Journal of Physical Education and Sport ® (JPES), Vol. 24 (issue 8), Art 209, pp. 1887- 1892, August 2024
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Kinematic analysis of hip extension during skipping and sprinting in junior high school students

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Published online: August 31, 2024
Accepted for publication : August 15, 2024
DOI:10.7752/jpes.2024.08209

Abstract
Problem Statement: Skipping is a warm-up and drill exercise used to enhance running ability in sports coaching. However, existing evidence on the efficacy of skipping in improving running ability is insufficient. Purpose: This study aimed to develop a skipping drill to enhance running ability by investigating the relationship between skipping and running motions. Approach: The study included 73 male junior high school students (mean height: 165.2±5.7 cm, mean weight: 54.7±9.7 kg, age range: 14–15 years). Each participant underwent a 30 m skipping test and 50 m sprint test, which were recorded via a video camera. Based on their sprint performance, participants were divided into two groups: higher (HP, faster than 7.3 s) and lower performance (LP, slower than 8.5 s) groups. We analyzed the motion of support limb in stance phase during sprinting and skipping using Frame DIAS VI, a motion analysis software. Results: The average angular velocity of hip extension in the HP group was significantly higher than in the LP group during sprinting and skipping. The maximal angular acceleration in hip extension during skipping was significantly higher than that during sprinting in both groups. Furthermore, during sprinting, the maximal angular acceleration in hip extension of the HP and LP groups appeared at approximately 40% of the foot contact period and immediately before take-off, respectively. Even in skipping, maximal angular acceleration in hip extension in the HP and LP groups appeared at approximately 50% of the foot contact period and past 80% of the period, respectively. Conclusion: These results indicated that maximal angular acceleration in hip extension of the HP group appeared earlier than that in the LP group in the stance phase during both sprinting and skipping. In conclusion, the kinematic characteristics of hip extension during the stance phase of skipping and sprinting reflect running ability.
Keywords: skipping, sprinting, kinematic analysis, hip extension, stance phase

Introduction

Physical inactivity and poor fitness among children and adolescents are increasing health burdens worldwide (Armstrong et al., 2016, Boreham & Riddoch, 2001, Kriemler et al., 2013). Conversely, appropriate school-based interventions reportedly increased their physical activity and fitness (Adi, et al., 2022, Capio, et al., 2015, Kriemler et al., 2013). Capio et al. (2015) reported that improvements, especially in fundamental movement skills proficiency for children, were closely related to increased activity. Therefore, increasing children's proficiency in fundamental movement skills is extremely important.

Recent research in Japan revealed that running ability, a fundamental movement skill, had markedly declined (JAPAN SPORTS AGENCY, 2024). Since running was frequently performed in various play and sports activities, increasing its proficiency could lead enriched physical activity and improved overall physical fitness. Therefore, skipping was considered as a potential means to improve the proficiency of running movement skills.

Childhood skipping typically emerges developmentally after running, galloping, and hopping and is adopted for playful reasons, which subsequently improves stability (Clark & Whitall, 1989, Minetti, 1998, Wickstrom, 1987). Moreover, skipping has been used as a transitional rehabilitation activity between walking and running (Johnson, 2005) and a common warm-up exercise for athletes in various sports (Gamma et al., 2014, Juraiporn et al., 2015, McGowan et al, 2016). Hence, skipping is easy for children to implement and highly versatile. Furthermore, it is the most popular drill in track and field coaching, and many different types are used (Whelan et al., 2016). Thus, skipping is considered an effective drill to improve running movement skills and is widely used. However, evidence on the efficacy of skipping in improving running ability still remains insufficient.

Therefore, to design the initial skipping drills, we attempted to clarify the relationship between running performance and skipping by conducting kinematic analysis. Moreover, this study focused on the hip extension

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angular velocity during running and skipping because it is very important to have velocity of hip extension at the stance phase of sprinting to create effective horizontal momentum (Hunter et al., 2005). Understanding these kinematic characteristics can provide valuable insights for coaches and educators in developing training programs that effectively improve running performance.

Material & methods

Participant

Participants were 73 male junior high school students (165.15±5.7 cm, 54.73±9.65 kg, aged 14–15 years). The study was approved by the Aichi University of Education Research Ethics Committee (AUE20220901HUM). All participants provided informed consent.

