Original Article

Technical tasks in forward upward circling performed by elementary school children according to skill level

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Abstract:

Forward upward circling is an exercise in which the body rotates around a horizontal bar using forward upward movement of the legs. This study aimed to clarify the technical tasks in forward upward circling performed by elementary school children according to skill level by constructing motion models of the exercise. Motions and body composition indices of 52 fifth-grade elementary school children were collected. Motions were recorded in two dimensions in the sagittal plane by using a high-speed camera. All participants were classified into excellent, good, poor, or unsuccessful groups based on subjective evaluation. There were no significant differences in body composition indices among the four groups, suggesting that technical characteristics have a greater effect on the success of forward upward circling compared with physical characteristics. In the excellent group, the maximum angular velocity of the swing leg was large and vigorous forward upward circling was performed in a short time. In the good group, the maximum angular velocity of the support leg appeared earlier but the trunk was not raised in a short time from the inverted suspended position. In the poor group, the trunk leaned backward during the non-support phase and the hip joint did not rotate close to the horizontal bar in coordination with the swinging motion of the swing leg. In the unsuccessful group, the trunk leaned backward and the elbow joint extended during the support phase and the head was not pulled away from the horizontal bar to provide the necessary momentum to rotate the body and raise the support leg.

KeyWords: physical education, motion analysis horizontal bar, gymnastics, motion model

Introduction

Forward upward circling is a gymnastic exercise in which the body is rotated around a horizontal bar with forward upward movement of the legs. This exercise is part of the elementary physical education curriculum in Japan, and elementary school children strongly desire to achieve it (Ogawa, 2017). However, the skill level of forward upward circling is likely to be directly linked to a child's attitude toward exercise ("I like it because I can do it" and "I do not like it because I cannot do it") (Hayashi et al., 2009). Children who cannot do forward upward circling may experience negative emotions such as feelings of sadness, frustration, and inferiority, which can cause them to dislike exercise in general (Hashizume and Matsuda, 2002; Hariya et al., 2019). Current elementary school curriculum guidelines state that the goal of physical education is to develop the qualities and abilities necessary for lifelong enjoyment of physical exercise and to cultivate practical abilities for the maintenance and improvement of health and physical fitness (MEXT, 2018a). Therefore, teachers should provide appropriate physical education guidance in elementary schools that will enable children to successfully perform forward upward circling.

Previous kinematic studies have compared the successful and unsuccessful attempts of children to perform forward upward circling. For example, Okuno and Domoto (2016) reported that the elbow joints flexed when the head was positioned at the lowest point and the shoulder joint extended after the support leg left the ground, which caused the upper limbs and trunk to approach the horizontal bar. Moreover, the hip flexion of the swing leg before and after the support leg left the ground and the hip and knee flexion of the support leg after the support leg left the ground caused the pelvis to approach the horizontal bar. In addition, Hashizume and Takamura (2005) compared the ground reaction force of the support leg in successful and unsuccessful attempts. Their study found that in the successful attempts, the ground reaction force acted towards the front direction of the support leg at the instant the swing leg left the ground, thereby increasing the momentum of the swing leg. After the swing leg left the ground, the ground reaction force acted toward the back direction of the support leg, causing the pelvis to move toward the horizontal bar. Furthermore, a kinetics study that analyzed upper limb joint torque (Konosu et al. 2017) and an energetics study that investigated the energy of the swing leg (Konosu et

al., 2018) reported various factors leading to successful attempts.

Meanwhile, some techniques are introduced as examples in the commentary of the government education guidelines for elementary schools (MEXT, 2018b), including swinging the legs, flexing the elbow joints, leaning the trunk backward, and twisting the wrists. According to the instruction book (Takahashi et al., 1992), 1) flexing the elbow joints to pull the horizontal bar closer, 2) swinging the swing leg up vigorously, 3) rotating the body around while putting the pelvis on the horizontal bar, and 4) raising the head while twisting the wrists, supported by the upper limbs. The individual movements of forward upward circling described in the guidelines and the instruction books agree with the findings of the previous studies such as Okuno and Domoto (2016) and Hashizume and Takamura (2005). However, these findings were obtained from comparisons between successful and unsuccessful attempts or from analyses of only successful attempts. In gymnastics, which includes horizontal bar exercises, performance is generally assessed based on success or failure; however, various skill levels are exhibited during attempts. The same applies to forward upward circling as well. In other words, even in successful attempts, sometimes the body rotates smoothly, and other times the body rotates while barely putting the pelvis close to the horizontal bar. Among unsuccessful attempts, there are close attempts in which the pelvis is raised up enough to achieve an inverted suspension position, and there are attempts that are far from successful in which the pelvis is not raised up to even the height of the horizontal bar. Considering this wide range of skill levels, the technical tasks that individual learners should prioritize and address differ according to their respective skill levels. Even among the many technical tasks, leaning the trunk backward during the non-support phase and swinging the swing and support legs must not only be performed in a short time, but also in coordination with other movements (Hashizume and Takamura, 2005), and are therefore considered difficult technical tasks. Thus, it is likely that there are differences among technical tasks that individual learners should prioritize and address to successfully perform forward upward circling.

Previous studies conducted evaluations based on successful or unsuccessful attempts and instruction books did not provide instructions according to skill level. Thus, when teaching the horizontal bar exercise, teachers have tended to present the exercise to children as a set of uniform technical tasks, which is not appropriate for each child, given their individual skill levels.

