Learning Outcomes for Physical Education in Long Jump: Is it Possible for 5th Graders to Learn Take-off Techniques that Enable Greater Vertical Velocity?*

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The purpose of this study was to determine whether physical education lessons focusing on the long jump for elementary school fifth graders would be able to improve their vertical jump velocity. Twenty-eight elementary school fifth graders were instructed in the long jump over 5 lessons. To gain a higher vertical velocity, participants were instructed to pull their swing legs forward at the instant of touchdown for take-off and to lean their trunks backward during take-off. Measurements were taken during the first and fifth lessons. To evaluate the jumping motion, the body’s center of gravity and segment angles were obtained using a high-speed video camera from a side angle.

The main results were as follows:
1) Since vertical velocity at toe-off and jumping distance were both significantly increased, elementary school fifth graders were able to learn take-off motion to gain a higher vertical velocity. However, the increase in jumping distance was not due to the increase in vertical velocity but rather a decrease in the distance lost during landing.
2) Although post-measurement showed that the swing legs at touchdown for take-off were pulled more forward than in pre-measurement, the change in that motion did not contribute to the increased vertical velocity.
3) In post-measurement, the trunk was inclined smaller during take-off than in pre-measurement. Therefore, forward rotation of the body during take-off was suppressed, which increased the vertical velocity. In addition, suppressing the forward rotation of the body strongly contributed to the decrease in distance lost during landing.

Keywords: motion analysis, jumping motion, behavior of center of gravity

1. Introduction

The long jump is a track and field event in which athletes execute a jump by taking off from one leg after a run-up of an optional distance and are judged according to their jumping distance. There is a strong correlation between run-up speed and performance, and previous studies involving elite athletes have indicated that a highspeed run-up is essential for improving performance (Bridgett and Linthorne, 2006; Coe, 1997; Hay et al., 1986; Lees et al., 1994). Similarly, previous studies that have examined the long jump at the school level—the long jump is initially learned in physical education classes during the higher grades of elementary school (Ministry of Education, Culture, Sports, Science and Technology, 2008a)—have reported a similar result (Nakagawa and Aoya, 1991, Ogata and Nakano, 1992, Ueya and Nakamura, 1984).

The long jump’s key kinetic characteristic is a combination of jumping and running. The horizontal velocity obtained in the run-up is converted into
vertical velocity during the take-off, which means that vertical velocity after take-off also impacts performance.*1 As a result, conversion of the horizontal velocity obtained in the run-up into vertical velocity during take-off and the acquisition of greater vertical velocity are regarded as the key points for teaching the long jump in physical education. However, Kinomura (2015) was concerned that if students were taught how to increase run-up speed during long jump lessons, then the twofold kinetic characteristic of the long jump might be overlooked and their learning would focus too closely on the acquisition of a high running speed, as in sprinting. He pointed out that the take-off ought to be the focus. The relevant teaching sequence for the period from elementary school to high school in the current curriculum [Ministry of Education, Culture, Sports, Science and Technology (MEXT), 2008a, 2008b, 2009] calls firstly for instruction on lengthening the run-up distance and increasing run-up speed, and, secondly, for the teaching of take-off techniques that enables greater vertical velocity (only to be instructed from the third year of junior high school onwards). However, there is reason to question this teaching content sequence. Elite long jump athletes typically start their training with a short run-up distance, then gradually increase it to the full run-up distance used in competitions (Fukashiro, 1983; The Japan Association of Athletics Federations, 1990, 2013). Shortening the run-up distance reduces the horizontal velocity acquired in the run-up, which makes it easier for jumpers to control their take-off motion (Fukashiro, 1983). In other words, when run-up speed is high, even elite long jump athletes who engage in specialist training find it hard to take off in such a way that successfully converts their horizontal velocity into vertical velocity. Thus, their training sequence first secures the athletes’ acquisition of vertical velocity on take-off, then raises their run-up speeds. This sequence utilized by elite athletes implies that the proper teaching sequence for students in the higher grades of elementary school, who are just learning the long jump, should first instruct students in a take-off technique that enables greater vertical velocity, then move on to increasing their run-up speed at a later stage.

Elsewhere (Ogata and Nakano, 1992; Ueyama and Nakamura, 1984), it has been suggested that, because there is no significant correlation for school children in the higher grades of elementary school between jumping distance and vertical velocity at the instant of toe-off for take-off, an increase in such vertical velocity does not lead to an increase in jumping distance. However, these suggestions are based on an analysis of children with no relevant lessons or other special training. In all likelihood, the long jump techniques that combine two types of movement—running and jumping—are first consciously learnt. Therefore, it is necessary to investigate the following points: (1) whether it is possible to learn a take-off technique that enables greater vertical velocity from lessons, and (2) whether jumping distance can be increased after these lessons. When Iwata and Saitou (2009) and Tanaka et al. (2002) instructed the long jump to children in the higher grades of elementary with a focus on take-off and an aim to teach them how to acquire greater vertical velocity at take-off, they saw successful outcomes. However, these studies only mention changes in recorded performances and do not clarify whether, after instruction, (1) the children had successfully learned the take-off technique that enables greater vertical velocity; or (2) whether the improvement in their jumping distance was due to learning the relevant take-off technique. Therefore, the present study aimed to clarify whether, in a long jump course of study offered to children in the higher grades of elementary school, it is possible for students to learn the take-off technique that enables greater vertical velocity.

2. Method

2.1 Date and subjects

Lessons were provided to a class of 33 fifth-graders between October 11 and 21, 2016.*2 Children who missed one or more lessons were excluded from the analysis. As a result, data was analyzed for a final total of 28 students (15 boys and 13 girls). None of the children had any prior experience of the long jump at school clubs or sports clubs outside school. Before the lessons began, the contents of this study and its potential safety issues were explained to the principal and relevant staff at the participating school, as well as protocol in the event of injury. The details of the study were also provided in writing to the participating children’s guardians, and their agreement for participation was obtained.
Learning Outcomes in Long Jump Physical Education Lessons

The following points were clearly explained to the guardians: (1) participation in the study was voluntary, (2) children would not be included in the study without their guardian’s consent, (3) this consent could be withdrawn at any time, and (4) there would be no repercussions for not agreeing to participate in the study. Lastly, this study was carried out with the approval of Kokushikan University ethical review committee (receipt number 16-MD008).