Procedure

All participants completed a 30 m skipping and 50 m sprint test with maximum effort. The tests were conducted on a cray surface of school yard on February 17, 2023. Each attempt was recorded via a video camera. The video camera (EX-100F, CASIO, Japan) captured motions of both the tests and number of frames and exposure time were set to 120 Hz and 1/1000 sec, respectively. To capture the skipping motion, the camera was set 25 m to the left from the starting point, and calibration marks were set at 1 m intervals from 22–28 m to convert the actual length. To capture the sprinting motion, the camera was set 43 m to the left from the starting point, and the calibration mark was set at 40–46 m.

Data collection

Times of the 50 m sprint were recorded via hand-held stopwatch. To investigate the relationship between sprinting ability and skipping motions, participants were divided into high performance (HP) and low performance (LP) groups based on the 50 m test results. Based on scores from Japan's physical fitness test, those with a 50 m running time of 7.3 seconds or less and 8.5 seconds or more were designated to the HP (n = 18) and LP groups (LP) (n = 11), respectively.

The movie was digitized via the video motion analysis system Frame-DIAS VI (DKH, Japan), and 23 points of the body and four calibration marks were converted into a 2D 4-point actual length. Running motion was analyzed from the time one foot touched the ground until the other foot touched the ground. Skipping motion was analyzed from the time one foot touched the ground (first step) until the same foot touched the ground again (second step).

Sprinting and skipping speeds were defined as the average horizontal movement speed of the greater trochanter in each analysis section. Running stride was defined as the distance from the contact point of one foot to that of the opposite foot. Stride frequency of running was the reciprocal of the time from the moment one foot touched the ground until the opposite foot also touched the ground. Stride length of skipping was defined as the distance from the point where one foot touched the ground until the ipsilateral foot touched the ground again. Angular velocity and acceleration of hip extension during the stance phase were calculated for both gaits.

Motion during the stance phase was expressed as the time elapsed from the instant of ground contact (0%) to just before take-off (100%) to examine any changes.

Statistical analyses

All data were analyzed via Pearson’s product-moment correlation coefficient to examine the correlation between moving speed and other variables. Additionally, an unpaired t-test was conducted to compare the significance of the differences between the two groups. All data were distributed (p <0.05).

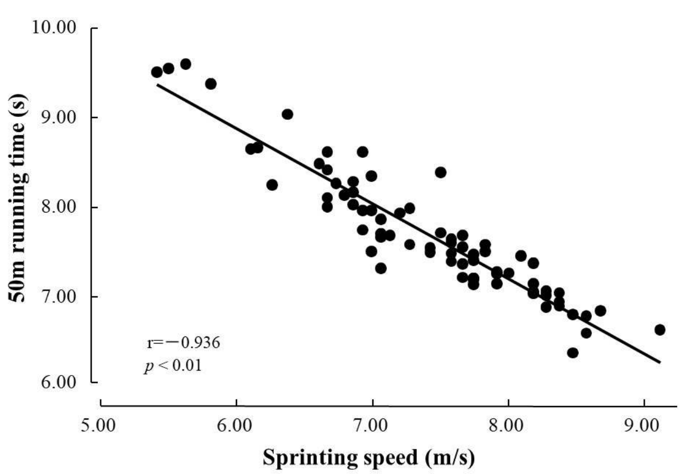

Fig.1. Relationship between sprinting speed and 50m running time

Results

As depicted in Fig. 1, 73 participants exhibited a significant positive correlation between their 50m running time and sprinting speed (r = -0.936, $p < 0.01$). A significant positive correlation was also observed between sprinting and

skipping speeds in each analysis section (r = 0.728, $p < 0.01$) (Fig. 2).

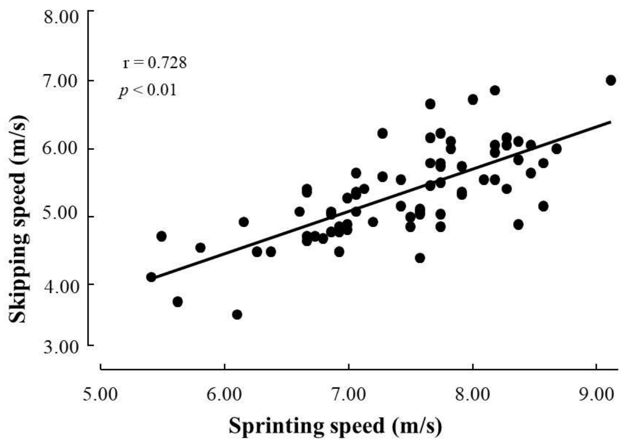

Fig.2. Relationship between sprinting and skipping speeds

Table 1. Speed and foot contact time of sprinting and skipping in high and low performance groups.