In addition, other studies have compared quantitative data, such as the joint angles and ground reaction forces of successful and unsuccessful attempts. However, it seems difficult to imagine the specific characteristics of motions associated with these quantitative data. In other words, in order to utilize the findings from previous studies, it is necessary to present them visually in actual instruction as specific motions that reflect quantitative data. One way to solve this problem is to use a standard motion model (Ae et al., 2007). In this method, a motion (mean) model is constructed based on multiple subjects. In so doing, quantitative data such as angle and speed can be presented visually along with a series of motions in chronological order (Kobayashi et al., 2012; Shimizu et al., 2018). By applying this method to the forward upward circling, the abovementioned problem can be solved.

The purpose of this study was to clarify the technical tasks involved in forward upward circling according to skill level by constructing motion models of elementary school children. In addition, the hypothesis of this study was that the technical tasks that should be addressed on a priority basis differ according to the learner's skill level. In particular, the degree to which the trunk can be leaned backward and the swinging motion of the swing leg and support leg differ according to skill level.

Materials & methods

Participants

Forward upward circling attempts were performed during the physical education class in October 2018 by 52 fifth-grade elementary school children (1st class of 27 children, 2nd class of 25 children; 27 boys, 25 girls; 26 successful attempts, 26 unsuccessful attempts).

Before the data collection, the content and safety of this study were explained to the principal of the elementary school, the physical education teacher, and the children, and approval to participate in the study was obtained. We explained that participation in this study was voluntary, consent to participate could be withdrawn at any time, and no disadvantage was incurred if consent to participate in the study was not given. This study was approved by the * University School of Human Sciences Ethics Committee (approval number 4, approved June 2018; expiration date, March 2021). This study was conducted in accordance with the directives of the Helsinki Declaration.

Data collection

The children were instructed to perform the forward upward circling exercise twice on a low horizontal bar. In this study, the children performed forward upward circling by swinging one leg, which is the most common method used in elementary school physical education classes in Japan.

The experiment was conducted in the gymnasium of the elementary school, using a low horizontal bar. Three heights (1.05 m, 1.10 m, and 1.15 m) were set based on the range that fit from the chest to the shoulder (Konosu et al., 2018), and the children were allowed to select any height. The children were allowed to perform the attempt using the reverse grip, which was based on a finding that there is no statistically significant

difference in the skill required to perform forward upward circling according to the grip used (Hashizume and Matsuda, 2002). Ten children used the reverse grip.

One high-speed camera (Exilim EX-F1, Casio Inc.) was used to record the attempts and was placed 15 m from the horizontal bar so that analysis could be performed from a two-dimensional sagittal plane. The recording speed was set at 300 fps, and the exposure time was set at 1/500 s. Before the data collection was started, calibration poles (height: 2.5 m) with six markers at 0.5-m interval were placed in three spots (width: 2.0 m) at 1.0-m intervals. Calibration was carried out so that the real length conversion could be performed using the two-dimensional direct linear transformation method.

In this study, height, weight, muscle mass (whole body, upper limbs, and lower limbs), skeletal muscle mass, body fat mass, percentage of body fat, waist circumference, body mass index, skeletal muscle index, Kaup index, and Laurel index were measured as body composition indices using a height scale and body composition meter (InBody 470, InBody Japan K.K.). In addition, grip strength was measured twice each on the left and right side using an analog grip meter (TKK5001, Toei Light Co., Ltd.), and the mean of the left and right measurements was used in the analysis.

Data processing

The collected video images were digitized at 100 Hz and converted to real length using Frame-DIAS 5 (DKH Inc.). Mean reconstruction errors were 0.2 cm on the X coordinate and 0.4 cm on the Y coordinate.

The motion analysis landmarks were the elbow joint, shoulder joint, toe, heel, ankle joint, knee joint, hip joint, head, ear, and the horizontal bar. In this study, the data were collected during the time constraints of the physical education class; therefore, markers could not be attached to each part of the body, and so each part of the body was digitized manually from the video images. In order to ensure the accuracy of the digitization, the toes, heels, ankles, and knees on the left and right half sides were digitized and the elbows, shoulders, and hips on the camera side (right half) were digitized. The digitizing process was based on the method of Okuno and Domoto (2016). In this study, three researchers with digitizing experience (one university faculty lecturer and two university students) confirmed and corrected the accuracy of all digitizations.

The two-dimensional coordinates obtained for each motion analysis point were smoothed using a Butterworth low-pass digital filter after determining the optimal cutoff frequency, following the Winter method (2009). The optimal cut-off frequency was 7.0–9.0 Hz.

The subjective evaluation of the forward upward circling attempts was performed by three evaluators; one university researcher with experience as a competitive gymnastic athlete and two university students majoring in health and physical education. The video images of all attempts were viewed by these three evaluators, and the forward upward circling proficiency of each student was evaluated on 10 levels: 5 levels for successful attempts and 5 levels for unsuccessful attempts (good evaluation: 10 points).

Then, based on the evaluation criteria provided by Kunii (2014), the mean score of the three evaluators was classified as “outstanding attempt” (9.0 points or more), “executed attempt” (7.0–8.9 points), and “barely executed attempt” (5.0–6.9 points), “almost executed attempt” (3.0–4.9 points), and “unsuccessful attempt” (2.9 points or less).

