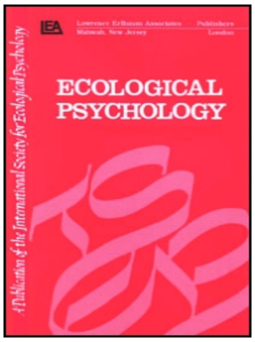

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Ecological Psychology

ISSN: 1040-7413 (Print) 1532-6969 (Online) Journal homepage: http://www.tandfonline.com/loi/heco20

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ECOLOGICAL PSYCHOLOGY
2017, VOL. 29, NO. 1, 1–22
http://dx.doi.org/10.1080/10407413.2017.1270147

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Perception of Affordances for Striking Regulates Interpersonal Distance Maneuvers of Intermediate and Expert Players in Kendo Matches

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ABSTRACT

In daily life and in many sports, people must adjust interpersonal distance between themselves and others based on task constraints and goals. For example, in martial arts such as boxing and kendo, players must adjust interpersonal distance before starting or defending strikes. However, it is not clear what players perceive and how players use this perceptual information to maneuver interpersonal distance and start strikes during real matches. We investigated players' perception of affordances and the criteria for perception and behaviors, and how these change with expertise, using real kendo matches as a one-on-one opponent task. Players perceived affordances for striking for themselves and for their opponent based on subtle interpersonal distance changes and clearly switched stepping forward and backward. In addition, players perceived affordances for strike success and entered closer interpersonal distance than the possible striking distance to increase their own striking ability and exited the closer distance to decrease their opponent's striking ability, respectively. Furthermore, expert players stayed in and moved into the critical interpersonal distance more frequently than intermediate players did. Our research indicates a relationship between action-scaled affordance perception of and maneuvers associated with interpersonal distance in one-on-one situations that occur in daily life and in many sports.

People try to leave an appropriate distance between individuals and objects (Hall, 1966). For example, if people are too close to a stranger, they move away, and if they are too far from their goals, they move closer so that they are at an appropriate distance. People also tend to avoid invading others' comfortable space, also called "personal space." People can change their behavioral goals based on distance and can adjust distance functionally to suit their goals (Sommer, 1959; Sundstrom & Altman, 1976).

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These distance adjustment behaviors offer clear evidence that people have the ability to accurately perceive what they and others can do in the environment, known as affordances (Fajen, 2007; Fajen, Riley, & Turvey, 2008; Mark, 2007). For example, people can directly perceive affordances for stepping on, sitting on, and passing through spaces based on their body scales in relation to the environment or task (Higuchi, Cinelli, Greig, & Patla, 2006; Mark, 2007; Stoffregen, Yang, & Bardy, 2005; Warren, 1984; Warren & Whang, 1987). In addition, people can directly perceive affordances for reaching based on their dynamic capabilities or action scales related to the environment or task (Pepping & Li, 1997, 2005; Ramenzoni, Davis, Riley, & Shockley, 2010; Ramenzoni, Riley, Davis, Shockley, & Armstrong, 2008; Ramenzoni, Riley, Shockley, & Davis, 2008a, 2008b; Rochat & Wraga, 1997; Wagman & Morgan, 2010). People can also accurately perceive affordances for other people's behaviors based on body and action scales (Mark, 2007; Ramenzoni et al., 2010; Ramenzoni et al., 2008; Ramenzoni et al., 2008a, 2008b). Thus, accurate perception of affordances makes it possible for people to adjust distance functionally.

Affordance perception and interpersonal distance adjustments under task constraints

The importance of interpersonal distance adjustment increases in tasks that have strict time constraints and require avoiding collisions with others, such as during locomotion in a crowd and driving vehicles on the road. In these tasks, rapid and accurate perception of affordances for the self and for others is required. Additionally, people need to rapidly and adequately control and coordinate their behaviors according to task constraints. Olivier, Marin, Crétual, and Pettré (2012) had participants walk in situations where their vision was restricted, and collision with another person was possible. Participants were able to subtly adjust their behaviors to avoid collisions (Cinelli & Patla, 2008; Gérin-Lajoie, Richards, & McFadyen, 2005; Olivier, Marin, Crétual, Berthoz, & Pettré, 2013). Similarly, Ducourant, Vieilledent, Kerlirzin, and Berthoz (2005) had two participants walk forward and backward in a face-to-face situation. One participant (the leader) was asked to try to change some set interpersonal distance, and the other participant (the follower) was asked to try to maintain the set distance. Followers were able to react rapidly when the leaders switched between stepping forward and backward (reaction time was about 0.2 s) and were able to maintain the interpersonal distance. These studies indicate that people can continually visually perceive affordances for themselves and for others during locomotion behaviors and can adjust interpersonal distance rapidly and adequately according to task constraints.

Affordance perception and distance maneuvers in sports

In sports, many situations demand more rapid and complex maneuvering of distance under stricter time constraints compared with those in most daily situations. This is due to the complex characteristics of tasks in which players cooperate with their teammates and compete with their opponents. Moreover, players acquire expertise in cognitive and motor skills over time. Recently, many sports scientists have started studying sports behaviors using ecological psychology methodologies (Araújo, Davids, Chow, & Passos, 2009; Balagué, Torrents, Hristovski, Davids, & Araújo, 2013; Beek, Jacobs, Daffertshofer, & Huys, 2003; Davids, Araújo, Hristovski, Passos, & Chow, 2012; Fajen et al., 2008; McGarry, Anderson, Wallace, Hughes, & Franks, 2002; Passos et al., 2009; Palut & Zanone, 2005; Schmidt, O'Brien, & Sysko, 1999; Vilar, Araújo, Davids, & Button, 2012).

In basketball (Bourbousson, Sève, & McGarry, 2010; Esteves et al., 2012) and football (Duarte et al., 2012; Duarte et al., 2010), players matched up with each other tend to move the same direction of the long axis of the court. In these sports, players perceive the directions, velocities, and distance of the ball, goals, teammates, and opponents in relation to themselves and control and coordinate their relative distance from these targets (Clemente, Couceiro, Martins, Dias, & Mendes, 2013; Cordovil et al., 2009; Esteves, de Oliveira, & Araújo, 2011; Passos et al., 2011; Travassos et al., 2012; Vilar, Araújo, Davids, & Button, 2012). In many group ball games, it is important for players to continually perceive the position and displacement of many objects and affordances for their own and others' athletic ability and to rapidly change their relative distances to these targets based on task constraints and goals.

In contrast, in one-on-one opponent tasks, such as almost all competitive martial arts like boxing and kendo, it is crucial that players accurately perceive affordances for the self and for the opponent and alter the interpersonal distance appropriately because such changes in the distance between the two players directly change the probability of the execution of behaviors. For example, at an interpersonal distance that is too near or far, the players only can strike with particular movements if at all. Hristovski, Davids, and Araújo (2006) had novice boxers strike a punching bag from some set distance and found that the boxers used different punches (e.g., straights, hooks, and uppercuts) depending on their distance from the bag. Thus, punching behavior is regulated by an appropriate interpersonal distance. In other words, interpersonal distance refers to the task constraints themselves, and it changes the perception of action-scaled affordances and behavioral goals in one-on-one opponent martial arts. This is called "affordance-based control of behaviors" (Fajen, 2007; Fajen et al., 2008).

