THE RELATIONSHIP BETWEEN LOWER LIMB STIFFNESS AND RUNNING ECONOMY IN CHILD SOCCER PLAYERS

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A RELAÇÃO ENTRE RIGIDEZ DOS MEMBROS INFERIORES E ECONOMIA DE CORRIDA EM JOGADORES DE FUTEBOL INFANTIL

LA RELACIÓN ENTRE LA RIGIDEZ DE LOS MIEMBROS INFERIORES Y LA ECONOMÍA DE CARRERA EN JUGADORES DE FÚTBOL INFANTIL

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ABSTRACT

Introduction: Lower limb stiffness has been shown to be associated with running economy (RE) in adults, but this relationship in children remains unclear. Objectives: The purpose of this study was to investigate the relationship between lower limb stiffness, RE, and repeated-sprint ability in child soccer players. Methods: Twenty-eight male child soccer players (mean age 11.8 ± 0.9 years) participated in the study. RE was determined by measuring the steady-state oxygen uptake (ml/min/kg) at submaximal running speeds of 8 and 9 km/h. Vertical and leg stiffness were calculated from the flight and contact time data obtained during two submaximal running tests. Additionally, vertical stiffness was measured during the maximal and submaximal hopping tests. All participants performed the repeated sprint test consisting of 10 × 20-m all-out sprints interspersed with 20-s active recovery. Results: During both submaximal running tests, vertical (r= –0.505 to –0.472) and leg stiffness (r= –0.484 to –0.459) were significantly correlated with RE (p< 0.05). Maximal (r= –0.450) and submaximal hopping stiffness (r= –0.404) were significantly correlated with RE at 8 km/h (p< 0.05). Maximal hopping stiffness was significantly correlated with the best sprint time (r= –0.439) and mean sprint time (r= –0.496) (p< 0.05). Vertical (r= –0.592 to –0.433) and leg stiffness (r= –0.612 to –0.429) at 8 and 9 km/h and submaximal hopping stiffness (r= –0.394) were significantly correlated with the fatigue index (p< 0.05). Conclusions: Current findings indicate that the lower limb stiffness may be an important determinant of both RE and repeated-sprint ability in child soccer players. ***Level of Evidence II; Diagnostic Studies - Investigating a Diagnostic Test.***

Keywords: Oxygen consumption; Running; Children.

RESUMO

Introdução: A rigidez dos membros inferiores demonstrou estar associada à economia de corrida (RE) em adultos, porém essa relação não é muito clara quando se trata de crianças. Objetivos: O objetivo deste estudo foi investigar a relação entre a rigidez dos membros inferiores, a RE e a capacidade de sprints repetidos em jogadores de futebol infantil. Métodos: Vinte e oito jogadores do sexo masculino de futebol infantil (idade média de 11,8 ± 0,9 anos) participaram do estudo. A determinação da RE ocorreu por meio da medição do consumo de oxigênio em estado estacionário (ml/min/kg) a velocidades submáximas de corrida de 8 km/h e 9 km/h. O cálculo da rigidez vertical e da rigidez das pernas baseou-se nos dados de tempo de voo e tempo de contato obtidos durante dois testes submáximos de corrida. Além disso, mediu-se a rigidez vertical durante os testes máximo e submáximo de salto (hop test). Todos os participantes realizaram o teste de sprints repetidos que consistiu em dez repetições de sprints em velocidade máxima de 20 m intercalados por recuperação ativa de 20 s. Resultados: Durante ambos os testes submáximos de corrida, a rigidez vertical (r= –0,505 a –0,472) e a rigidez das pernas (r= –0,484 a –0,459) estavam significativamente correlacionadas à RE (p<0,05). A rigidez de salto máximo (r= –0,450) e a de salto submáximo (r= –0,404) demonstraram uma correlação significativa com RE em 8 km/h (p<0,05). A rigidez de salto máximo estava associada, de forma substancial, ao melhor tempo de sprint (r= –0,439) e ao tempo médio de sprint (r= –0,496) (p< 0,05). A rigidez vertical (r= –0,592 a –0,433), a rigidez das pernas (r= –0,612 a –0,429) em 8 km/h e 9 km/h e a rigidez de salto submáximo (r= –0,394) estavam expressivamente correlacionadas ao índice de fadiga (p< 0,05). Conclusões: Os achados atuais indicam que a rigidez dos membros inferiores pode ser um determinante fundamental tanto de RE quanto de capacidade de sprints repetidos em jogadores de futebol infantil. ***Nível de evidência II: Estudos diagnósticos - Investigando um teste diagnóstico.***

