An Alternative Approach to the Acquisition of a Complex Motor Skill: Multiple Movement Training on Tennis Strokes

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This study examined an alternative approach to the acquisition of a complex motor skill, using constraints. To determine the efficacy of two alternative methods of learning tennis strokes, forehand and backhand strokes were practiced over five successive days using two contrasting training methods. The novel, multiple movement method required alternate forehand and backhand strokes, whereas the traditional, simple movement method required repeated forehand or backhand strokes as separate series of events. Five subjects were randomly assigned to each of the two conditions. Their strokes were recorded and analyzed kinematically before and after the training sessions. The simple movement method resulted in no changes in the range of trunk rotation perse, but the center of the range shifted unfavorably, in the direction opposite to that in which the ball was struck, for both forehand and backhand strokes. By contrast, the multiple movement method increased the range of trunk rotation, and the center of the range shifted favorably in the direction toward which the ball was struck, for both strokes. These differences were confirmed by the trajectories observed in hyper-cylindrical phase space as dynamical systems. In the multiple movement group, the forehand and backhand clusters converged after training, whereas in the simple movement group the two clusters diverged after training. From a dynamical systems perspective, we argue that the multiple movement method achieves its superiority by exploiting the inertia of the trunk rotation movement as a constraint that is produced by the preceding striking action, whether it be forehand or backhand.

Keywords: motor learning, striking action, dynamical system approach, constraints

1. Introduction

Human movement control is called an ill-posed problem. It is effectuated by solving problems of degrees-of-freedom in the musculoskeletal and neuromuscular systems which comprise multiple joints. Self-organization of behavior called coordinative structures may be necessary to solve the problems of degrees-of-freedom and to realize complex movement [Bernstein, (1967); Kugler, Kelso, & Turvey, (1980)]. Since self-organization of behavior is guided various constraints, this study aims to examine the possibility of complex motor skills learning by these constraints.

1.1. Constraints and self-organization of behavior

Newell (1986) has classified the constraints that affect self-organization of behavior into three types: organism, environment, and task. Organismic constraints consist of such structural constraints as body height and weight and such functional constraints as synaptic connections. They include anticipatory postural control preceding arm movement [Gahéry & Massion, (1981); Layne, (1990); Woollacott, Bonnet, & Yabe, (1984)]; symmetric constraints which are seen in bimanual coordination and coordination between limbs, called coordination dynamics [Carson,

Environmental constraints, in many cases, mutually relate to task constraints. Environmental constraints are not tasks manipulated by experimenters but are environmental features such as gravity, temperature, light, etc., which affect human movement control. Environmental constraints include the stepping reflex of a newborn infant, which vanishes four weeks after birth on the ground but recurs in water with little gravity [Thelen, (1983)], and anticipatory postural control to avoid obstacles [Zettel, McIlroy, & Maki, (2002)].

Task constraints are represented by the Fitts' law that claims speed-accuracy trade-off, in which the movement time is longer as the target is smaller in achieving movement while the movement time is shorter as the target is bigger [Fitts, (1954); Plamondon & Alimi, (1997)]. Also, task constraints were observed in an abrupt change of reaching pattern with supination or pronation of the forearm to grasp a handle by the initial position of the handle and the target position of rotating the same handle [Kelso, Buchanan, & Murata, (1994); Rosenbaum, Vaughan, Barnes, & Jorgensen, (1992)].

Human movements may be controlled to be optimized by these constraints, and motor acquisition using constraints has been proposed. In view of computational theory, learning methods have been examined using constraints of the amount of information given in the learning process. Jordan (1990), for instance, has integrated smoothness of trajectory formation as organismic constraint in the neural network model, in which the optimal trajectory is learned in a coordination system of multiple degrees of freedom, and, as an evaluation function, information relating to errors between target motor output and actual motor output as task constraint. In actual motor skill learning, a learning method that principally restricts visual information as environmental constraint was examined. Learners can obtain learning effects through the search of kinesthesia information other than restricted visual information [Bennett & Davids, (1997); Bennett, Button, Kingsbury, & Davids, (1999); Williams, Weigelt, Harris, & Scott, (2002). It can be said that these are the utilization of self-organization of behavior by constraints in motor acquisition.