In this study, the leg that took off first was defined as the swing leg, while the leg that took off second was defined as the support leg. Moreover, 90-deg, 180-deg, and 270-deg points were defined counterclockwise from the standard point (0-deg), which was perpendicular to the horizontal bar. Some passage frames of the foot of the support leg or the head were obtained from the coordinate data or the video images.

The following frames were collected for successful attempts: ① the frame when the foot of the swing leg left the ground, ② the frame when the foot of the support leg left the ground, ③ the frame when the foot of the support leg passed the 90-deg point, ④ the frame when the foot of the support leg passed the 180-deg point, ⑤ the frame when the foot of the support leg passed the 270-deg point, and ⑥ the frame when the head passed the 90-deg point.

The following frames of events were collected for unsuccessful attempts: ① the frame when the foot of the swing leg left the ground, ② the frame when the foot of the support leg left the ground, ③ the frame when the foot of the support leg passed the 90-deg point, ④ the frame when the foot of the support leg reached its maximum elevation, ⑤ the frame when the foot of the support leg passed the 90-deg point a second time, and ⑥ the frame when the foot of the leg first landed. For unsuccessful attempts, as described later, the foot of the support leg did not pass the 90-deg point, and data for events ③ to ⑤ could not be collected. Consequently, the data from only frames ①, ②, and ⑥ were collected.

Based on each event, the first phase was defined as frames ① and ②, the second phase as frames ② and ③, the third phase as frames ③ and ④, the fourth phase as frames ④ and ⑤, and the fifth phase as frames ⑤ and ⑥. Finally, the motion time of each phase and the percentage of the total motion time were calculated and the time-series data were normalized such that frames ①–⑥ totaled 100%.

Analysis data and calculation method

The following kinematic variables were calculated with reference to previous studies on forward upward circling (Okuno and Domoto, 2016; Okamoto, 2017).

a) Trajectory of the head and hip joint: changes in the relative coordinates of the head and hip joint with the horizontal bar as the origin were used to calculate the trajectory.

b) Take-off position of the swing leg and support leg: the horizontal distance from the horizontal bar to the toe of the swing leg and that of the support leg were defined as the take-off positions of the swing leg and the support leg, respectively.

c) Trunk angle: the angle between the vector from the shoulder joint to the hip joint and the vertical line was defined as the trunk angle. Positive values were taken counterclockwise, while negative values were taken clockwise from the vertical line.

d) Joint angles: the angle between the vector from the elbow joint to the horizontal bar and the vector from the elbow joint to the shoulder joint was defined as the elbow joint angle. The angle between the vector from the knee joint to the hip joint and the vector from the knee joint to the ankle joint was defined as the knee joint angle. The angle between the vector from the hip joint to the shoulder joint and the vector from the hip joint to the knee joint was defined as the hip joint angle.

e) Angular velocities of the swing leg and support leg: the angle between the vector from the hip joint to the ankle joint and the vertical line was defined as the swing leg and support leg angle, and the angular velocities of the swing leg and support leg were calculated by differentiating the swing leg and support leg angle by time.

Construction of a motion model

The Kaup index was calculated from the height and weight of the children; the body segment inertia coordinates were calculated using the Kaup index and the body segment inertia coefficient of Yokoi et al. (1986). The averaged motion models were obtained as normalized coordinate data by each motion phase time and the child's height, as given by the following equations (Ae et al., 2007).

$$\begin{aligned} \mathbf{r}_{i,j} &= \mathbf{R}_{i,j} - \mathbf{R}_{rp,j} \\ \mathbf{nr}_{i,j} &= \frac{\mathbf{r}_{i,j}}{H} \\ \mathbf{r}_j &= \frac{\sum_{i=1}^n \mathbf{nr}_{i,j}}{n} \\ \overline{\mathbf{R}_{rp}} &= \frac{\sum_{j=1}^n \mathbf{R}_{rp,j}}{n} \\ \overline{\mathbf{R}_i} &= \overline{\mathbf{r}_i} + \overline{\mathbf{R}_{rp}} \end{aligned}$$

Here, $\mathbf{r}_i$ is the relative coordinate vector from $\mathbf{R}_{i,j}$ to $\mathbf{R}_{rp,i}$ (coordinate vectors of landmark **i** and reference point (**rp**) for children **j**, both of which were normalized to motion phase time), $\mathbf{nr}_i$ is the vector normalized to height (**H**), $\overline{\mathbf{r}_i}$ is the mean normalized coordinate vector, **n** is the number of individuals, $\mathbf{R}_{rp}$ is the mean normalized coordinate vector of the **rp**, and $\overline{\mathbf{R}_i}$ is the mean normalized coordinate vector of the landmark number **i** (Shimizu et al., 2018).

Statistical analysis

The differences in averaged data for the forward upward circling attempts that were grouped by subjective evaluations were compared using non-parametric tests. The chronological change was excluded from the discussion in this study. The Mann–Whitney U-test (hereafter, the “U-test”) was used to test the differences between the two groups, and the Kruskal–Wallis H-test (hereafter, the “H-test”) was used to test the differences among the three groups. If a significant difference was found in the H-test, a post-hoc test was performed using Bonferroni's multiple comparison test (hereafter “posthoc test”). In all tests, the level of significance was below 5%.

