Association between hip and knee muscle torque and running kinematics in runners and non-runners

Asociación del torque muscular de cadera y rodilla con la cinemática de carrera en corredores y no corredores

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Abstract

Introduction: Running kinematics and lower-limb muscle performance are potentially modifiable factors; however, their relationship in asymptomatic individuals remains unclear.
Objective: To examine the associations between range of motion in the early stance of running and hip and knee muscle strength in runners and non-runners.
Methodology: Twenty-nine asymptomatic adults (17 runners and 12 non-runners) underwent two-dimensional kinematic analysis of treadmill running at a self-selected speed and isokinetic assessment of the hip and knee muscles. Trunk, pelvis, hip, knee, and ankle ranges of motion between initial foot contact and peak knee flexion during stance were analyzed in the sagittal and frontal planes. Muscle strength was expressed as peak torque normalized to body mass. Associations were examined using Pearson correlations, controlling for running speed.
Results: The results revealed group-specific associations. In the total sample, only hip internal rotator peak torque was associated with ipsilateral trunk inclination. In non-runners, eccentric peak torque of the knee flexors was associated with ankle dorsiflexion. In runners, higher hip and knee peak torque values were associated with smaller trunk and knee ranges of motion in the sagittal plane.
Discussion: The heterogeneous associations observed suggest that isolated muscle strength does not uniformly explain running kinematics and that these relationships may vary according to running experience.
Conclusions: The relationship between muscle performance and running kinematics is specific and influenced by running experience.

Keywords

Biomechanics; kinematics; muscle torque; running.

Resumen

Introducción: La cinemática de la carrera y el rendimiento muscular de los miembros inferiores son factores potencialmente modificables; sin embargo, su relación en individuos asintomáticos aún no está clara.
Objetivo: Examinar las asociaciones entre el rango de movimiento durante la fase inicial de apoyo de la carrera y la fuerza muscular de la cadera y la rodilla en corredores y no corredores.
Metodología: Veintinueve adultos asintomáticos (17 corredores y 12 no corredores) se sometieron a un análisis cinemático bidimensional de la carrera en cinta a una velocidad autoseleccionada y a una evaluación isocinética de los músculos de la cadera y la rodilla. Se analizaron los rangos de movimiento del tronco, la pelvis, la cadera, la rodilla y el tobillo entre el contacto inicial del pie y la flexión máxima de la rodilla durante la fase de apoyo, en los planos sagital y frontal. La fuerza muscular se expresó como torque máximo normalizado a la masa corporal. Las asociaciones se examinaron mediante correlaciones de Pearson, controlando la velocidad de carrera.
Resultados: Los resultados revelaron asociaciones específicas según el grupo. En la muestra total, solo el torque máximo de los rotadores internos de la cadera se asoció con la inclinación ipsilateral del tronco. En los no corredores, el torque máximo excéntrico de los flexores de la rodilla se asoció con la dorsiflexión del tobillo. En los corredores, valores más altos de torque máximo de la cadera y la rodilla se asociaron con menores rangos de movimiento del tronco y la rodilla en el plano sagital.
Discusión: Las asociaciones heterogéneas observadas sugieren que la fuerza muscular aislada no explica de manera uniforme la cinemática de la carrera y que estas relaciones pueden variar según la experiencia en carrera.
Conclusiones: La relación entre el rendimiento muscular y la cinemática de la carrera es específica y está influenciada por la experiencia en carrera.

Palabras clave

Biomecánica; carrera; cinemática; torque muscular.

Introduction

Estimates of injury incidence among runners are high, ranging from approximately 19% to 79%, depending on the population and study design (Hino et al., 2009; Mucha et al., 2017; Taunton et al., 2002; Van Gent et al., 2007; Videbæk et al., 2015). The etiology of these injuries is multifactorial, involving training-related factors, individual characteristics, and biomechanical aspects of movement (Buist et al., 2010; Correia et al., 2024; Hein et al., 2014; Mousavi et al., 2019). Among biomechanical factors, both running kinematics and lower-limb neuromuscular capacity have received considerable attention because they are potentially modifiable through training and rehabilitation. In this context, alterations in running kinematics and lower-limb muscle performance have frequently been identified as potential factors associated with running-related injuries.