1.2. Motor skill learning

In many concepts of conventional motor skill learning, motor skill is considered to be the summation of individual lower skills. This is based on the motor system approach [Reed, (1982)] to elaborate the skills by breaking them down into each element of the individual skills. It is a method to proceed step by step from learning simple motor skills to complex motor skills. Here, simple motor skills correspond to discrete movement and complex motor skills are continuous movement to repeat a single discrete movement or complex movement to continue movement by switching among multiple discrete movements. In the practice of movements, making tennis strokes for instance, learners repeat the practice of forehand strokes of balls that are tossed from a close position, then gradually extend the distance of the flying ball, to hit balls that are thrown from around the baseline. Later, in many cases, backhand strokes are practiced in a similar way. Here, striking action is practiced as a single discrete movement that repeats the exact same movement to elaborate the motor program of each movement while utilizing feedback. Once forehand and backhand strokes are acquired, these two types of strokes are tried by rallying with an opponent. This aims to integrate these movements of strokes. In other words, motor skill learning is based on the motor system approach, in which a movement in the same movement class is individually learned using the same generalized motor program [Schmidt, (1975, 1988)]. It is followed by learning continuous or complex movements like rallying in tennis or badminton. Motor learning that restricts visual information, mentioned above, applies this motor program learning in the same movement class.

Meanwhile, in the action system approach, motor skills are considered to be more than the summation of lower skills. Bernstein (1967) notes that organization of total motor skills passes three stages: first, freezing the number of degrees of freedom which is seen in synchronization of flexion and extension of more than one joint; second, release of degrees of freedom which is seen in economized transmission...
of power by asynchronization of these more than one joint; third, utilization of reactive phenomena that is arise by movements other than muscle strength [Newell & Vaillancourt, (2001)]. While Vereijken, van Emmerik, Whiting, and Newell (1992) have clarified these stages from freezing to releasing the number of degrees of freedom, Schneider, Zernicke, Schmidt, and Hart (1989) have explained utilization of counteractive power that is created by movements other than muscle strength through repeated practice of the movements. These three stages are regarded as those that respectively fulfill three constraints: task constraints, organismic constraints, and environmental constraints. In the rudimentary stage of learning, degrees of freedom are reduced to fulfill only task constraints. With the progress of learning, fulfillment of not only task constraints but organismic constraints leads to release of degrees of freedom. At the stage where learning is greatly progressed, fulfillment of environmental constraints can utilize and exploit the reactive phenomena that arise in movement control.

1.3. Physical principles operated in complex striking action and its learnability

Yamamoto and Gohara (2000) have applied a non-autonomous dynamical system that takes consideration of time-varying external input into complex movement of forehand and backhand strokes in tennis, and explained a simple principle that is hidden in the seemingly complex striking action. In this system, a cluster of stable trajectories is observed in continuous movement that repeats either forehand or backhand strokes. In a complex movement, forehand and backhand strokes are repeated in a random order so that according to the type of strokes the trajectory is entrained toward the trajectory set that is seen in each continuous movement. A cluster of stable trajectories seen in continuous movement is called the excited attractor, which means it is an attractor excited corresponding to an input. Also, it is clarified that, by the second-order sequence effects, eight types of different movements are regularly generated in an orderly and self-similar manner although random-order complex movement against two types of external inputs seems to be complex. Since this regularity agrees with the hierarchical structure of the Cantor set with rotation which gives a simple fractal structure, the transition of fractal-like trajectories that is seen in complex movement is called fractal transition between excited attractors.

This regularity is thought to be caused by inertia of trunk rotation movement and the physical principles operating in the organism have created phasic fusion between the regular end phase and the preparatory phase. In other words, the rotation direction of the follow-through of the forehand stroke is the same as that of the backswing of the backhand stroke, and the direction of trunk rotation in the follow-through of the backhand stroke corresponds to that of the backswing of the forehand stroke. Accordingly, in the repetition of the same class of movement of the forehand stroke, the direction of the trunk rotation should be switched to move from follow-through to the next backswing.