Results

Three evaluators subjectively evaluated the forward upward circling attempts of all 52 children. Thirteen children (6 girls) were evaluated as “outstanding attempt” (excellent group), 13 children (6 girls) as “executed attempt” (good group), 0 children as “barely executed attempt”, 12 children (5 girls) as “almost executed attempt” (poor group), and 14 children (8 girls) as “unsuccessful attempt” (unsuccessful group).

Table 1 shows the average body composition indices (height, weight, muscle mass, skeletal muscle mass, body fat mass, body fat percentage, abdominal circumference, body mass index, skeletal muscle index, Kaup index, and Laurel index) and the grip strength of the four groups. No significant differences were found between any of the body composition indices and grip strength.

Table 1. Body composition indices and grip strength

	Excellent (n=13)		Good (n=13)		Poor (n=12)		Unsuccessful (n=14)		Statistical analysis Kruskal-Wallis H-test		
	M	S.D.	M	S.D.	M	S.D.	M	S.D.	χ^2	p	
Height (cm)	138.45	7.88	140.86	7.61	143.23	7.19	145.73	4.83	6.03	0.11	n.s.
Weight (kg)	32.80	3.92	35.58	7.75	35.20	4.53	36.21	5.96	2.43	0.49	n.s.
Muscle mass whole body (kg)	25.52	3.19	27.36	4.79	26.85	3.10	27.46	3.50	2.45	0.48	n.s.
Muscle mass upper limbs (kg)	2.02	0.28	2.32	0.64	2.12	0.40	2.14	0.53	1.80	0.61	n.s.
Muscle mass lower limbs (kg)	7.42	1.42	7.94	1.61	7.80	1.29	8.02	1.50	1.32	0.72	n.s.
Skeletal muscle mass (kg)	14.17	2.01	15.29	3.05	14.91	1.93	15.26	2.28	1.95	0.58	n.s.
Body fat mass (kg)	5.72	1.38	6.56	3.20	6.65	2.53	7.01	3.38	0.93	0.82	n.s.
Percentage of body fat (%)	17.36	3.47	17.77	5.48	18.65	5.35	18.66	6.63	0.35	0.95	n.s.
Waist circumference (cm)	59.04	2.07	61.58	5.17	60.67	2.80	62.08	4.05	4.61	0.20	n.s.
Body mass index (BMI)	17.10	1.20	17.83	2.68	17.30	1.68	17.02	2.43	0.02	0.99	n.s.
Skeletal muscle index (SMI)	4.90	0.45	5.13	0.68	4.85	0.51	4.76	0.81	1.04	0.79	n.s.
Kaup index	17.08	1.20	17.80	2.64	17.13	1.62	17.02	2.44	0.05	0.99	n.s.
Laurel index	123.87	12.55	126.40	17.53	119.89	13.04	116.92	16.97	1.33	0.72	n.s.
Grip strength (kg)	15.08	2.53	16.31	3.60	14.79	2.94	14.89	3.22	1.23	0.75	n.s.

The top part of Figure 1 shows the sticks of the model motion constructed from the forward upward circling attempts of the excellent and good groups. The time when the foot of the support leg left the ground in the excellent group was at 15% normalized time and that in the good group was at 13% normalized time. The time when the foot of the swing passed the 180-deg point in the excellent group was at 36% normalized time and that in the good group was at 33% normalized time. The time when the foot of the support leg passed the 180-deg point in the excellent group was at 46% normalized time and that in the good group was at 42% normalized time.

The bottom part of Figure 1 shows the sticks of the model motion constructed from the forward upward circling attempts of the poor and unsuccessful groups. The time when the foot of the support leg left the ground in the poor group was at 17% normalized time and that in the unsuccessful group was at 30% normalized time. The foot of the support leg of the poor group did not pass the 180-deg point and that of the unsuccessful group did not pass the 90-deg point.

The take-off position of the swing leg was 0.36 ± 0.09 m for the excellent group, 0.36 ± 0.12 m for the good group, 0.28 ± 0.13 m for the poor group, and 0.28 ± 0.21 m for the unsuccessful group. There was no significant difference among the four groups from the results of the H-test ($\chi^2 = 4.330$, $p = 0.228$). Similarly, the take-off position of the support leg was 0.31 ± 0.09 m in the excellent group, 0.24 ± 0.11 m in the good group, 0.28 ± 0.08 m in the poor group, and 0.27 ± 0.12 m in the unsuccessful group. There was no significant difference among the four groups from the results of the H-test ($\chi^2 = 3.245$, $p = 0.355$).

Figure 1. Sticks of the model motion of the successful and unsuccessful attempts

The top row of Table 2 shows the motion phase time and the percentage of each phase for all phases of the excellent and good groups. The fourth phase (excellent group: 0.380 ± 0.182 s, good group: 0.558 ± 0.214 s, $|z| = 2.285$, $p = 0.022$) and the whole time (excellent group: 1.574 ± 0.321 s, good group: 1.759 ± 0.204 s, $|z| = 2.437$, $p = 0.015$) were significantly shorter in the excellent group than in the good group.

The bottom row of Table 2 shows the motion phase time and the percentage of each phase for all phases of the poor and unsuccessful groups. The first phase was significantly shorter in the poor group than in the unsuccessful group (poor group: 0.233 ± 0.031 s, the unsuccessful group: 0.269 ± 0.048 s, $|z| = 2.437$, $p = 0.015$). Meanwhile, the total motion time from the second phase to the fifth phase (poor group: 1.201 ± 0.249 s, unsuccessful group: 0.728 ± 0.302 s, $|z| = 3.268$, $p = 0.001$) and the whole time (poor group: 1.434 ± 0.245 s, unsuccessful group: 0.996 ± 0.295 s, $|z| = 3.267$, $p = 0.001$) were significantly longer in the poor group than in the unsuccessful group.