2.2. Unit plan

Figure 1 shows the unit plan. Five forty-five minutes lessons were instructed. In the first lesson, as a pre-measurement, the children took two long jumps with a freely chosen run-up distance of around 15-20 meters. In the fifth lesson, as a post-measurement, they took two long jumps with a run-up distance of 13 strides. In both the “pre” and “post” measurement processes, the children took two practice jumps before the measured jumps. In addition, in the second, third, fourth, and fifth lessons, the children were taught the long jump material known as the “rhythmic run-up”. In the second lesson, the children practiced with a five-stride run-up and then participated in a competition; in the third, they practiced with a nine-stride run-up and then competed; and in the fourth, they practiced with a 13-stride run-up and landing practice. The number of strides in the run-up increased as the unit progressed. During the practice with five-, nine-, and 13-stride run-ups in the second, third, and fourth lessons, the teacher gave instructions on the number of strides in the run-up and how to use rhythm as a verbal accompaniment. Then, to help the students remember the number of run-up strides and the accompanying rhythm, the children performed the motions of the run-up to the teacher’s verbal accompaniment while standing in place. Next, in rows of five, the children twice practiced jumping into the sand pit, again with the teacher’s verbal accompaniment. The children’s performance was measured twice during the unit, during competitions in the second and third lessons. These recorded performances were turned into a score that correlated with each child’s standing jump performance as measured ahead of the unit. Great care was taken to motivate children who recorded low performances. Instruction relating to the landing motion was delivered in the fourth lesson. The key landing-motion teaching point was the instruction to land with both feet together, following the MEXT elementary school Course of Study (MEXT, 2008a). To heighten the children’s awareness of this relevant motion, they were told that, when observed from the side at the moment of landing, the body of the person jumping should resemble the Japanese hiragana character “ん”. First, the children went through the motions of this movement while standing in place four times to aid memorization. Then, they twice practiced landing with both feet together by jumping off a 40 cm high platform facing the sand pit. The landing instruction was delivered in the fourth lesson, i.e., the latter half of the unit, because it was thought that, by then, the children

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
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<tr>
<td>Warming-up exercise</td>
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<tr>
<td>Practice for measurement of long jump × 2 (Run-up distance is arbitrary)</td>
<td>Practice of long jump with a run-up distance of 5 strides</td>
<td>Practice of long jump with a run-up distance of 9 strides</td>
<td>Practice of landing motion</td>
<td>Practice for measurement of long jump × 2 (Run-up distance is 13 strides)</td>
</tr>
<tr>
<td>Pre measurement × 2 (Run-up distance is arbitrary)</td>
<td>Competition × 2 (Run-up distance is 5 strides)</td>
<td>Competition × 2 (Run-up distance is 9 strides)</td>
<td>Practice of long jump with a run-up distance of 13 strides</td>
<td>Post measurement × 2 (Run-up distance is 13 strides)</td>
</tr>
</tbody>
</table>

Summary: Writing an instrument for Formative Evaluation

Figure 1  Unit plan
would have managed to acquire greater vertical velocity in take-off than in the earlier part of the unit. Furthermore, the flight phase from take-off until landing would also be longer, which would make it easier for the children to become conscious of landing with both their feet together. Please note that team teaching was used to deliver this lesson content. The researcher served as Teacher 1, and the classroom teacher at the school (male, with ten years of teaching experience, but not a physical education specialist) served as Teacher 2. Neither Teacher 1 nor Teacher 2 had specialist long-jump competition experience or training.

2.3 Teaching materials

Previous studies of elite long jump athletes and elementary school children studying the long jump, when describing how the motion of the support leg relates to vertical velocity at the instant of toe-off for take-off, have reported the following points: (1) the take-off leg touches down in front of the body’s center of gravity (Coe, 1997, Lees et al., 1994); and (2) flexing of the knee during the early part of the take-off phase is reduced (Lees et al., 1994). However, Kinomura et al. (2012) suggest that, when elite long jump athletes touch the take-off leg down in front of their center of gravity, the leg is unable to withstand the burden of the take-off and may indeed flex. In addition, Shiga and Ogata (2004) report that knee extension strength is required to reduce knee flexing during take-off. Based on these reports, it was not deemed suitable to undertake improvements to this specific movement in an elementary school course of study, which was aimed at a large number of children with significantly different degrees of muscular strength and whose muscular strength would not be able to show greater development than elite long jump athletes. A relationship between the motion of the swing leg, the trunk, and the vertical velocity at the instant of toe-off for take-off has also been reported. Previous research that has examined children in the higher grades of elementary school suggests two motions of the swing leg that impact the maximum jumping height in the flight phase, which is more or less synonymous with vertical velocity at the instant of toe-off (c.f. Nakagawa and Aoya, 1991): (1) flexing of the knee joint of the swing leg at the instant of touchdown for take-off; and (2) bringing the thigh further forward. As for the motion of the trunk, in another study of children in the higher grades of elementary school, Ohmiya et al. (2009) have reported that vertical velocity at the instant of toe-off for take-off is higher for those whose trunk is inclined backward at the instant of touchdown and toe-off for take-off.