If we think this way relating to such side striking action as a ground stroke in tennis, beginners or learners under developmental stages show arm domination in which they mainly use the upper extremities; in the next stage, they progress to show unitary movement in which they concurrently rotate their trunk and hips as a single element in harmony with the swings of the upper extremities; in the advanced stage, at last, they achieve the opening pattern in which each section of their body moves separately not as a single element [Yamamoto, (1996); Wickstrom, (1975)]. Considering these, it is suggested that complex striking movement learning may be possible by using the inertia of the trunk’ s rotatory movement in the end phase. If we put it differently, a new method of motor skill acquisition may be conceived by regarding striking movement as a non-autonomous dynamical system. The purpose of this study is to examine a learning environment that promotes self-organization of behavior that utilizes physical constraints of the biological system.

2. Method

2.1. Subjects

The subjects were five female college students who hardly had previous experience playing tennis. We randomly assigned these five students into two groups, three students in the multiple movement
Table 1: Learning methods on simple and multiple movement training conditions.

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Simple movement</th>
<th>Multiple movement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Grip and paddling</td>
<td>Same as Simple movement training condition</td>
</tr>
<tr>
<td></td>
<td>• Short stroke : 50 alternately as for forehand and backhand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Machine stroke : 20 continuously respectively as for forehand and backhand × 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Machine stroke : 20 continuously respectively as for forehand and backhand (recorded as pre-test)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Manually thrown : 50 alternately as for forehand and backhand</td>
<td></td>
</tr>
</tbody>
</table>

Day 2

<table>
<thead>
<tr>
<th>Day 2</th>
<th>Simple movement</th>
<th>Multiple movement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Manually thrown : 25 continuously respectively as for forehand and backhand × 4 (200)</td>
<td>• Manually thrown : 20 alternately as for forehand and backhand × 10 (200)</td>
</tr>
<tr>
<td></td>
<td>• Racquet delivery : 25 continuously respectively as for forehand and backhand × 2 (100)</td>
<td>• Racquet delivery : 20 alternately as for forehand and backhand × 5 (100)</td>
</tr>
</tbody>
</table>

Day 3

<table>
<thead>
<tr>
<th>Day 3</th>
<th>Simple movement</th>
<th>Multiple movement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Manually thrown : 25 continuously respectively as for forehand and backhand × 4 (200)</td>
<td>• Manually thrown : 20 alternately as for forehand and backhand × 10 (200)</td>
</tr>
<tr>
<td></td>
<td>• Racquet delivery : 25 continuously respectively as for forehand and backhand × 4 (200)</td>
<td>• Racquet delivery : 20 alternately as for forehand and backhand × 10 (200)</td>
</tr>
</tbody>
</table>

Day 4

<table>
<thead>
<tr>
<th>Day 4</th>
<th>Simple movement</th>
<th>Multiple movement</th>
</tr>
</thead>
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<tr>
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</tbody>
</table>

Day 5

<table>
<thead>
<tr>
<th>Day 5</th>
<th>Simple movement</th>
<th>Multiple movement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Manually thrown : 25 continuously respectively as for forehand and backhand × 2 (100)</td>
<td>• Manually thrown : 20 alternately as for forehand and backhand × 5 (100)</td>
</tr>
<tr>
<td></td>
<td>• Racquet delivery : 25 continuously respectively as for forehand and backhand × 2 (100)</td>
<td>• Racquet delivery : 20 alternately as for forehand and backhand × 5 (100)</td>
</tr>
<tr>
<td></td>
<td>• Machine stroke : 20 continuously respectively as for forehand and backhand (recorded as post-test)</td>
<td>• Machine stroke : 20 continuously respectively as for forehand and backhand (recorded as post-test)</td>
</tr>
</tbody>
</table>

As a learning method of ground strokes in tennis, we divided the subjects into a simple movement group and a multiple movement group. In the simple movement group, the subjects always repeated forehand or backhand strokes that are used in the traditional learning process of tennis lessons. In the multiple movement group, the subjects alternated between forehand and backhand strokes. As with the conditions in the simple movement group, the direction of movement was different in the end phase and the next preparatory phase in the repeated practice of striking movement that belongs to the same movement class. In the multiple movement group, their conditions were: they continued the striking movement that belonged to the different movement class; the direction of movement was the same in the end phase and the next preparatory phase; it created an environment that may easily cause phasic fusion which effectively utilized the inertia of trunk rotation.