Descritores: *Consumo de oxigênio; Corrida; Crianças.*

RESUMEN

Introducción: Se ha demostrado que la rigidez de los miembros inferiores está relacionada con la economía de carrera (RE) en los adultos, sin embargo esta relación no es muy clara cuando se trata de niños. Objetivos: El objetivo de este estudio fue investigar la relación entre la rigidez de los miembros inferiores, la RE y la capacidad de sprints repetidos en jugadores de fútbol infantil. Métodos: Veintiocho jugadores de fútbol infantil de sexo masculino (edad media de 11,8 ± 0,9 años) participaron en el estudio. La determinación de la RE se produjo

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midiendo el consumo de oxígeno en estado estacionario (ml/min/kg) a velocidades de carrera submáximas de 8 km/h y 9 km/h. El cálculo de la rigidez vertical y de la rigidez de las piernas se basó en los datos de tiempo de vuelo y de contacto obtenidos durante dos tests submáximos de carrera. Además, se midió la rigidez vertical durante los tests submáximos y máximos de salto (hop test). Todos los participantes realizaron el test de sprints repetidos, que consistía en diez repeticiones de sprints a velocidad máxima de 20 m intercalados por una recuperación activa de 20 s. Resultados: Durante ambos tests submáximos de carrera, la rigidez vertical (r= -0,505 a -0,472) y la rigidez de las piernas (r= -0,484 a -0,459) se correlacionaron significativamente con la RE (p<0,05). La rigidez de salto máximo (r= -0,450) y la rigidez de salto submáximo (r= -0,404) demostraron una correlación significativa con la RE a 8 km/h (p<0,05). La rigidez de salto máximo se asoció sustancialmente con un mejor tiempo de sprint (r= -0,439) y con el tiempo medio de sprint (r= -0,496) (p< 0,05). La rigidez vertical (r= -0,592 a -0,433), la rigidez de las piernas (r= -0,612 a -0,429) a 8 km/h y 9 km/h y la rigidez de salto submáximo (r= -0,394) se correlacionaron significativamente con el índice de fatiga (p< 0,05). Conclusiones: Los hallazgos actuales indican que la rigidez de los miembros inferiores puede ser un determinante clave tanto de RE como de la capacidad de sprints repetidos en jugadores de fútbol infantil. ***Nivel de evidencia II: Estudios diagnósticos - Investigación de una prueba diagnóstica.***

Descriptores: *Consumo de oxígeno; Carrera; Niños.*

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INTRODUCTION

Running economy (RE) is an important physiological determinant of endurance running performance.[1] RE, representing the energy demand of running at a constant speed, is expressed as the steady-state oxygen uptake (VO_2) at a given submaximal running speed.[1,2] Runners with good RE use less oxygen and therefore spend less energy than runners with poor RE at the same constant running speed.[2] RE is one of the crucial parameters to consider when testing the physical capacities of soccer players.[3] In soccer players, RE is important in active recovery periods after the maximal intensity periods of the game.[4] Among soccer players with similar maximal oxygen uptake (VO_{2max}), players in the higher division have been shown to have better RE.[3]

Studies investigating the contribution of mechanical and neuromuscular characteristics have shown that the elastic behavior of leg muscle-tendon units affects the energy cost of running.[5,6] The storage and release of elastic energy in the series-elastic element reduce the work done by the contractile element during the propulsion (concentric) phase during running.[2,7] Lower-limb stiffness during running or hopping can be used to evaluate the elastic energy storage capacity of the whole muscle-tendon complex.[5,7,8] Leg stiffness (k_{leg}) and vertical stiffness (k_{vert}) are the two components that composed the stiffness of the spring-mass model.[7] k_{leg} is associated with leg spring deformation when it comes to horizontal motion, while k_{vert} is a characteristic of the leg spring pattern associated with the vertical motion of the center of mass.[6,7,9]

Greater lower-limb stiffness has been shown to be associated with a better RE in adult runners.[5,10,11] To the best of our knowledge, no studies have been found investigating the relationship between stiffness and RE in children. In this study, we aimed to investigate the relationship between lower-limb stiffness and RE and repeated-sprint ability in child soccer players.