In addition, although not shown in Table 2, the first and second phases could be collected even in the poor group. Therefore, the H-test was performed in the excellent, good, and poor groups but not in the unsuccessful group. The H-test results of the three groups showed no significant difference in the first phase ($\chi^2 = 0.757$, $p = 0.684$) but did in the second phase ($\chi^2 = 8.006$, $p = 0.018$). In addition, as a result of the post-hoc test in the second phase, the poor group (0.278 ± 0.034 s) showed a significantly longer motion phase time compared with the excellent group (0.238 ± 0.044 s) and the good group (0.237 ± 0.023 s) ($p < 0.05$).

Table 2. Motion phase time of forward upward circling

	Excellent group (n=13)		Good group (n=13)		Statistical analysis Mann-Whitney U-test	
	M	S.D.	M	S.D.	Z	p
First phase: a	0.225s (14.5%)	0.051s (3.1%)	0.220s (12.7%)	0.039s (2.9%)	0.000	1.000
Second phase: a	0.238s (15.4%)	0.044s (3.4%)	0.237s (13.6%)	0.023s (1.6%)	0.364	0.716
Third phase: a	0.242s (15.7%)	0.057s (4.0%)	0.273s (15.6%)	0.083s (4.8%)	0.874	0.382
Fourth phase: a	0.380s (23.4%)	0.182s (7.9%)	0.558s (31.3%)	0.214s (9.8%)	2.285*	0.022
Fifth phase: a	0.488s (30.9%)	0.167s (6.9%)	0.471s (26.8%)	0.126s (7.4%)	0.590	0.555
Total: a	1.574s (100.0%)	0.321s (0.0%)	1.759s (100.0%)	0.204s (0.0%)	2.437*	0.015

	Poor group (n=12)		Unsuccessful group (n=14)		Statistical analysis Mann-Whitney U-test	
	M	S.D.	M	S.D.	Z	p
First phase: a	0.233s (16.8%)	0.031s (4.3%)	0.269s (29.4%)	0.048s (9.8%)	2.437*	0.015
Second phase: a	0.278s (19.8%)	0.034s (5.2%)	※ 0.728s (70.6%)	0.302s (9.8%)	3.268*	0.001
Third phase: b	0.386s (25.5%)	0.227s (13.4%)				
Fourth phase: b	0.282s (19.0%)	0.188s (10.4%)				
Fifth phase: b	0.260s (18.9%)	0.045s (6.1%)	0.996s (100.0%)	0.295s (0.0%)	3.267*	0.001
Total: b	1.434s (100.0%)	0.245s (0.0%)				

a : Phase definition used for successful attempt

b : Phase definition used for unsuccessful attempt

※ Unsuccessful group did not pass the 90-deg point, so total time from the second phase to the fifth phase

Figure 2 shows the changes in the head and hip joint trajectories.

The minimum value of the head X coordinate and the time of appearance was -0.34 ± 0.08 m (at 15% normalized time) in the excellent group, -0.38 ± 0.05 m (at 16% normalized time) in the good group, -0.36 ± 0.08 m (at 18% normalized time) in the poor group, and -0.34 ± 0.07 m (at 30% normalized time) in the unsuccessful group. The H-test showed no significant difference among the four groups ($\chi^2 = 0.818$, $p = 0.930$).

The minimum value of the head Y coordinate and the time of appearance was -0.48 ± 0.09 m (at 40% normalized time) in the excellent group, -0.51 ± 0.06 m (at 39% normalized time) in the good group, -0.49 ± 0.08 m (at 46% normalized time) in the poor group, and -0.30 ± 0.26 m (at 77% normalized time) in the unsuccessful group. The H-test showed a significant trend among the four groups ($\chi^2 = 7.540$, $p = 0.057$). The post-hoc test showed that the minimum value of the head Y coordinate of the unsuccessful group was significantly larger than that of the good group ($p < 0.05$).

The maximum value of the hip joint X coordinate and the time of appearance was 0.15 ± 0.03 m (at 36% normalized time) in the excellent group, 0.20 ± 0.03 m (at 30% normalized time) in the good group, 0.24 ± 0.04 m (at 42% normalized time) in the poor group, and 0.24 ± 0.12 m (at 81% normalized time) in the unsuccessful group. In addition, the H-test showed significant differences among the four groups ($\chi^2 = 11.798$, $p = 0.008$). The post-hoc tests showed that the maximum value of the hip joint X-coordinate was significantly smaller than in the poor group and the unsuccessful group ($p < 0.05$).

The maximum value of the hip joint Y coordinate and the time of appearance was 0.07 ± 0.02 m (at 67% normalized time) in the excellent group, 0.06 ± 0.02 m (at 77% normalized time) in the good group, -0.14 ± 0.06 m (at 50% normalized time) in the poor group, and -0.21 ± 0.08 m (at 41% normalized time) in the unsuccessful group. In addition, the H-test showed significant differences among the four groups ($\chi^2 = 42.787$, $p = 0.001$). The post-hoc tests showed that the maximum values of the hip joint Y-coordinate of the excellent

group and the good group were significantly larger than those of the poor group and the unsuccessful group ($p < 0.05$).