Table 1 shows the specific learning methods.
Every day each subject separately practiced ground strokes for about an hour on the tennis court. On the first and the last days of the experiment, we videotaped the subjects under the condition of simple movement group hitting forehand and backhand shots of balls from the ball-projection machine. They were analyzed respectively as a pretest and a posttest in the movement to examine the learning effects.

The learning method and the content in the first day were the same in both groups. From day 2 to day 5, we manipulated the learning method in both groups. We did not vocally instruct them on forms in either group, so only the learning method was different. We set the number of daily hitting for the subjects of both groups, with the total of 1520. On day 1, 180 balls, day 2, 300, day 3 and day 4, 400, and day 5, 240 (760 balls for forehand and backhand respectively). On both conditions, hand-throw toss came out in an interval of approximately 45 to 50 balls a minute from the service line of the court where the subject stood, and the racket toss came out in an interval of approximately 32 to 38 balls a minute from the net line where the subject stood. In these conditions, not all the subjects received balls in the same interval every time because the balls were thrown in synchronization with the movement of the subject, in the shortest interval possible, with the limit that the subject could hit the ball. The average speed of hand-throw toss was approximately 4 m/s and that of racket toss was approximately 7 m/s.

Every subject received follow-up coaching in the next week after the experiment with verbal instructions for an hour.

2.3. Motion analysis procedures

Figure 1 shows the filming conditions. The ball-projection machine (Tennis Tutor M2) is placed on the rotary board and balls were shot at the same average speed as a racket toss of approximately 7m/s, with an interval of 2.14s (28 balls/min). We changed the facing direction of all machines to make one bound on either side of forehand or backhand within the space of 1m long and 0.4m wide that contacts with 1m lines from both sides of the center mark and 2m line inside the baseline. Since the subjects were novice players, performance was not measured. Color cones were placed at 1m from both sides of the center mark of the opposite court and 2m inside as a target space.

The experiment was recorded using the DLT method [Abdel-Aziz & Karara, (1971); Nigg & Cole, (1994)] that reconstructs three-dimensional coordinates from two-dimensional images filmed by more than one camera. Striking action was filmed by synchronizing two cameras at 60Hz while resetting the time counter by a photoelectric SW (Omron E3V3-T61) that was set at the opening of the ball machine. It aimed to identify the time of ball shooting. A shutter speed of 1/250s was used to vivify fast-moving images. Three dimensional coordinate were set in the right-handed coordinate
system with Z axis in the vertical direction (upward direction), X axis in the hitting direction in parallel with the sideline, and Y axis being orthogonal with other two axes and facing outward. The measuring error in the DLT method between the mean at 16 control points and the standard deviation was -1.4 ± 6.6 cm in the X-axis direction, -1.1 ± 2.6 cm in the Y-axis direction, and -0.3 ± 4.8 cm in the Z-axis direction, respectively at pretest. At posttest, the error between the mean of 10 control points and the standard deviation was -0.1 ± 0.8 cm in the X-axis direction, -0.1 ± 0.2 cm in the Y-axis direction, and -1.3 ± 1.3 cm in the Z-axis direction respectively.

2.4. Data Analysis

From videotapes shot in each camera, using a two-dimensional video motion analyzer (OKK Motion Grabber), we digitized 60 frames each per second with four-point coordinates of both shoulder joints and both hip joints in 10 continuous trials out of 20 forehand and backhand shots in the pretest, and from the third trial to the fifteenth trial in the posttest. The reason to analyze 10 trials for the pretest was because we only had ten continuous trials due to the recording status in each of the 5 subjects in which both shoulder joints and both hip joints were filmed. Digitized data were first reconstructed in three-dimensional coordinates by the DLT method, then were smoothed by a second-order Butterworth filter with 3 Hz cutoff frequency, and finally calculated the segment angle at the shoulders and hips. The segment angle for the shoulders and hips were defined as the angle between the reverse of vector Y and vector from the left to the right shoulder and hip projected onto the X-Y plane, the reverse direction of the Y-axis 0 rad, CW being plus and CCW minus. These were the directions of shoulders and hips for analysis.

