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Hand-motion analysis for development of double-unders skill

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Abstract

Double-unders is one of interesting physical skills combining multiple primitive motions of different frequencies. This paper discusses an analyzing method of trajectory on hand-motion in double-unders. It also tackles to design an environment for the staged learning in acquisition process of the skill. We focus on the radius of motion-trajectory of the hand and spatial positions of moving hand. We measure some parameters relating to the hand-motions, and observe relative hand positions to the body. Then, we observe the difference of them between persons who have acquired the skill and others who have not acquired the skill yet. As a result, it has clarified that our proposal relating to the hand-motions is not irrelevant to success or failure of double-unders.

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Keywords: motor skill, learning supporting, double-unders, image processing

1. Introduction

1.1. Back ground

Jump rope is one of the famous sports all over the world as well as soccer, ski, judo and running. In particular, it is an exercise which many people have the experience in Japan, because it is programed in a physical education of an elementary school. Generally, we find various approaches in jump rope. It can be divided into two types which are "competitive sport" and "lifelong sport". Competitive sport has an objective that a player try to defeat opponents or exceed the performance being superior to other players; i.e. in Olympic games or professional sports. By contrast, lifelong sport has another type of objective for improving or keeping health or feeling pleasure. A lot of sports bring both brain and body burden to each performer. Besides, movement tasks of each performer depend on characteristic of sports. In other words, the weight of key point are different in each scene. For example in baseball, the task of fast running between bases is only composed of physical activity for quick motion whereas hitting a ball is required both

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an accurate prediction of a ball trajectory and the appropriate bat control by the judgment ability based on acquired knowledge. Jump rope also has many tasks. Therefore, performers need making and retaining "skill" to perform the tasks throughout repeating practice. Skill is the ability which is acquired through learning in common. According to sports psychology, they call skill which consists of “motor skill” and “cognitive skill”. The former one is what main determinant to success is in quality or quantity of movement and the latter one is what cognitive and decision in the tasks are important. In this paper, authors regard "the ability relating to the human body which can acquire throughout learning" as "motor-skill". Then we describe supporting for motor-skill acquisition.

1.2. Jump rope

This study tackles to support learning jump rope as lifelong sport. Jump rope is produced by combination of physical motions of body parts. Therefore, there are many types of tricks such as single-bounce and double-unders. Single-bounce is one of the fundamental trick. Some advanced studies have demonstrated that learners can acquire single-bounce in stabilizing form by Kamura et al. (2010) [1] and Nabeshima et al. (2008) [2]. By contrast, few studies have focused on comparatively difficult tricks, which are skills of double (or more) rotations of a rope in a jump. Especially, to perform the applied tricks with complex motions, the ability of simple double-unders is the prerequisite subject.

Meanwhile, we estimate difficulty of the double-under skill compared with single-bounce because many performers who can play the double-under skill try to acquire single-bounce being prior to the double-unders. After that, they try to jump higher and rotate the hand faster when they tend to apply single-bounce skill to the double-under skill. However, many beginners who want to acquire the double-under skill are confronted with problems. They are neither understanding what/how to do nor taking proper actions in spite of understanding them. Johnson et al. (1961) [3] reported that it is good for learners to be coached in order in training of motor skill. It starts with form, accuracy, speed and adaptation. Among these four aspects, form stability should be acquired at first. It means that we need the ability of completed coordination of physical body motions. However, it is hard for beginners who cannot execute two rotations of the rope during jumping by training themself. Therefore, for beginners in particular, to jump higher is required because they used to exercise all motion slowly. On the other hand, we consider that lots of beginners who can execute single-bounce are not comparatively difficult to jump higher consciously. Then, in this study, we focus on the hand-motion without discussing the control ability relating to height of jump as primitive movement elements in the training. By contrast, we consider that it is too difficult for beginners to imagine the trajectory of the hand. Thus, we regard hand-motions as more difficult motion than jump-motions. Therefore, this paper discusses the analysis of the primitive hand-motion and design of an environment to support learning the double-under skill for learners in early stage of the learning process. Here, we call the hand-motion a hand-skill. At first, we summarize ongoing analysis about hand movements. Secondly, we also describe designing a learning environment for improving the movement based on the result in this study.

