Effects of different types of ropes on jump cycle while skipping

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Abstract

This study aimed to determine the effects of different types of jump ropes on jump cycles while skipping. Thirteen youth volunteers performed the basic jump and the alternate-foot jump using two ropes differing in diameter and weight. Two-way ANOVA revealed that the main effects of skipping patterns and type of rope were significant in cycle time, contact time, and takeoff time, respectively ($P < 0.05$ for all variables). In the coefficient of variations (CVs) for each measured variable, the main effect was significant in skipping patterns ($P < 0.05$ for all variables) but not in the type of rope ($P > 0.05$ for all variables). However, a clear difference was found between the two ropes for correlation coefficient of CV in cycle times between skipping patterns. These results suggested that different types of ropes affect jump cycles while skipping.

Key words : Skipping, Jump ropes, Jump cycle, Cycle time, Coefficient of variation

Introduction

Jumping is a fundamental human movement. Obviously, it is a method of reaching a required height. Although jumping movements are involved in many sports, such as the high jump, gymnastics, volleyball, and basketball, jump movements in sports mostly involve no or few repetitions. Furthermore, the greater the required height, the greater is the needed effort. Therefore, making several repeated jumps in sports activities is difficult. In contrast, skipping as an exercise involves continuous, low jumps. In other words, skipping is unique as a jumping activity that requires continuity and durability and not height or power. Naturally, the skipper needs a jump rope. The main purpose of skipping is physical training, and it is widely practiced not only in schools (1) but also on playgrounds outside schools (2).

Several studies on skipping have indicated relatively great energy costs (3,4) and relatively high exercise intensity (5). Further, these studies examined the energy costs (or oxygen uptake) for various skipping rates (jump cycle frequencies) and reported no significant metabolic differences between skipping rates except for particularly high frequencies (5). However, Yamaguchi *et al.* (6) reported regarding the effect of skipping rates on vertical peak force in ground reaction force. They observed the lowest vertical peak force at 92 skips·min^{-1}. Based on their data, vertical peak force was 2.5–4 times the body weight (in the range of 72–132 skips·min^{-1})—which is, if taking a high estimate, equivalent to jumping in rhythmic gymnastics (4.3 times the body weight) (7). Yamaguchi *et al.* (8) also reported that the utilization of muscles and tendons' elastic components increased with skipping rates of more than 100 skips·min^{-1}. Furthermore, many studies have reported that training by skipping enhances aerobic endurance (9,10,11) and increases bone mineral density (12,13,14). Thus, skipping can clearly be a weight-bearing exercise effective in physical training.

From another perspective, jump ropes for skipping have recently been made almost entirely from resin, with many variations in the types of resin used and the diameter and weight of ropes. Although most studies on skipping have focused on the relation between physiological and/or biomechanical data and skipping rates (cycle frequencies), no studies have examined differences in the types of ropes. Moreover, skipping rates are self-selected, but in some previous studies, it has been set by a metronome. As a self-selected pace of skipping includes individual variability, it should be treated similar to a self-selected walking speed (15). If the skipping rate is affected by the type of rope, the difference in ground reaction force might be observed as indicated by Yamaguchi *et al.* (6). This might cause trainers or skippers to choose certain ropes for training purposes or even lead to development of new

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rope products. Incidentally, the skipping rate is expressed as a reciprocal number of skipping (jump) cycle time. To investigate whether skipping rates depend on the type of rope, we must examine in detail the time required for jump cycles.

Therefore, this study proposed to determine the effects of different rope types on jump cycles during skipping.

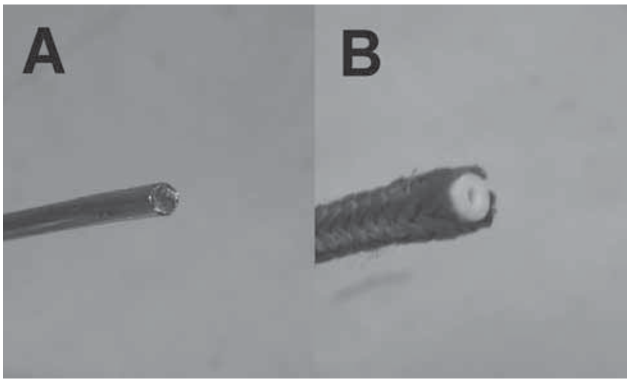

Figure 1. Cross-section views of two ropes (A: Thin and light type, TL; B: Not-thin and not-light type, NTNL)

