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The Effect of Different Rowing Stroke Rates on Kinematics of Lower Extremity Joints Related to Overuse Injuries in Professional Teenager Rowers: A Cross-Sectional Study

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Original Article

Abstract

Introduction: The purpose of this study was to determine the effects of different rates of rowing stroke on kinematics of lower extremity joints related to overuse injuries in professional teenager rowers.

Materials and Methods: 15 elite young rowers volunteered to participate in this study. Lower extremity kinematic data were recorded during incremental rowing test on ergometer with seven Vicon cameras at a sampling rate of 200 Hz. Seven rowing cycles were selected from each stroke rate and the kinematic data were compared between different rowing stroke rates using analysis of variance (ANOVA) and statistical parametric mapping (SPM) method.

Results: Increase in rowing rate resulted in significant increase in foot plantarflexion (P = 0.048) and knee (P = 0.018) and hip (P = 0.036) extension during late drive phase. Moreover, hip and knee flexion range of motion (ROM) (P = 0.001) in all recovery phase, and foot dorsiflexion ROM (P = 0.001) in first 70% of recovery phase significantly increased with increase in rowing stroke rate.

Conclusion: Increasing rowing rate may increase knee flexion in late recovery phase and increase knee, hip, and ankle extension in late drive phase that may put the knee at the risk of injury.

Keywords: Rowing; Joint kinematics; Rowing stroke rate; Overuse injury

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Introduction

Rowing is a complex physical and technical sport that requires high endurance, high power generation, efficient technique, and high speed of movement. Rowing efficiency depends on both the development of the rower output power and the good and efficient technical skill of the athlete and is influenced by the performance characteristics of the rower such as power, stroke rate, rowing length, and progress per row (1). In closed-chain sports activities, such as rowing, in which the pattern of movements can be predicted, identifying the optimal technique through biomechanical evaluation can improve performance and reduce sports injuries (2). Therefore, the kinematic study of the rowing athlete is very important in identifying and correcting the wrong technique, which can play a role in improving performance and reducing the risk of overuse injuries (2,3).

Biomechanically, a rower must use his energy in such a way that it leads to the highest average speed of the boat during a 2000-m race (standard Olympic length). Performing the correct technique and maintaining it throughout the race track and in all rowing intensities requires movement stability in the limbs (4-6). While rowing, the contact forces between the boat and the equipment act on the legs, seats, and row. These forces are created by muscle contractions and acceleration applied by the rower. Therefore, accurate sequencing of different parts of the rower's body is important in maximizing power generation

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capacity in rowing (7).

On the other hand, given the nature of this sport, to increase the speed of movement, the athlete needs to change the rate of rowing, which requires different use of muscles and joints. This change in muscle and joint function, as well as the repetitive nature of rowing, can potentially lead to overuse injuries such as chronic low back pain (LBP), compression injuries to the ribs, shoulders, knees, and pelvis in joints of the professional rowers (8-11). Therefore, identifying the kinematic changes of the joints in different intensities of rowing tasks can provide a better view of the cause of overuse injuries in rowing athletes and can also help trainers and rehabilitators in designing athlete training programs and rehabilitation exercises following overuse injuries.

Previous studies on rowing biomechanical have examined differences in good and poor technique (12), the effect of change in kinematics during long rowing (13), kinematic changes in high intensity rowing (14), the effect of different rowing rates on spinal and pelvic coordination variability in healthy rowers with chronic LBP (15), and the effect of long-term training on movement kinematics (16). The research focused mainly on the kinematics of the spine and pelvic joints, which yielded contradictory results given the community of athletes of different ages. Given that the prevalence of knee joint overuse injuries in rowers is the second most common overuse injury after LBP (17, 9), there are very few studies that have addressed the biomechanics of the lower extremities (2,8) and studies have focused mainly on the biomechanical function of the back and spine (4,12-14,16,18-21). At the same time, adolescent athletes who are in the early stages of their professional life are more prone to overuse injuries due to technical errors and failure to follow standard training methods due to their advanced age and lack of experience. Prevention of injury to this group of athletes, while increasing the chances of continuing their activities in the adult age group and earning medals and setting valuable records, is important from the perspective of athletes' health and minimizing the risk of recurrent injuries and their serious complications that lead to early quitting of the sports field or make the need for invasive and costly interventions such as surgery inevitable. The question arises as how does a change in rowing rate affect the kinematic performance of the lower limb joints? The aim of this study was to investigate the effect of different rowing rates on the kinematics of lower limb joints associated with overuse injuries in professional rowers.