2. Motor learning & motor skill

2.1. Motor learning

Learning has two aspects generally, which are motor learning and cognitive learning. They cannot be distinguished clearly because it occurs simultaneously in daily life. Schmidt (1991) [4] states that "Motor learning is a set of [internal] processes associated with practice or experience leading to relatively permanent changes in the capability for responding". Moreover, he proposed schema theory. A learner acquires a set of rule which associates a result of a performance with adequate parameters by practice repeatedly. It is so called schema. It is so important for beginners to acquire the schema in the first learning phase.

Fitts et al. (1967) summarizes a process of motor learning in three stages [5]. At the cognitive phase, learners try to comprehend what exactly to do. In addition, many body parts of the movement are controlled consciously. Hence, cognitive learning is regarded as important in this stage. Secondly, the associative phase is characterized by more fine movement of adjustments. Inefficient movements are gradually reduced, and the movements become more economical. At last, the autonomous phase is characterized by that movement becomes efficient and requires little muscular energy relatively. However, the boundary between each stage has overwrapping terms, and the skill of performers are improved gradually. Especially in the associative phase, feedback is made with much importance. There are two types in feedback. The first one is "action feedback" which is consisted of sensory information during exercise. The other is "augmented feedback" that is KR and KP. Knowledge of results (KR) is encouragement or indication given from a coach or a teacher. This is the information relating to the result of response rather than the movement itself. By contrast, knowledge of performance (KP) is derived from the information relating to all movement. It is difficult for beginners to recognize their own motions. The KR can make the beginners recognize differences which arise between the actual executed motions model and internal motions model. In addition, Salmoni et al. (1984) suggested the guidance hypothesis [6]. Their hypothesis is that advance in learning is prevented through getting excessive KR during learning, where learners rely on it. In addition, learners also become insufficient that they detect errors and pay attentions to internal sensors. Then, the hand-motion in the double-under skill is too fast for a learner to confirm the motion during jumping. Therefore, it is better to give augmented feedback at every trial-end in the learning of the double-under skill.

2.2. Motor skill

Guthrie (1952) defines a skill as the ability to bring about some end result with maximum certainty and minimum outlay of energy or of time and energy [7]. It is important to exercise more economical. Therefore, it is considered that the important thing for learners is the associative phase in three stages of Fitts et al. (1967). Besides, just trying the act of learning by following examples of experts is too difficult for beginners to understand the motor sensation of experts. Then, feedback should give learners well when they learn the skill. Thus, this paper proposes the feedback by the system, because, it is difficult for beginners to recognize motion of themselves. We focus on the visual information by a technique of image processing. Then, this paper defines beginners as those who cannot execute the double-under skill on two times or more in a trial.

2.3. Procedure to support learning

Being based on the above literatures, we can conjecture that it is reasonable for beginners to learn in the following procedure. First of all, a learner learns the knowledge about the double-under skill. After that, a learner learns by the motor-learning cycle as the following. At first, a learner tries to perform the double-under skill. Secondly, the learner recognizes his own performance by given KP and KR. Finally, the learner revises the errors of any motion or differences between the internal motion models and actual motion models, and plans strategy for improvement toward the next trial. The outline is shown in Fig. 1.