Changes of affordance perception and interpersonal distance maneuvers in martial arts

In real boxing and kendo matches, the players do not simply strike their opponents but also maneuver interpersonal distance between each other before starting strikes. These interpersonal distance maneuvers are crucial for the players and form prerequisite conditions for strikes and defenses. Generally, a nearer interpersonal distance makes players' strikes easier because of shortening of the displacement distance, whereas a farther distance makes players' strikes relatively more difficult because of the lengthening of the displacement distance. However, despite staying closer to their opponents, players are unable to strike them at all times due to their own and the opponents' states, such as decision making for defense and loss of body balance for offense. Therefore, the players need to continue varying interpersonal distance to create their own strike opportunities and avoid those of their opponents according to these states in one-on-one opponent martial arts.

Dietrich, Bredin, and Kerlirzin (2010) considered the changes in the task constraints based on the differences in the interpersonal distance between two players during kendo and simulated players' forward and backward displacements before strikes. They found a correspondence between the results of their simulation and a real match. Okumura et al. (2012) found that, in real matches, kendo players switched the interpersonal distance maneuvers based on 10-cm distance differences. The switching behaviors tended to maintain or increase interpersonal distance between players at a near distance, which makes it easier to strike and more difficult to defend than in the case of a far distance. Additionally, they observed a tendency to decrease interpersonal distance at a far distance, which makes it easier to defend and more difficult to strike than in the case of a near distance. The researchers concluded that the kendo players understood these task constraints, continuously perceived affordances of each other's strike and defense ability, and continually maneuvered interpersonal distance on a movement-to-movement basis.

What are the criteria for affordance perception and interpersonal distance maneuvers in martial arts?

Previous studies clearly indicate that players in one-on-one opponent martial arts such as kendo change their interpersonal distance maneuvers by stepping forward and backward before strikes and do so based on their perception of affordances that changes according to distance or task constraints, following which they strike toward their opponents. However, how does perception of affordances lead the players to switch between stepping forward and backward or to start strikes? The players who have extensive experience in athletic martial arts would likely engage in these important behaviors regularly. Indeed, it is likely that players would have some clear body or action-scaled criteria for varying interpersonal distance and starting strikes during real matches (e.g., Warren, 1984; Warren & Whang, 1987). However, the criteria are unclear.

Based on previous studies, we can also postulate that perception of affordances gradually improves as sporting expertise is acquired. Many studies have shown that people can learn to perceive their affordances for themselves and those for others for both simple behaviors, such as jumping and reaching (Fajen et al., 2008; Pepping & Li, 2005; Ramenzoni et al., 2010; Ramenzoni et al., 2008; Ramenzoni et al., 2008b), and highly learned rapid and complex behaviors, such as sports skills (Kijima at al., 2012; Pepping & Li, 1997). Expert players in one-on-one opponent tasks can also anticipate and react to their opponents more rapidly and accurately than novice and intermediate players can (Di Russo, Taddei, Apnile, & Spinelli, 2006; Gutiérrez-Dávila, Rojas, Caletti, Antonio, & Navarro, 2013; Hagemann, Schorer, Cañal-Bruland, Lotz, & Strauss, 2010; Mori, Ohtani, & Imanaka, 2002; Rosalie & Müller, 2013; L. R. T. Williams & Walmsley, 2000). These studies indicate that players gradually become experts and learn to perceive affordances for themselves and for their opponents and behave rapidly and accurately in response to task constraints or goals. Thus, acquiring expertise in sports would lead to the refinement of perception–action coupling, and players' expertise level ought to affect their perception of action-scaled affordance and affordance-based control of behaviors. If so, expert players in one-on-one opponent tasks ought to be able to maneuver interpersonal distance and strike more accurately and rapidly than intermediate players can based on perceiving affordances.

Research hypotheses

Kendo players with extensive experience would tend to continuously perceive their own and opponents' affordances for striking and continuously varying interpersonal distance with the task constraints, which would require them to calibrate perception and behavior accurately and stably. If they were not able to perceive such affordances immediately and continuously, they would overlook not only their own striking opportunities but also those of their opponent. Therefore, we hypothesized that (a) kendo players would have a tendency to maintain a preferred interpersonal distance for keeping a balance between offensive and defensive behaviors. In other words, they would avoid staying at either a meaningless or dangerous interpersonal distance for kendo. (b) Perception of affordances for striking for the self and for the opponent should be a criterion for stepping forward and backward and for striking behaviors during matches. For example, they would step forward from a farther distance and step backward from a closer distance for striking and defending, respectively. On the other hand, previous research indicates that there are clear expertise differences in diverse perceptual and behavioral skills in any sports. Therefore, we hypothesized that (c) kendo players at different expertise levels would exhibit differences in terms of the perceptual and behavioral aspects of their interpersonal distance maneuvers during matches. For instance, expert players might be able to step and strike more accurately and frequently based on perception of affordances for striking than can intermediate players.

To clarify these research hypotheses, we analyzed players' behaviors in two expertise groups during real kendo matches. We particularly focused on their stepping behaviors for altering interpersonal distance and strike-related behaviors. In a subsequent experiment (using the same participants), we investigated perceptual judgement of interpersonal striking distance. We compared their behaviors in the matches and their perceptual judgment in the experiment and examined the relationship between the affordance perception and the behaviors exhibited during the matches. We also compared players from two expertise groups and examined potential differences in perception and behaviors based on expertise.

Method

Participants

Participants were male members of a kendo club at University of Tsukuba. The expert group consisted of 6 players who participated in formal competitions for Japan and regional universities, and the intermediate group consisted of 6 players who did not have formal competition experience.[1] This club team has won the Japan university championships five times since 2001. The expert group had high athletic skills at the university level (Japan has won the world team championship 15/16 times). The average age (*SD*) of the participants in the expert group was 20.7 (0.7) years, and they had an athletic experience of 14.2 (1.8) years. Their average kendo rank was 3.2 (0.4) dan,[2] average height was 172.9 (2.7) cm, and average weight was 77.4 (12.0) kg. Those in the intermediate group had an average (*SD*s) age of 21.2 (1.6) years, athletic experience of 13.8 (0.7) years, a kendo rank of 3.2 (0.4) dan, height of 170.3 (4.5) cm, and weight of 69.5 (9.2) kg. All players were in good health and continued their athletic activities during the experiment.

All players provided written informed consent prior to the commencement of the experiment. The procedure was approved by the Internal Review Board of the Research Center of

[1] Baker, Wattie, and Schorer (2015) claimed that, in future research, expert players should be grouped as "advanced players" for a more precise definition of expertise levels. However, we treated them as expert players based on comprehensibility and conventionality.

[2] On the skill rank system of "dan" in kendo, university players can get up to fourth dan based on the qualifications of examination.