Materials and Methods

This was a cross-sectional study performed in 2020 in the laboratory of the Faculty of Physical Culture, Palacký University, Olomouc, Czech Republic.

Statistical population and sampling: In the present study, sampling was conducted using the convenience method from among juvenile rowers present in professional sailing clubs in Olomouc, Czech Republic in 2020. 15 juvenile male and female rowers participated in professional rowing clubs in Olomouc, and after explaining the purpose of the study, all 15 professional juvenile rowers participated in the study voluntarily, so sample size estimation was not performed. All participants were competitive athletes and had experience of training with a rowing ergometer (Concept II, Morrisville, USA). The present study was approved by the Ethics Committee of Palacky Olomouc University in the Czech Republic and the informed consent form was signed by the participants, their families, and their coach before the evaluation session. In the interview and review of the subjects' medical records, none of them had a history of musculoskeletal injury in the last six months or surgery on the lower and upper limbs, and they completed a medical health questionnaire before participating in the study.

Methods: On the day of the experiment, the subjects presented at the biomechanics laboratory of the university in November and December 2020. They were asked not to do strenuous exercise for at least 24 hours before the test and to eat a small meal at least 3 hours before the test. A brief report on the test method and test process was given to all individuals. A researcher-made questionnaire was used to assess the history of injury and professional exercise, to determine pre-test behaviors that might affect the outcome of the study (recent physical activity behaviors, dietary concerns, etc.). The subjects were asked to put on their own shoes and, after being placed on the ergometer, put the straps in the desired position. The ergometer monitor was adjusted to provide information about the rowing time and rate (Figure 1).

Figure 1. Status of the subject on the ergometer with motion cameras and indicators

Each subject was able to withdraw from the study at any stage. The principle of confidentiality was observed in the preservation of the collected data, especially in relation to personal characteristics. The height and weight of the subjects were measured using a gauge and digital scale (Seca, Chino, USA). In order to record healthy and error-free data, the test environment was calibrated before each test. For VICON system (VICON, UK), a space with dimensions of 2 × 1 × 4 meters was considered as data capture environment and static and dynamic three-dimensional calibration was performed using L-Form and Wand, respectively. The spatial accuracy of the system was less than 0.03 mm. 40 markers were placed on specific body landmarks based on the Plug-in Gait model (Figure 1).

Initially, a static test was taken to capture images of all markers standing in anatomical position, and then the subjects were asked to warm up for 5 minutes at the desired rowing rate, but at selected ranges. They were instructed to set the rowing rate at a level that did not cause fatigue. In addition, they could view on the ergometer monitor the start time of each attempt, the remaining time for each attempt, the start time of the rest period, and the remaining time to complete the rest period between attempts at each step separately. According to the proposed rowing program (Table 1), the individuals were asked to maintain the rowing rate as rotations per minute (RPM) predicted for each stage and were reminded to adjust the rowing rates using the ergometer display. To ensure compliance, the rowing rate and time were controlled and expressed by the test manager. The subjects continued this program until the end of the test and the kinematic data were recorded for each rowing rate for 30 seconds. They then rested for 30 seconds between the attempts.

Table 1. Rowing program

Step	Description	Rowing rate (RPM)	Warm-up
Warm-up	Warm-up	Arbitrary	5
Test	Attempt A	17-20	1
	Attempt B	20-24	1
	Attempt C	24-28	1
	Attempt D	28-36	1
Cooling-down	Cooling-down	Arbitrary	3

RPM: Rotations per minute

The protocol was based on testing the rowers in the form of incremental training intensities. The purpose of this method was to study the biomechanical and physiological parameters in different workloads to the point of exhaustion. Therefore, each researcher uses this protocol depending on the index being measured. The rowing rates reported in various attempts were selected based on the 2000-meter Olympic rowing. At each stage, the rowing rate had to be maintained within the specified range. For example, in attempt A, the athlete had to maintain a rowing rate between 17 and 20 RPM.