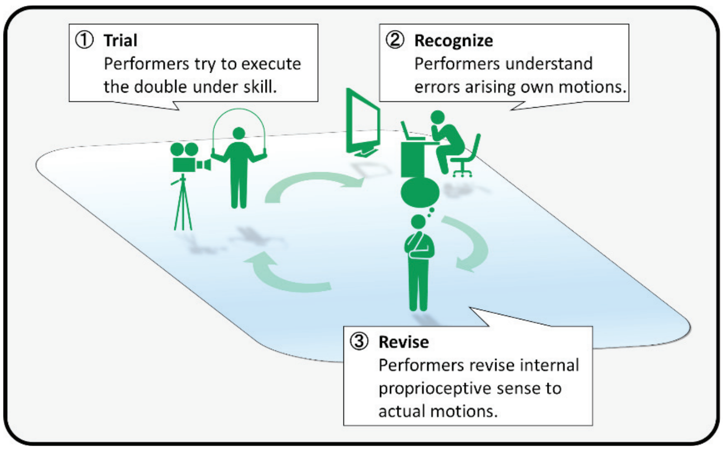

Fig. 1. The outline of support environment for asynchronous motor-learning cycle

3. Methodology

This section discusses a methodology to learn the double-under skill. When learners have already acquired single-bounce, they can perform easily to just jump high and to rotate their hands one rotation during one jump. Moreover, it is not difficult for them to combine these motions. In such people, they must satisfy the following 3 conditions in order to acquire the double-under skill. The first condition is to execute jump higher than jump of single-bounce because they must take time to rotate their hands two times during one jump. Then, second condition is to rotate their hands two times during one jump. It is required angular-velocity of hands faster than jumping of single-bounce. The third condition is to combine the hand-motion with the jump-motion. That is to execute the act of simultaneously managing the two rhythms having different periods. However, it is considered that learners complete the both first and second conditions in order to acquire the third condition. Therefore, this study makes learners acquire each motion in order. On the other hand, there are lots of other conditions to exercise the double-under skill. Especially, the hand-motion is one of important conditions above all because a control object which is a rope is operated by the performed operation of hands. In addition, it is considered that the motion of jumping higher in a simple way is a primitive motion. Hence, this paper focuses on the hands motion, and makes learners acquire the hand-skill as the first. It is shown in Fig. 2.

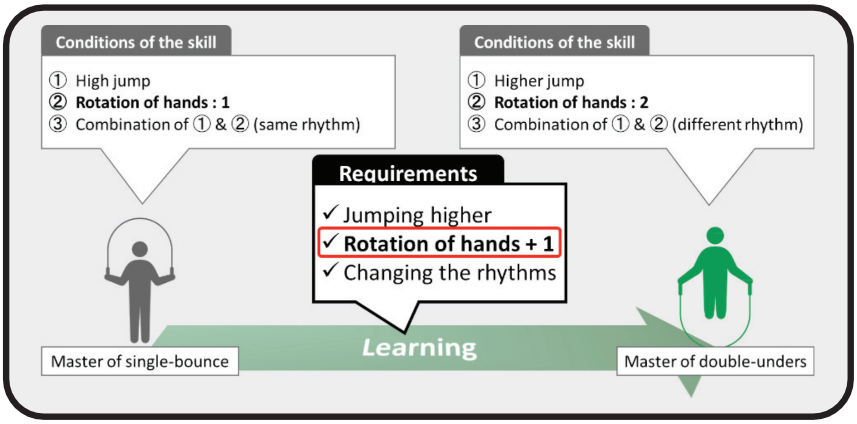

Fig. 2. Requirements for those who have acquired single-bounce and try to double-under skill.

4. The double-under skill

4.1. Focused properties

This study determines the master condition of double-under skill as who can execute a double-under continuously. On the several theoretical sides, there are some categories to classify motor skills or movement tasks. Here, the double-under skill can be corresponded to the following with each task or skill based on those theories. By the each theory on sport psychology or motor learning, repetitive movement is regarded as "continuous task". In addition, an exercise is regarded as "closed skill" under the conditions that variation of physical environment is small and the prediction of motions is easy. The double-under skill is positioned on these categories. Therefore, some important things for the double-under skill are to aim at learning pre-set motion pattern and to immobilize movement in an amount within a certain limit, and also to stabilize the environment including motions of performers him-/herself. The hand motion also has the similar meaning as the double-under skill. Besides, Kamura et al. (2010) [1] clearly indicated some of important requirements in many jump rope skills. It is stated by him about hand-motion. It is important to stabilize hand-motion at both closed area of the waist and foreside of the body.

4.2. Requirements of the hand-skill

The human requires combination of various movement patterns to perform complex motor behavior. It is also the same as the double-under skill, and it is realized by combining a rotary of hand-motion and a jumping exercise. When we observe them separately, there are individual motor patterns in each. As mentioned previously, the difficulties of the double-under skill for beginners are neither to understand nor to be able to do motion as intended by themselves. Here, we would like to make the requirement of the only hand-movement in order for beginners to succeed the double-under skill before finding the elements of all motion. With beginners, the conceivable requirements of hands movement in the double-under skill are to control rotational speed of hand and to adjust the timing associated with jump. If rotational movement of hands are regarded as a circular movement, the rotational speed depends on the radius and the velocity, that is, the angular velocity of the hand is determined by the values of 2 elements which are hand speed and size of turning trajectory. Then, this paper calls the half diameter of turning trajectory the radius. However, to train the muscular strength in order to increase motion speed of the hands, it is beyond the scope of the learning support of skill in this paper. Furthermore, the target motion in this study is to improve stable and smooth hands movement. In other words, it is economical movement. Accordingly, we focus on control of the radius of hand-trajectory in this study as controlling method of the angular velocity of the hands. In concrete, we take up "the stabilization of the moving spatial position of the hand" and "the control of the trajectory radius of the hands" as desired requirements of the hands in the double-under skill.