However, as Nakada et al. (2003) discovered from analyzing the sprinting motion of sprinters before and after training, because of ground reaction forces, it is easier and faster by about one-tenth of a second for runners to adjust the motion of their swing leg than that of their support leg. For the same reason, in the case of coaching sprinters, instruction also focuses on the motion of the swing leg (Miyashita, 1990). Considering the findings of these reports in light of the fact that the long jumps shares kinetic characteristics with sprinting (e.g., sprinting movement, movement phases, and time taken in each phase), it is reasonable to presume that adjusting the motion of the idle leg (i.e., the swing leg) would be easier for long jumpers than adjusting of the motion of the support leg. Because ground reaction forces do not act directly on support or flight time, it is also likely that it would be comparatively easy for long jumpers to likewise adjust their trunk motion. Therefore, these strategies for improving the motion of the swing leg and the trunk were judged to be suitable for physical education lessons taught to a large number of children whose athletic skills and physical fitness levels varied greatly.

As already discussed, long jump athletes and physical fitness students of the long jump who enable greater vertical velocity at take-off (by bringing the swing leg forward and inclining the trunk backwards) approach touchdown in the take-off phase with a posture enabling greater vertical velocity. However, this kind of posture at the instant of touchdown for take-off is considered to be the result of take-off preparation in the last stride, or even earlier in the run-up. Accordingly, in this study, in order to prepare for take-off in a way that improved the motion of the swing leg and the trunk during take-off, the students’ long jumps were executed utilizing the material of a rhythmic run-up. The rhythmic run-up material was chosen in reference to prior research (Kawamoto and Kijinami, 1999); the onlooking children were asked to provide a vocal accompaniment for the jumping child by saying
“tan, tan, ta, ta, tan’’* in time with the touchdown of the jumping child’s five strides, beginning with the fourth-to-last in the run-up to take-off. This material was implemented to facilitate the jumping child’s rotation of the legs in front of the body and inclination of the trunk backwards during take-off. By changing the “tan” beat of the fourth- and third-to-last strides to the shorter “ta” beat in the second-to-last and last strides, the support leg was brought forward more swiftly (rather than kicked backward) and the swing leg was also brought more swiftly forward. The rhythms were set as follows: “one, two, three, four, tan, tan, ta, ta, tan” in the nine-stride run-up; and “one, two, three, four, one, two, three, four, tan, tan, ta, ta, tan” in the 13-stride run-up. Calling out this beat to the children without the use of the words “swing leg” or “trunk” took their developmental stage into consideration and demonstrated to them how to execute a long jump in time to the rhythm of the verbal accompaniment.

2.4 Data collection and analysis method

2.4.1 Formative evaluation

To ascertain the children’s assessments of the lessons they received, at the end of each lesson, they were asked to complete a formative evaluation (Hasegawa et al., 1995). From the total number of points each child awarded per item, average evaluation scores for each category (outcome, motivation and interest, learning method, and cooperation) and overall evaluation totals were calculated, as well as a grade.

2.4.2 Measurement

In order to compare the long jump students’ jumping distances before and after receiving instruction, measurements were taken in the first and fifth lessons. The pre-measurement in the first lesson was conducted according to MEXT’s Elementary School Course of Study (MEXT, 2008a), which allowed the children to freely determine the length of their run-up within a range of 15-20 meters. The post-measurement were taken in the fifth lesson, when the run-up was limited to 13 strides. The measurement sessions took place at the school’s sports area, utilizing untreated surfaces and the sand pit, and the children wore their own footwear. The researcher measured the children’s jumping distance with a tape measure. All measurements were taken twice. “Jumping distance” was measured as the distance from the point where the child’s toe touched down within the touchdown phase of take-off to the first mark in the sand pit made by any part of the child’s body upon landing. The attempt with the farthest distance was included in the analysis and subjected to the jumping motion analysis outlined below. In both measurement sessions, run-up distance was also measured.

2.4.3 Jumping motion

Two high-speed cameras (Casio EXILIM EX-F1) were positioned at two points: one meter and five meters in front of the run-up sand pit and fifteen meters to the side. The camera angle was adjusted to ensure that the range of filming included four meters on either side of the camera’s position and one meter and five meters from the run-up sandpit, which allowed for the filming of the motion from the fourth-to-last stride until take-off. Filming speed was 300 fps and the length of the exposure was 1/1000th of a second. In order to convert digitized coordinates to real coordinates, calibration marks were placed at 3-meter intervals along both sides of the track inside the filming zone. The filmed images were then used to calculate the time durations per stride for the fourth-to-last to the last strides. In addition, using a program created using computational software (MathWorks MATLAB) to analyze the participants’ jumping motions, the motions from the five frames depicting the moments before toe-off of the last stride until the five frames after toe-off for take-off were digitized utilizing 23 body landmarks and four calibration marks at 100 frames per second. Digitized coordinates were converted to real coordinates using calibration markers. The Butterworth digital filter was used for smoothing at the optimal cut-off frequency (4-9 Hz) determined using the Wells and Winter (1980) method for each coordinate component. The center of gravity for the whole body was calculated from the two-dimensional coordinate values for the body landmarks, according to Ae’s (1996) body segment inertia parameters. Utilizing the obtained two-dimensional coordinate values for the body’s center of gravity and the body segments, the following items for analysis were derived: (1) the horizontal velocity of the body’s center of gravity (“horizontal velocity”); (2) the vertical velocity of the body’s center of gravity (“vertical velocity”); (3) the toe-off distance (i.e. the horizontal distance from the body’s center of
gravity at the instant of toe-off for take-off to the toe of the supporting leg); (4) the trajectory distance (as pointed out by Ogata and Nakano [1992], jumping in the long jump can be regarded as a “trajectory of the body’s center of gravity”, where “trajectory distance” denotes the theoretical value of the horizontal distance until the arrival of the center of gravity in the sand pit, and is calculated from the height of the center of gravity, vertical velocity, and horizontal velocity at the instant of toe-off for take-off); (5) the distance lost during landing (i.e. the sum of the toe-off distance and the trajectory distance minus the jumping distance); (6) the measured variables shown in Figure 2; (7) the trunk angle (i.e. the clockwise angle between “the line linking the mid-point of the left and right great trochanter and the suprasternal” and the perpendicular, given a positive value); and (8) the trunk angular velocity. During the jumping movement that is characteristic of the long jump (i.e. in which the jumper takes off from one foot after a run-up), the acquisition of vertical velocity is not only a result of flexing and extending the leg, but also of the forward rotation of the body (Muraki, 1982). This method of acquiring vertical velocity can be explained by the inverted pendulum model (Figure 3) of Jacobs and van Ingen Schenau (1992), in which the jumping motion is seen as an imaginary line that links the body’s center of gravity with the support point of the foot and that contracts and expands while rotating forward (Fujibayashi et al., 2014; Kinomura et al., 2012). By using this model, it is possible to clarify whether the vertical velocity acquired during take-off is attributable to rotation or contraction/extension. In this model, the change in velocity in the take-off phase is expressed by the following formulae:

\[
\begin{align*}
\hat{X} &= l \dot{\theta} \sin \theta \\
\hat{Y} &= -l \dot{\theta} \cos \theta \sin \theta
\end{align*}
\]