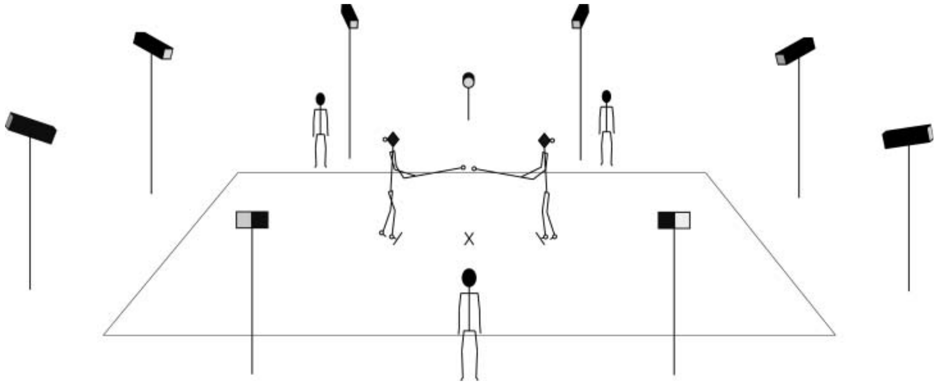

Figure 1. Experimental setting in Task 1: Matches. Each match was judged by three referees, lasted for 5 min, and was played on a square 11.00 × 11.00 m court based on official kendo rules. Movement trajectories were recorded using an optical motion capture system with eight different cameras and a video camera placed at roughly equal intervals around the court. Movements were detected using large reflective markers, which were attached to the back of each player's head, right and left ankles, and at the top of the shinai.

Health, Fitness, and Sport at Nagoya University, and the study conformed to the principles of the Declaration of Helsinki.

Tasks

Task 1: Matches

In Task 1, we recorded all the behaviors of the players during real matches (see Figure 1). All players used about the same length (about 1.2 m) and weight (little more than 510 g) of shinai (bamboo sword) according to official kendo rules and took the same ready stance "chudan" during matches. Six players were matched against 4 different opponents from the same group; a total of 12 matches were played in each group. Each match lasted for 5 min in accordance with official rules.

Task 2: Perceptual judgment of interpersonal striking distance

In Task 2, we measured interpersonal distance, that is, the players' perceived interpersonal striking distance (see Figure 2). We conducted Task 2 immediately after Task 1 at the center of the same court. We asked players to report the interpersonal distance from which they could strike four areas of an opponent (head upper temple, i.e., "men"; forearm, i.e., "kote"; abdomen, i.e., "dou"; and throat, i.e., "tsuki") with a rapid and brief offensive behavior. A player faced an opponent and maintained a ready stance for strikes. The player stepped toward and away from the opponent and stopped where he felt he was able to strike. The interpersonal distance for each player was measured eight times, that is, as the players moved forward and backward once against each of the 4 opponents in Task 1. This was an assessment of interpersonal distance perception in a static environment where interpersonal distance did not change rapidly and the opponent stood still.

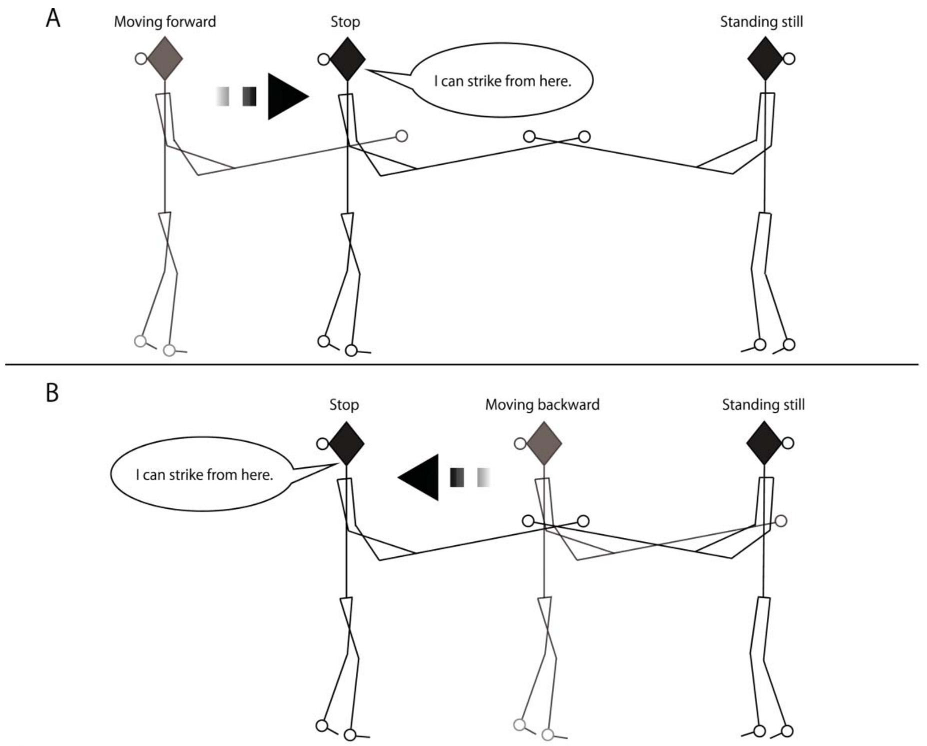

Figure 2. Experimental setting in Task 2: Perceptual judgment of interpersonal striking distance. After Task 1, we asked the players to report the interpersonal distance from which they could strike an opponent with a rapid and brief offensive behavior. In the example shown here, a left player faced a right opponent and kept a ready stance for strikes. The left player stepped toward (A) and away (B) from the opponent and stopped where he felt he could strike the opponent. Interpersonal distance did not change rapidly and the opponent stood still. The right player then executed the procedures against the left player. All players completed this procedure against the 4 opponents who competed in Task 1.

Procedure

Experimental apparatus

In Tasks 1 and 2, the movement trajectories of the players were recorded using an optical motion capture system with eight different cameras (100 Hz, OQUS300, Qualysis, Inc.) and a video camera placed at roughly equal intervals around the court (see Figure 1). Movements were detected using large reflective markers, which were attached to the back of each player's head, their right and left ankles, and the top of the shinai.

Scene extraction

First, the experimenter eliminated unrelated scenes for Task 1, such as when the referees stopped the match when the players scored or committed a foul, and those in which the reflective markers could not be seen because the players were outside the court or the field of view of the optical motion capture system. Consequently, the average match duration included in the analyses for the expert and intermediate groups was 4 min 19 s ($SD = 17$ s) and 4 min 26 s ($SD = 22$ s) per match, respectively, because the matches actually lasted for 5 min.

Data analysis

Preferred interpersonal distance

To analyze players' preferred interpersonal distance in Task 1, the players' head marker positions were expressed as time-dependent vectors (x(t),y(t)) and (u(t),v(t)). These time series vectors were calculated using a software package (Qualysis Track Manager, Qualysis, Sweden) and smoothed using a fourth-ordered Butterworth filter with a cutoff frequency of 6 Hz. The time series of the Euclidean distance (D(t)) between 2 players was calculated using Equation (1).

$$D(t) = \sqrt{(x(t) - u(t))^2 + (y(t) - v(t))^2} \quad (1)$$

We calculated the interpersonal distance for the entire duration of each of the 12 matches (see Figures 1 and 3), and the frequencies of interpersonal distance where the players stayed for each match.

