Analyzing Individual Unique Body Movements in the Skill Acquisition Processes

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Abstract. In sports and traditional arts, novices acquire motor skills through practice. For skill acquisition that requires periodic body movements, less variability in body movements is crucial; (1) less torso movement; (2) less variable arm swing; and (3) a stable swinging rhythm. However, the following question arises: Do novices always establish such stability as a prototype? To resolve this question, the present study experimentally investigated the motor skill acquisition processes of a sample of novice jugglers, who practiced three-ball cascade juggling over a period of one week. The findings revealed that two of the five jugglers who performed more than 100 successive catches produced individual unique body movements rather than establishing stable body movements as the prototype. Considering the participants' verbal reports, the results also indicated that such unique body movements were related to intentional control. This study identified the mutual relationship between automatic and controlled processing such as body movements and planning (Bebko, Demark, Im-Bolter, & MacKewn, 2005).

Keywords: Motor Skill Acquisition Process, Three-dimensional Motion Recording, Verbal Reporting.

1 Introduction

In sports and traditional arts, novices acquire motor skills through practice. In this regard, skill acquisition is usually evaluated according to the performance improvement criteria that includes task scores (e.g., [1]). In general, less variability in body movements is necessary for acquiring motor skills [1]. Especially, for skill acquisition that requires periodic body movements, establishing stable body movements is crucial. For example, Yamamoto and Gohara [2] discussed how variability in the arm swing of expert tennis players decreased during repeated strokes and how spatial flows converged into fixed patterns.

However, during practice, learners often invent and develop individual strategies for improving performance through trial-and-error [3]. In such situations, it is assumed that they do not always establish a prototype regarding effective or stable body movements. As a result, learners tend to scaffold their training temporarily and solve their problems by producing individual unique body movements. Such unique body movements may be related to one's intentional control for achieving optimum learning during practice. Bebko, Demark, Im-Bolter, and MacKewn [4] indicated that, during complex motor tasks, controlled and automatic processing build motor skills. In this regard, controlled processing is associated with deliberate and conscious processing such as planning, whereas automatic processing emerges as body movements when excessive attention to certain motor tasks decreases with improving performance. It is assumed that intentional control is important when learners produce individual unique body movements and solve their problems.

Therefore, our study investigates whether novices produce individual unique body movements during motor skill acquisition processes. In addition, it examines the verbal reports of a sample of novices regarding the most important factors for achieving a task to confirm whether such unique body movements are related to intentional control. More specifically, this study investigates the motor skill acquisition process in three-ball cascade juggling, which requires periodic body movements of tossing and catching each ball. The overall performance of the jugglers is based on the number of successive catches.

Previous studies (e.g., [5, 6]) revealed that for achieving a high performance level, it is crucial to establish stable body movements; this is especially with regard to the following three aspects: (1) less torso movement; (2) less variable arm swing; and (3) a stable swinging rhythm. For example, Haibach et al. [5] confirmed that the range of torso movement in the lateral direction and the variability of time intervals between one catch and the subsequent catch decreased with practice. Hashizume and Matsuo [6] also demonstrated that the variability of each hand's position in the lateral direction, at the timing of toss, decreased. Furthermore, Beek and van Santvoord [7] distinguished the different stages of learning in the motor skill acquisition process of three-ball cascade juggling. First, they defined the hand cycle time (HCT) as the time interval between one toss and the subsequent toss in a hand. HCT was subsequently divided into the time loaded (TL), which is the time spent holding a ball and the time unloaded (TU), which is the time spent not holding a ball. The ratio of holding a ball was calculated by the TL divided by HCT (TL+TU). When the ratio reached approximately 0.75, learning moved onto the next stage, following which the jugglers continued to practice cascade juggling by self-organizing stable body movements (i.e., a stable swinging rhythm).

In the present study, the participants practiced three-ball cascade juggling over a period of one week. Since the participants could perform more than 100 successive catches, they were regarded as intermediate level jugglers (e.g., [6, 7, 8, 9]). Considering previous studies (e.g., [5, 6]), this study defined the establishment of stable body movements according to the three aforementioned aspects (i.e., (1), (2), and (3) mentioned above), and regarded body movements other than these as "individual unique movements." It also recorded the intentional control of jugglers autonomously found during practice, based on their verbal reports wherein they highlighted the most important factors for improving their performance.