Studies conducted in symptomatic populations indicate that individuals with patellofemoral pain syndrome or iliotibial band syndrome exhibit distinct kinematic patterns during running, such as increased hip internal rotation, knee adduction, and trunk inclination, often associated with deficits in hip muscle performance (Noehren et al., 2014; Souza & Powers, 2009). These findings support the hypothesis that muscle capacity may influence movement control during running.

However, in asymptomatic individuals, evidence supporting a direct association between muscle performance and running kinematics remains inconclusive. Recent evidence syntheses have highlighted inconsistent associations between musculoskeletal and biomechanical factors and running-related outcomes (Correia et al., 2024). Similarly, systematic reviews investigating the relationship between hip muscle strength and lower-limb kinematics have also failed to demonstrate consistent associations (Cashman, 2012; Dix et al., 2019). While some studies have observed associations between reduced hip abductor strength and greater knee range of motion in the frontal plane (Heinert et al., 2008), others have not identified significant associations in asymptomatic runners (Brund et al., 2018). These conflicting findings suggest that isolated measures of muscle performance may not fully explain running kinematics in asymptomatic individuals.

Isolated measures of muscle performance represent only one component of the neuromuscular demands of running, a task that depends on intersegmental coordination, motor control, and the regulation of lower-limb stiffness. Consequently, individuals with similar muscle performance may adopt different movement strategies during running. Furthermore, repeated running exposure promotes neuromuscular adaptations that may influence how muscular capacity is translated into movement. Supporting this concept, Schmitz et al. (2014) reported differences in running kinematics between runners and physically active non-runners. Therefore, running experience may partly explain the inconsistent associations previously reported between muscle performance and running kinematics.

Understanding whether these associations differ according to running experience may help explain the inconsistent findings reported in previous studies and improve the interpretation of movement-related adaptations during running. Given the scarcity of studies simultaneously investigating early stance running kinematics and muscle performance in asymptomatic runners and non-runners, the aim of this study was to examine the associations between range of motion in the early stance of running and hip and knee muscle strength in runners and non-runners. It was hypothesized that the associations between muscle strength and running kinematics would be specific and dependent on the group analyzed.

Method

Participants

Two groups participated in this cross-sectional study: runners and non-runners. The runner group included 17 individuals (10 men and seven women; age: 29.24 ± 4.73 years; body mass: 63.35 ± 7.34 kg; height: 1.69 ± 0.07 m) who met the following criteria: age between 18 and 35 years; weekly running volume ≥ 15 km over the previous 12 months; and absence of running-related injury in the last 12 months, defined as any condition that prevented participation in at least one training session (Buist et al., 2010).

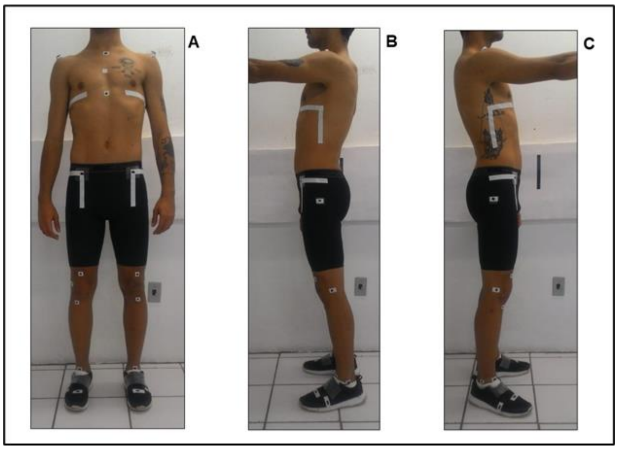
The non-runner group consisted of 12 individuals (six men and six women; age: 26.17 ± 4.23 years; body mass: 71.06 ± 12.28 kg; height: 1.72 ± 0.11 m), aged between 18 and 35 years, with no participation in structured running training in the previous two years, a score between zero and three on the Tegner Activity Level Scale (Briggs et al., 2009; Ventura et al., 2010) and no injury in the last 12 months, defined as a condition that prevented the performance of activities of daily living for at least one day.