Methods

1. Subjects

Subjects were 13 healthy and physically active youths: males aged 16-23 years old (Means ± SDs of age: 18.2 ± 2.4 years old, stature: 1.71 ± 0.05 m, weight: 60.1 ± 8.7 kg). This study followed the Declaration of Helsinki; that is, all subjects received explanation of the experiment's purpose and procedures, including its risks—for example, fatigue of lower extremities, stress on the cardiovascular system, and unpredictable, sudden changes in physical condition. In addition, subjects were required to perform warm-ups, and staff members monitored the entire experiment to minimize risk. Finally, written informed consent was obtained from all subjects.

2. Procedures

Subjects were instructed to perform 50 consecutive jumps (skips) under different conditions. Two types of commercial rope products available in Japan were used, one made from polyurethane rubber and the other from polyvinyl chloride covered with synthetic fiber. The polyurethane rope weighed 10.7 $g \cdot m^{-1}$ and had a diameter of 3.6 mm; the polyvinyl chloride rope weighed 26.0 $g \cdot m^{-1}$ and had a diameter of 6.4 mm (shaped like a pipe with a cavity of 1.1 mm) (Figure 1). Both ropes had lightweight grips at each end. Additionally, all subjects adjusted the ropes' lengths to their respective heights. The polyurethane rope is extremely lightweight and thin, whereas the polyvinyl chloride is a more common type of rope. In this study, therefore, these two types were expressed as thin and light type (TL) and not-thin and not-light type (NTNL), respectively. Because diameter reflects the project area for air resistance and weight is associated with centrifugal force or inertia (Diameter: TL < NTNL; Weight: TL < NTNL), the two ropes were regarded as contrary in ease of rotation.

Using the two different ropes, subjects skipped consecutively with basic jumps (both legs: BJ) and alternate-foot jumps (switching legs after every jump: AFJ). The four trials (two ropes × two patterns) required of subjects were in random order, and adequate rests (more than 5 min) were included between trials. Subjects tried to keep jumping to avoid failure. The experiment's staff told subjects to finish jumping after the staff counted 50 jumps. If subjects failed a trial, they performed the trial again. During consecutive jumps, the timings to contact and takeoff from the floor were measured electrically using an originally developed switch mat.

3. Analysis of jump cycles

The timings of contact (with) and takeoff (from) the floor were detected by a switch mat (0.45 × 0.50 m). The data were sampled at $1 \cdot 1000^{-1}$ s using an A/D converter and recorded by a personal computer. The switch mat was constructed of two layers of conducting foil with a slight gap. When a subject stood on the mat, the gap disappeared, and the foil sheets were in contact, thus closing a timing switch. As shown in Figure 2, a jump cycle was defined as a combination of contact phase and the following takeoff phase. The contact phase began at "foot- or feet-on" the switch mat when the last takeoff phase ended, and finished at "foot- or feet-off" the mat when the following takeoff phase began. The takeoff phase lasted until foot- or feet-on. BJ was supported by both legs during the