5. Absolute trajectory and relative trajectory

This section describes a method of the measurements of the hands. The important requirements of a monitoring tool are not only precision of motion measuring but also easiness or convenience for learning. Therefore, we use a video camera as the monitoring tool in this study. Thereby, we measure each position of requisite body parts for analysis of motion from the motion picture data utilizing image processing by OpenCV. Besides, we monitor two-spindle of motion directions of performers in each a sagittal plane and a frontal plane by camera based on the anatomical position. This paper defines bottom-left corner as origin in each frame image. In this study, we consider that the double-under skill is combined two types of movement patterns. They are hand-motion and jump-motion. Therefore, hand-motions during exercise in an absolute coordinate system include own jump-motion. Altogether, the hand-motion involved in jump-motion is the movement of an absolute coordinate in the space, and it is observed from the viewpoint of a third party. However, it is considered that the trajectory in the absolute coordinate is difficult to be imagined by performers during the exercise. By contrast, we expect that it is easy for performers to recognize the relative hand-motion for their own body during exercise. In addition, the expectation is different from relative hand-motion. Then, in order to measure hand-motions whose estimation is recognized by themselves, we measure relative hand-positions for body of performers against space.

The relative hand-position is obtained in the following way. At first, a video image of a performer exercising the double-under skill is recorded from left side of her/his body by a video camera. Then, some characteristic points are extracted through colored markers attached to the body of a performer. The points are the coordinate of their head, left-hand, and left-foot in the motion video. The position coordinates acquired here are the absolutely defined for space. Secondly, the coordinate of head on the first of all frame image is set as a reference point. After the first frame, displacement of the vertical from reference point is regarded as current coordinate of the head. The displacement is occurred by performing jump movement of body. Then, by sliding the entire image to the opposite direction of the above vector of the displacement based on the result, the motion video which is fixed the vertical direction coordinates of the head in all frame image is captured. Finally, we regard coordinate of the hand in each frame in the slided motion video as relative position for their own body. Each example of the absolute locus for the space and relative trajectory for the body of mastering the double-under skill are shown in Fig. 3. Then, we measure each part of the body relating to the double-under skill by the above method. We try to test two requirements took up above the hand-skill based on this trajectory.

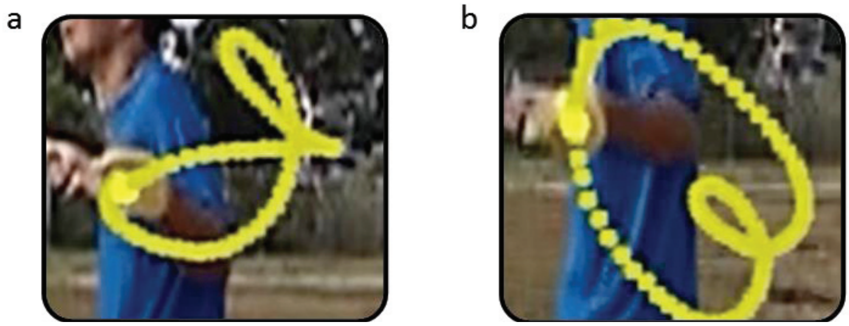

Fig. 3. (a) the trajectory in the absolute coordinate system; (b) the trajectory in the relative coordinate system of acquired the double-under skill