Participants were excluded if they reported pain during data collection, had a history of lower-limb surgery in the previous two years, or had any medical condition (cardiac, pulmonary, or neurological) that limited participation. The study was approved by the Human Research Ethics Committee of the Universidade do Estado de Santa Catarina – CEPSH (CAAE: 87478418.5.0000.0118; approval no. 2,670,942/2018). All participants were informed about the data collection procedures, as well as the potential risks and benefits. All participants provided written informed consent, as well as consent for photo, video, and audio recording.

Running assessment

Running kinematics were assessed using two-dimensional analysis in the sagittal and frontal planes during treadmill running on a motorized treadmill (Super ATL, Inbramed, Brazil). Markers made with adhesive tape were placed on anatomical landmarks previously described in the literature, including the lower limbs, pelvis, and trunk (Figure 1). To improve the identification of potentially obscured landmarks, 15-cm reference projections were marked on the anterior superior iliac spine and the xiphoid process.

Figure 1. (A) Marker placement in the frontal plane. (B) Marker placement in the sagittal plane (left side). (C) Marker placement in the sagittal plane (right side).



Source: Authors.

Participants performed a six-minute warm-up, during which the self-selected running speed was determined using an incremental protocol (Van Oeveren et al., 2017). The initial speed was set at 6 km/h for non-runners and 7 km/h for runners, with increments of 0.5 km/h every 20 seconds until participants reported being able to maintain running for at least 10 minutes with a rating of perceived exertion between 12 and 14 on the Borg scale (1982).

After the warm-up, running was recorded for two minutes using a digital camera (CASIO EX-FH20, Japan) operating at 210 Hz. The recordings were analyzed using Kinovea software (version 0.8.15), and the instants of initial foot contact and maximum knee flexion during the stance phase were identified. The angular difference between these instants was used to calculate the ranges of motion (ROM) of the trunk, hip, knee, ankle, and pelvis in the sagittal and frontal planes.

Four consecutive strides of the dominant limb were analyzed during the middle third of the trial. This number was defined based on a prior repeatability analysis, in which six of the seven variables demonstrated high reliability (ICC = 0.83–0.95), except for the ankle in the sagittal plane (ICC = 0.70). The mean value of the four strides was used for statistical analysis. Limb dominance was defined as the limb used to kick a ball as far as possible (Belhaj et al., 2016; De Baldon et al., 2013; Hollman et al., 2012).

Isokinetic assessment

Hip and knee muscle strength was assessed using an isokinetic dynamometer (Biodex System 4 Pro, Biodex Medical Systems Inc., USA). Hip abduction/adduction and internal/external rotation, as well as knee flexion/extension, were tested. Hip musculature was assessed in the concentric mode at 30°/s, while knee musculature was assessed at 60°/s in both concentric and eccentric modes.

The order of testing was randomized in blocks, considering body position and the limb tested. Participants performed a protocol consisting of warm-up (five submaximal repetitions), familiarization (three sets of three repetitions with progressively increasing intensity), and assessment (five maximal repetitions), with standardized verbal encouragement. Rest intervals of 30 seconds were provided between sets and one minute before the assessment phase.

Data were acquired at 100 Hz, exported in .txt format, and analyzed using a custom routine in Matlab (R2018b, MathWorks Inc., USA). Signals were filtered using a second-order Butterworth low-pass filter (10 Hz). Peak torque of the dominant limb was extracted from the five maximal repetitions, normalized to body mass ($N \cdot m \cdot kg^{-1}$), and used for statistical analysis.

Statistical analysis

Data were analyzed using descriptive statistics (mean and standard deviation). Normality was assessed using the Shapiro–Wilk test before inferential analyses. Associations between peak torque and running range of motion were examined using partial Pearson correlation analyses, controlling for running speed. Since the assumptions of normality were met, partial Pearson correlation coefficients were calculated for the total sample and separately for runners and non-runners. Correlation magnitudes were interpreted according to Cohen's criteria (1988), and statistical significance was set at $p < 0.05$. All analyses were performed using SPSS software (IBM Corp., Armonk, NY, USA).

