings of the current study revealed that the coordination variability of the studied segments while running at different speeds was not different between the two groups of genu varum and normal knees. However, the coordination variability of the thigh flexion/extension to shank flexion/extension during the running phase was significantly lower (≤ 5); While in the other two cases the variability value was significantly higher. Previous studies have identified increased variability in coordination as a factor in reducing the risk of overuse injuries such as patellofemoral pain and iliotibial band (ITB) syndrome (24,27).

Therefore, it can be concluded with caution that the risk of overuse injuries to the knee joint while running is higher than the ankle joint.

Based on the results of the present study, the shank flexion/extension to the foot plantar/dorsiflexion coordination variability during mid-distance (11 to 15% of the running cycle), initial swing (49 to 52% of the running cycle), and late swing (86 to 100% of the running cycle) and the coordination variability of the shank flexion/extension to the foot internal/external rotation during the late-stance (30 to 35% of the running cycle) were different in different running speeds and this difference was not significant between the two groups. Previous studies on the coordination variability has reported different results. For example, decreased coordination variability in the lower limb segments and joints has been reported with increasing running speed on the treadmill while running (15,17,26), which reported the increased running speed as a limiting factor for degrees of freedom of movement (17). Floria et al. reported no change in the coordination variability of the lower limb joints while running at different speeds (25). However, the results of the present study, unlike previous studies, showed an increase in the segment coordination variability with a decrease in velocity. Among the reasons for the differences between the results of the present study and previous studies, we can point to different segmental and articular couplings and the method of coordination calculations and coordination variability of these studies. Due to the novelty of nonlinear dynamics calculations in human biomechanics studies, there is still no certainty about the use of different methods and that which method is better, and each method is along with advantages and disadvantages. Therefore, in studies, analysis is performed only using different methods, and each study examines a series of joint or segmental couplings, depending on the need and importance of the subject under study. Considering the possibility of reduction of the incidence of overuse injuries by increasing coordination variability (24,25), it can be concluded with caution that increasing running speed by reducing coordination variability increases the likelihood of overuse injuries of the studied segments in the mid-stance as well as the initial- and late-swing phases.

Limitations

In the present study, only the coordination and coordination variability of the three segments were examined. However, the study of the coordination pattern of other segments as well as the lower limb joints is necessary for better insight into the differences in running performance of individuals with genu varum and normal knees. On the other hand, in the present study, the CRP analysis method was employed to quantify the coordination patterns. It is possible that other methods such as vector coding and DRP analysis present different results than those of the present study that can be examined.

Recommendations

Conducting similar studies on the lower limb coordination pattern with the trunk and upper extremities while running using vector coding and DRP analysis, as well as examining female athletes can yield valuable results.

Conclusion

In general, the results of the present study revealed that the coordination pattern of the studied segments while running was not different between the two groups with genu varum and normal knees, but significant differences were observed in these patterns in different running speeds in both groups. On the other hand, the coordination variability of the segments was not different between the two groups, howevr increasing the running speed reduced the coordination variability in the initial- and late-swing and mid-distance phases in both groups, which could increase the likelihood of overuse injuries in these phases.

Acknowledgments

The present study was extracted from a PhD thesis on sports biomechanics with ethics code IR.SSRI.REC.1399.995, approved by Kharazmi University. The authors would like to appreciate all the participants in this test, as well as the Research Council, School of Physical Education and Sports Sciences, Kharazmi University.

Authors' Contribution

Mehdi Arabkhazaeli: study design and ideation, attracting financial resources for the study, study support, executive, and scientific services, providing study equipment and samples, data collection, analysis and interpretation of results, specialized statistics services, manuscript preparation, manuscript evaluation in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments; Ali Abbasi: study design and ideation, study support, executive, and scientific services, providing study equipment and samples, analysis and interpretation of results, specialized statistics services, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be sent to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments; Mehdi Khaleghi-Tazji: study design and ideation, analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be sent to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments; Amir Letafatkar: study design and ideation, analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments.

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The present study was prepared based on the analysis of a part of the information extracted from the PhD thesis in sports biomechanics with the code of ethics IR.SSRI.REC.1399.995 and without the financial support of a specific organization. Kharazmi University did not comment on the data collection, analysis, and reporting, manuscript preparation, and final approval of the article for publication.

Conflict of Interest

The authors do not have a conflict of interest. Dr. Ali Abbasi, Dr. Mehdi Khaleghi-Tazji, and Dr. Amir Letafatkar have been working as assistant professors at Kharazmi University since 2012. Mehdi Arabkhazaeli is studying as a PhD student in Sports Biomechanics at Kharazmi University.

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