Intensity of interpersonal distance maneuvers

Based on the same method used to examine the preferred interpersonal distance, we calculated the interpersonal distance peak and valley frequencies from the data of the entire duration of each of the 12 matches (see Figure 3). The peak is the point where the interpersonal distance between competing players started to decrease, and the valley is the point where the interpersonal distance started to increase. Peak and valley frequencies reflect the intensity of interpersonal distance maneuvers for offensive and defensive behaviors. For example, we could assume that peaks approaching two players tend to give the players strike opportunities and valleys separating two players tend to deprive them of strike opportunities at a far distance, and vice versa at a near distance, as already described.

Perceptual judgment of possible interpersonal striking distance

To analyze players' perceptual judgment of possible interpersonal striking distance, D(t) was calculated by utilizing Equation (1), where players stopped on the basis of the measure in Task 2 (see Figure 2).

Strike start interpersonal distance and movement time

To clarify players' actual striking ability and task constraints in Task 1 compared with Task 2, an experimenter with more than 30 years of kendo experience analyzed (a) strike start interpersonal distance and (b) strike movement time in the matches by focusing on the first strike from a near or far distance[3] using the data from the optical motion capture system and video camera. We defined a strike movement as follows: (a) strike started with an upward movement of the sword end point or a leg displacement and (b) strike finished at the end of downward movement of the sword end point. The strike start interpersonal distance was defined as the interpersonal distance at the onset of (a), and the strike movement time was defined as the duration between (a) and (b).

To verify the reliability of the analyses, the experimenter selected 50 scenes randomly and analyzed these variables again; the intraclass correlation coefficients were 1.00 for strike start

[3]We eliminated the second strike of the combination strike and the second player's strike when two players struck simultaneously because in those situations, the strike start interpersonal distance and movement time were extremely short.

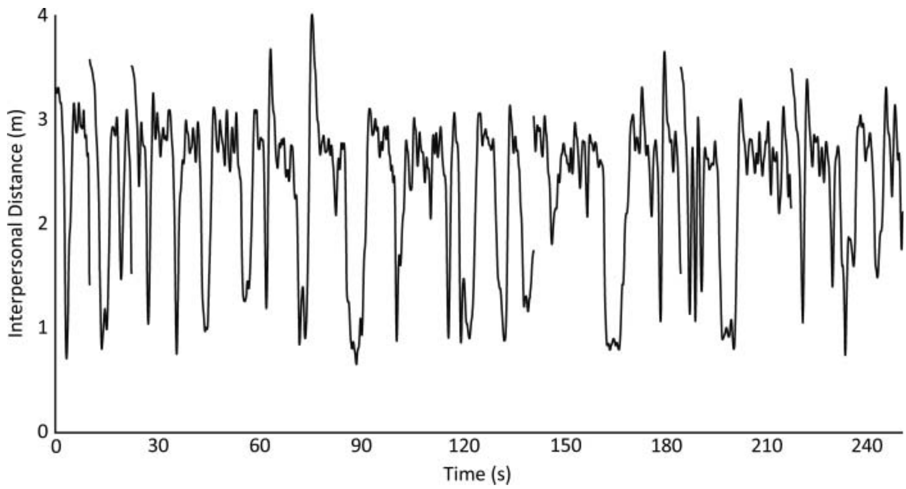

Figure 3. Sample data on the interpersonal distance in a match. The Y axis represents the interpersonal distance (m) and the X axis is the match timeline (s). Interpersonal distance ranged practically from 0.7 to 3.5 m. Specifically, there were many peaks and valleys at a near (0.7–1.3 m) and far (2.2–3.5 m) distance. Data interruptions indicate referee stops when players scored or committed a foul and so on.

interpersonal distance and 0.92 for strike movement time. We calculated the average of the strike start interpersonal distance and movement time for each match.

Statistical analyses

We set the expertise level as an independent variable and an α value of .05 was used for all analyses. To examine the matches, we only used interpersonal distance data from 0.7 to 3.5 m because this interpersonal distance range provided sufficient data for our analyses (see Figure 3).

To examine the preferred interpersonal distance, we calculated the rates of interpersonal distance frequencies (average [*SD*s] of data frequencies per match: expert group 4 min 19 s [17 s] and intermediate group 4 min 26 s [22 s] $\times$ 100 Hz, respectively) for each 0.1 m interpersonal distance region (from 0.7 to 3.5 m) per match. To examine the intensity of interpersonal distance maneuvers, we calculated the rates of peaks and valleys (average [*SD*s] of data frequencies per match: for peaks and valleys, expert group 167.17 [16.56] and 170.83 [16.64] and intermediate group 155.83 [19.52] and 155.75 [18.94], respectively)[4] for each interpersonal distance region per match. We then subjected these ratio data to an angular transformation. The data were analyzed using repeated-measures ANOVAs, where the repeated variables were frequencies of preferred interpersonal distance and peaks and valleys at each interpersonal distance region. Sphericity assumptions were verified using the Mauchly's test. The Bonferroni method was used for multiple comparisons.

To examine the perceptual judgment of possible interpersonal striking distance, we calculated the average interpersonal distance that was measured in Task 2 (average of four measurements in a match: 2 opposing players $\times$ stepping forward and backward) and used independent *t* tests for the analysis; equality of variance was verified using the Levene test.

[4]We divided the analyses of peaks and valleys for ease of analyses and discussions.

To examine the strike start interpersonal distance and movement time, we calculated the average of the strike start interpersonal distance and movement time for each match (average [*SD*s] of strike frequencies per match: from a near and far interpersonal distance, expert group 1.67 [1.46] and 26.33 [2.84] and intermediate group 2.50 [2.33] and 24.92 [6.24], respectively) and used independent *t* tests and the Levene test to analyze the two variables.

Results

Preferred interpersonal distance

In Figure 4A, the curved lines represent the frequencies of preferred interpersonal distance at each region; the black and gray lines represent the expert and intermediate groups, respectively. The data exhibited bimodality at around 1.00–1.10 and 2.70–2.80 m in each group. In the near interpersonal distance of around 1.00–1.10 m, called "tsubazeriai" in kendo, players engaged in behaviors such as the boxing clinch. In the far interpersonal distance of around 2.70–2.80 m, players showed frequent interpersonal distance maneuvers and strikes. Players did not spend much time at an interpersonal distance between the near and far interpersonal distance (see Figure 3). To simplify the analyses, we calculated total interpersonal distance frequencies and distributions in both groups and divided the data into three regions: near (0.70–1.30 m), middle (1.30–2.20 m), and far (2.20–3.50 m) interpersonal distance. A two-way ANOVA revealed a significant interaction effect, $F(2, 44) = 11.32$, $p < .001$, $\eta_p^2 = .34$; see Figure 4B. Although the effect size was small, the difference is important with reference to athletic behaviors because players in the two groups had a similar athletic experience and behavioral tendencies. Thus, it is difficult to find a behavioral difference superficially. The results of the simple main effect tests revealed that the expert group spent more time at the far than at the middle interpersonal distance and at the middle than the near interpersonal distance, and the intermediate group spent more time at the far than the near interpersonal distance. Furthermore, the intermediate group spent more time in the near interpersonal distance than the expert group did, and the expert group spent more time in the far interpersonal distance than the intermediate group did (average percentage of time [95% CI] for the expert and intermediate groups, respectively: near interpersonal distance = 45.56 [39.07, 52.04] and 62.93 [56.44, 69.41], middle interpersonal distance = 66.94 [60.23, 73.65] and 72.06 [65.35, 78.74], and far interpersonal distance = 162.84 [156.40, 169.29] and 145.31 [138.86, 151.75]; values after angular transformation have been reported). Thus, both groups preferred to stay at a far than at a near interpersonal distance. Also, the expert group preferred to stay at a far interpersonal distance and the intermediate group preferred to stay at a near interpersonal distance, respectively.