Figure 2. Head and hip joint trajectories

Figure 3 shows the changes in the trunk angle and the elbow, hip, and knee joint angles of each group. At the top of the graph, the time when significant differences were found among the four groups in the post-hoc test results after the H-test are marked for clarity ($p < 0.05$). In both successful and unsuccessful attempts, the movements from the 50% normalized time onward were structurally different. Therefore, comparisons between the four groups were not performed after the 50% normalized time. However, comparisons between two groups were performed for successful and unsuccessful attempts.

Figure 3a shows the changes in the trunk angle. Backward lean of the trunk was significantly greater in the higher skill level group between the excellent and poor groups ($\square$) at 50% normalized time, the excellent and unsuccessful groups ($\triangle$) at 10%–50% normalized time, the good and poor groups ($\diamond$) at 30%–50% normalized time, the good and unsuccessful groups ($\blacktriangle$) at 10%–50% normalized time, and the poor and unsuccessful groups ($\blacklozenge$) at 20% normalized time.

Figure 3b shows the changes in the elbow joint angle. Flexion of the elbow joint was significantly greater in the unsuccessful group between the excellent and unsuccessful groups ($\triangle$) at 20%–40% normalized time; the good and unsuccessful groups ($\blacktriangle$) at 30%–50% normalized time, and the poor and unsuccessful groups ($\blacklozenge$) at 40%–50% normalized time.

Figure 3c shows the changes in the hip joint angle of the swing leg. Flexion of the hip joint was significantly greater in the good group between the good and poor groups ($\diamond$) at 20% normalized time and the good and unsuccessful groups ($\blacktriangle$) at 20% normalized time.

Figure 3d shows the changes in the knee joint angle of the swing leg. Flexion of the knee joint was significantly greater in the unsuccessful group between the excellent and unsuccessful groups ($\triangle$) at 0%–10% normalized time and the poor and unsuccessful groups ($\blacklozenge$) at 60%–70% normalized time.

Figure 3e shows the changes in the hip joint angle of the support leg. Flexion of the hip joint was significantly greater in the lower skill level group between the excellent and unsuccessful groups ($\triangle$) at 10% normalized time, the good and unsuccessful groups ($\blacktriangle$) at 10% normalized time, the poor and unsuccessful groups ($\blacklozenge$) at 10% normalized time, the excellent and good groups ($\circ$) at 20% normalized time, and the good and poor groups ($\diamond$) at 20% normalized time. Moreover, extension of the hip joint was significantly greater in the lower skill level group between the good and poor groups ($\diamond$) at 30% normalized time, the excellent and unsuccessful groups ($\triangle$) at 40% normalized time, the good and unsuccessful groups ($\blacktriangle$) at 30%–50% normalized time, and the poor and unsuccessful groups ($\blacklozenge$) at 40%–50% normalized time.

Figure 3f shows the changes in the knee joint angle of the support leg. Flexion of knee joint was significantly greater in the unsuccessful group between the excellent and unsuccessful groups ($\triangle$) at 10% normalized time and the good and unsuccessful groups ($\blacktriangle$) at 10% normalized time. Flexion of the knee joint was significantly greater in the good group between the excellent and good groups ($\circ$) at 20% normalized time,

the good and poor groups ($\diamond$) at 20% normalized time, and the good and unsuccessful groups ($\blacktriangle$) at 20%–30% normalized time. Moreover, flexion of the knee joint was significantly greater in the unsuccessful group between the good and unsuccessful groups ($\blacktriangle$) at 50% normalized time. In addition, flexion of the knee joint was significantly greater in the poor group between the poor and unsuccessful groups ($\blacklozenge$) at 30% normalized time, and was significantly greater in the unsuccessful group at 60% normalized time.

Figure 3. Changes in trunk angle and joint angle

Figure 4 shows the changes in the angular velocity of the swing leg and support leg. At the top of the graph, the time when significant differences were found among the four groups in the results of the post-hoc test performed after the H-test are marked for clarity ($p < 0.05$). Similar to the trunk and joint angles (Figure 3), the motions from the 50% normalized time onward were structurally different. Therefore, comparisons between the four groups were not performed after the 50% normalized time. However, comparisons between the two groups were performed for the successful and unsuccessful attempts. Moreover, in order to present the time points at which the maximum value for each group appeared in detail, the appearance of the maximum values in all groups up to the 50% normalized time were presented at 5% normalized time intervals.

Figure 4a shows the changes in the angular velocity of the swing leg. Positive angular velocity of the swing leg was significantly greater in the excellent group between the excellent and poor groups ($\square$) at 5% normalized time and the excellent and unsuccessful groups ($\triangle$) at 5% normalized time. In contrast, positive angular velocity of the swing leg was significantly greater in the unsuccessful group between the excellent and unsuccessful groups ($\triangle$) at 30% normalized time, the good and unsuccessful groups ($\blacktriangle$) at 25%–40% normalized time, and the poor and unsuccessful groups ($\blacklozenge$) at 30% normalized time.