Results

The means and standard deviations of trunk, pelvis, hip, knee, and ankle ranges of motion between initial foot contact and maximum knee flexion during running are presented in Table 1.

Table 1. Mean (standard deviation) of the range of motion of the joints and segments of interest for the participants included in the study.

Range of Motion (degrees)	Total (n=29)	Runners (n=17)	Non-runners (n=12)
Sagittal Plane			
Trunk (+ flexion)	6,25 (5,78)	6,93 (6,6)	5,29 (4,36)
Knee (+ flexion)	25,80 (7,31)	24,35 (8,0)	27,87 (5,82)
Ankle (+ dorsiflexion)	11,67 (5,30)	11,72 (5,30)	11,60 (5,52)
Frontal Plane			
Knee (+ abduction/valgus)	-0,76 (2,93)	-0,99 (3,24)	-0,43 (2,53)
Hip (+ adduction)	3,84 (2,75)	3,56 (2,63)	4,24 (2,98)
Pelvis (+ contralateral drop)	2,55 (2,33)	2,83 (2,36)	2,16 (2,34)
Trunk (+ ipsilateral lean)	-0,70 (2,23)	-0,99 (1,89)	-0,29 (2,67)

In the total sample, a moderate positive correlation was observed between the trunk range of motion in the frontal plane and hip internal rotator peak torque ($r = 0.38$; $p = 0.04$), indicating that higher hip internal rotator peak torque values were correlated with greater ipsilateral trunk inclination during running. No other significant correlations were identified between hip or knee muscle peak torque and the analyzed ranges of motion in the total sample (Table 2).

Table 2. Correlation between peak torque and range of motion for the total sample of participants included in the study (n = 29).

Peak Torque	Sagittal Plane						Frontal Plane							
	Trunk		Knee		Ankle		Trunk		Pelvis		Hip		Knee	
	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value
Hip														
Abductors	-0,24	0,20	0,02	0,91	0,08	0,66	0,34	0,07	-0,24	0,20	-0,07	0,71	0,22	0,26
Adductors	-0,13	0,49	0,12	0,51	-0,03	0,87	0,09	0,63	-0,25	0,18	-0,14	0,46	0,12	0,52
Internal Rotators	-0,28	0,14	0,16	0,41	-0,21	0,26	0,38	0,04	-0,09	0,64	0,007	0,97	0,05	0,79
External Rotators	-0,36	0,06	-0,009	0,96	-0,15	0,42	0,32	0,08	-0,07	0,70	-0,05	0,80	0,16	0,40
Knee														
Extensors (concentric mode)	-0,25	0,19	-0,26	0,18	0,04	0,82	0,06	0,73	-0,17	0,37	-0,03	0,86	0,29	0,13
Flexors (concentric mode)	-0,28	0,24	-0,21	0,26	-0,07	0,70	-0,06	0,73	-0,22	0,25	-0,10	0,59	0,26	0,18
Extensors (eccentric mode)	-0,32	0,09	-0,009	0,96	-0,14	0,45	0,30	0,11	-0,16	0,39	-0,27	0,16	-0,16	0,41
Flexors (eccentric mode)	-0,22	0,24	-0,21	0,27	0,06	0,73	0,25	0,19	-0,35	0,06	-0,25	0,19	0,15	0,43

In the non-runner group, eccentric peak torque of the knee flexors showed a strong positive correlation with ankle dorsiflexion range of motion (r = 0.61; p = 0.04), indicating that higher eccentric knee flexor torque values were correlated with greater ankle dorsiflexion during running. No other significant correlations were observed in this group (Table 3).

Table 3. Correlation between peak torque and range of motion for the participants included in the non-runner group (n = 12).