Data processing: After initial review of data at each rowing rate, seven cycles were selected for calculation, analysis, and evaluation. Kinematic data were filtered with a fourth-order low-pass filter and an 8 Hz cut-off frequency. After recording, storing, and filtering the information, 7 cycles of rowing were used at each rate. Given the reciprocating motion in rowing, the drive phase means the application of force to the ergometer and the recovery phase means the return of the body to its original position and the beginning of the movement. The cycles were identified by the horizontal movement of the marker placed on the right wrist and the ergometer handle on the Y (anterior-posterior) movement plane. Thus, when it had the greatest horizontal distance from the origin of motion, it was considered as the moment of the beginning of the rowing cycle and the moment when this marker was placed at the farthest point in the horizontal axis, it was considered as the end of the cycle.

Labeling the markers and eliminating the interval between their recording paths were performed in Nexus software (Nexus 2.8.1, Vicon, United Kingdom). All data processing actions were carried out in the Nexus software environment. Marker information was used to derive the angular position of the thighs, legs, and feet while rowing on the ergometer (calculated in the software). The angular position and range of motion (ROM) of the lower limb joints were obtained directly from the initial information of the Vicon device. For each rowing rate, the mean ROM of each 7 cycles for each joint was taken separately on both sides of the body and used as a representative of changes of the ROM of the desired joint for that effort. The data of each rowing cycle was separated and normalized to 100 datapoints, with the first 50% showing the drive phase and the second 50% showing the recovery phase.

Mean and standard deviation (SD) were calculated for all descriptive characteristics of the subjects and the Shapiro-Wilk test was utilized to check the normal distribution of the subjects' demographic data in SPSS software (version 22, IBM Corporation, Armonk, NY, USA). Examining the amount of angular changes in each joint at each rowing rate and selecting the desired cycles were performed in MATLAB software (Mathlab R2018a, MathWorks®, Natick, Massachusetts, United States).

Table 2. Demographic characteristics of the participants

Variable	Total	Girl	Boy	P
Number of participants	15	7	8	-
Age (years)	13.83 ± 1.19	13.42 ± 1.58	13.90 ± 1.43	0.942
Height (cm)	172.43 ± 8.04	171.88 ± 5.43	175.21 ± 7.78	0.860
Weight (kg)	68.34 ± 13.07	59.41 ± 10.73	69.15 ± 11.75	0.325
Rowing experience (years)	4.04 ± 0.89	4.75 ± 2.63	5.55 ± 2.72	0.438

Data are reported as mean ± standard deviation (SD).

The repeated measures analysis of variance (ANOVA) test was employed to determine the difference in kinematic characteristics of each lower limb in the four attempts during one rowing cycle. All statistical methods were performed using Statistical Parametric Mapping (SPM) statistical package in MATLAB software.

Results

The total number of members of the Czech Republic National Youth Rowing Team was 15, all of whom entered the study and passed all the steps correctly. Therefore, the dropout rate of the participants in the present study was zero. The demographic information of the subjects is presented in table 2.

The amount of plantar flexion of both ankles at the end of the drive phase and the amount of dorsiflexion of the ankle in the recovery phase increased significantly with increasing speed (P = 0.001) (Figure 2).

The amount of knee extension at the end of the drive phase and knee flexion in the recovery phase increased significantly with increasing speed (P = 0.001) and at the beginning of the drive phase, the acceleration increased the left knee flexion (P = 0.018). (Figure 3). In professional subjects, with increasing speed, the ROM of the hip extension at the end of the drive phase (P = 0.036) and the ROM of hip flexion of both left and right legs in the recovery phase (P = 0.001) increased significantly (Figure 4).

Discussion

The aim of this study was to investigate the effect of different rowing rates on the ROM of the lower limb in adolescent professional rowers. The findings suggested that with increasing the rowing rate, the ankle plantar flexion ROM, knee extension, and hip extension increased at the end of the drive phase. Perhaps this change in the ROM of the joints was in response to the demand for more force generation by the muscles of the lower limbs to create more force to progress more rapidly (14). Although in the present study the forces exerted on the joints or produced by the muscles were not measured, it is possible that based on the velocity-muscle force rule, increasing the ROM of the joints at higher speeds reduces the amount of force produced by muscles and rowing athletes compensate for this decrease in force by increasing the rowing rate (14,22,23). Increasing the ROM at the end of the drive phase can cause more tensile and compressive forces to be applied to the joints of the lower limbs at this time, and since in this phase the ankle and knee joints are in their closed pack position, repetitive forces in this phase at higher speeds can increase the risk of overuse injuries in these two joints.