2 Method

2.1 Participants

The participants in this study consisted of five right-handed male students who were requested to juggle three balls and performed more than 100 successive catches.

2.2 Procedure

On the first day (Day 1), the participants were provided three juggling balls and asked to train for approximately 60 minutes, while referring to an instruction sheet numerating the procedure of performing three-ball cascade juggling and a video demonstrating its expert performance. The following section includes a description regarding the procedure of performing three-ball cascade juggling [7].

1. If a juggler is right handed, then he has two balls in the right hand and one in the left hand.
2. Toss the right-hand ball toward the left hand.
3. As the second ball falls, toss the final ball in the right hand toward the left hand. Catch the second ball in the right hand.
4. As the final ball falls, toss the first ball in the left hand toward the right hand. Continue with this sequence for performing three-ball cascade juggling.

From the second day (Day 2) to the last day (Day 7), the participants were asked to train for at least 60 minutes without the instruction sheet and video. Their performances were measured from Day 2 to Day 7 in the laboratory. More specifically, on each day, 10 trials were performed within a frame border (70 cm x 70 cm) on the floor.

During the performance measurements, a three-dimensional motion recording system captured the positions of seven light-reflecting markers (in the three-dimensional space) using nine infrared cameras at a sample rate of 100 Hz (Hawk type, Hawk: four; Hawk-i: five, NAC Ltd., California, USA). The cameras were focused on the following anatomical locations: the left and right wrists, the left and right elbows, the left and right shoulders, and the chest. The anterior direction (X-axis), lateral direction (Y-axis), and vertical direction (Z-axis) of each location were recorded in the three-dimensional space.

Before and after the performance measurements on each day, the interviews were conducted in which the participants were required to describe the most important factors for improving their three-ball cascade juggling performance.

3 Analysis procedures and results

3.1 Performance

The five participants performed more than 100 successive catches in at least one trial during this study. Fig. 1 presents the means for the first, second, and third best performances of each participant on each day. The horizontal axis represents the dates of the measurements (i.e., from Day 2 to Day 7), while the vertical axis indicates the means of the successive catches for the first, second, and third best performances. According to the figure, Participant E performed more than 100 successive catches (128 successive catches) in one trial on Day 5.

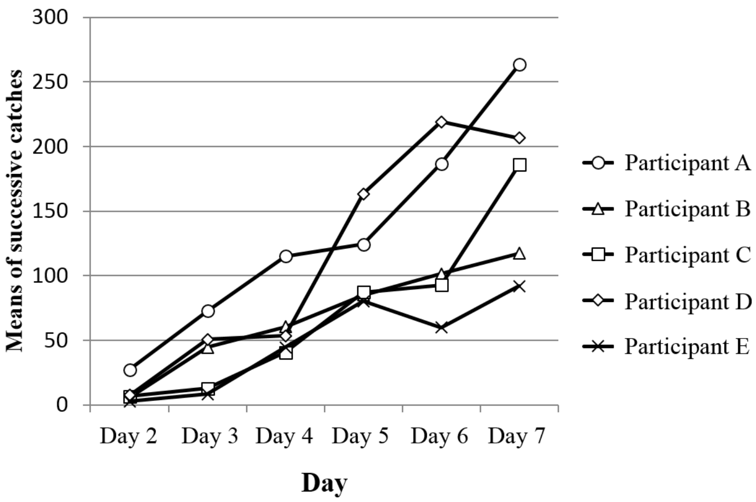

Fig. 1. Transition of successive catches.

3.2 Body movement

Analysis procedure. For evaluating the stability of body movements, the following three indexes of catching and tossing were examined: (1) the stability of chest movements (representing torso movements) was analyzed by using the first index, the fluctuations in the chest positions between one catch and the subsequent catch, and between one toss and the subsequent toss; (2) the stability of wrist movements (representing arm swing) was examined by using the second index, the fluctuations in the wrist positions between one catch and the subsequent catch, and between one toss and the subsequent toss; and (3) the stability of time intervals (representing swinging rhythm) was examined by using the third index, the standard deviations (*SD*s) of time intervals between one catch and the subsequent catch, and between one toss and the subsequent toss.