\(\hat{X}\) expresses horizontal velocity and \(\hat{Y}\) expresses vertical velocity. The right side terms of the equations were “velocity due to rotation + velocity due to contraction or extension”. \(l\) denoted the length between the support point of the foot and the body’s center of gravity, and \(\theta\) represented the angle formed by the horizontal and “the line linking the support point of the foot and the body’s center of gravity”. The direction of travel was set as 0°, the angle was calculated anti-clockwise, and the direction of travel was towards the right. In this study, this method was used to calculate vertical velocity due to contraction/extension and vertical velocity due to rotation during take-off. Furthermore, in this

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**Figure 2** The definition of measured variables

**Figure 3** The definition of inverted pendulum model
study, the ball of the take-off foot at the midpoint of the moment of touchdown and the moment of toe-off was considered to be “the support point of the foot”.

Next, we evaluated the motion of the swing leg. According to Fujibayashi et al. (2014), the behavior of the swing leg is regarded to follow a pendulum-style rotating movement model with the pendulum linking the great trochanter (the swing leg’s point of origin) and the swing leg’s center of gravity, which is a synthesis of the center of gravity of the thigh, shank, and foot (Figure 4). In this study, the swing leg angle was taken to be the clockwise angle formed by the perpendicular and “the line linking the great trochanter and the swing leg’s center of gravity” with a negative value. Swing leg angular velocity was also calculated. These analysis items were examined within the zone of toe-off of the last stride until toe-off for take-off.

Regarding the analysis items related to jumping motion, the variable of “time” was normalized into the support phase (from touch-down to toe-off) and the flight phase (from toe-off until the opposite leg touches down). It is important to note that, because the ratio of the flight time during last-stride and support time during take-off was around 1 to 2 in both the pre and post measurement, the flight phase of last-stride was normalized at 50% and the support phase of take-off at 100%, with comparisons made at 10 percentage point intervals.

2.5 Data handling

To test the average difference of each analysis item before and after instruction, applicable t-tests were carried out. The Pearson product-moment correlation coefficient was used to test the correlation between the analysis items. A within-subject design with two-factor dispersion analysis was conducted regarding the time per stride from the fourth-to-last stride to the last stride, with stride number (fourth-to-last, third-to-last, second-to-last, and last) and timing (pre- or post-measurement) serving as the within-subject factors. Where significant interaction was confirmed, simple main effect testing and multiple comparison testing were carried out. In addition, the children were classified into an “increased group” (vertical velocity due to rotation at the instant of toe-off improved after instruction) and a “decreased group” (vertical velocity due to rotation at the instant of toe-off decreased after instruction), and a mixed design two-factor dispersion analysis was carried out regarding the distance lost during landing, with timing (pre- or post-measurement) as a within-subject factor and group classification (“increased” or “decreased”) as a between-subjects factor. When significant interaction was confirmed, simple main effect testing was carried out. Five percent was considered the statistically significant level. Also, to identify trends in the changes within each analysis item, elements in the charts below where \( .05 \leq p < .10 \) are marked with a † symbol.

3. Results

3.1 Formative evaluation

Table 1 shows the average formative evaluation

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Motivation</th>
<th>Way of learning</th>
<th>Cooperation</th>
<th>Overall</th>
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<tr>
<td></td>
<td>Mean</td>
<td>Grade</td>
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</tbody>
</table>

Table 1 Mean and grade of formative evaluation of each lesson.
values of the student participants and their grades for each lesson. These grades are based on the diagnostic criteria for track and field lessons presented by Hasegawa et al. (1995). Data from the second lesson are missing because the preceding lesson on the children’s timetable overran, leaving insufficient time for the children to fill in the formative evaluation sheets. However, in light of the overall trend of the unit, this aberration was not judged problematic. The formative evaluation grade were as follows: “outcome” was graded as 3 throughout the duration of the unit; “motivation & interest” remained consistent at 4; “way of learning” rose from 3 to 4 as the unit progressed; and “cooperation” remained steady at 3 throughout the unit. The overall evaluation grade was 3 for the first half of the unit and 4 for the second half.

### 3.2 Jumping distance

Table 2 shows the means and standard deviations of jumping distance, toe-off distance, trajectory distance, distance lost during landing, horizontal and vertical velocity at the instant of touchdown and the instant of toe-off for take-off before and after instruction, as well as applicable t-test results. In post measurement, jumping distance and vertical velocity at the instant of toe-off for take-off showed significantly large values. However, the values for toe-off distance and distance lost on landing were significantly small. In addition, the mean and standard deviation of run-up distance before and after instruction were 15.89 ± 0.59 m and 17.38 ± 1.37 m, respectively. The relevant section in the Course of Study for Elementary Schools (MEXT, 2008a) prescribes a run-up distance of around 15-20 m for students in higher grades, and the run-up distance found in both the pre- and post-measurement sessions in this study confirmed this guideline.