	High performance group		Low performance group	
	Sprinting	Skipping	Sprinting	Skipping
Speed (m/s)	8.32 ± 0.32 ^{a,b}	6.16 ± 0.49 ^{a}	6.17 ± 0.50 ^{b}	4.77 ± 0.52
Foot contact time (s)	0.12 ± 0.01 ^{a,b}	0.15 ± 0.02	0.16 ± 0.02	0.17 ± 0.03

Values are mean ± SD.
^{a} $p < 0.05$ vs. Low performance group. ; ^{b} $p < 0.05$ vs. Skipping in each group.

Table 1 presents the sprinting and skipping speeds and ground contact times of the HP and LP groups in each analysis section. Both sprinting and skipping speeds were faster in the HP group than in the LP group ($p < 0.05$). Furthermore, sprinting speed was faster than skipping speed in both groups ($p < 0.05$). Foot contact time of sprinting in the HP group was shorter than that in the LP group ($p < 0.05$), which was also shorter than foot contact time of skipping ($p < 0.05$).

Table 2 presents the average angular velocity and maximum angular acceleration of hip extension during sprinting and skipping in the HP and LP groups. The average angular velocities of hip extension in sprinting and skipping were faster in the HP group than LP group ($p < 0.05$). Furthermore, those of sprinting were faster in both groups than those of skipping ($p < 0.05$). The maximum angular acceleration of hip extension in sprinting was lower than that of skipping in both groups ($p < 0.05$).

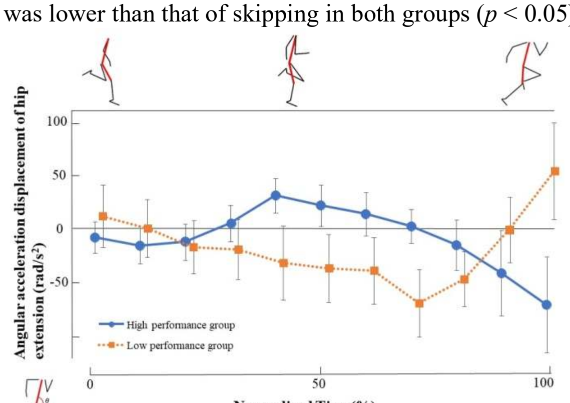

Fig.3. Acceleration displacement of hip extension angle during stance phase in sprinting

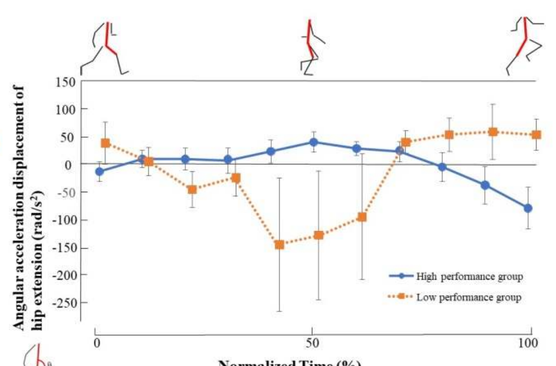

Fig.4. Angular acceleration displacement of hip extension angle during stance phase in skipping

Table 2. Kinematic variables of sprinting and skipping in high and low performance groups.

	High performance group		Low performance group	
	Sprinting	Skipping	Sprinting	Skipping
Average angular velocity (rad/s)	7.42 ± 1.65 [a,b]	5.48 ± 1.31 [a]	4.30 ± 1.73 [b]	3.71 ± 1.45
Maximal angular acceleration (rad/s²)	114.81 ± 44.73 [b]	165.53 ± 70.64	104.03 ± 49.22 [b]	161.91 ± 76.06

Values are mean ± SD.
[a] $p < 0.05$ vs. Low performance group. ; [b] $p < 0.05$ vs. Skipping in each group.

Figs. 3 and 4 present the deviation of the angular acceleration of hip extension during the stance phase of sprinting and skipping, respectively. Angular acceleration of the hip extension for sprinting in the HP group was negative at landing, turned positive at the 30% point, peaked at the 40% point, subsequently decreased, and turned negative at the 80% point. Conversely, angular acceleration was positive at landing, immediately turned negative, turned positive at the 90% point, and peaked at the foot-off in the LP group. The angular acceleration of hip extension for skipping in the HP group was negative at landing, peaked at the 50% point, subsequently decreased, and turned negative at the 80% point. Conversely, angular acceleration was positive at landing, immediately turned negative, turned positive at the 70% point, and peaked just before the foot-off in the LP group.