In addition, the following analytical procedures were employed. For identifying the timing of catching and tossing, our study focused on wrist movement. Since wrist movement was periodically repeated upward and downward, the peaks and valleys in this vertical movement were regarded as the catching and tossing points [10]. Regarding the timing of catching and tossing points, this study captured the positions of two locations (i.e., the chest and wrists) in the three directions and calculated the values of three indexes. For the first and second indexes, the fluctuations in the chest and wrist positions were analyzed between the *k* th and *k*+1 th catching points and between the *k* th and *k*+1 th tossing points. For example, regarding the fluctuations in the positions of the locations in the anterior direction between the catching points, this study analyzed $\overline{\Delta x_p}$ and used Equation (1). Here, $x_{p_k}$and $x_{p_{k+1}}$ represent the positions of the locations in the anterior direction at the *k* th and *k*+1 th catching points, while *n* indicates the number of catching points:

$$\overline{\Delta x_p} = \frac{\sum_{k=1}^{n-1} \left| x_{p_{k+1}} - x_{p_k} \right|}{n-1} \quad (1)$$

Our study also analyzed the fluctuations in the positions of the locations in the lateral and vertical directions between the catching points, $\overline{\Delta y_p}$ and $\overline{\Delta z_p}$. Moreover, it analyzed the fluctuations in the positions of the locations in the three directions between the tossing points, $\overline{\Delta x_v}$, $\overline{\Delta y_v}$, and $\overline{\Delta z_v}$. For the third index, this study analyzed the *SD*s of time intervals between the *k* th and *k*+1 th catching points and between the *k* th and *k*+1 th tossing points. For example, regarding the *SD* of time intervals between the catching points, it analyzed s_{t_p}, calculated by Equations (2), (3), and (4), where t_{p_k} and $t_{p_{k+1}}$ represent the timing of the *k* th and *k*+1 th catching points, while $\overline{\Delta t_p}$ indicates the mean of time intervals between the *k* th to the *k*+1 th catching points:

$$\Delta t_{p_k} = t_{p_{k+1}} - t_{p_k} \quad (2)$$

$$\overline{\Delta t_p} = \frac{\sum_{k=1}^{n-1} \Delta t_{p_k}}{n-1} \quad (3)$$

$$s_{t_p} = \sqrt{\frac{\sum_{k=1}^{n-1} (\Delta t_{p_k} - \overline{\Delta t_p})^2}{n-1}} \quad (4)$$

Similarly, this study analyzed the *SD* of time intervals between the tossing points, s_{t_v}.

Finally, for capturing the stable body movements that had reached a steady state, this study excluded the initial and last two successive catching and tossing points in each hand. Moreover, it analyzed the means of the values of three indexes for each hand. These are averaged with both hands. Meanwhile, for the trials in which less than 15 successive catches were performed, it analyzed them in all ranges of the catching and tossing points. These trials were then eliminated from the statistical analysis. In sum, the three trials that achieved the first, second, and third best performances on each day were analyzed, and the means of the values for the three trials were calculated. If the recording system failed to capture the positions of two locations for the three trials that achieved the first, second, and third best performances, and the loss rate in recording for each of the three trials exceeded 20%, then this study analyzed the trials that made the fourth (and any subsequent) best performance.

Results. Fig. 2, 3, and 4 present the transitions regarding the values of three indexes for each participant. The horizontal axes represent the dates of the measurements, while the vertical axes in Fig. 2 and 3 demonstrate the means of the fluctuations in the chest and wrist positions (in mm) between the catching points and between the tossing points. The vertical axis in Fig. 4 indicates the means of the *SD*s of time intervals (in sec) between the catching points and between the tossing points. The error bars indicate standard errors. The gray bars depict the means of the trials in which less than 15 successive catches were performed. In addition, the baselines represent the values for the three expert jugglers who had acquired the complete skills for performing five-ball cascade juggling. The data for the expert jugglers was from the study by [10].

Characteristics regarding a prototype of body movements. The findings indicated the following three points regarding the prototype of body movements since these points were consistent with the results of previous studies [5, 9].

First, the fluctuations in the chest and wrist positions on Days 2 and 3 were much greater than those on the other days, especially when the participants performed less than 15 successive catches. The participants significantly decreased the fluctuations in their body movements from the initial stage during practice. Meanwhile, from Day 4 to Day 7, the fluctuations in the positions of two locations and the *SD*s of time intervals did not decrease. 6 (Day: Days 2, 3, 4, 5, 6, and 7) x 2 (Event: catching and tossing points) ANOVAs were performed on the fluctuations in the wrist and chest positions and the *SD*s of time intervals for each participant. The data in which less than 15 successive catches were performed were eliminated from the statistical analysis. Among the 35 cases of ANOVAs performed, only three (Cases 1, 6, and 26 in Fig. 2 and 3) revealed a significant effect of the Day factor, illustrating that the fluctuations in the positions of two locations significantly decreased through the training sessions (ps $< .05$).