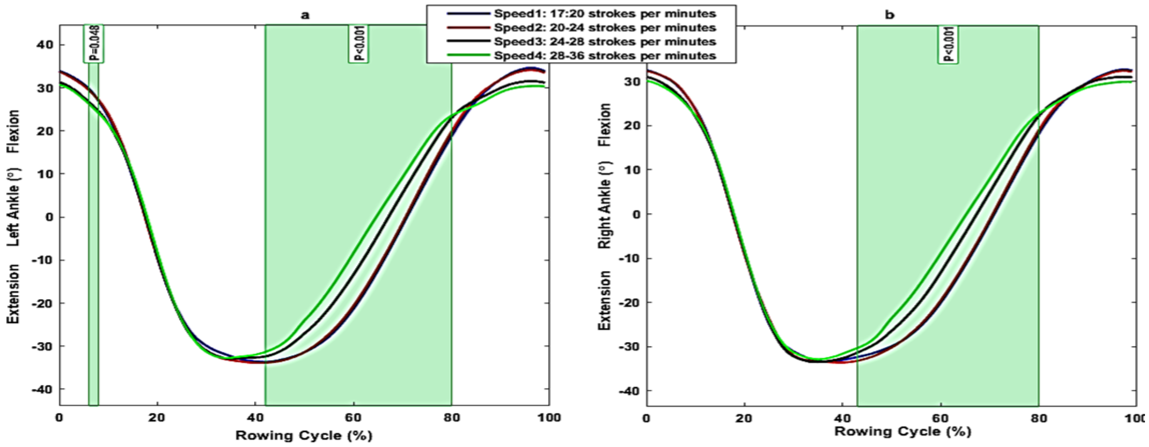

Figure 2. Analysis of variance (ANOVA) test results for left ankle (a) and right ankle (b) joint angular changes at four speeds while rowing

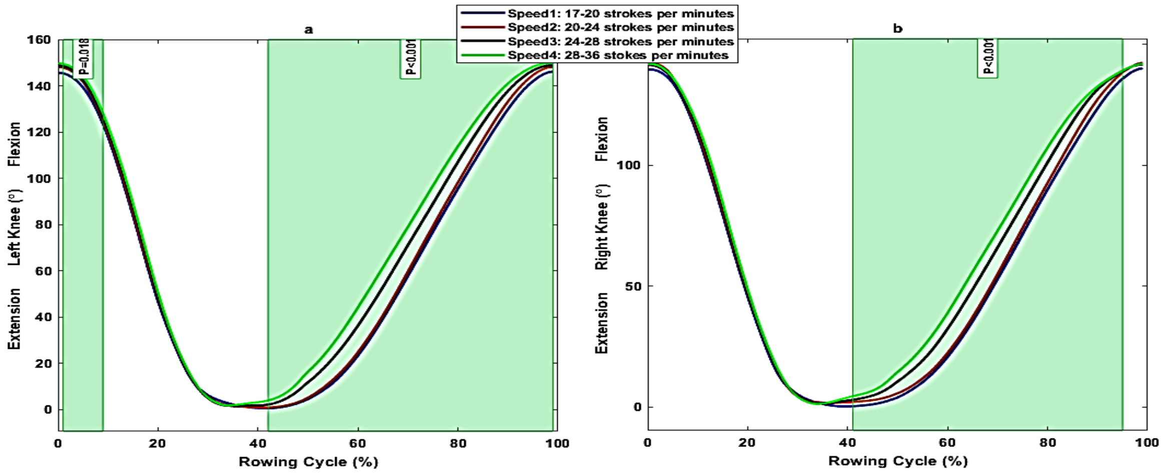

Figure 3. Analysis of variance (ANOVA) test results for angular variation in left knee joint (a) and right knee (b) at four speeds while rowing