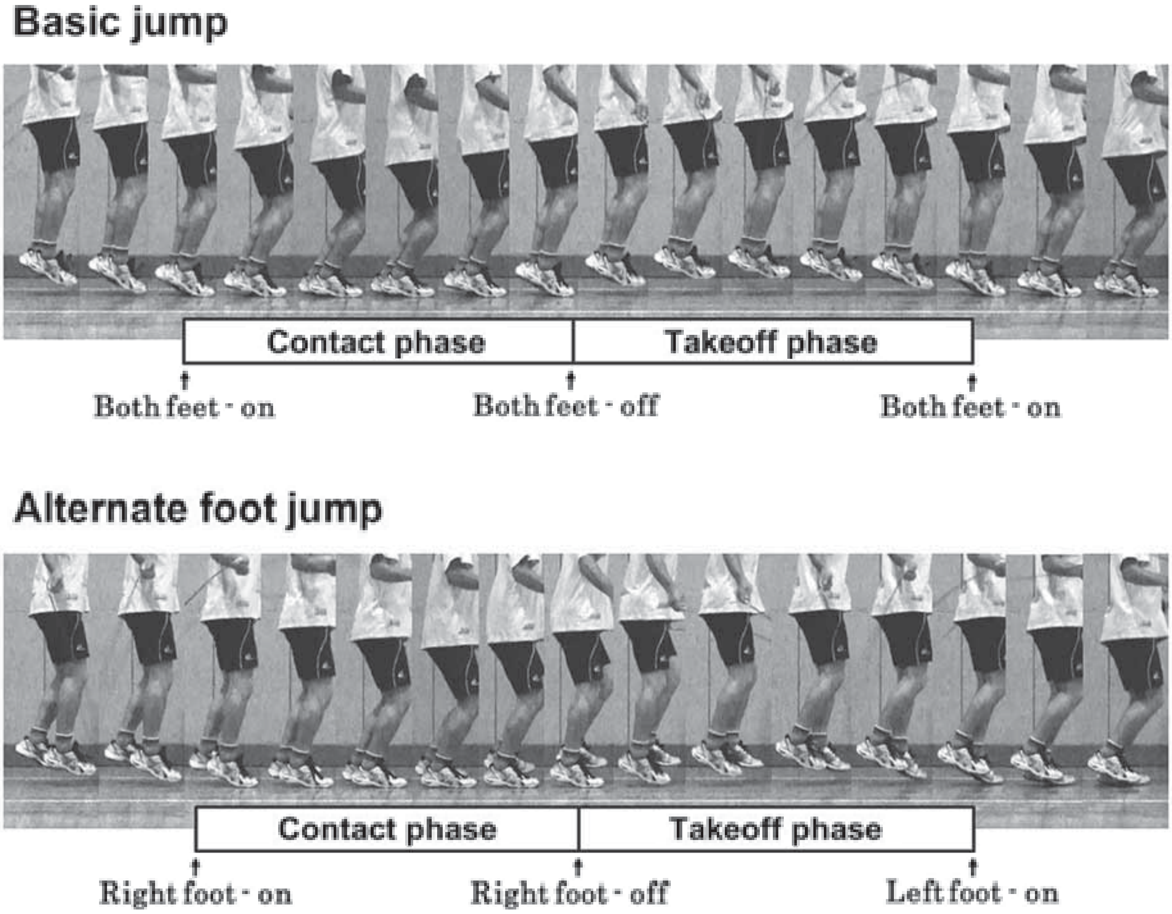

Figure 2. Definition of the jumping cycle of basic jump (upper panel) and alternate foot jump (lower panel)

contact phase, whereas AFJ was supported by a single leg, and the supporting leg was interchanged at every jump (see Figure 2). Each contact and takeoff time during 50 jumps was first determined as the duration for contact and takeoff phase. Then cycle time was calculated as a total of contact time and the following takeoff time. Averages of 50 jumps for each variable were represented as each value. Furthermore, it was considered that the variation of jump cycles should be focused because jumping while skipping was characterized by its continuity. Therefore, the coefficient of variations (CV) of cycle time, contact time, and takeoff time were calculated using the following equation:

$$CV\ (\%) = SD \cdot \overline{X}^{-1} \times 100$$

where SD is the standard deviation, and $\overline{X}$ is the mean of 50 jumps. Before the experiment was set up, a preliminary survey was conducted to identify the number for stable consecutive jumps (skipping) and for obtaining valid CVs in both BJ and AFJ conditions. Few subjects failed to complete less than 50 consecutive jumps in all conditions, and CVs calculated by approximately 50 jumps were almost equal to those of more than 50 jumps. For these reasons, the number of consecutive jumps was set at 50 in this study.

4. Statistics

A two-way repeated measures analysis of variance (ANOVA) was used to compare all variables in two conditions each of rope type (TL and NTNL) and of skipping pattern (BJ and AFJ). Pearson product moment correlation coefficients were calculated to assess the relationships for all variables between skipping patterns in the same type of rope. A P value < 0.05 was considered significant for all statistical analyses.