Second, the fluctuations in the chest and wrist positions and the *SD*s of time intervals on Day 7 for each participant were significantly greater than those for the expert jugglers. All the *t*-tests revealed significant differences between each participant and expert jugglers regarding the fluctuations in the positions of two locations and the *SD*s of time intervals at both the catching and tossing points (ps $< .05$).

Third, for arm swing, the fluctuations in the wrist positions and the *SD*s of time intervals between the tossing points were significantly less than those between the catching points. 6 (Day: Days 2, 3, 4, 5, 6, and 7) x 2 (Event: catching and tossing points) ANOVAs were performed on the fluctuations regarding the wrist positions and the *SD*s of time intervals for each participant. Among the 20 cases of ANOVAs performed, 17 revealed a significant effect of the Event factor (ps $< .05$). the 16 (from Cases 16 to 35, excluding Case 31 in Fig. 3 and 4) of these cases demonstrated that the fluctuations in the wrist positions and the *SD*s of time intervals between the tossing points were significantly less than those between the catching points.

Concerning the first point, Haibach et al. [5] reported that body movements became stabilized from the early to middle acquisition processes in three-ball cascade juggling, which was critical for establishing a prototype of body movements. Regarding the second point, van Santvoord and Beek [9] confirmed that stability in the hand movements of expert jugglers was higher than that of intermediate jugglers who had acquired the skills to perform three-ball cascade juggling. Finally, for the third point, van Santvoord and Beek [9] reported that the stability of hand positions at the time of tossing was higher than that at the time of catching.

Characteristics of unique body movements. Since different characteristics from those mentioned above were confirmed in two of the 35 cases, these body movements indicated the possibility of individual unique body movements.

First, the fluctuations in the chest positions in the lateral direction for Participant E was much greater than those for the other participants (see Case 10 in Fig.2). Even if he performed more than 100 successive catches, $\overline{\Delta y_p}$ and $\overline{\Delta y_v}$ demonstrated the fluctuations of more than 35 mm, and these values did not decrease from the initial stage during practice. This characteristic significantly differed from the first point regarding the characteristics of the prototype of body movements.

Second, the *SD* of time intervals between the tossing points for Participant A was much greater than those for the other participants (see Case 31 in Fig. 4). The *SD*s were more than 0.10 sec through the six training sessions. A 6 (Day: Days 2, 3, 4, 5, 6, and 7) x 2 (Event: catching and tossing points) ANOVA was performed on the *SD*s of time intervals, revealing a significant effect of the Event factor ($p < .001$). Meanwhile, the *SD* of time intervals between the tossing points was significantly greater than that between the catching points. This result was contrary to the third point regarding the characteristics of the prototype of body movements.