3. Results

3.1. Kinematics of striking action

Table 2 shows the range of shoulder and hip rotation in the pretest and posttest of each subject and the minimum angle at backswing with the maximum angle of follow-through. It also shows the result of comparison between both groups in each variable by applying a randomization test [Edgington, (1995); Todman & Dugard, (2001)].

In the forehand, the rotation range of the subjects

<table>
<thead>
<tr>
<th>Forehand Shoulder</th>
<th>Pref</th>
<th>Post</th>
<th>Pref</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Subj. 1</td>
<td>0.46</td>
<td>1.14</td>
<td>0.68</td>
<td>-0.08</td>
</tr>
<tr>
<td>Subj. 2</td>
<td>0.31</td>
<td>1.18</td>
<td>0.87</td>
<td>-0.27</td>
</tr>
<tr>
<td>Subj. 3</td>
<td>0.52</td>
<td>1.53</td>
<td>1.01</td>
<td>-0.48</td>
</tr>
<tr>
<td>Simple Subj. 4</td>
<td>-0.33</td>
<td>1.06</td>
<td>1.38</td>
<td>0.02</td>
</tr>
<tr>
<td>Subj. 5</td>
<td>-0.33</td>
<td>1.26</td>
<td>1.59</td>
<td>-0.06</td>
</tr>
<tr>
<td>probability</td>
<td>0.1</td>
<td>0.7</td>
<td>0.1</td>
<td>0.2</td>
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</table>

<table>
<thead>
<tr>
<th>Forehand Hip</th>
<th>Pref</th>
<th>Post</th>
<th>Pref</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Subj. 1</td>
<td>0.24</td>
<td>1.10</td>
<td>0.85</td>
<td>-0.21</td>
</tr>
<tr>
<td>Subj. 2</td>
<td>0.51</td>
<td>1.55</td>
<td>1.04</td>
<td>-0.18</td>
</tr>
<tr>
<td>Subj. 3</td>
<td>0.46</td>
<td>1.72</td>
<td>1.27</td>
<td>-0.27</td>
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<tr>
<td>Simple Subj. 4</td>
<td>-0.63</td>
<td>1.20</td>
<td>1.84</td>
<td>-0.07</td>
</tr>
<tr>
<td>Subj. 5</td>
<td>-0.24</td>
<td>1.32</td>
<td>1.56</td>
<td>0.11</td>
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<tr>
<td>probability</td>
<td>0.1</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Backhand Shoulder</th>
<th>Pref</th>
<th>Post</th>
<th>Pref</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Subj. 1</td>
<td>-1.62</td>
<td>-0.02</td>
<td>1.60</td>
<td>-1.67</td>
</tr>
<tr>
<td>Subj. 2</td>
<td>-1.56</td>
<td>-0.43</td>
<td>1.12</td>
<td>-1.69</td>
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<tr>
<td>Subj. 3</td>
<td>-1.30</td>
<td>-0.16</td>
<td>1.14</td>
<td>-1.62</td>
</tr>
<tr>
<td>Simple Subj. 4</td>
<td>-1.45</td>
<td>-0.19</td>
<td>1.27</td>
<td>-1.63</td>
</tr>
<tr>
<td>Subj. 5</td>
<td>-1.68</td>
<td>0.03</td>
<td>1.71</td>
<td>-1.93</td>
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<tr>
<td>probability</td>
<td>0.7</td>
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<table>
<thead>
<tr>
<th>Backhand Hip</th>
<th>Pref</th>
<th>Post</th>
<th>Pref</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Subj. 1</td>
<td>-1.43</td>
<td>-0.29</td>
<td>1.14</td>
<td>-1.63</td>
</tr>
<tr>
<td>Subj. 2</td>
<td>-1.47</td>
<td>-0.67</td>
<td>0.80</td>
<td>-1.52</td>
</tr>
<tr>
<td>Subj. 3</td>
<td>-1.24</td>
<td>0.18</td>
<td>1.41</td>
<td>-1.48</td>
</tr>
<tr>
<td>Simple Subj. 4</td>
<td>-1.22</td>
<td>-0.19</td>
<td>1.03</td>
<td>-1.46</td>
</tr>
<tr>
<td>Subj. 5</td>
<td>-1.28</td>
<td>0.07</td>
<td>1.35</td>
<td>-1.80</td>
</tr>
<tr>
<td>probability</td>
<td>0.3</td>
<td>0.7</td>
<td>0.9</td>
<td>0.7</td>
</tr>
</tbody>
</table>