METHODS

Subjects

Twenty-eight healthy male children playing in the same amateur soccer club voluntarily participated in the study (Table 1). The players had 2.2±0.9 years of soccer training experience and took part in the regional league, some of them in the national championships. Players performed two training sessions and one official match per week during the competitive season. Parental consent and player assent were obtained, and ethical approval was granted by the University's Ethics Committee (83/22/2018). Each player avoided any exercise until 24-h before the testing procedures.

The maturational status of the players was assessed noninvasively by calculation of years from peak height velocity (PHV) using the sex-appropriate equation of Mirwald et al.[12] derived from anthropometric variables, including standing height, sitting height, leg length, age, and body mass. Maturity offset (year) was calculated by subtracting the chronological age at the time of measurement from the age in PHV. Negative values (-) are interpreted as pre-PHV and positive values (+) as post-PHV (Table 1).

Experimental Design

Players took part in three test sessions at least 48-h intervals during the in-season period. Laboratory measurements of the experiment were carried out during two sessions on a motorized treadmill (h/p/Cosmos-Quasar-med,Nussdorf-Traunstein, Germany). An incremental treadmill test was performed to determine VO_{2max} in the first session, and submaximal running tests of 6-min at 8 and 9 km/h to determine RE in the second session. In the third session, maximal hopping, submaximal hopping, and repeated-sprint tests were performed at least 15-min apart in the indoor court, respectively. k_{leg} and k_{vert} were calculated from the flight and ground contact times data obtained during submaximal running and hopping tests. All players were performed a standardized 15-min warm-up period and were given the opportunity to familiarize themselves with testing protocols before starting data collection.

Incremental treadmill test

Throughout all laboratory tests, breath-by-breath gas measurements were taken using an indirect calorimetric system (Quark-PFT-ergo, Cosmed, Rome, Italy). The heart rate was recorded continuously by telemetry using a heart rate monitor (Cosmed, Rome, Italy). To determine VO_{2max}, performed a progressive protocol with an initial speed of 6 km/h with

Table 1. Mean values for descriptive details of the participants.

Variables	Mean ± SD
Age (years)	11.8 ± 0.9
Maturity Offset (years)	-1.99 ± 0.7
Bodyweight (kg)	38.1 ± 6.6
Height (cm)	148.5 ± 0.05
VO_{2max} (ml/min/kg)	51.3 ± 3.9

speed increments of 1 km/h at a constant 1% incline every minute until they could no longer keep the running pace.

Submaximal running test

RE was determined by measuring the steady-state VO_2 per body mass (ml/min/kg) for 6-min during submaximal running tests performed at 8 and 9 km/h separated by a 30-min rest period. The last-minute VO_2 and RER data of two submaximal running tests were averaged to represent the steady-state value for further analysis.

Submaximal running test variables for the evaluation of stiffness

During both submaximal running tests, the flight and ground contact times were determined with a high-speed digital camera at 240Hz (GoPro-HERO3+Black edition), placed behind the treadmill (~1m). The video sequences were recorded in the last minute of two running tests and analyzed with open-source software (Kinovea-v0.8.15, www.kinovea.org). One stride cycle from the heel strike to the next heel strike of the right leg was analyzed for both running speeds.[13]

Ground contact time was defined as the time frame between the beginning of the foot contacts and the foot toes off the treadmill. The flight time was defined as when the first foot took off until the first time the foot landed on the treadmill. All steps for the right leg were analyzed and averaged as representative values of ground contact and flight times (in seconds) during the last one-minute recording period. Step time was obtained from the sum of ground contact and flight times. Stride frequency (SF) was defined as the number of steps taken per second and was computed by the equation *SF(Hz)= 1/step time*. The stride length (SL) was established as the length from the right foot contact to the next contact of the same foot and was computed by the equation *SL(m)= running speed(m/s)/SF*. Relative SL was calculated as the ratio of SL to leg length.

k_{vert} and k_{leg} were calculated from the variables of peak ground reaction force, vertical displacement of the center of mass and the change in leg length previously identified by Morin et al.[9] (Equations 1-5).

$$F_{max} = m.\,g\,.\frac{\pi}{2}\,.\left(\frac{tf}{tc}+1\right) \qquad (1)$$

Where $Fmax$ (kN) represents peak ground reaction force, m represents body mass (kg), g represents gravitational acceleration constant, tf (s) represents flight time, and tc (s) represents ground contact time.

$$\Delta y_c = \frac{F_{max}\,.tc^2}{m\,.\pi^2} + g\,.\frac{tc^2}{8} \qquad (2)$$

Where Δyc (m) represents the vertical displacement of the center of mass when it reaches its lowest point during contact.

$$\Delta L = L - \sqrt{L^2 - (\frac{v.tc}{2})^2} + \Delta y_c \qquad (3)$$

Where ΔL(m) represents the change in leg length, L (m) represents leg length and v (m/s) represents the running speed.