Discussion

We compared the sprinting and skipping motions of junior high school students to examine whether skipping was an effective drill to improve sprinting ability. A significant positive correlation was observed between the 50 m running time and sprinting speed among the 73 participants (40–46 m). Furthermore, a significant positive correlation was observed between the sprinting and skipping horizontal movement speeds. These results indicated that the two gait abilities were closely related.

Fast sprinters had a shorter ground contact time during the support phase than slow sprinters and could obtain higher propulsive force during this time (Chu & Korchemny, 1989; Kale et al., 2009). Therefore, we focused on the stance limb during ground contact and examined the differences in limb motions between the HP and LP groups. Ground contact time during sprinting was significantly shorter in the HP group than in the LP group, which was similar to results reported in previous studies (Chu & Korchemny, 1989; Kale et al., 2009). Additionally, although not statistically significant, the HP group had shorter ground contact times during skipping than the LP group, which was similar to the pattern observed in sprinting.

Since a positive correlation was observed between the backward swing speed of the leg and sprinting speed during the stance phase of sprinting (Ito et al. 1998), this study investigated the hip extension angular velocity of the stance limb during both sprinting and skipping. Average hip extension angular velocity during sprinting was significantly faster in the HP group than in the LP group. In addition, a similar trend was observed during skipping. These results showed that the HP group produced a higher propulsive force than the LP group owing to a shorter ground contact time and faster hip extension angular velocity in both sprinting and skipping.

Conversely, the maximum angular acceleration of skipping was higher than that of sprinting in both the groups. Since acceleration was proportional to the force developed, these results suggested that the hip extensor muscles exerted hyper-explosive force capacity during skipping rather than sprinting, regardless of running ability. This result was consistent with McDonnell et al.'s report (2017) that the knee joint torque during the stance phase of skipping was greater than that during running.

Although no difference was observed in the maximum angular acceleration of hip extension during sprinting and skipping between the two groups, the average angular velocity was higher in the HP group than in the LP group. Since this phenomenon assumed that the maximum angular acceleration appeared at the difference point after ground contact, we investigated the angular velocity deviation during the stance phase. The maximum angular acceleration of hip extension in the HP group translated to a positive rate relatively early in both sprinting and skipping after, whereas that in the LP group remained negative rate until the latter half. Furthermore, the maximum angular acceleration of hip extension in the HP group appeared in the first half (50%) of the stance phase for both sprinting and skipping; however, it appeared in the latter half (70%) in the LP group.

Hunter et al. (2005) found that, to increase the horizontal impulse (i.e., propulsive force) during the stance phase, generation of a vertical impulse that could withstand the impact of ground contact and simultaneously increase the hip extension angular velocity was necessary. Chelly and Denismo (2001) also reported that to increase hip extension angular velocity during the stance phase, sufficient muscle strength was required to overcome the vertical load when it was the highest. According to these previous studies, the LP group had weaker hip extension muscles than the HP group. Therefore, they were unable to generate a vertical impulse to withstand the impact of landing and instantly translate the maximum angular acceleration of hip extension into a positive rate.

Furthermore, the maximum angular acceleration of hip extension in the HP group translated into a negative rate from the latter half of the stance phase during both sprinting and skipping. It was reported that elite sprinters exerted power to flex their hip joints to quickly swing their legs forward during the latter half of the stance phase (Toyoshima & Sakurai 2018, Yada, et al., 2012). Therefore, participants in the HP group performed a preparatory motion of the forward swing of the opposite limb during the latter half of the stance phase. Conversely, participants in the LP group maintained their running speed by increasing their angular velocity during the latter half of the stance phase when the vertical load was relatively low.

Hence, increasing the hip extension angular velocity early in the stance phase was an important factor to obtain propulsive force in both sprinting and skipping.

Conclusions

The results of this study indicated a relationship between skipping and running. Specifically, the kinematic characteristics of the hip extension reflected running ability during the stance phase of skipping and sprinting. This study also showed that strengthening the hip extensor muscles and accelerating the onset of maximum angular acceleration of hip extension during the stance phase is important to improve running ability. Skipping required higher hip extension muscle strength than sprinting; however, its movement was easier to control. These findings can provide basic data for designing skipping drills to improve running ability.

Conflicts of interest

There are no conflicts of interest to declare.

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