Peak Torque	Sagittal Plane						Frontal Plane							
	Trunk		Knee		Ankle		Trunk		Pelvis		Hip		Knee	
	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value
Hip														
Abductors	-0,51	0,10	0,004	0,99	0,31	0,35	0,24	0,47	-0,45	0,15	-0,31	0,35	-0,08	0,81
Adductors	-0,11	0,73	0,53	0,09	0,24	0,47	0,03	0,91	-0,49	0,11	-0,44	0,16	-0,05	0,87
Internal Rotators	-0,44	0,17	0,10	0,76	-0,03	0,92	0,22	0,50	-0,34	0,29	-0,40	0,21	-0,36	0,27
External Rotators	-0,38	0,24	0,09	0,78	0,13	0,70	-0,09	0,78	-0,48	0,13	-0,56	0,07	-0,20	0,53
Knee														
Extensors (concentric mode)	-0,11	0,73	-0,26	0,43	-0,21	0,52	-0,26	0,43	-0,43	0,18	-0,25	0,44	0,27	0,40
Flexors (concentric mode)	-0,05	0,88	0,11	0,73	0,01	0,96	-0,35	0,28	-0,25	0,45	-0,19	0,56	0,09	0,78
Extensors (eccentric mode)	0,32	0,33	0,42	0,19	-0,08	0,80	-0,02	0,93	-0,47	0,13	-0,47	0,13	0,14	0,66
Flexors (eccentric mode)	-0,37	0,25	0,30	0,37	0,61	0,04	0,02	0,94	-0,49	0,12	-0,48	0,13	0,07	0,83

In the runner group, negative correlations were observed between trunk flexion range of motion in the sagittal plane and peak torque of the hip external rotators, eccentric knee extensors, and concentric knee flexors, indicating that higher peak torque values were correlated with smaller trunk flexion during running.

In addition, negative correlations were identified between knee flexor peak torque, in both concentric and eccentric modes, and knee flexion range of motion in the sagittal plane, indicating that higher knee flexor torque values were correlated with smaller knee flexion during running.

In the runner group, significant correlations were identified between hip abductor peak torque and knee kinematics in the frontal plane (Table 4).

Table 4. Correlation between peak torque and range of motion for participants included in the runner group (n = 17).

Peak Torque	Sagittal Plane						Frontal Plane							
	Trunk		Knee		Ankle		Trunk		Pelvis		Hip		Knee	
	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value
Hip														
Abductors	-0,29	0,26	-0,28	0,28	-0,01	0,96	-0,04	0,86	-0,26	0,32	0,02	0,93	0,53	0,03
Adductors	-0,17	0,51	-0,14	0,60	-0,19	0,46	-0,14	0,60	-0,15	0,54	-0,002	0,99	0,22	0,41
Internal Rotators	-0,22	0,39	0,08	0,77	-0,37	0,15	0,32	0,22	0,04	0,85	0,24	0,35	0,28	0,28
External Rotators	-0,59	0,02	-0,28	0,29	-0,28	0,29	0,26	0,31	0,05	0,84	0,20	0,45	0,34	0,19
Knee														

Extensors (concentric mode)	-0,47	0,07	-0,46	0,07	0,35	0,27	0,03	0,99	-0,07	0,78	0,08	0,76	0,29	0,26
Flexors (concentric mode)	-0,56	0,02	-0,57	0,02	-0,06	0,82	0,06	0,81	-0,31	0,24	-0,52	0,84	0,37	0,15
Extensors (eccentric mode)	-0,57	0,01	-0,35	0,18	-0,09	0,72	0,13	0,62	-0,19	0,47	-0,36	0,16	-0,37	0,16
Flexors (eccentric mode)	-0,46	0,06	-0,52	0,03	-0,05	0,84	0,12	0,64	-0,44	0,08	-0,28	0,29	0,15	0,56

Discussion

The aim of this study was to examine the correlations between range of motion during the early stance phase of running and hip and knee muscle strength in runners and non-runners. As an exploratory investigation, the results revealed a heterogeneous pattern of correlations that varied according to running experience, the joint analyzed, the plane of motion, and the contraction mode. Overall, the findings suggest that isolated measures of muscle strength are not uniformly associated with running kinematics in asymptomatic individuals. This variability is consistent with the current understanding that running biomechanics is influenced by complex interactions between musculoskeletal capacity, neuromuscular control, and task-specific adaptations. In line with this perspective, a recent umbrella review indicates that many proposed biomechanical and musculoskeletal factors show inconsistent associations with running-related outcomes across studies (Correia et al., 2024).