In addition, the maximum value and the time of appearance was $768.2 \pm 117.1 \text{ deg/s}$ (at 7% normalized time) in the excellent group; $627.2 \pm 136.2 \text{ deg/s}$ (at 7% normalized time) in the good group, $614.2 \pm 156.3 \text{ deg/s}$ (at 8% normalized time) in the poor group, and $553.8 \pm 121.2 \text{ deg/s}$ (at 15% normalized time) in the unsuccessful group. Moreover, the H-test results showed significant difference among the four groups ($\chi^2 = 15.194$, $p = 0.002$). The post-hoc test showed that the excellent group had a significantly higher maximum positive angular velocity in the swing leg compared with the good, poor, and unsuccessful groups ($p < 0.05$).

Figure 4b shows the changes in the angular velocity of the support leg. Positive angular velocity of the support leg was significantly greater in the unsuccessful group between the excellent and unsuccessful groups ($\triangle$) at 5% normalized time, and the good and unsuccessful groups ($\blacktriangle$) at 5% normalized time. In contrast, positive angular velocity of the support leg was significantly smaller in the unsuccessful group between the excellent and unsuccessful groups ($\triangle$) at 15%–30% normalized time, the good and unsuccessful groups ($\blacktriangle$) at 10%–30% normalized time, and the poor and unsuccessful groups ($\blacklozenge$) at 25%–35% normalized time. In addition, positive angular velocity of the support leg was significantly smaller in the poor group between the good and poor groups ($\diamond$) at 10%–20% normalized time. Positive angular velocity of the support leg was

significantly smaller in the good group between the good and unsuccessful groups ($\blacktriangle$) at 45%–50% normalized time.

In addition, the maximum value and the time of appearance was $601.0 \pm 142.3 \text{ deg/s}$ (at 25% normalized time) in the excellent group, $641.8 \pm 49.4 \text{ deg/s}$ (at 21% normalized time) in the good group, $570.5 \pm 73.1 \text{ deg/s}$ (at 29% normalized time) in the poor group, and $335.5 \pm 164.1 \text{ deg/s}$ (at 42% normalized time) in the unsuccessful group. The H-test showed significant differences among the four groups ($\chi^2 = 27.917$, $p = 0.001$). The post hoc tests showed that the maximum positive angular velocity in the support leg was significantly higher in the excellent, good, and poor groups compared with the unsuccessful group ($p < 0.05$).

Figure 4. Changes in the angular velocity of the swing leg and support leg

Discussion

Success or failure of forward upward circling

The forward upward circling attempts of all 52 participants in this study were classified into four groups by the three evaluators: the excellent group ($n = 13$), the good group ($n = 13$), the poor group ($n = 12$), and the unsuccessful group ($n = 14$). There were no significant differences in body composition indices and grip strength among the four groups (Table 1). These results suggest that physical characteristics do not affect the success of forward upward circling in elementary school children. In other words, technical characteristics are considered to have a greater effect on the success of forward upward circling compared with physical characteristics.

Technical tasks of successful attempts

First, the skill level of technical tasks for performing forward upward circling were clarified by comparing the excellent and good groups. The technical characteristics of the excellent group showed that (1) the motion phase time during the fourth phase and the whole time was significantly shorter (Table 2), (2) the extension of the hip and the knee joint of the support leg at 20% normalized time was significantly larger (Figure 3e and f), (3) the maximum angular velocity of the swing leg was significantly greater (Figure 4a), and (4) the maximum angular velocity of the support leg tended to appear later (Figure 4b).

Konosu et al. (2018) reported that the momentum of the swing leg and the energy flow from the thigh of the swing leg to the trunk during the first-half phase contributed substantially to the success of forward upward circling. These results suggest that it is important to raise the swing leg vigorously, that is, to increase the maximum value of the angular velocity of the swing leg during the first-half phase, to successfully perform forward upward circling. In contrast, the energy of the swing leg decreases in the latter half of forward upward circling, and so the energy of the support leg must be used more effectively. In the excellent group, the extension of the hip and the knee joint of the support leg at 20% normalized time significantly increased, which seems to have caused a delay in the time when the maximum value of the support leg angular velocity appeared (excellent group at 25% normalized time; good group at 21% normalized time), and passage of the support leg at the 180-deg point was delayed (excellent group at 46% normalized time; good group at 42% normalized time). Moreover, although there was no significant difference, the angular velocity of the support leg tended to be smaller at 30%–70% normalized time in the good group compared with that in the excellent group (Figure 4b). These results suggest that the excellent group could maintain the momentum of the backward rotation of the

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body until the end phase of forward upward circling by delaying the swing of the support leg. This is likely why the fourth phase in the excellent group was completed in a shorter time compared with the good group.

The above results indicate that the gap between 'good' and 'excellent' performances could be closed by (1) vigorously swinging the swing leg and (2) delaying the swing of the support leg to maintain the momentum of the backward rotation of the body until the end phase. Technical tasks related to the swing leg have been described in previous research (Hashizume and Takamura, 2005) and in instruction manuals (MEXT, 2018b; Takahashi, 1992). However, technical tasks related to the support leg have not been reported. That is, the present study is the first to use motion analysis to describe these technical tasks according to the skill level.

Technical tasks of unsuccessful attempts

Next, the good and poor groups were compared to clarify the technical tasks of the poor group. The technical characteristics of the poor group showed motion until the inverted suspension position; however, the foot of the support leg did not pass the 180-deg point. Moreover, focusing on the trajectory of the hip joint, the maximum value of the X-coordinate of the hip joint and the time point of appearance (0.24 ± 0.04 m, at 42% normalized time) of the poor group were significantly larger and delayed compared with those of the good group (0.20 ± 0.03 m, at 30% normalized time) (Figure 2a and b). These findings suggest that the key technical task of the poor group is rotating the hip joint away from the horizontal bar during the second and third phases.