Intensity of interpersonal distance maneuvers

Regarding the intensity of the interpersonal distance maneuvers, we divided the data into the same three interpersonal distance regions: near (0.70–1.30 m), middle (1.30–2.20 m), and far (2.20–3.50 m). We analyzed the frequencies of peaks and valleys.

In Figure 4C, the curved dashed and solid lines represent peaks and valleys, and the black and gray lines represent the expert and intermediate groups, respectively. The analysis of peak frequencies revealed a significant interaction effect, $F(2, 44) = 4.90$, $p = .012$, $\eta_p^2 = .18$;

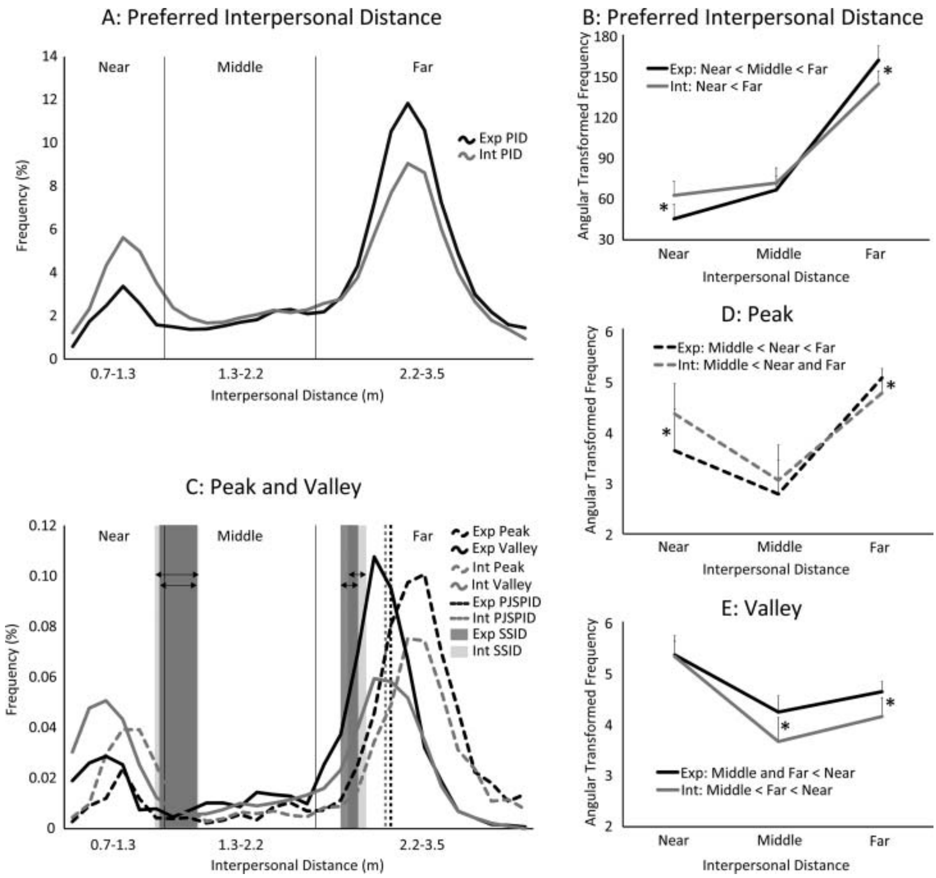

Figure 4. The relationships among frequencies of preferred interpersonal distance, peak, and valley. The black and gray ones indicate the results of the expert (Exp) and intermediate (Int) groups, respectively. A: The curved lines are the frequencies of preferred interpersonal distance (PID) in each region. B: The results of the interpersonal distance frequency analysis relevant to near, middle, and far distances. C: The curved dashed and solid lines are frequencies of peak and valley, respectively. The straight dashed vertical lines are the results from the perceptual judgment of possible interpersonal striking distance (PJSPID) performed in Task 2. The translucent zones are the averages $\pm$ *SD*s of the strike start interpersonal distance (SSID) in the matches conducted in Task 1. D: The results of the peak frequency analysis relevant to three distances. E: The results of the valley frequency analysis relevant to the three distance. The percentages of the total data have been shown in A and C. The values after angular transformation have been shown in B, D, and E. The peak and valley frequencies were divided by preferred interpersonal distance frequencies at each distance region before analyses to compute D and E, respectively. $^{*}p < .05$.

see Figure 4D. Although the effect size was small, the result is important for the reason explained earlier. The results of the simple main effect tests revealed that the expert group had more peaks at the far than at the near interpersonal distance and at the near than at the middle interpersonal distance. The intermediate group had more peaks at the near and far interpersonal distance than those at the middle interpersonal distance. Both groups had the fewest peaks at the middle interpersonal distance. In addition, the intermediate group had relatively more near interpersonal distance peaks, and the expert group had relatively more far interpersonal distance peaks (average percentage of time [95% CI] for expert and intermediate groups, respectively: near interpersonal distance = 3.64 [3.19, 4.01] and 4.37 [3.91, 4.82], middle interpersonal distance = 2.79 [2.32, 3.25] and 3.06 [2.60, 3.52], and far interpersonal distance = 5.07 [4.92, 5.23] and 4.78 [4.62, 4.94]; the values after angular transformation have been reported).

The analysis of valley frequencies revealed a significant interaction effect, $F(2, 44) = 3.29$, $p = .049$, $\eta_p^2 = .13$; see Figure 4E. The results of the simple main effect tests revealed that the expert group had more near than middle and far interpersonal distance valleys. The intermediate group had more near than far interpersonal distance valleys and more far than middle interpersonal distance valleys. Thus, both groups had more near interpersonal distance valleys. These results were due to the overall low near interpersonal distance frequencies (see Figure 4A and C; to calculate the rates, the frequencies of peaks and valleys were divided by the frequency of interpersonal distance in each region). In other words, both groups had a reduced tendency to stay at the near interpersonal distance and tended to move away from each other. In addition, the expert group had more middle and far interpersonal distance valleys than the intermediate group did, but there was no difference between the groups at the near interpersonal distance (averages [95% CI] for the expert and intermediate groups, respectively: near interpersonal distance = 5.39 [5.17, 5.60] and 5.36 [5.14, 5.57], middle interpersonal distance = 4.26 [4.01, 4.52] and 3.68 [3.43, 3.93], and far interpersonal distance = 4.66 [4.47, 4.85] and 4.17 [3.99, 4.36]; the values after angular transformation have been reported).