Table 1. Means and standard deviations in each variable and the results of two-way ANOVA

Variables	TL		NTNL		ANOVA (F value)		
	BJ	AFJ	BJ	AFJ	Type of the rope	Skipping pattern	Interaction
Cycle time (s)	0.476±0.029	0.420±0.043	0.481±0.028	0.437±0.035	12.57*	55.00*	2.74
Contact time (s)	0.201±0.032	0.236±0.036	0.207±0.028	0.240±0.038	5.54*	42.15*	0.07
Takeoff time (s)	0.275±0.029	0.185±0.026	0.274±0.023	0.196±0.020[a]	3.64	316.60*	6.56*
CV of cycle time (%)	2.39±0.61	3.31±1.19	2.44±0.50	3.41±1.08	0.15	15.16*	0.02
CV of contact time (%)	4.64±0.94	4.46±1.23	4.28±0.85	4.40±0.98	2.20	0.01	0.43
CV of takeoff time (%)	3.81±1.46	6.80±2.23	3.86±1.31	5.76±1.36	2.42	25.78*	2.96

n = 13
TL: Thin and light type; NTNL: Not-thin and not-light type
BJ: Basic jump; AFJ: Alternate foot jump
CV: Coefficient of variation
* Significant at $P < 0.05$
[a] Significantly different between BJ and AFJ in NTNL at $P < 0.05$

Table 2. Correlation coefficients between BJ and AFJ in each variable

Variables	TL	NTNL
Cycle time	0.706 *	0.794 *
Contact time	0.758 *	0.904 *
Takeoff time	0.662 *	0.761 *
CV of cycle time	-0.043	0.618 *
CV of contact time	-0.264	0.380
CV of takeoff time	0.115	0.355

n = 13
TL: Thin and light type
NTNL: Not-thin and not-light type
CV: Coefficient of variation
*Significant at P < 0.05

Results

Table 1 displays the ANOVA results. The main effects of rope type and skipping pattern for cycle time were significant, respectively (both $P < 0.05$), but interaction was not significant ($P > 0.05$). Contact time and takeoff time had significant main effects of rope type ($P < 0.05$) and skipping pattern ($P < 0.05$), respectively, and the interaction in takeoff time was also significant ($P < 0.05$). Cycle time and contact time in BJ were shorter than in AFJ, whereas takeoff time in AFJ was longer than in BJ. NTNL made cycle time and contact time longer compared to TL. In addition, takeoff time in AFJ was longer than in BJ when using NTNL. Thus, rope type affected cycle time (as well as contact time) both in skipping patterns and takeoff time in AFJ. In CV of cycle time, the main effect of skipping pattern was significant ($P < 0.05$), but that of rope type was not ($P > 0.05$). Furthermore, there were no significant main effects in CV of contact time (both $P > 0.05$). The CVs of cycle time and takeoff time in AFJ were greater than in BJ. Thus, the jump cycle (especially cycle time and takeoff time) was affected only by skipping pattern (not by type of rope).

On the other hand, significant correlation coefficients between skipping patterns were found in cycle time, contact time, and takeoff time for each rope (Table 2, all $P < 0.05$). However, in cycle time of NTNL, a significant correlation coefficient was found only in CVs of measured variables (Table 2, $r = 0.618$, $P < 0.05$). This means that individual variability in jump cycles was related between skipping patterns for each rope, but such a relation in CV of jump cycles (cycle time) was observed in TL. In other words, results indicated that rope type could make a difference in the relation of individual variability between skipping patterns.

Discussion

The two ropes' diameters differed, and this reflected a difference in projected area. Therefore, it was thought that NTNL would not be as easy to rotate because its air resistance might be greater than that of TL. And NTNL was not light compared to TL. However, the centrifugal force of NTNL might also be greater than that of TL. Those were the ropes' physical aspects. However, according to subjects' introspections—psychological aspects—all of them reported that TL would be easy to rotate and that they would not feel the merit of NTNL's centrifugal force.

Contact time was shorter in TL than in NTNL, and this resulted in TL's shorter cycle time. In other words, quick turns between contact and takeoff would be required when using TL. Yamaguchi *et al*. (6) reported that contact time was decreased when jump cycle frequency was made to decrease by using a metronome. Their finding explains that decreased cycle time would be associated with decreased contact time in TL. Yamaguchi *et al*. (6) also reported that vertical peak force of ground reaction force decreased with a decreased jump cycle frequency of more than 92 skips·min^{-1} (less than 0.65 s of cycle time). It is assumed that vertical peak force in TL would decrease because cycle time decreased more in TL than in NTNL. Possibly, TL might reduce mechanical stress according to less ground reaction force induced by shorter cycle time. Moreover, Yamaguchi *et al*. (8) reported that greater utilization of muscles and tendons' elastic components was found when jump cycle frequency increased (cycle time decreased) while skipping. As to their findings, it was thought that utilization of muscles and tendons' elastic components, along with muscles' stretch-shortening cycle, would be greater in TL than in NTNL (16,17,18). Furthermore, it was thought that the jump height of AFJ in

NTNL would be greater than in TL because AFL takeoff time with NTNL was longer than with TL. In other words, more strong steps might be required for AFJ in NTNL at each jump (skip). It was postulated that greater jump height would result from trying not to fail to maintain AFJ (the height of which was lower than the height of BJ). This could result in longer takeoff time with NTNL than with TL.