#### 3.3 Jumping motion

Table 3 shows the means for the time per stride from the fourth-to-last stride to the last stride, standard deviations, and the results of the two-factor dispersion analysis and multiple comparison testing. For the purpose of clarifying how instructing the long jump to children by utilizing the material of a rhythmic run-up with a vocal accompaniment affected the time per stride from the fourth-to-last stride to the last stride, a within-subject design two-factor dispersion analysis was conducted. The

### Table 2  Comparison of measured variables between pre- and post-measurement.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pre M</th>
<th>SD</th>
<th>Post M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
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<tr>
<td>Jumping distance (m)</td>
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<td>2.70</td>
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<td>Toe-off distance (m)</td>
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<td>Distance lost during landing (m)</td>
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<td>0.00</td>
<td>0.00</td>
<td>4.25*</td>
<td>.000</td>
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<td>Horizontal velocity at touchdown of take-off (m/s)</td>
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<td>0.46</td>
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<td>0.42</td>
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<td>Horizontal velocity at toe-off of take-off (m/s)</td>
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<td>Vertical velocity at touchdown of take-off (m/s)</td>
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<td>0.13</td>
<td>-0.50</td>
<td>0.21</td>
<td>-1.47</td>
<td>.153</td>
<td>.33</td>
</tr>
<tr>
<td>Vertical velocity at toe-off of take-off (m/s)</td>
<td>1.46</td>
<td>0.29</td>
<td>1.60</td>
<td>0.24</td>
<td>-2.60*</td>
<td>.000</td>
<td>.55</td>
</tr>
</tbody>
</table>

*: p < .05

### Table 3  Comparison of time per stride between pre- and post-measurement.

<table>
<thead>
<tr>
<th></th>
<th>fourth to last stride</th>
<th>third to last stride</th>
<th>second to last stride</th>
<th>last stride</th>
<th>Step</th>
<th>F value</th>
<th>Multiple Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Step Time</td>
<td>Step × Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre</td>
<td>M 0.261</td>
<td>0.249</td>
<td>0.274</td>
<td>0.254</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD 0.024</td>
<td>0.029</td>
<td>0.032</td>
<td>0.038</td>
<td>0.001*</td>
<td>.004*</td>
<td>.000*</td>
</tr>
<tr>
<td>post</td>
<td>M 0.305</td>
<td>0.285</td>
<td>0.263</td>
<td>0.248</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD 0.028</td>
<td>0.029</td>
<td>0.025</td>
<td>0.027</td>
<td></td>
<td></td>
<td>Pre (2L &gt; 3L, L)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Post (4L &gt; 3L, 2L, L), Post (3L &gt; 2L, L)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pre 4L &lt; Post 4L, Pre 3L &lt; Post 3L</td>
</tr>
</tbody>
</table>

*: p < .05
within-subject factors were stride number (fourth-to-last, third-to-last, second-to-last, last, and take-off) and timing (pre- or post-measurement), and values were compared. This analysis revealed significant interaction \([F(3, 81) = 34.859, p < .05, \eta^2 = .564]\); therefore, simple main effects testing was carried out for each factor. When simple main effects testing was carried out for the within-subject factor (stride number), significant simple effect was found for both the pre-measurement \([F(3, 25) = 8.414, p < .05, \eta^2 = .502]\) and post-measurement \([F(3, 25) = 19.436, p < .05, \eta^2 = .700]\) values. When a multiple comparison test was carried out, the second-to-last stride in pre-measurement was found to be significantly longer than the third-to-last stride and the last stride in pre-measurement. The fourth-to-last stride in post-measurement was significantly longer than third-to-last, second-to-last, and last strides in post-measurement. The third-to-last stride in post-measurement was significantly longer than the second-to-last and last strides in post-measurement. When the simple main effects testing was carried out for the within-subject factor (time), a significant simple main effect was found for the fourth-to-last stride \([F(1, 27) = 46.406, p < .05, \eta^2 = .632]\) and the third-to-last stride \([F(1, 27) = 40.649, p < .05, \eta^2 = .601]\). No significant simple main effect was seen for the second-to-last stride \([F(1, 27) = 3.159, n.s., \eta^2 = .105]\) or the last stride \([F(1, 27) = .786, n.s., \eta^2 = .028]\).

Beginning with the top graph, Figure 5 shows the displacement of vertical velocity during take-off, vertical velocity due to rotation, and vertical velocity due to contraction/extension before and after instruction. Vertical velocity significantly improved at the instant of toe-off for take-off (100%), while vertical velocity due to rotation from the middle part of the take-off phase to the instant of toe-off for take-off (60-100%) significantly improved in post-measurement. Vertical velocity due to contraction/extension at the instant of touchdown for take-off (0-10%) was significantly higher in post-measurement; subsequently, the graph depicts how the difference between values before and after instruction reverses, and, from the middle part of the take-off phase to the late part (60-80%), vertical velocity was significantly lower in post-measurement.

Figure 6 shows swing leg angle and swing leg angular velocity from toe-off of the last stride to the instant of toe-off for take-off before and after instruction. There was no significant difference in swing leg angle in the flight phase of the last stride, but at the instant of touchdown for take-off (0-10%), as it was significantly higher after instruction, the swing leg was brought further forward. Subsequently, no difference was seen before and after instruction in the middle part of support phase for take-off, however, as the values of the pre-measurement from the middle part to the late part of the take-off phase (60-80%) were significantly greater than those of the post-measurement, the swing leg was brought higher. As the swing leg
Angular velocity of post-measurement was significantly higher during the whole flight phase for the last stride (−40 to −10%), the swing leg was brought swiftly forward. Thereafter, there was no significant difference in swing leg angular velocity, but in the late part of the take-off phase (80%), as the difference was again significantly large, the swing leg was raised swiftly.

Figure 7 shows trunk angle and trunk angular velocity from toe-off of the last stride until the instant of toe-off for take-off. The difference before and after instruction in trunk angle gradually increased after touchdown of the take-off leg. From the middle part of the support phase for take-off to the toe-off for last-stride (60-100%), as the values for trunk angle of post-measurement decreased significantly, the forward incline of the trunk became shallower. In addition, as the values for trunk angular velocity of post-measurement decreased significantly after immediately the toe-off for last-stride (−50 to −40%), the trunk was inclined backwards with momentum. Thereafter, there was no difference between values before and after instruction, but after touchdown for take-off (10-20%), the value of post-measurement showed a significantly smaller value.