As a whole, it is clear that the expert group changed the interpersonal distance more intensively at the far interpersonal distance. In contrast, the intermediate group changed modestly at the far interpersonal distance and did so more intensively at the near interpersonal distance. These results also explain the distribution of preferred interpersonal distance. Players repeatedly stepped forward and backward while staying at the near and far interpersonal distance, leading to the bimodality of the interpersonal distance frequency.[5]

Perceptual judgment of interpersonal striking distance

The vertical, straight, and dashed lines in Figure 4C show the perceptual judgment of possible interpersonal striking distance in Task 2, where the black and gray lines represent the expert and intermediate groups, respectively. The averages (*SDs*) of perceptual judgment of possible striking distance were 2.65 (0.06) m and 2.62 (0.08) m in the expert and intermediate groups, respectively. A t test revealed no significant difference in perceptual judgment between the two groups, $t(22) = 0.93$, *ns*, $r = .20$. Thus, it is clear that there were no differences in the perceptual judgment of possible striking distance, or possible interpersonal striking distance, between the two groups.

It is also clear that, at far interpersonal distance, the highest peak frequencies were observed at farther distance, and the highest valley frequencies were observed at closer distance in terms of perceived possible striking distance. This suggests that both groups switched between stepping forward and backward to maneuver interpersonal distance based on their perceptual judgment of their own and their opponents' possible striking distance as a boundary.

[5]In both groups, the results indicate that the peak frequencies at a far distance are higher than those at a near distance, and the valley frequencies at a near distance are higher than those at a far distance because, in many situations, players need to approach each other from far to near distance and to separate each other from near to far distance for strike or defense behaviors at the end of situations. As a result, the relative frequencies become higher for peaks at a far distance and for valleys at a near distance.

Strike start interpersonal distance

The gray zones in Figure 4C show the average (*SD*s) of the strike start interpersonal distance. The averages (*SD*s) of the start interpersonal distance were 1.38 (0.11) m and 1.37 (0.13) m from around near interpersonal distance with moving backward and 2.40 (0.05) m and 2.44 (0.05) m from around far interpersonal distance with moving forward for the experts and intermediates, respectively. A *t* test revealed a marginally significant effect, indicating that the experts tended to strike from a closer interpersonal distance, whereas the intermediates did so from a farther interpersonal distance, $t(22) = 2.05$, $p = .053$, $r = .40$, but both groups started strikes from a very similar interpersonal distance range (we could not analyze strikes from the near interpersonal distance because there were no data in many matches; see strike directions in Appendix). In addition, there were very few strikes from around the far interpersonal distance where the players reported the perceptual judgment of possible interpersonal striking distance in Task 2.

At a far interpersonal distance, the results of the analysis of the strike start interpersonal distance suggest that players entered a closer interpersonal distance for actual strikes in matches than the perceived possible striking distance that was reported in Task 2. The strike start interpersonal distance in the matches was 0.2–0.3 m closer to the distance of the perceptual judgment of the possible striking distance. These results suggest that the players perceived affordances for striking differently in real matches (as in Task 1) than in Task 2 because the environmental changes occurred rapidly and complexly in matches, and the players were not able to anticipate the changes completely. Moreover, there was a high possibility of occurrence of opponent counterstrikes. Thus, the players needed to make strikes with certainty in such changing environments, and therefore, they decreased the distance between two players to increase the possibility of strike success.

At a near interpersonal distance, we also found the same relationships among the frequency of preferred interpersonal distance, the frequencies of peaks and valleys, and the strike start interpersonal distance. From a practical perspective, it is clear that the players lengthened the interpersonal distance for strikes and shortened it for defenses during matches. So we could assume reasonably the occurrence of the same phenomena at both near and far interpersonal distance. And that is why the players always avoided the middle distance between near and far interpersonal distance (see Figures 3 and 4). At the middle interpersonal distance, the players could strike their opponents more easily but could not defend against their opponents' strikes with high certainty, leading to shift between offensive and defensive successes.

In addition, the average number of successful strikes was 0.17 (0.37) and 0.08 (0.28) from the near interpersonal distance and 3.25 (1.64) and 2.83 (1.57) from the far interpersonal distance per match for the experts and intermediates, respectively, $\chi^2(1) = 0.02$, *ns, Cramer's* $V = .02$. Further, both groups had about 10 times more successful strikes from the far than from the near interpersonal distance (see Appendix), suggesting that the far interpersonal distance is particularly important for kendo.

Strike movement time

We calculated strike movement time from the near interpersonal distance when moving backward and far interpersonal distance when moving forward. The average (*SD*s) strike movement time was 0.32 (0.05) s and 0.34 (0.04) s from the near interpersonal distance and 0.31 (0.02) s and 0.34 (0.02) s from the far interpersonal distance for experts and intermediates, respectively. A *t* test revealed that the experts struck significantly more rapidly than the intermediates did from the far interpersonal distance, $t(22) = 3.10$, $p = .005$, $r = .55$; we did not analyze the strike data from the near interpersonal distance because of a data deficit; see Appendix. Thus, the expert group could strike faster and was under stricter time constraints for defensive movements than the intermediate group was, but the intermediate group performed little less than the expert group, and both groups had to perceive similar offensive and defensive time constraints. These results also indicate extremely intense time constraints for defensive behaviors in kendo.

Discussion

A criteria of interpersonal distance maneuvers: Possible interpersonal striking distance

The results showed that both groups had a similar bimodal distribution of preferred interpersonal distance (the black and gray curved lines in Figure 4A). The distribution of the preferred interpersonal distance corresponded with the distribution of peaks and valleys, suggesting that it was based on repeatedly stepping forward and backward to maneuver interpersonal distance (the black and gray curved lines in Figure 4C). As we hypothesized, the players with more athletic experience could maintain an interpersonal distance appropriate for balancing both offensive and defensive behaviors during real matches.

In addition, the boundary for the distribution of peaks and valleys was based on the players' perception of affordances for interpersonal striking (the vertical black and gray broken lines in Figure 4C). These results also corresponded with our hypothesis on the criterion of interpersonal distance maneuvers. At the far interpersonal distance, players stepped toward their opponents because they could not engage in an offensive strike from an interpersonal distance farther than their possible interpersonal strike distance. Players engaged in defensive stepping away from their opponents to deprive their opponents of an offensive opportunity. The reverse was observed at the near interpersonal distance, where players stepped backward for strikes and stepped forward for defenses, as in boxing clinch situations. Thus, changing interpersonal distance also changed the task constraints and goals for offense and defense before starting strikes, based on the boundary for possible strike distance. Therefore, as a criterion for successfully competing in kendo, players need to perceive affordances for their own and opponents' possible interpersonal striking distance and subsequently perform skillful interpersonal distance maneuvers.