All values are shown in radians except probabilities.
in the simple movement group was greater than those in the multiple movement group in the pretest. In the posttest all the subjects in the multiple movement group increased their range of trunk rotation, while those in the simple movement group showed no change or decreased their range of rotation. It may be explained that their range of trunk rotation converged to 90 deg (1.57 rad) and that the range of trunk rotation in the forehand in the simple movement group was already great before learning, while the multiple movement group changed more through learning. In the backhand, most players in both the simple movement and multiple movement groups showed an increase in the range of trunk rotation. It can be said that, in the greatness of the range of trunk rotation, not only the multiple movement group but the simple movement group had a learning effect.

Figure 2 shows the mean of the minimum angle, the maximum angle, and the range of rotation angle as well as its center of each subject by presenting them on the X-Y plane in order to see the range of how the shoulders and hips rotated. The upper is the range of the shoulder rotation and the lower that of the hips. The inner circle is the pretest and the outer the posttest. The X direction is the direction of the ball-projection machine (hitting ball direction) and on the Y-axis 0 deg is the state of facing to the ball-projection machine. When it exceeds 0 deg, the rim of the circle locates over the Y-axis. To roughly summarize, they show the rotation range of the right shoulder and hip of the subject in forehand, and that of the left shoulder and hip in backhand.

The figure clearly shows that the center of the range of trunk rotation approaches 0 deg, and the range increases in the multiple movement group. Yet, even if the range of trunk rotation increases, the center of the range is far from 0 deg in the simple movement group. That is, in the simple movement group, the range of trunk rotation did not show a great change before and after learning but the backswing, or preparatory phase, became bigger. On the contrary, in the multiple movement group, the range of trunk rotation increased and the terminal end phase, or follow-through, became bigger. And follow-through in this group was bigger than that of the simple movement group.
3.2. Striking action dynamics

In Figure 3, the horizontal axis shows the shoulder segment angle ($x_1$) and the vertical axis the hip segment angle ($x_2$) with one cycle being from the time of ball shooting to the next ball shooting. One trajectory circulating the cylinder of this figure shows the status of one stroke. The section in gray in this figure shows the moment of the shooting ball. The upper is of the pretest and the lower of the posttest. This figure, called hyper-cylindrical phase space $\mathcal{M}$, with N-phase space ($\mathbb{R}^N$) and one cycle period being circumference ($S$), shows an expanded state space in the discrete dynamical system in conventional non-linear dynamics into the continuous dynamical system [Gohara & Okuyama, (1999)].

In the pretest, each subject of the multiple movement group had separated trajectories for forehand and backhand while, in the posttest, the two clusters of trajectories seemed to converge on the Poincaré section when the ball was shot. On the contrary, in the simple movement group, the trajectories were not converged either before or after learning and the separation became clear. Figure 4

![Figure 3](image1)

**Figure 3** The trajectories in hyper-cylindrical phase space in pre- and post-test.

![Figure 4](image2)

**Figure 4** Poincaré section $\Sigma$ for the pre- and post-test for each participant.
shows Poincaré mapping on the Poincaré section $\Sigma$.
As we calculated the distance between mean values of
forehand and backhand in the pretest and posttest in
each subject in each Poincaré mapping, we obtained
10% in the ratio that incidentally caused some
difference between groups by the randomization test.