6. Analysis of the hand-motion

6.1. Analysis of relative motion trajectory of the hand

Eight students of under graduate and master course (Male: 7, Female: 1) who acquired single-bounce were subjects for this analysis. They performed the double-under skill. Each of them tried it five times on the same day (about 3 seconds / 1 trial). The succeeded times per one trial was approximately five times of jumping. We recorded the trial from left side of the subjects using the video camera (Sony, HDR-TD20V, about 100 fps), and monitored their motions in the sagittal plane. We noted the subjects to take care not to move horizontally during exercise at that time. Then, we focus on the temporal transition data of the vertical components of the head. In terms of one jump from the wave form, n-th local minimum and n+1-th local minimum of the data was detected. We divide all frame image in each jump, and we obtain the average per jump of relative hand-coordinates (x: horizontal component, y: verticality component). We regard this average as the center point of the hand-locus in one jump. Then, in all frames, we obtain the Euclidean distance from the center point (x, y) to the hand point (x, y) in each frame image. We regard this distance as the radius of movement trajectory of the hand. Here, one jump and the radius are illustrated in Fig. 4. Furthermore, this paper considers the difference in physical characteristic and individual differences, and obtains the ratio of the radius to the stature in each subject. The stature is measured maximum of Euclidian distance from head point (x, y) to foot point (x, y) in all frame in each video. Then, we obtain the standard deviation and the mean value of the radius. Besides, we plot the temporal transition of the relative hand point (x, y), and regard this transition as

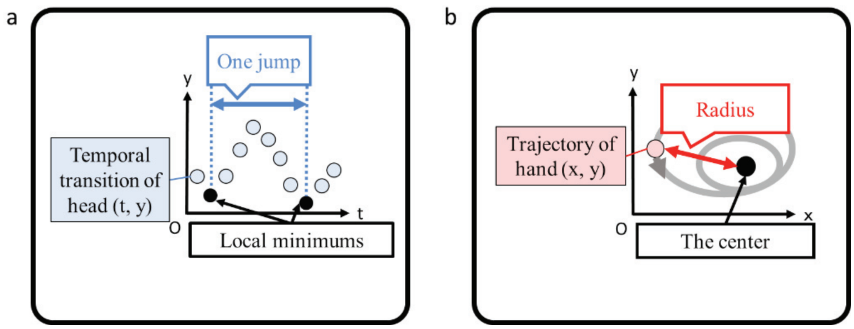

Fig. 4. (a) determination method of the one jump; (b) how to determine the radius

the hand locus.

6.2. Analysis of relative spatial position of the hand

In the same way as the previous section, we measured the spatial positions of relative movements of the hand for performer's own body. However, this paper considers personal difference in the arms and legs, and excludes the vertical component of hand-point. At first, we obtain the mean values (=M) of the x coordinate of both head and foot in each frame from the motion video. Then, we obtain the mean from the M in all frame. The difference between the body trunk and the hand-x coordinate of each subject in the sagittal plane is regarded as the relative hand-position against the body trunk in the plane. In addition, in order to measure the hand-positions of the subjects in the frontal plane, we observe the performance from the front of their body by the video camera. By similar way with the previous section, the subjects performed the double-under skill three trials (3 second / 1 trial). The number of success per one trial was approximately five times of jumping. The mean of the x coordinate of both head and foot in each frame is regarded as the body trunks of the subjects in the frontal plane in the frame. Then, the difference between the body trunks and the x coordinate of left hand on the frontal plane in each frame is regarded as the hand-position for the body trunk in the plane. Moreover, this study takes into account of differences in physical structures and individual differences, and obtains the ratio of the hand-positions to the stature in each subjects. Then, we obtain the standard deviation and the mean value of the values shown in Table 1. Fig. 5 shows the hand-position for body trunk in the frontal plane and in the sagittal plane.

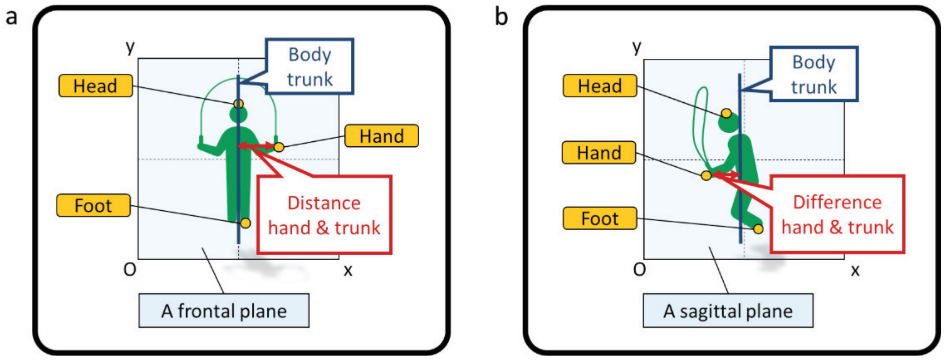

Fig. 5. (a) the hand-position for the body trunk in a frontal plane; (b) the hand-position for the body trunk in a sagittal plane

6.3. Findings

The hand-trajectories of the masters of the double-under skill suggest that they exercise in a fixed range and similar locus in each jump. The system plots relative hand-points. By contrast, the hand-trajectory of the novice of the skill is very large and varies widely among jumps. In addition, we find a tendency that the radius of the hand-trajectory is small by the masters. The average of the radius in each subject is shown in Fig. 6.