The first chart depicted in Figure 8 shows the scales of change in swing leg angle and vertical velocity during take-off due to rotation and the correlation coefficient of the two. The second chart depicted in Figure 8 shows the scales of change in swing leg angle and vertical velocity due to contraction and extension during take-off and the correlation coefficient of the two. When focusing on the coefficient of the correlation between the scales of change in swing leg angle and vertical velocity due to rotation (as depicted in the first chart in Figure 8) from toe-off for take-off to the middle part of the take-off phase (0-40%), a significant negative correlation was seen. For 0-30%, the scale of change in swing leg angle had a positive
value, and the scale of change in vertical velocity due to rotation had a negative value, which implies that, for those who brought the swing leg further forward, vertical velocity due to rotation was reduced. However, at 40%, the positive and negative values were reversed, meaning that for those who did not bring the swing leg forward, vertical velocity due to rotation increased. Meanwhile, on an examination of the coefficient of the correlation between the scale of change in swing leg angle and the scale of change in vertical velocity due to contraction/extension (as depicted in the second chart in Figure 8), a significant positive correlation was observed from touchdown for take-off to the late part of the take-off phase (0-70%). At 0-30%, because the values for both the scale of change in swing leg angle and vertical velocity due to contraction/extension were positive, it can be conjectured that, for those who brought the swing leg further forward, vertical velocity due to contraction/extension increased. Meanwhile, at 40-70%, because both values were negative, it can be surmised that those who did not pull the swing leg forward recorded lower vertical velocity due to contraction/extension.

The first chart depicted in Figure 9 shows, the scales of change in trunk angle and vertical velocity due to rotation during take-off and the coefficient of the correlation between the two. The second chart depicted in Figure 9 shows the scales of change in trunk angle and vertical velocity due to contraction/extension during take-off and the coefficient of the correlation between the two. The left-hand axes show the scale of change in trunk angle, while the right-hand axes show the scale of change in vertical
velocity due to rotation or contraction/extension and the size of the correlation coefficient of the two. The coefficient of the correlation between the scale of change in trunk angle and in vertical velocity due to rotation (as depicted in the first chart in Figure 9) from the middle part of the take-off phase to toe-off (60-100%) showed a significant negative correlation. In post-measurement, the students whose trunks were more upright thus increased their vertical velocity due to rotation. Meanwhile, the coefficient for the correlation between the scale of change in trunk angle and vertical velocity due to contraction/extension was insignificant in all phases of the take-off (as depicted in the second chart in Figure 9).

To clarify the impact of the change in vertical velocity due to rotation at the instant of toe-off for take-off on the distance lost during landing, the children were classified into two groups: (1) those for whom vertical velocity due to rotation at the instant of toe-off for take-off improved after instruction (the “increased group”); and (2) those for whom it fell (the “decreased group”). The mean and standard deviation were as follows: (1) “pre” for the increased group, 99.8 ± 32.7 cm; (2) “post” for the increased group, 63.2 ± 14.3 cm; (3) “pre” for the decreased group 80.7 ± 20.6 cm; and (4) “post” for the decreased group, 74.5 ± 16.9 cm. Then, we conducted a mixed-design two-factor dispersion analysis using the groups (either “increased” or “decreased”) as the between-subjects factor and timing (pre- or post-measurement) as the within-subject factor, and compared the distances lost during landing. Since the results showed that the interaction was significant, [F(1, 26) = 7.018, p < .05, \( \eta^2 = .213 \)], simple main effects testing was carried out for both factors. When a simple main effects test was applied to the between-subjects factor (group), no significant simple main effect was found either pre-measurement [F(1, 26) = 2.758, n.s., \( \eta^2 = .096 \)] or post-measurement [F(1, 26) = 3.509, n.s., \( \eta^2 = .119 \)]. When a simple main effects test was applied to the within-subject factor (timing), a significant simple main effect was seen for the “increased” group [F(1, 26) = 28.607, p < .05, \( \eta^2 = .524 \)], but no significant simple main effect was seen for the “decreased” group [F(1, 26) = 0.466, n.s., \( \eta^2 = .018 \)] (Figure 10).

4. Discussion

4.1 The quality of the lessons

Lesson quality strongly impacts learning outcomes. In other words, even when excellent teaching materials and teaching content appropriately matched to the students’ developmental stage have been prepared, if the teacher is inexperienced or discipline is lacking, satisfactory learning outcomes will be hard to achieve. Therefore, Therefore, to clarify how good the lessons were done, it was necessary to evaluate that lessons. To this end, formative evaluation sheets\(^*5\) (Hasegawa et al. 1995) were used to gauge how the students evaluated the lessons. The grades for each lesson varied by evaluation item, but the first half of the unit received an overall grade of 3, and the second half received a 4 (Table 1). Based on the criteria of Hasegawa et al. (1995), the lessons delivered in the first half of the unit devised for this study were of a “normal” standard, while those delivered in the second half were “good”. Thus, the lessons delivered as part of this study were not in themselves excellent lessons, which implies that the changes in jumping distance and motion this study identified (outlined below) should be replicable. However, it should not be forgotten that these lessons were only evaluated using this single formative evaluation indicator.

4.2 The impact of rhythmic long jump run-up on time per stride

In the physical education lessons provided in this study, the participating children were not given in-
instructions about swing leg and trunk motion in concrete terms. Rather, the researcher’s intention was to improve their motion through utilization of rhythmic run-up to the long jump using vocal accompaniment. To investigate whether the children were able to change their run-up rhythm after instruction, time per-stride before and after instruction for the four strides from the fourth-to-last stride to the last stride were compared (Table 3). This comparison revealed that, before instruction, the second-to-last stride was longer than the third-to-last and last strides, which indicated that the run-up rhythm did not become shorter for the second-to-last and last strides when compared with the fourth-to-last and third-to-last strides. However, after instruction, the second-to-last and last strides were shorter than the fourth-to-last and third-to-last strides, and the run-up rhythm shortened for the second-to-last and last strides in comparison to the fourth-to-last and third-to-last strides. Therefore, it can be said that, as a result of the instruction provided by the physical education lessons in this study, the children were able to change their run-up rhythm as intended.