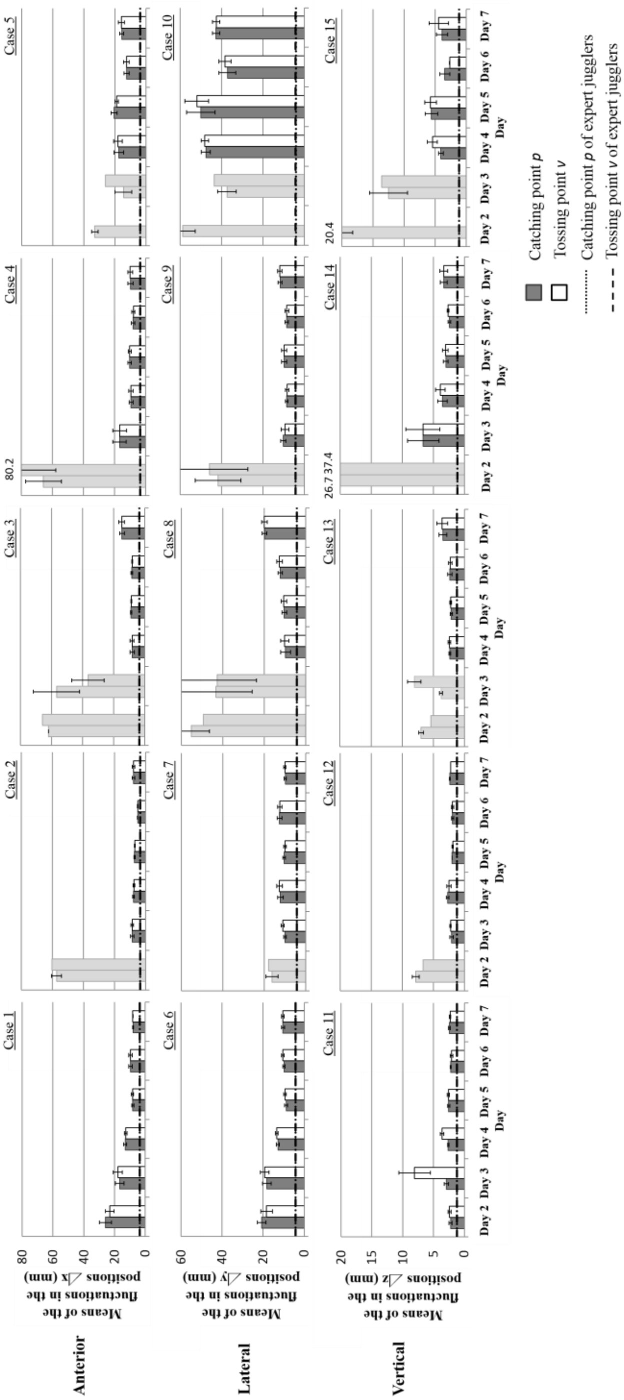

Fig. 2. Transitions regarding the fluctuations in the chest positions.

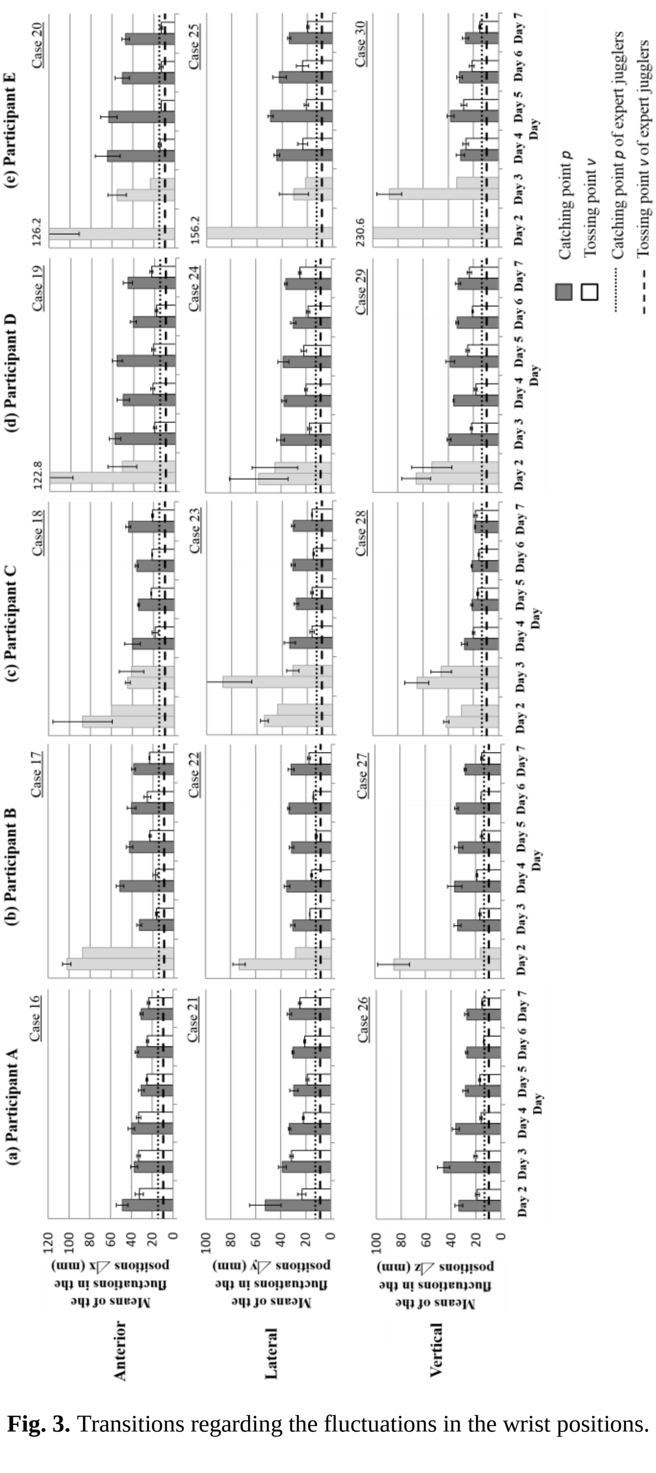

Fig. 3. Transitions regarding the fluctuations in the wrist positions.