Contrary to the results of the present study, in the study by Buckeridge et al., a decrease in foot kinematics was observed in many 20- to 24-year-old rowers who were unable to maintain or even achieve foot extension at the end of the drive phase (8). They considered this finding due to numerous factors such as instability in the trunk and pelvis or inflexibility in the hamstring muscle group (8) and perhaps the difference between the above-mentioned findings and those of the present study can be attributed to the difference in age range of athletes in the two studies. The angles of the knee in the sagittal plane on the ergometer and in water are said to be similar in different rhythms and rowing rates (24). However, a study found that knee and thigh angles vary with different types of ergometers (25). Previous studies have used the linear analysis method to compare the angles of the lower limbs (8,14,22-25) in which the maximum ROM was considered; while in the present study, using SPM statistical method, the total kinematic data of the joints in all phases of rowing movement were compared with each other.

The results of the present study indicated that increasing the rowing rate more affected the ROM of the lower limb joints in the recovery phase; So that the amplitude of hip and knee flexion and dorsiflexion of the ankle increased more at higher rowing rates in the recovery phase.

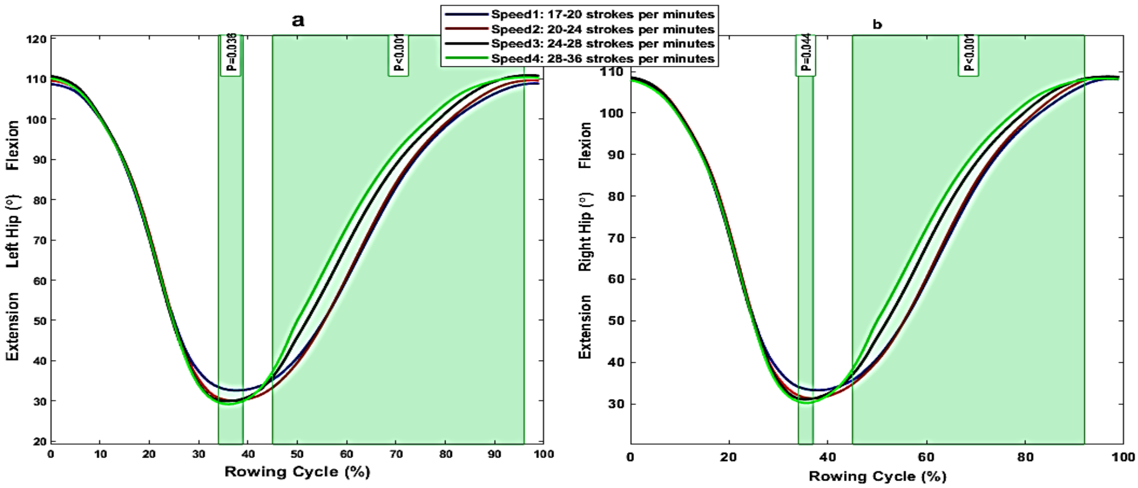

Figure 4. Analysis of variance (ANOVA) test results for angular variations in left hip (a) and right thigh (b) at four speeds while rowing

In fact, dorsiflexion of the ankle initially followed this rule until the middle of the recovery phase, and the difference was statistically significant, but the knee and hip flexion was statistically different throughout the recovery phase except for the end. In the recovery phase, the joints are actively flexed to prepare the athlete for the next drive phase. Increasing the amount of hip and knee flexion at higher speeds in rowing athletes can indicate the preparation of muscles and joints to apply more force in the next drive phase. In other words, the stretches created in the higher ROM at higher speeds may make the spindles more active so that the athlete is able to produce more force by his extensor muscles during the drive phase (14). However, increasing the ROM of knee flexion at the end of the recovery phase at higher rowing speeds can exert a large load at full knee flexion on this joint, and this factor in high repetitions can predispose the joint to overuse injuries (2,10,11,23). In the present study, these results were observed only using joint kinematics. However, using kinetic tools and comparing the amount of torque and load on the lower limb joints, especially the knee joint at different rowing intensities, future studies can show a better understanding of the biomechanical performance of the joints and the potential for overuse injuries in these athletes.