4.3 Factors affecting change in jumping distance

After instruction, the vertical velocity at the instant of toe-off for take-off improved significantly (Table 2). In addition, when focusing on vertical velocity due to rotation versus contraction/extension, at the instant of toe-off for take-off, only vertical velocity due to rotation showed significant improvement (Figure 5). Therefore, it is reasonable to assume that an increase in vertical velocity due to rotation led to the overall increase in vertical velocity, which indicates that it is possible for children in the higher grades of elementary school to learn a take-off technique that enables greater vertical velocity. However, trajectory distance, which is calculated from the center of gravity and the horizontal and vertical velocity at the instant of toe-off for take-off, did not improve significantly. It can thus be considered that the improvement in vertical velocity at that instant of toe-off made only a small impact on trajectory distance. Furthermore, the distance lost during landing declined significantly. Given that the scales of change for distance lost during landing and total jumping distance before and after instruction almost matched, any decline in distance lost during landing can be considered to have a significant effect on improvement in jumping distance.

4.4 The relationship between change in vertical velocity and jumping motion

In this study, participating children were instructed with an intention to improve swing leg and trunk motion in order to acquire greater vertical velocity on take-off. Therefore, it was investigated whether the children had learned these motions after instruction, and also how their improvement in these motions impacted their acquisition of vertical velocity.

Beginning with the motion of the swing leg, the results showed that, as the swing leg was brought forward with momentum, swing leg angle velocity was significantly larger in the last stride flight phase (−40 to −10%). As a result, when the swing leg was brought further forward, swing leg angle at the instant of touchdown for take-off (0-10%) increased (Figure 6), which implies improvement in swing leg motion. Next, to clarify the impact of the change in swing leg motion at the instant of touchdown for take-off on the acquisition of vertical velocity, we focused on the coefficient of the correlation between the scale of the change in swing leg angle and vertical velocity due to rotation and to contraction/extension (Figure 8). In the instant of touchdown for take-off (0-10%), when a significant difference in swing leg angle was observed, the correlation with vertical velocity due to rotation had a negative coefficient (as depicted in the first chart in Figure 8) and the correlation with vertical velocity due to contraction/extension had a positive coefficient (as depicted in the second chart in Figure 8). In other words, for those who brought the swing leg further forward at the instant of touchdown for take-off, vertical velocity due to contraction/extension increased, but vertical velocity due to rotation decreased. Indeed, because vertical velocity due to contraction/extension at the instant of touchdown for take-off (0%) increased significantly, while vertical velocity due to rotation exhibited a downward trend (Figure 5), it can be said that changes in vertical velocity due to the two different factors cancelled each other out. When the swing leg is positioned further forward with regard to the direction of travel at the instant of touchdown for take-off, the body’s center of gravity is positioned relatively further forward. Therefore, the line linking
the support point of the foot and the body’s center of gravity touches down closer to the perpendicular. The closer to perpendicular that the line linking the support point of the foot and the body’s center of gravity becomes, the smaller the impact on vertical velocity due to rotation. This could explain why the vertical velocity due to rotation declined. Meanwhile, while the support point of the foot is further forward than the body’s center of gravity (i.e., while the line that links them inclines backwards), the leg is bent, and a decline in horizontal velocity is seen. Touching down with the line linking the support point of the foot and the body’s center of gravity closer to the perpendicular shortens the time during which the support point of the foot is further forward than the body’s center of gravity. Therefore, it is considered that flexing of the leg is suppressed, and vertical velocity due to contraction/extension is increased. Previous research involving children in the higher grades of elementary school (Nakagawa and Aoya, 1991) has reported that those who pull the thigh of the swing leg forward at the instant of touchdown for take-off have high maximum jumping height during the flight phase, which is more or less equivalent to vertical velocity at the instant of toe-off. However, the results of this present study are not in line with those of the previous research, due to our findings concerning swing leg motion in the late part of take-off. In post-measurement, the angle of the swing leg was significantly small in the latter part of take-off (60-80%), nor was the swing leg pulled up. Pulling up the swing leg in the latter part of take-off raises the body’s center of gravity and is seen as contributing to the acquisition of vertical velocity due to contraction/extension. Indeed, in the 60-70% section of the take-off period, a significant positive correlation with vertical velocity due to contraction/extension was observed (Figure 8); meanwhile, for participants who did not pull up the swing leg in the latter part of the take-off phase, vertical velocity due to contraction/extension was reduced. In other words, in this study, pulling the swing leg further forward at the instant of touchdown for take-off was not observed to lead to subsequent upward lift. Therefore, it was conjectured that it is not possible to acquire greater vertical velocity using this method. It is difficult to clarify the factors that gave rise to this kind of change in motion using the data obtained in this study. However, for the long jumps that utilized the material of a rhythmic run-up in the lessons in this study (where the onlooking children provided the jumping child with the vocal accompaniment “tan, tan, ta, ta, tan” in time with the touchdown of the five strides from the fourth-to-last stride of the run-up to take-off), it was expected that, as a result of this material, the attention of the child jumping would be focused on the moment of touchdown, and that this awareness would lead to the child pulling the swing leg further up at the instant of touchdown for take-off. It is possible, though, that this material did not lead to the swing leg being raised in the later part of the take-off phase. However, as already mentioned, because pulling the swing leg up further at the instant of touchdown for take-off is thought to shorten the period in which horizontal velocity is reduced, it is important that students learn this motion before moving on to junior high school, where they are required to take off more swiftly utilizing run-up speed (MEXT, 2008).