In the simple movement group condition, which
is the test condition in this experiment, Poincaré
mapping convergence is thought to be necessary
for switching between forehand and backhand,
and it is also suggested that the Poincaré mapping
of higher skill level players is more approximate
than that of lower level players [Yamamoto &
Gohara, (2000)]. Those in the learning group of
multiple movement had acquired coordinative
structures that enable continuous switching of
different movements in the biological system.

4. Discussion

To examine the effectiveness of the learning
method by the multiple movement group, we applied
the learning methods of the simple movement
group which repeatedly practiced the same class
of movement and the multiple movement group
which alternately repeated two different classes of
movement to the learning process of novice players.

As a result, in the simple movement group, their
range of trunk rotation showed no great change
and the center of rotation range in the forehand and
backhand changed to the backswing direction that
was the preparatory phase. In the multiple movement
group, the center of rotation range changed to the
follow-through direction that was the end phase with
the increase of the range of trunk rotation.

From analysis of the dynamical system, the
convergence of forehand and backhand trajectories
could be recognized through learning in the multiple
movement group while, in the simple movement
group, the two trajectories seemed to be separated.

The groups were set up to acquire coordinative
structures of two different movements by two types
of practice methods. It can be said that, in the simple
movement group, the trunk rotation movement
of forehand and backhand was being separated
as individual movement because there were no
varied demands from the environment and only the
preparatory phase was emphasized. On the contrary,
in the multiple movement group, the trunk rotation
movement increased to adapt to environmental
diversity so that two different movements merged as
a consequence of emphasis of the end phase.

In the multiple movement group, the learners
practiced in a way that the direction of the trunk
rotation in the end phase matched with that of the
next preparatory phase. In this way, we set conditions
in their practices in which the end phase and the next
preparatory phase are fused into the intermediate
phase from forehand to backhand, or from backhand
to forehand. Thus, phasic fusion acquired in their
practice could also maintain learning effects in the test
trials in the simple movement condition in which the
same class of movement are repeated. The movement
acquired in the multiple movement condition could
be maintained in forehand and backhand strokes
by the single movement condition which had no
environmental diversity; it can be said that the
learners could maintain so-called 'big movement' in
the strokes and this big movement might easily was
followed by the next movement and that they could
have acquired coordinative structures that conform to
the switching of continuous movement.

In this acquisition, no verbal instructions
were given and only the practicing method was
manipulated. Still, movement had been acquired in
accordance with each practicing method. In other
words, because there was a difference in biological
constraints operating on the physical system between
the two learning environments, the simple movement
group and the multiple movement group, different
organization was generated as a result. Although
repetition of the same movement class can thus
be effective on elaboration of its motor program,
it cannot correspond to environment that requires
performance by switching movement among different
classes of movement. Alternately repeating different
types of movement was effective on acquisition of
connection of different types of movements as well as
simple movements. In this respect, to acquire motor
skills that require various combinations of striking
movements, a learning environment which intends
that the end phase and the next preparatory phase are
shown to be "fused in" the intermediate phase in the
multiple movement condition is effective. It may
also be effective in learning for the simple movement condition that repeats the movement within the same movement class.

In case of the groundstroke in tennis, the balls can fly anywhere. When a quick action is required when a ball flies to either the foreside or backside, it is quite important for the player to face the net to get ready. When a player becomes higher in skill level, the player can get ready more quickly after hitting a ball. To coach novice players, “getting ready quickly” is frequently advised. It is suggested from the multiple movement condition in the present study that, without such verbal instructions, players can acquire the most appropriate stance by practicing the multiple movement method. There is a problem for novice players that their backswing is so big that they cannot round their hips in the follow-through. To correct this problem, multiple movement learning may be effective.

The difference of motor skills from daily motion that requires only relatively small muscle strength is that the momentum obtained by the movement is big. Accordingly, it can be effective to think of such a learning environment or motor task that can help the learner smoothly enter into the preparatory phase of movement that should be required by utilization of the momentum of its movement. Human movement contains some physical constraints such as the momentum of movement and gravity. It is important for the acquisition of complex skills of human movement to design a learning environment that does not oppose the physical constraints but uses them positively.

References
Acquiring a Complex Motor Skill


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