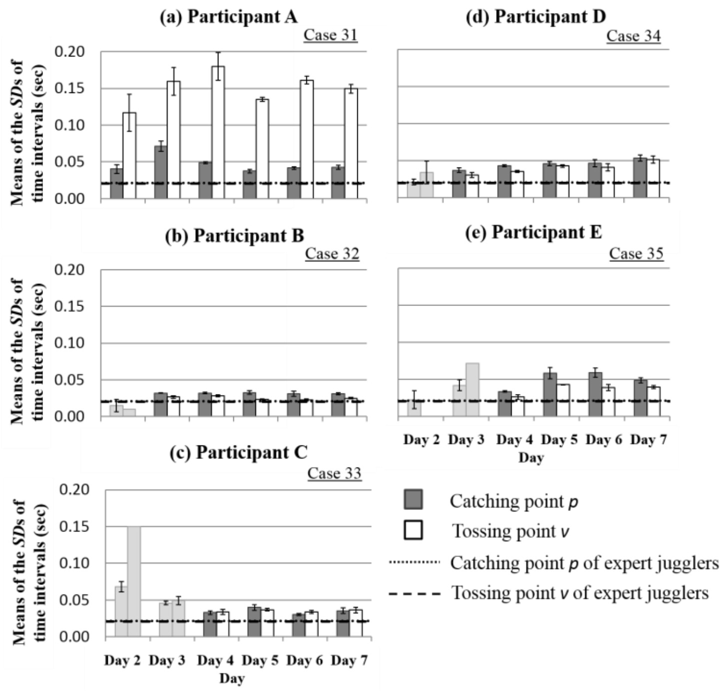

Fig. 4. Transitions regarding the *SD*s of time intervals.

3.3 Verbal reporting

Analysis procedure. This study also recorded the verbal reports of the participants in terms of the factors that assisted them in achieving optimum learning over the six training sessions. After transcribing and generalizing the verbal reports, intentional control was apparent from the bottom up. The verbal reports were also separated into the following three categories, since previous studies confirmed that these categories were important for performing three-ball cascade juggling [5, 6, 7, 8].

The first category referenced the procedure for performing three-ball cascade juggling (e.g., toss the ball on the inside of the falling ball). As shown earlier, some points on the instruction sheet were explicitly described. The second category referenced the attention to the spatial structure of the manipulated balls (e.g., watching around the zenith of the parabolic trajectory for predicting where the ball will fall). The third category referenced the establishment of stable body movements and ball trajectories. More specifically, it indicated finding a rhythm of throwing the balls, consistently throwing and catching the balls at the same position, and attempting to fix the trajectories of balls for attaining a consistent arch shape.

Result. Table 1 presents the number of categories that the participants mentioned over the six training sessions. All the participants mentioned the three categories (stated above) at least once. Table 2 demonstrates the details of their unique verbal reports.

Table 1. Number of categories in the verbal reports.

	Participant				
	A	B	C	D	E
References to the procedure for performing three-ball cascade juggling	3	9	9	11	3
References to the attention to spatial structure of the manipulated balls	3	1	2	1	3
References to the establishment of stable body movements and trajectories	15	5	9	7	11

Table 2. Unique verbal reports.

Participant	Unique verbal report (Day)
A	Toss a ball by the fingertips after adjusting the grip (Day 4)
B	Perform an arm swing and toss a ball straight up toward the opposite hand (Days 2 and 3)
	Raising one's arm high to throw a ball (Days 2 and 3)
D	Raising one's arm high to throw a ball (Day 3)
E	Snap the wrist to throw a ball (Days 4 and 5)
	Toss a ball by performing an arm swing with "whole body movements" (Days 3, 4, and 5)
	Toss a ball like you are "pushing out" (Day 6)
	To toss a ball, raise the "right arm" high and raise the "left arm" like it is approaching the opposite hand (Day 7)
	To toss a ball, raise one's arm vertically, while keeping the upper arms close to the body (Day 7)

3.4 Summary of results

For Participant A, the *SD* of time intervals between the tossing points was much greater than those for the other participants. Moreover, during the interview on Day 4, he reported tossing a ball by the fingertips for attaining a consistent arch-shaped trajectory (see Table 2). He attempted to adjust the grip to control each ball more accurately. This showed the high variability in time intervals between the tossing points that represented a swinging rhythm (see Case 31 in Fig. 4).