Here, we use a correlation coefficient by Spearman's rank correlation coefficient (1). It is calculated between the mean of hand-positions of front-back directions for the body trunk in the sagittal plane and the standard deviation hand-positions of left-right directions for the body trunk in the frontal plane. As a result, it is found to have a positive correlation between two values (rs=.642857). Table 1 shows the means and standard deviation in all subjects. These values are the hand-position for body trunks in the sagittal plane and the hand-position for body trunk in the frontal plane.

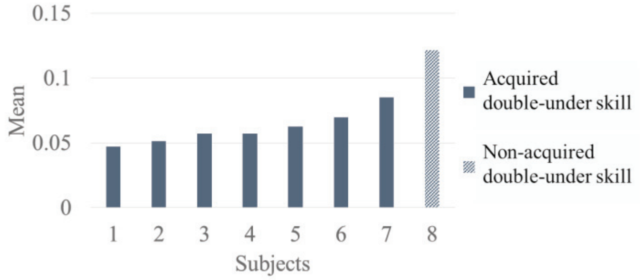

Fig 6. The average of proportion of the hand-radius to the stature in each subject

$$rs = 1 - \frac{6 \cdot \sum_{i=1}^{N} d_i^2}{N^3 - N} \quad (1)$$

Table 1. Hand-positions for body trunks in all subjects

	A sagittal plane (percentage for the stature)	A frontal plane (percentage for the stature)
Mean	-0.014030	0.006225
S.D.	0.049053	0.006058

7. Discussion

It is presumed that the player exercises by greatly moved all of the arm or does not exercise the hand in parallel to the frontal plane when s/he moves her/his hand at backward in the sagittal plane. It is conjectured that the hand-movement of frontal-horizontal axis becomes stable by putting the spatial hand-location to a front for the body trunk in the sagittal plane. According to the above discussion, the issue of the performance of hand-movement in the double-under skill is not irrelevant to the movement performance in the whole body.

In addition, seven subjects were originally able to execute the double-unders skill in this experiment. It is a possibility that the double-unders skill has relation to the single-bounce skill level.

As the future issue, this study is going to design a supporting environment for beginners to develop the double-under skill based on this study. Besides, due to the features of double-unders that the trick combine a rotary of hand-motion and a jumping exercise, we have to take into account of the following aspects as the required conditions for the success of the double-under skill. The implications are balance of a body trunk, a center of gravity, timing between hand-motion and jump-motion, and so on. This study will continuously carry out additional investigations about the relevance between these motions and the double-under skill.

Furthermore, it needs to examine performances of non-acquired double-unders skill by different subjects.

8. Conclusion

An object of this study is to support learning in the double-under skill as part various jump rope skills. Double-unders is a performance consisting of coordination movement by several body parts. Thereby, we focus on the hand-motion during jumping exercise as early stage of the learning process of the double-under skill. Furthermore, we focus on the hand-motion during jumping exercise as early stage of the learning supporting process of the double-under skill. Then, we try initial analysis of the hand-motion as primitive actions based on various theories of motor skill learning. Concretely, we take up "the stabilization of the moving spatial position of the hand" and "the control of the trajectory radius of the hands" as desired requirement of the hands in the double-under skill. We monitor the performance of a player by using video camera. Then, to focus on only the hand-motion, we obtain the relative hand-position to the body based on the analysis result of motions by OpenCV. Then, here evaluate the tentative theories. These results suggests the possibility that "the stabilization of the moving spatial position of the hand" and "the control of the trajectory radius of the hands" are significant for the double-under skill. Thus, we can consider that the hand exercise has much to do with the double-under skill.

As the future issue, we are going to design a supporting environment targeted at beginners for developed the double-under skill based on this paper as a staged supporting. Besides, due to being able to regard double-unders as performing by combined a rotary of hands motion and a jumping exercise, it should be added that linkages with balance of a body trunk, a center of gravity, a timing between hand-motion and jumping, and so on as the required conditions necessary for the executing double-under skill. After this, we will carry out additional investigations about the relevance between these motions and the double-under skill.

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