A criteria of starting strikes: Probability of strike success

Surprisingly, the strike start interpersonal distance was around 2.40–2.50 m in the far interpersonal distance situation in real matches, and the players approached 0.20–0.30 m closer to their opponents than the possible strike interpersonal distance or perception of possible striking distance reported in Task 2.

These results suggest that players could strike their opponent with certainty from a closer interpersonal distance and that players increase the possibility of striking their opponent and decrease the possibility of counterstrikes in matches. For example, people create larger spatiotemporal margins from moving objects that have the possibility of collisions (Cinelli &

Patla, 2008; Gérin-Lajoie et al., 2005; Higuchi, 2014). Additionally, immediately before riding a moving ascending escalator, people gain waking velocity and lean forward to maintain postural balance (Fukui, Kimura, Kadota, Shimojo, & Gomi, 2009). As seen in these examples, players preliminarily compensate for their own offensive behaviors by approaching their opponents in matches or in other dynamic environments.

On the other hand, the strike movement time was about 0.30 s from an interpersonal distance of about 2.40–2.50 m, and it seems that this closer interpersonal distance negatively affected the players' defensive reactions and movement time. However, this interpersonal distance maintains an optimal balance between the possibility of offensive and defensive successes for highly experienced players who have practiced interpersonal distance maneuvers and other kendo skills for more than 10 years.

Interpersonal distance maneuvers in kendo matches consist of repeatedly entering and exiting a range of 2.40–2.50 m, which subtly changes affordances for task constraints and goals. Thus, players need to perceive affordances of the possibility of offensive and defensive successes to increase their own striking ability and to decrease their opponents' striking ability in dynamic environments.

The functions and expertise of affordance perception

As mentioned earlier, perceiving affordances for striking is necessary to step forward and backward for creating offensive and defensive opportunities before strikes. Further, perceiving affordances of offensive and defensive successes is necessary to start strikes with high certainty in real kendo matches. Therefore, the perception of two action-scaled affordances is an important criterion for offensive and defensive behaviors, particularly to maneuver interpersonal distance before and starting strikes in kendo. The behaviors based on the perception of these affordances should enhance behavioral "efficiency" (Stoffregen, 2003).

People inexperienced in kendo would have difficulty perceiving these affordances. Only experienced players can perceive those affordances that are likely to be specific to martial arts, especially kendo. In kendo or many other one-on-one opponent tasks, players maneuver their interpersonal distance regularly because they learn and perceive the action-scaled affordances or task constraints that are not appreciated by novices.

In fact, the players' perception and behaviors were highly attuned, and their actions and reactions were extremely rapid in our match experiments. For example, the players reached the peak and valley frequencies at an average (*SD*) of 1.24 (0.12) times per second. Similar to our experimental results, previous research indicates that players perceive action-scaled affordances based on 10 cm interpersonal distance differences while maintaining an interpersonal distance of more than 2 m between themselves and their opponents, and then they select and switch between offensive and defensive behaviors rapidly and continuously (Kijima et al., 2012; Okumura et al., 2012). Expert players in sports have to and can anticipate and react to environmental events contextually (McPherson, 2000; Sève, Saury, Ria, & Durand, 2003) and instantaneously (Gutiérrez-Dávila et al., 2013; Hagemann et al., 2010; Rosalie & Müller, 2013) and modify their behaviors while moving (Bootsma & van Wieringen, 1990; Kida, Oda, & Matsumura, 2005; Matsuo & Kasai, 1994). Thus, players gain expertise by acquiring the ability to perceive affordances in dynamic environments where task constraints and goals change rapidly, and in a complex manner, due to changing interpersonal distances, and then behave accordingly.

Expertise differences at affordance perception and interpersonal distance maneuvers

The expert and intermediate groups had a similar amount of athletic experience and similar distribution of preferred interpersonal distance, peaks, and valleys. However, as we hypothesized, we found important differences between the expert and intermediate groups. The expert group spent more time and had more peaks and valleys at the far interpersonal distance than the intermediate group did (see Figure 4), explaining the group differences in the preferred interpersonal distance and intensity of interpersonal distance maneuvers. In addition, with reference to the actual strike and strike success frequencies, the far interpersonal distance is particularly important in competitions.

In particular, the expert group had a greater valley frequency at the far interpersonal distance. A valley is the starting point of separation between two players. Generally, stepping backward happens at a lower velocity and is more difficult than stepping forward. In addition, it is quite difficult to remain ready to make stepping forward and backward movements and to reach a strike about 0.30 s from about 2.40 m. Muscular strength and balance are important and develop with expertise (Barone et al., 2011; Butler, Southers, Gorman, Kiesel, & Plisky, 2012; Hrysomallis, 2011), and preliminary behaviors play an important role in rapid whole-body reactions (Avilés, Benguigui, Beaudoin, & Godari, 2002; Uzu, Shinya, & Oda, 2009). Presumably, the intermediate group was not as proficient as the expert group in these fundamental motor skills.

There were no differences in the interpersonal distance while switching between stepping forward and backward and in the strike start interpersonal distance. Additionally, both groups perceived interpersonal distance based on affordances for striking possible distance with high precision during matches. However, sports researchers have indicated that players can improve cognitive accuracy and speed with expertise (Mann, Williams, Ward, & Janelle, 2007; A. M. Williams, Ford, Eccles, & Ward, 2011; A. M. Williams, Huys, Cañal-Bruland, & Hagemann, 2009). Experts have more precise perception and decision making when they have observed more instantaneous and dynamic behaviors (Huys, Smeeton, Hodges, Beek, & Williams, 2008; A. M. Williams, 2009; A. M. Williams et al., 2009). Further, perception and behaviors are linked (Aglioti, Cesari, Romani, & Urgesi, 2008; Fajen, 2007; Knoblich, 2008), which suggests that subtle differences in the cognitive and motor skills between the expert and intermediate groups led to differences in the affordance perception for interpersonal distance maneuvers, which led to the observed behavioral differences.

Unfortunately, our research cannot elucidate the cause of the expertise differences because the environments, perception, behaviors, and their relationships in matches are extremely complex. Nevertheless, it is highly probable that the expert group is more skillful in perception and maneuvering interpersonal distance than the intermediate group is.

Conclusion

We proposed that affordance perception is crucial for interpersonal distance maneuvers and strikes in sports, using kendo as an example of a one-on-one opponent task, and we discussed the criteria for perception and behaviors. As we hypothesized, players had preferred near and far interpersonal distances to maintain a balance of offensive and defensive behaviors. Players also altered interpersonal distance based on the perception of affordances for striking distances for themselves and for their opponents. At the far interpersonal distance, they stepped forward to their opponents to enable their own offense and stepped backward from their opponents to disable their opponents' offense. Additionally, they rapidly switched between these behaviors. Surprisingly, players decreased the interpersonal distance to increase the possibility of strike success, and increased the interpersonal distance to increase the possibility of defensive success at a far distance, and vice versa at a near distance. These interpersonal distance maneuvers are based on task constraints and goals and enhance behavioral efficiency. Perception of these action-scaled affordances is crucial for perception and behaviors, and they improve with athletic experience.