Meanwhile, for Participant E, the fluctuations in the chest positions in the lateral direction were much greater than those for the other participants (see Case 10 in Fig. 2). In the interviews from Day 3 to Day 5, he reported tossing a ball by performing an arm swing with ``whole body movements" to avoid the collision of a held ball and a ball falling from the parabolic arc's zenith (see Table 2). This showed the significant fluctuations in chest movements that represented torso movements.

These results demonstrated that the individual unique body movements for the two participants were mutually related to their verbal reports.

4 Discussion

4.1 Causality between individual unique body movements and intentional control

Our study confirmed individual unique body movements were related to their intentional control for achieving optimum learning during practice. However, the results did not depict that such unique body movements were caused by the intentional control of the jugglers. Therefore, it is important to carefully examine the casual relationship. In this respect, Participant A on Day 4 reported tossing a ball by the fingertips. However, before that day, the recording showed that he had already adjusted the grip. Likewise, Participant E on Day 3 reported tossing a ball by performing an arm swing with ``whole body movements." However, before this report, he had already implemented this action.

Ericsson, Krampe, and Tesch-Römer [11] reported that activities and deliberate goals are mutually related. This suggests that intentional control not only causes an improvement in activities but also ensures that such an improvement can guide deliberate goals. However, our study did not determinate whether the jugglers consciously noticed that they had performed individual unique body movements. Instead, this study simply identified the mutual relationship between automatic and controlled processing [4]. In addition, Gray and Lindstedt [3] confirmed that learners repeatedly invent and develop strategies, and practice in the processes of skill acquisition. This also suggest they acquire skills through the mutual relationship between body movements and intentional control.

4.2 Function of individual unique body movements for the expert level

The jugglers who performed five- or more than five-ball cascade juggling were regarded as experts [12]. Meanwhile, in the present study, the participants who performed three-ball cascade juggling reached the intermediate level [8, 9] and remained on track toward the expert level. Fig. 2, 3, and 4 confirmed that the stability of body movements for expert jugglers was higher than that for the participants with intermediate skills.

Participant A succeeded in performing more than 400 successive catches on Day 7 (see Fig. 1). However, his unique body movements may prevent him from reaching the expert level. For five-ball cascade juggling, the performers must shorten the time loaded (TL), while lengthening the time between tossing and catching a ball [13]. In this regard, the TL for Participant A was much longer than those for the other participants, owing to his unique body movement (i.e., adjusting the grip). Furthermore, it is evident that the number of balls in the air in five-ball cascade juggling is more than that in three-ball cascade juggling. In this study, Participant E attempted to toss a ball by performing an arm swing ``with whole body movements." However, this strategy may be ineffective for skill acquisition in five-ball cascade juggling since implementing ``whole body movements" is more difficult when manipulating more balls in the air. As a result, Participant E may also face difficulties in reaching the expert level.

For reaching the expert level, Participants A and E were asked to transform their intentional control related to their individual unique body movements. Thus, in general, some expert jugglers display individual unique body movements that significantly differ from the individuality observed in the present study.

4.3 Future works

This study confirmed that individual unique body movements were related to intentional control. However, we have the three future works.

First, according to **4.1**, we need to develop the method to analyze the casual relationship between such unique body movements and intentional control, and examine what extent the jugglers consciously noticed the unique body movements.

Second, in terms of **4.2**, we need to examine whether the individual unique body movements observed in the present study eventually disappear during the practice of five-ball cascade juggling, in reaching the expert level.

Third, we should discuss coupling of body movements and visual information. It is important to coordinate body movements and visual information for performing juggling. The jugglers tend to adjust arm swing to watch around the zenith of the parabolic trajectory during three-ball cascade juggling [8]. We found that the participants reported visual information as the factors that assisted them in achieving optimum learning (e.g., watching around the zenith of the parabolic trajectory for predicting where the ball will fall). The interest is to examine the relationship between individual unique body movements and visual information.

5 Acknowledgement

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