The modeled k_{vert} (kN/m) was calculated as the ratio of the modeled peak ground reaction force over the modeled vertical displacement of the center of mass.

$$k_{vert} = \frac{F_{max}}{\Delta y_c} \qquad (4)$$

The modeled k_{leg} (kN/m) was calculated as the ratio of modeled peak ground reaction force over the modeled leg length variation during ground contact.

$$k_{leg} = \frac{F_{max}}{\Delta L} \qquad (5)$$

Maximal and submaximal hopping tests

Maximal and submaximal hopping tests were performed on a contact mat. Flight and contact time data were collected instantly via a hand--held personal digital assistant (Witty-timer, Microgate, Bolzano, Italy). Both hopping protocols were carried out according to those previously reported by Lloyd et al.[14] Players performed three trials for each hoping tests and the best trail values were used for subsequent analysis. Players were asked to keep their hands on their hips to avoid upper body interference, then to jump and land at the same point.

The maximal hopping test involved players performing five repeated bilateral maximal vertical hops on the contact mat. Players were asked to maximize jump height and minimize ground contact time. The first hop was excluded from the data analysis, and the remaining four hops were averaged.[14]

The submaximal hopping test was performed at a hopping frequency of 2.5 Hz.[14] Players were asked to perform 20 consecutive bilateral vertical hops on the contact mat. Hopping frequency was maintained via an audio signal from a digital metronome (TempoPerfect Metronome, NCH-Software). The first and last five hops were excluded from the data analysis, and the ten consecutive hops were averaged and used for further analysis.

During both tests, k_{vert} was calculated using the equation proposed by Dalleau et al.[15] (Equations 6).

$$k_{vert} = \frac{[m\,.\pi\,(tf+tc)]}{tc^2[(tf+tc\,/\,\pi)-(\,tc\,/\,4)]} \qquad (6)$$

Where k_{vert} (kN/m) represents vertical stiffness, m(kg) represents body mass, tf(s) represents flight time, and tc(s) represents ground contact time.

Repeated-sprint test

Players performed the repeated-sprint test involving ten repetitions of 20-m all-out sprints with active rest periods every 20-s. During active rest periods, the players jogged back to the starting line. Sprint times were recorded by two electronic photocells (Witty-Wireless Training Timer, Microgate, Bolzano, Italy) placed at the start and the finish lines. The recovery time was controlled by a hand-held stopwatch. The fastest preliminary sprint time was used as the criterion score for evaluating the performance repeated sprint test's first sprint. If the performance in the first sprint was 2.5% worse than the criterion score, the repeated sprint test was immediately terminated and repeated after a 5-min rest.

The best sprint time, mean sprint time (mean time of ten sprints), and the fatigue index were selected for the analysis from the test data. The fatigue index (FI) was expressed as a percentage and calculated according to Fitzsimmons et al.[16]

Statistical analyses

Data are reported as the means±standard deviation (SD). Statistical significance was accepted at $p<0.05$. The assumption of normality was assessed through the Shapiro-Wilk test. Pearson correlation coefficients were used to examine the relations between variables. IBM-SPSS 21 software (IBM-SPSS Statistics 21 Inc., Chicago, IL) was used for the statistical analyses.

RESULTS

The results obtained during hopping tests, submaximal running tests, and repeated-sprint test are shown in (Table 2).

Both maximal and submaximal hopping k_{vert} had a negative relationship with RE at 8 km/h ($p<0.05$), but no significant relationship was observed with RE at 9 km/h (Table 3). During both submaximal running tests, k_{vert} and k_{leg} had a negative relationship with RE ($p<0.05$). During the running speed of 9 km/h, RE was significantly negatively correlated with SF and positively correlated with SL ($P<0.05$). RE did not significantly correlate with SF and SL at 8 km/h. Relative SL was positively correlated with RE at 8 and 9 km/h ($p<0.05$).