It is crucial for players in many sports to develop the ability to perceive affordances for themselves and others and to adequately maneuver interpersonal distance. In real matches, only 1 s delay or one mistake in perception and behavior could result in a loss. Thus, players need to develop perceptual and behavioral skills and to execute stable, rapid, and precise perception and behaviors. Subtle differences in the perception and behaviors between the expert and intermediate groups led to crucial differences in athletic performance.

Our research is important for understanding the perception and behaviors related to interpersonal distance maneuvers over the course of expertise, which is part of many sports. However, there are still a number of outstanding questions on skillful perception and behaviors in complex daily life and sports environments. It is necessary for future research to examine these skills in valid ecological environments such as in real daily living and sports environments.

Funding

This research was supported in part by Grant-in-Aid for Scientific Research (A) 20240060 and 24240085 from the Japan Society for the Promotion of Science.

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Appendix

Players' strategic differences

We verified the strategic differences between each player in matches. If there were marked strategic differences between players in each group, we could not unify the group data and would need to analyze each player's data individually. On the other hand, if the players' strategy was similar within each group, we could unify the group data.

The experimenter, who also conducted the players' strike start interpersonal distance and movement time measurements, analyzed (a) strike areas (head upper temple, forearm, abdomen, and throat), (b) strike directions (forward and backward), (c) strike times in one scene (simple or combination), and (d) strike players in one scene (one player or both players) by observing the data from the optical motion capture system and video camera. For (a), we simply counted the frequency of striking the four strike areas. In (b), when analyzing situations in which the players struck the opponent with moving forward or backward motions, we counted the frequency of the two strike directions. For (c) and (d), we divided entire scenes in the matches into one scene if the interval was more than 1 s from the completion of the previous strike to the start of the next strike (with regard to definition of strike start and finish, see the method of determining the strike start interpersonal distance and movement time). In (c), if one player started the next strike within 1 s after completion of the previous strike, we counted the continuous strikes as a combination strike in one scene. In (d), if one player started return or mutual strikes within 1 s after the completion of the other player's strike, we counted the situations as both players' strike in one scene.

We calculated the rates of strike areas, strike directions, strike times, and strike players for each category in four matches for each player (average [*SD*s] of strike frequencies per player: expert players 84.83 [8.77] times and intermediate players 75.17 [16.49] times) and then subjected these ratio data to an angular transformation. To verify the reliability of the analyses, the same experimenter selected 50 scenes randomly and analyzed these variables again. Then, the intraclass correlation coefficients were 100 % for all the analyses.

These variables were analyzed using repeated-measures ANOVAs to analyze differences in expertise. The repeated variables in strike areas were head upper temple, forearm, abdomen, and throat; those in strike directions were forward or backward; in strike times were simple or combination; and in strike players were one player or both players. Sphericity assumptions were verified using Mauchly's tests. The Bonferroni method was used for multiple comparisons.

Table A1 shows the strategic differences between each expert and intermediate player. In terms of strike areas, a two-way ANOVA revealed no significant interaction effect, $F(3, 30) = 0.55$, *ns*, $\eta_p^2 = .05$, or main effect for expertise, $F(1, 10) = 0.20$, *ns*, $\eta_p^2 = .02$, but a significant main effect for strike areas, $F(3, 30) = 127.12$, $p < .001$, $\eta_p^2 = .93$. The results of multiple comparison tests revealed that the players struck the head upper temple and forearm more frequently than they did the abdomen and throat.

In terms of strike directions, the ANOVA revealed no significant interaction effect, $F(1, 10) = 0.01$, *ns*, $\eta_p^2 = .00$, or main effect for expertise, $F(1, 10) = 0.00$, *ns*, $\eta_p^2 = .00$, but a significant main effect for strike directions, $F(1, 10) = 156.22$, $p < .001$, $\eta_p^2 = .94$. The results of multiple comparison tests revealed that the players struck with moving forward more frequently than with moving backward.

Regarding strike times in one scene, the ANOVA revealed no significant interaction effect, $F(1, 10) = 0.06$, *ns*, $\eta_p^2 = .01$, or main effect for expertise, $F(1, 10) = 0.00$, *ns*, $\eta_p^2 = .00$, but a significant main effect for strike times, $F(1, 10) = 50.04$, $p < .001$, $\eta_p^2 = .83$. The results of multiple comparison tests revealed that the players struck with simple strikes more frequently than with combination strikes in one scene.

With reference to strike players in one scene, the ANOVA revealed no significant interaction effect, $F(1, 10) = 4.12$, *ns*, $\eta_p^2 = .29$, or main effect for expertise, $F(1, 10) = 0.00$, *ns*, $\eta_p^2 = .00$, but a significant main effect for strike players, $F(1, 10) = 7.69$, $p < .020$, $\eta_p^2 = .44$. The results of multiple comparison tests revealed that only one player struck more frequently than two players did mutually in one scene.

All the analyses of players' strategic differences indicated that the expert and intermediate groups exhibited very similar strategies in the matches and that the variations in each group were not large. Therefore, for the entire analysis, we judged that the data within each group could be unified.

Table A1. Strategic differences between expert and intermediate players.

	Strike areas (%)				Strike directions (%)		Strike times (%)		Strike players (%)	
Participants	Head upper temple	Forearm	Abdomen	Throat	Forward	Backward	Simple	Combination	One	Both
Expert 1	59.1	31.8	4.5	4.5	88.6	11.4	63.6	36.4	44.3	55.7
Expert 2	50.6	42.7	4.5	2.2	89.9	10.1	83.1	16.9	51.7	48.3
Expert 3	48.5	45.5	4.5	1.5	98.5	1.5	93.9	6.1	59.1	40.9
Expert 4	57.6	39.1	1.1	2.2	94.6	5.4	70.7	29.3	50.0	50.0
Expert 5	55.6	37.8	5.6	1.1	97.8	2.2	70.0	30.0	46.7	53.3
Expert 6	41.7	53.6	1.2	3.6	92.9	7.1	71.4	28.6	60.7	39.3
Average	52.2	41.7	3.6	2.5	93.7	6.3	75.5	24.5	52.1	47.9
SD	6.0	6.8	1.8	1.2	3.7	3.7	10.1	10.1	6.0	6.0
Intermediate 1	71.6	27.2	1.2	0.0	93.8	6.2	77.8	22.2	53.1	46.9
Intermediate 2	46.6	52.1	1.4	0.0	87.7	12.3	64.4	35.6	46.6	53.4
Intermediate 3	45.4	40.2	7.2	7.2	85.6	14.4	93.8	6.2	72.2	27.8
Intermediate 4	50.0	47.7	2.3	0.0	100.0	0.0	68.2	31.8	61.4	38.6
Intermediate 5	55.7	40.0	2.9	1.4	100.0	0.0	82.9	17.1	68.6	31.4
Intermediate 6	73.3	23.3	2.3	1.2	82.6	17.4	76.7	23.3	76.7	23.3
Average	57.1	38.4	2.9	1.6	91.6	8.4	77.3	22.7	63.1	36.9
SD	11.3	10.3	2.0	2.6	6.8	6.8	9.6	9.6	10.6	10.6