There are two intervals in the recovery phase where differences in lower limb angles occur at different rowing rates; In the first interval, at the beginning of the recovery phase, the hands, arms, and shoulders gently follow the row handle with extension, and then the pelvis and trunk move forward with hip flexion. In the second interval, the trunk and pelvis rotate continuously over the hip joint, and the hamstring and gluteal muscles are stretched. The knee is gradually raised and the boat seat accelerates forward, and the rower moves forward in a controlled and gentle manner given the rowing rate (8). On the basis of the results of the present study, in order to control the rowing rate at low speeds, the athlete needs to control the ROM of his joints to complete the recovery phase with restriction and more slowly and adjust the rowing rate correctly. However, as the rowing speed and thus the rowing rate increase, the less control the athlete has over the speed of the recovery phase, and as a result, the joints create the desired ROM with less restraint, and as the speed increases, the ROM increases (14). On the other hand, with increasing the rowing rate, pressure and demand on soft tissues seem to increase (21). Due to the constant different rates in the present study, in each rowing rate, the athletes were required to overcome a constant intensity. Therefore, it is assumed that in the drive phase they used the same muscle group and ROM to generate force, but to control the rowing speed in the recovery phase, they increased the ROM of their joints with the speed increase to control pressure and distribute pressure over more tissues. Therefore, based on the present results, it can be concluded that the change in rowing speed leads to kinematic changes in the recovery phase and it is likely that the change in rowing rate can change the kinematics of the lower limb in the drive phase.

Limitations

In the present study, because the number of juvenile rowing athletes in the national team camp was 15 boys and girls, all of them were selected and evaluated as subjects, and these results can only be generalized to juvenile professional rowers. In addition, due to the small number of professional male and female subjects in the present study, gender may be involved in the results and different results may be obtained if kinematic variability is examined in only one group of girls or boys. In the present study, the kinematics of the joints was investigated only in the sagittal plate; While the kinematic changes of these joints in the frontal and horizontal planes can provide a better understanding of the biomechanical changes in these joints at different rowing speeds. On the other hand, in the present study, the kinematics of each joint was examined separately and compared at different rowing rates; While performing kinematic analyses using nonlinear dynamic analysis methods such as vector coding and continuous relative phase (CRP) analysis, considering coupling and joint coordination can provide a better understanding of the performance of lower limb joints at different rowing speeds.

Recommendations

Given the results of the present study, most of the kinematic changes occurred at the end of the drive phase and during the rowing recovery phase. Therefore, rowing coaches and athletes are recommended to pay attention to the control of joint movement at the end of the ROM at higher rowing speeds so as not to increase the overuse pressure on the joints, especially the knee joint.

Conclusion

The knee will go into full extension and full flexion at the end of the drive phase and at the end of the recovery phase, which increases with increasing rowing speed and, thus increasing the probability of injury at these moments. In other words, given the results, it can be concluded that with increasing rowing rate, the amount of knee flexion at the end of the recovery phase and the amount of knee, thigh, and ankle extensions at the end of the drive phase may increase, which may put the knee joint at risk and paying attention to this issue during training is very important to follow the athlete's injury.

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Authors' Contribution

Faezeh Pakravan: study design and ideation, study support, executive, and scientific services, providing study equipment and samples, data collection, analysis and interpretation of results, specialized statistics services, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, final approval of the manuscript to be submitted to the journal office, responsibility to maintain the integrity of the study process from the beginning to the 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 the manuscript in terms of scientific concepts, final approval of the manuscript to be submitted to the journal office, responsibility to maintain the integrity of the study process from the beginning to the publication, and responding to the referees' comments; Zdenek Svoboda: study design and ideation, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, final approval of the manuscript to be submitted to the journal office, responsibility to maintain the integrity of the study process from the beginning to the 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, final approval of the manuscript to be submitted to the journal office, responsibility to maintain the integrity of the study process from the beginning to the publication, and responding to the referees' comments.

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Conflict of Interest

The authors do not have a conflict of interest. Dr. Ali Abbasi and Dr. Mehdi Khaleghi-Tazji have been working as assistant professors at Kharazmi University, Tehran, Iran, since 2012. Faezeh Pakravan is a PhD student in Sports Biomechanics at Kharazmi University and Dr. Zdenek Svoboda is an Associate Professor, Faculty of Physical Culture, Palacký University, Olomouc, Czech Republic.

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