Moving on to the results of motion of the trunk, in post-measurement, it was observed that, after touchdown for take-off (10-20%), as trunk angular velocity became significantly small, the trunk inclined backwards with momentum. Thereafter, although the motion of the trunk showed no significant difference in the later part of the take-off phase (60-80%), trunk angular velocity displayed a tendency to be small. As a result, from the middle phase of take-off to toe-off for take-off (60-100%), after instruction, as the trunk angle was small, the trunk was upright (Figure 7). This result implies that there was an improvement in the motion of the trunk during take-off. Next, in order to clarify the impact of the change in the angle of the trunk during take-off on acquisition of vertical velocity, a coefficient was sought for the correlation between the scale of the change in the angle of the trunk during take-off and the scale of change in vertical velocity due to contraction/extension and rotation (Figure 9). As a result, at 60-100%, when trunk angle was significantly reduced, a significant negative correlation with vertical velocity due to rotation was seen, thus vertical velocity due to rotation increased for children with straighter trunks after instruction (Figure 9, first chart). Improvement in vertical velocity at the instant of toe-off for take-off is attributable, not to improvement in vertical velocity due to contraction/extension, but to improvement
in vertical velocity due to rotation. Therefore, it can be said that vertical velocity increased via improvement in the motion of the trunk. Meanwhile, as already mentioned, increase in students' jumping distance was only impacted to a small extent by increase in their trajectory distance, due to the reduction in distance lost during landing's considerable impact on their improvement in vertical velocity at the instant of toe-off for take-off.

However, previous research (Fukashiro, 1986) has suggested that inclining the trunk backwards during take-off controls the forward rotation of the body at the instant of toe-off for take-off and leads to better posture upon landing. Because improvement in vertical velocity at the instant of toe-off for take-off is attributable to improvement in vertical velocity due to rotation caused by the backward inclination of the trunk, it is possible to conjecture that the children whose vertical velocity due to rotation at the instant of toe-off improved were those who were able to learn how to take off in a way that allowed for the acquisition of greater vertical velocity. To clarify how learning a take-off technique that enables greater vertical velocity impacts the distance lost during landing, the distances lost during landing before and after instruction for the “increased group” (whose vertical velocity due to rotation at the instant of toe-off for take-off improved in post-measurement) and the “decreased group” were compared (Figure 10). This comparison showed a significant reduction in the distance lost during landing for the “increased group” in post-measurement. Meanwhile, the “decreased group” saw no change in the distance lost during landing before and after instruction. In addition, whereas the average difference in the distance lost during landing by the “decreased group” in the post-measurement compared to that in pre-measurement was 6.3 cm, for the “increased group”, this figure was 36.6 cm, around six times that of the “decreased group”’. These results indicate the following two points: (1) reduction in the distance lost during landing is not attributable to simple improvement in landing technique, but is the outcome of having learned how to take off in a way that enables greater vertical velocity; and (2) although the increase in trajectory distance due to an improvement in vertical velocity at the instant of toe-off for take-off was small, overall jumping distance showed a large increase thanks to the reduction in distance lost during landing. These findings, which indicate that it is possible to increase jumping distance by raising vertical velocity during take-off, differ from the previous studies involving children in the higher grades of elementary school (Ogata and Nakano, 1992; Ueya and Nakamura 1984) that have suggested that an increase in vertical velocity on take-off is not linked to an increase in jumping distance. Therefore, this study showed that there is value for physical education teachers in selecting a take-off technique that enables the acquisition of greater vertical velocity as learning content, not only from the viewpoint of the sequence of learning content as discussed in the Introduction, but also from the viewpoint of obtaining the desired learning outcome, i.e. increasing jumping distance.

5. Conclusion

This study investigated whether it is possible in long jump physical education lessons delivered to fifth-graders to teach a take-off technique that enables greater vertical velocity via an improvement in the motion of the swing leg and trunk during take-off. As a result, in post measurement, increases were seen in jumping distance and vertical velocity at the instant of toe-off for take-off. It was, therefore, elucidated that it is indeed possible for fifth-graders to learn take-off techniques that enable greater vertical velocity, thereby increasing their jumping distance. In addition, reduction in the distance lost during landing was found to have a large impact on the increase in jumping distance. This reduction in distance lost during landing was not the result of a simple improvement in landing technique, but rather due to the acquisition of greater vertical velocity due to rotation during take-off.

Acknowledgments

We are very grateful for the wonderful cooperation from the staff and children at the school where we conducted this study.

Notes

*1 Previous studies investigating the relationship between performance and vertical velocity after take-off obtained different results. For example, Hay et al. (1986) report no significant correlation between performance and vertical velocity after take-off. However, the subjects in that study consisted of a narrow group of extremely competitive elite athletes with personal bests of 7.72-8.79 m. In studies where subjects included athletes with a broader performance range (Ota et al., 2010) or children in the higher grades of elemen-
tary school with no particular training experience (Ohmiya et al., 2009), significant positive correlation was observed, implying that vertical velocity after take-off is a factor that impacts performance.

*2 The MEXT Course of Study (MEXT, 2008a) outlines learning content for fifth- and sixth-graders together under the “high grades” umbrella. This study focused exclusively on fifth-graders on the assumption that, if fifth-graders were successfully able to learn a take-off technique enabling acquisition of greater vertical velocity, then more developmentally advanced sixth-graders would also be able to do so.

*3 A scoring system was created according to the ratio of the long jump to standing jump performances. For example, if a student’s long jump performance was 1.1 times better than his or her standing jump performance, then 1 point was awarded; when it was 1.2 times better, 2 points were awarded, and so forth.

*4 There is a custom that “tan” and “ta” are each used to express a quarter note and eight note as the rhythm of the verbal accompaniment in Japanese schools.

*5 We used this type of lesson formative evaluation in this study because, in addition to clearly delineating criteria that allow students to judge the quality of the lessons, it also enables convenient collection of the evaluations from all the students taking part in the lessons in question.

References


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