In this study, the CVs calculated ranged from 2% to 4% on average. There is no report on the CV of jump cycles in skipping. However, it was similar to CVs of step length in walking (2%–6%) in almost the same cycle frequency (0.4–0.6 steps·min^{-1}) as reported by Yamazaki *et al*. (19). Although step length is not a temporal parameter, cycle frequency is regarded as a function of step length and walking speed. At a given walking speed, variation of step length is bound to reflect that of cycle frequency. Thus, CV of cycle time of skipping could be at the same level as that of walking. In addition, a difference between skipping patterns in CVs of jump cycles (cycle time and takeoff time) was found, besides the fact that rope type made no difference in CVs of jump cycles. The CV of jump cycles in AFJ was greater than in BJ. The greater CV of cycle time seemed produced by that of takeoff time. This might relate to the jumping method, whether using both legs (BJ) or single leg (AFJ). Because gait asymmetry results from functional difference in lower extremities' laterality (20), possibly AFJ might also have laterality and cause a difference between the right and left legs while skipping. Therefore, CV of takeoff time in AFJ would be greater than in BJ. Significant correlations between skipping patterns for both ropes were found in cycle time, contact time, and takeoff time, whereas a correlation was significant in CV of cycle time only when using NTNL. Because NTNL caused takeoff time (the AFJ height of each jump) to increase, it seemed as if AFJ were close to BJ. As it remains within the realm of speculation, the CV associated with that of BJ might be found in cycle time and takeoff time in NTNL. Conversely, TL caused a difference in takeoff time between BJ and AFJ; also, TL made a clear difference in CV of cycle time between skipping patterns.

Consequently, TL reduced contact time and shortened cycle time because it was easy to rotate. TL is also expected to decrease vertical peak ground reaction force and increase utilization of muscles and tendons' elastic components. On the other hand, NTNL was not so easy to rotate that it increased cycle time regardless of skipping patterns and led to a greater jump height in AFJ (longer takeoff time). Therefore, CV of cycle time in AFJ was related to that in BJ when using NTNL. These results might provide rope skippers or trainers a concrete purpose for using different types of ropes. For instance, TL would lend itself well to consecutive jumps for several minutes because it does not require high jumps, especially in AFJ. As decreasing cycle time leads efficient cyclic exercise due to increasing utilization of muscles and tendons' elastic components, TL could extend exercise duration in endurance training. On the contrary, longer takeoff time, along with greater jump height, such as observed in NTNL, has a high utility value for jump training. Especially, increasing the takeoff time of AFJ in NTNL would increase the load to a supporting leg. Therefore, it was supposed that the difference in jump cycles would be caused by rope type, and this information could be useful for different training purposes. Moreover, to investigate the difference of jump cycles and their variation in detail, using many types of ropes with different diameters and/or weights could yield possibilities for developing specialized rope for various training purposes. This is a subject for further research.

Conclusion

This study examined effects of commercial types of ropes on jump cycles during skipping. Two ropes with different diameters and weights showed differences in cycle and contact times. Presumably, this difference was associated with vertical peak ground reaction force and utilization of elastic components of muscle and tendon. Furthermore, rope type affected takeoff time in alternate-foot jumps so that type might relate to jump height. On the other hand, the cycle variability of skipping, on average, showed no difference according to rope type. However, type of rope did make a difference in correlation between skipping patterns. In NTNL, a significant correlation was found in CV of cycle time between skipping patterns. Probably, CV of cycle time in NTNL between skipping patterns is associated with that in TL. This might be associated with greater AFJ jump height with NTNL. In AFJ, NTNL made takeoff time increase, and subjects tried to jump high. This seems as if AFJ were close to BJ so that the CV related to CV of cycle time in BJ might lead. Thus, this study's results suggested that different rope types would affect jump cycles during skipping. Possibly, moreover, the type of rope used for skipping could be chosen according to training purpose if exercise stimuli depend on the rope.

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