One of the factors that brought the hip joint closer to the horizontal bar is the coordinated movement required to perform forward upward circling. Hashizume and Takamura (2005) reported that leaning the trunk backward and swinging the swing leg after the foot of the support leg left the ground in a coordinated manner affected the backward rotation of the body in successful forward upward circling attempts. In addition, Takahashi (1989) pointed out that even children with weak muscles could successfully perform the exercise by leaning the trunk backward. Although leaning of the trunk backward at 30% normalized time was significantly smaller in the poor group than in the good group (Figure 3a), the maximum value of the angular velocity of the swing leg in the poor group was similar to that of the good group (Figure 4a). Therefore, in the case of the poor group, leaning the trunk backward should be more strongly emphasized and performed in a coordinated manner with the leg swing. In this study, data on the effect of the ground reaction force on the kicking motion of the support leg was not collected. However, it was assumed that leaning the trunk backward and swinging the swing leg in a coordinated manner led to a vigorous backward rotation of the whole body after the foot of the support leg left the ground. These findings suggest that this coordinated movement functions to keep the hip joint from leaving the horizontal bar.

Finally, the technical tasks of the unsuccessful group were obtained by comparison with the other groups. The technical characteristics of the unsuccessful group showed that the foot of the support leg did not pass the 90-deg point and the inverted suspension position was not achieved. The minimum value of the Y coordinate of the head was significantly higher in the unsuccessful group (-0.30 ± 0.26 m) than in the good group (-0.51 ± 0.06 m). Even when compared with the other groups, the head of those in the unsuccessful group passed close to the horizontal bar (Figure 2a and b). In addition, compared with the excellent and good groups, the unsuccessful group showed a significantly smaller backward leaning of the trunk at 10% normalized time (Figure 3a), and a significantly larger flexion of the elbow joint during the 20%–50% normalized time (Figure 3b).

Okamoto and Ichikawa (2018) pointed out that, in the forward support rotation, moving the head as far as possible from the horizontal bar increased the radius of rotation between the head and the horizontal bar, thereby enabling the momentum of the forward rotation of the body (angular momentum) to increase. In forward upward circling, it is important to maintain a large radius of rotation and momentum of backward rotation by increasing the extension of the elbow joint, leaning the trunk backward, and moving the head trajectory away from the horizontal bar as much as possible. Therefore, the technical task of the unsuccessful group was to pass the head close to the horizontal bar while maintaining their position close to the bar.

In addition, compared with the other groups, the maximum values of the angular velocities of the swing leg and support leg in the unsuccessful group were significantly smaller and the appearance time was also delayed (Figure 4a and b). As mentioned above, success in forward upward circling requires vigorously swinging the swing leg upward. However, Ogawa (2017) pointed out that if the swing leg was swung up vigorously, it would be difficult for unskilled children to synchronize the swinging of the support leg. The unsuccessful group in the present study did not swing their swing leg up vigorously enough, rather than having inappropriate timing of swing up. Therefore, the unsuccessful group needs to practice more vigorously swinging their swing leg. Such motion improvements will allow them to raise the hip joint of their support leg by increasing the momentum of the backward rotation.

One of limitations of previous studies on forward upward circling is that they evaluated successful and unsuccessful attempts without considering the skill level of the children and all the technical tasks were handled uniformly. In addition, previous studies did not use a motion model to visualize differences in quantitative data. Therefore, in this study we constructed four motion models according to skill level and presented the technical characteristics of each group visually. We found that the technical tasks and motion phases requiring improvement differed among the four groups. In particular, there were differences in leaning of the

trunk backward at 10%–50% normalized time and the maximum angular velocity of the swing leg and support leg as well as the time point when they appeared. Those findings support the hypothesis of this study.

Conclusions

The purpose of this study was to clarify the technical tasks of forward upward circling according to skill level by constructing motion models of elementary school children. The forward upward circling attempts of 52 children were classified into excellent, good, poor, and unsuccessful groups based on the subjective evaluation of three evaluators. The technical characteristics according to skill level were as follows.

There were no significant differences in the body composition indices and grip strength among the four groups, suggesting that technical characteristics have a greater effect on the success of forward upward circling compared with physical characteristics. In the excellent group, the maximum angular velocity of the swing leg was large, and a vigorous forward upward circling could be performed in a short time. In the good group, the maximum angular velocity of the support leg appeared earlier, and the trunk was not raised in a short time from the inverted suspension position. In the poor group, there were technical tasks with leaning the trunk backward during the non-support phase, and the hip joint was not rotated close to the horizontal bar in coordination with the swinging motion of the swing leg. In the unsuccessful group, there were technical tasks with leaning the trunk backward and extending the elbow joint during the support phase, and the head was not pulled away from the horizontal bar to provide momentum to the rotation of the body and to raise the support leg. These results suggest that the technical tasks and motion phases that should be improved differed among the four groups.

Thus, it is necessary to present motion models and technical tasks according to the skill level of children during actual instruction.

In this study, “barely executed attempt” did not apply to any children. Therefore, further research is necessary to clarify the technical characteristics of “barely executed attempt.”

Conflicts of interest

The authors declare no conflicts of interest.

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