In the frontal plane, few significant correlations were observed between hip and knee muscle peak torque and running kinematics, which is broadly consistent with previous studies reporting limited or inconsistent associations between muscle strength and frontal-plane kinematics in non-injured populations (Brund et al., 2018; Cashman, 2012; Ford et al., 2013; Schmitz et al., 2014). These findings suggest that frontal-plane kinematics during running may not be strongly associated with isolated measures of hip and knee strength in asymptomatic individuals. One possible explanation is that frontal-plane control during running depends not only on muscle strength but also on neuromuscular coordination, trunk stability, and individual movement strategies. This interpretation aligns with previous literature indicating that biomechanical variables associated with running-related injuries often present inconsistent relationships across studies (Correia et al., 2024). Therefore, when the objective is to influence frontal-plane movement patterns, often considered potentially injurious, interventions focusing solely on isolated muscle strengthening may not be sufficient to meaningfully alter running kinematics.

In contrast, moderate to strong correlations were observed in the sagittal plane, particularly among runners. Higher hip and knee peak torque values were correlated with smaller trunk and knee flexion ranges of motion, suggesting greater proximal control and reduced reliance on large joint excursions. This pattern may reflect a more efficient strategy to regulate center of mass displacement and attenuate mechanical loads during running. These results are consistent with biomechanical models emphasizing the role of eccentric musculature in controlling the center of mass and modulating forces during the stance phase of running (Hamner et al., 2010).

An interesting finding was the positive association between frontal-plane knee motion (varus/valgus) and hip abductor strength. This association can be interpreted in two non-mutually exclusive ways: (i) greater hip abductor strength being associated with increased valgus motion, or (ii) greater hip abductor strength being associated with reduced varus motion. Given that a portion of the running sample demonstrated varus motion while a similar proportion demonstrated valgus motion, and that the overall magnitude of frontal-plane excursion was small, without evidence of excessive or potentially injurious movement, this correlation does not appear to reflect a clear or clinically meaningful biomechanical phenomenon.

In non-runners, a distinct pattern was identified in which eccentric knee flexor peak torque was correlated with greater ankle dorsiflexion. Differences in movement patterns may be expected in individuals with limited running experience, as novice runners have been shown to present higher injury incidence compared with more experienced runners, possibly reflecting differences in neuromuscular adaptation and movement strategies developed through running exposure (Kemler et al., 2018). In this context, the present findings suggest that greater eccentric force-producing capacity of the hamstrings may be associated with increased ankle dorsiflexion excursion during running. One possible explanation is that greater eccentric capacity allows these individuals to better tolerate larger joint excursions and potentially increase the time available for load dissipation across the lower-limb joints during stance (Schmitz et al., 2014; Souza & Powers, 2009).

From a practical perspective, strategies aiming to modify running mechanics should not rely exclusively on isolated muscle strengthening. Previous literature suggests that rehabilitation and injury-prevention programs for runners should integrate strength training with movement retraining approaches. Interventions such as step rate manipulation, running gait retraining with visual or verbal feedback, and strengthening of hip stabilizing muscles have been proposed as effective strategies to improve lower-limb biomechanics and reduce excessive joint loading during running (Fernández-López & Rojano-Ortega, 2020). These approaches reinforce the importance of combining musculoskeletal capacity with motor control adaptations when addressing biomechanical factors associated with running performance and injury risk.

Taken together, these results indicate that the relationship between muscle performance and running kinematics is context-dependent and influenced by running experience, reinforcing the importance of integrated approaches that consider muscle strength, neuromuscular control, and task-specific adaptation.

Conclusions

The correlations between hip and knee muscle strength and running kinematics were specific and dependent on running experience. In asymptomatic individuals, isolated muscle strength did not comprehensively explain movement patterns during running. These findings underscore the need for integrated assessments and suggest that running experience modulates the relationship between muscle performance and kinematics.

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