Maximal hopping k_{vert} had a negative relationship with the best and mean sprint time ($p<0.05$) but did not have a significant relationship with the fatigue index (Table 4). Submaximal hopping k_{vert} was negatively correlated with the fatigue index ($p<0.05$). Both k_{vert} and k_{leg} at 8 and 9 km/h had a negative relationship with the fatigue index ($p<0.05$). These stiffness values were not significantly related to mean and best sprint times.

DISCUSSION

The main finding of this study indicated that the higher the lower--limb stiffness, the better the RE in child soccer players. k_{vert} calculated from the maximal hopping was negatively related to the best sprint and mean sprint times, suggesting that maximal hopping k_{vert} may play an important role in determining the sprint performance. In addition to that, submaximal hopping k_{vert} as well as k_{vert} and k_{leg} during submaximal running were negatively related to the fatigue index. Thus, high lower--limb stiffness during submaximal hopping and running may minimize the development of fatigue during repeated sprints.

Table 2. Mean values for variables determined from hopping tests, submaximal running tests, and repeated sprint test. Mean ± SD.

	Submaximal running at 8 km/h		Submaximal running at 9 km/h
RE (ml/min/kg)	35.9 ± 2.9		38.5 ± 3.3
RER	0.95 ± 0.03		0.96 ± 0.03
SF (Hz)	1.48 ± 0.09		1.46 ± 0.08
SL (m)	1.50 ± 0.09		1.71 ± 0.09
RSL (m)	2.14 ± 0.11		2.45 ± 0.13
k_{leg} (kN/m)	2.34 ± 0.60		2.46 ± 0.51
k_{vert} (kN/m)	2.91 ± 0.74		3.08 ± 0.60
	Maximal hopping		Submaximal hopping
k_{vert} (kN/m)	9.4 ± 4.0		17.7 ± 3.4
	Best sprint time (s)	Mean sprint time (s)	Fatigue index (%)
	3.43 ± 0.26	3.56 ± 0.30	3.74 ± 2.38

RE = running economy, SF= stride frequency, SL= stride length, RSL= relative stride length, k_{vert} = Vertical stiffness, k_{leg} = Leg stiffness.

Table 3. Correlation coefficients (r) between stiffness values and running economy (RE), stride frequency, absolute and relative stride length at two running speeds.

	RE at 8 km/h		RE at 9 km/h	
Variáveis n=28	r	p	r	p
Max hopping k_{vert}	-0.450*	0.016	-0.174	0.375
Submax hopping k_{vert}	-0.404*	0.033	-0.106	0.591
k_{leg} em 8 km/h	-0.484**	0.009	-0.398*	0.036
k_{vert} em 8 km/h	-0.505**	0.006	-0.400*	0.035
k_{leg} em 9 km/h	-0.382*	0.045	-0.459*	0.014
k_{vert} em 9 km/h	-0.385*	0.043	-0.472*	0.011
SF at 8 km/h	0.029	0.885	-0.167	0.394
SL at 8 km/h	-0.017	0.932	0.163	0.407
RSL at 8 km/h	0.388*	0.041	0.375*	0.049
SF at 9 km/h	0.018	0.929	-0.433*	0.021
SL at 9 km/h	-0.006	0.977	0.442*	0.019
RSL at 9 km/h	0.379*	0.046	0.612**	0.001

Correlations are significant for p < 0.05 (*) and p < 0.01 (**). RE = running economy, Max= maximal, Submax= submaximal, k_{vert} = Vertical stiffness, k_{leg} = Leg stiffness, SF= stride frequency, SL= stride length, RSL= relative stride length.

Table 4. Pearson's Correlations coefficients (r) between stiffness values and repeated-sprint test variables.

	Best sprint time		*Mean sprint time*		Fatigue index	
Variáveis n=28	r	p	r	p	r	p
Max hopping k_{vert}	-0.439*	0.022	-0.496**	0.009	-0.361	0.064
Submax hopping k_{vert}	0.043	0.833	-0.073	0.717	-0.394*	0.042
k_{leg} at 8 km/h	-0.151	0.452	-0.298	0.132	-0.592**	0.001
k_{vert} at 8 km/h	-0.151	0.452	-0.303	0.125	-0.612**	0.001
k_{leg} at 9 km/h	-0.013	0.950	-0.129	0.521	-0.433*	0.024
k_{vert} at 9 km/h	0.015	0.942	-0.103	0.608	-0.429*	0.026

Correlations are significant for p < 0.05 (*) and p < 0.01 (**). Max= maximal, Submax= submaximal, k_{vert} = Vertical stiffness, k_{leg} = Leg stiffness.

The metabolic cost of running is largely determined by the generating vertical force on the ground to support body weight and the horizontal propulsive force exerted on the ground.[17] Our findings indicate that k_{vert} and k_{leg} at 8 and 9 km/h were positively correlated with RE (i.e., greater stiffness is associated with lower VO_{2max}). Furthermore, both maximal and submaximal hopping k_{vert} also showed significant correlations with RE at 8 km/h. During a given submaximal running speed, RE has been shown to quite different among groups of distance runners matched in terms of age, gender, and performance.[18] Lower-limb stiffness studied previously to explain interindividual variability of RE in adults. Dalleau et al.[5] showed that greater stiffness of the propulsive leg was significantly associated with a better RE in middle--distance runners. Similarly, Heise and Martin[6] demonstrated an association between RE and k_{vert} during submaximal running in recreational runners. Also, lower-limb stiffness calculated from running[11] and maximal hoping[10] has been shown to be correlated with RE in well-trained distance runners.

The increase in lower-leg muscle-tendon stiffness resulting from plyometric or resistance training has been shown to have the potential to improve RE through greater utilization of stored energy during running.[19,20] However, to our knowledge, the relationship between RE and lower-limb stiffness has not previously been examined in children. Hence, our data represents a rather novel finding, showing that higher k_{vert} and k_{leg} is associated with better RE in child soccer players. Training interventions to improve lower-limb stiffness may also be important to improve RE in young and prepubertal soccer players.

Another finding of the study is that the higher SF and the shorter SL at 9 km/h are significantly associated with better RE. Furthermore, a lower relative SL value (ratio of stride length to leg length) was associated with better RE at 8 and 9 km/h. Consistent with our findings, Tartaruga et al.[21] found that better RE was associated with higher SF and shorter SL during submaximal running in long-distance runners. Similarly, Tam et al.[22] showed that more economical runners exhibited greater SF during constant-speed running. On the other hand, different investigators have shown that RE was not associated with SF and the ratio of SL to leg length during submaximal running in prepubertal boys.[23,24] However, the children in these studies were not athletes, and this may explain the contradictory with the results of our study. It has been shown that trained athletes may naturally choose their stride frequency–length combination that minimizes metabolic cost.[25] Presumably, successful runners can increase their SF while minimizing ground contact time to achieve optimal metabolic efficiency during constant-speed running.[22] The ratio of stride length to leg length at a given submaximal running speed may be an important determinant of RE in prepubertal boys.

The repeated-sprint ability is another physical fitness component for determining the performance of soccer players. Having greater stiffness is thought to provide a faster release of elastic energy during sprinting, where angular joint displacement is minimal.[26] There is evidence that lower-limb stiffness is a crucial determinant of maximal sprint velocity in adults[26] and children.[27] Our study showed that children with greater maximal hopping k_{vert} had better both best and mean sprint performances during repeated-sprint test. k_{vert} during hopping and sprinting were found to be significantly associated with sprint performance in children and adolescent athletes, which is consistent with our data.[27,28]

Submaximal hopping k_{vert} together with k_{vert} and k_{leg}, which calculated during both submaximal running speeds, had a negative relationship with the fatigue index. It has been reported that failure to maintain k_{leg} during running causes the early onset of changes in stride mechanics, resulting in a decrease in performance.[29] Reduction k_{vert} during repeated sprint running has been found to be correlated with the decrease in stride frequency.[29] During repeated sprints, minimizing the decrease in step frequency through maintaining lower extremity stiffness may be a prerequisite for improving repeated-sprint ability.[30]

CONCLUSION

To the best of our knowledge, this is the first study to show the correlation between lower-limb stiffness and RE in children. The results of the present study indicated that greater k_{vert} and k_{leg} was associated with better RE as well as the repeated-sprint ability in child soccer players. Calculation of relative stride length may be important for determining RE.

All authors declare no potential conflict of interest related to this article

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