Cognitive and motor control mechanism for ballgame defenders in 1-on-1 defensive situation

KEISUKE FUJII

Cognitive and motor control mechanism for ballgame defenders in 1-on-1 defensive situation

KEISUKE FUJII

A dissertation presented to the

Graduate School of Human Environment Studies,

Kyoto University

In Partial Fulfillment of the Requirement

For the Degree of Doctor of Philosophy

(Human and Environmental Studies)

2014

Motoki Kouzaki

Supervisor of Dissertation

論　文　要　旨

バスケットボールのような侵入型球技の選手は、正確な認知能力を有し、巧みな動きを実行する。これまでの多くの研究においては、認知と運動制御が別々に研究されてきたが、実際に球技選手が発揮した技術に関しては焦点を置いていなかった。そこで本学位申請論文では、多くの球技に共通する、1対1の防御の局面における防御者の認知と運動制御を同時に測定し、そのメカニズムを解明することを目的とした。

本学位申請論文は、以下の8章から構成される。第1章では、研究の背景と先行研究の概略、論文構成について述べた。申請者は最初に防御者の認知的側面の研究として、映像を使ったアプローチで防御者の予測メカニズムを検討した（第2・3章）。第2章では、攻撃者の方向転換時の最終的な移動方向に関する手がかりを防御者が検出する時刻を推定した。第3章では、防御者がどのようにしてその手がかりから攻撃者の最終的な移動方向を予測するのかを検討するため、攻撃者の身体重心と足の情報を使って防御者が予測しているという仮説を、倒立振子モデルを用いた順力学シミュレーションを用い検証した。その結果、モデルが予測する手がかり時刻と、実際の防御者が検出した手がかり時刻は有意な正の相関が認められた。このことから、防御者は攻撃者の移動方向を予測する際に、従来言われていた重心だけでなく、足も見る必要があることが示唆された。

第4章から第6章においては、防御者が実際に1対1の局面において発揮する動作の運動制御機構について検討した。第4章では、実際に防御者がどのようにして攻撃者を止めるのかを明らかにするため、光学式動作解析装置を用いてバスケットボールのドリブル1対1課題を行い、動き出し時刻とピーク移動速度を用いて防御成功試行が3つのパターンに分類できることを明らかにした。申請者は次に、地面反力計を用いて防御者の早いタイミングの動き出しと速いスピードの動きの運動制御機構について検討した（第5・6章）。第5章では、上下に揺れる準備動作がサイドステップの動き出しを早めることを明らかにした。特に、方向刺激点灯直後の抜重状態がサイドステップの早い動き出しを実現する理想的な力学的準備状態であることが示唆された。第6章では、バスケットボールのドリブル1対1課題における、防御者の力学的準備状態について検討した結果、動き出しを遅くする加重状態が攻撃者に突破される要因となり、動き出しが遅くなるのを防ぐ非加重状態が防御成功の要因となることを示した。動きの速度に関しては、防御成功の要因であるというよりは、結果に過ぎない可能性が示唆された。

第7章では、以上すべての研究を総括して議論した。本学位申請論文は近年始まった対人スポーツ研究の基礎に位置づけられており、第7章では今後の発展的な研究の可能性について論じた。第8章では、本研究により得られた知見に基づき現場への応用方法を検討した。バスケットボールの1対1の防御の局面において、高い確率で防御を成功させるためには動き出しを遅くしないために防御者は重心と足を見て予測を行うことと、非加重状態を作って準備する必要があることが示唆された。

本研究の結論として、バスケットボールの1対1の防御の際の認知・運動制御において、高い確率で防御を成功させるためには、準備状態を揺さぶるドリブラーに対し、動きを早くして対応するというよりは、動き出しを遅くしない戦略を取るべきだということが示された。特に、認知過程においては、重心と足を中心に見て移動方向を予測することと、運動制御過程においては地面反力が大きくならない非加重状態をつくり準備しておくことが重要であることが示唆された。

Abstract

Skilled players in invasive ballgames such as basketball execute accurate, quick and strong decision making and motor control. In the ballgame, an attacker with the ball aims for the scoring point, and a defender stops the aim of the attacker. However, many researchers have separated cognitive and motor aspects, and have not focused on the skill actually executed by ballgame players. Therefore, the present thesis simultaneously focused on cognitive and motor skill in defending an attacker, which is in common among various invasive ballgames.

In the thesis, first, anticipatory (cognitive) mechanism in replicated 1-on-1 defensive situation was investigated using video-based approach. In study I, the timing for the detection of relevant information in the attackers' final running direction during their cutting maneuvers was examined. In Study II, to investigate how defenders process this information to decide on their opponents' running direction, the hypothesis that defenders extract information regarding the position and velocity of the attackers' center of mass (CoM) and the contact foot was tested. The model simulates the future trajectory of the attacker's CoM based upon an inverted pendulum model (IPM). The model-estimated IPM cue timing and the empirically observed defender's cue timing were comparable in median value and were significantly correlated. I discussed that defenders may be able to anticipate the future direction of an attacker by forwardly

simulating inverted pendulum movement.

In Study III, to clarify the defending-dribbler mechanism, a real-time, 1-on-1 subphase of the basketball was investigated. Defenders in guarding trials initiated their movements earlier and moved quicker than the defenders in penetrating trials. Furthermore, the guarding trials were further categorized into three defensive patterns. In Study IV and V, the defender's motor control mechanism of the earlier and quicker movement was investigated using force plates. In Study IV, the movement creating an unweighted state was proposed. The preparatory vertical movement shortened the time of their sidestep initiation and reaching performance but did not increase their peak ground reaction force or movement velocity. Specifically, after the direction signal, the unweighted state can shorten the time required to initiate the sidestepping than the weighted state. In Study V, the effect of this kinetic preparatory state in 1-on-1 subphase of the basketball was investigated. The non-weighted state made guarding in 78.8% probability, whereas the weighted state did so in 29.6%. The defenders would adopt the non-weighted strategy to prevent delaying the step before the time to peak velocity of the player in the determination phase.

In conclusion, in both cognitive and motor control strategies, the thesis suggests that because skilled dribblers have a variety of deceptive movement, defenders should take strategies to prevent slow step initiation due to the weighted state and being deceived by the dribbler's deceptive signals other than the information of CoM, rather than strategies to achieve quick step initiation by the unweighted state and excessive anticipation using specific body parts.

Table of Contents

Chapter 1: General introduction

Humans in a group interact with each other using their bodies by changing their actions, perceiving the actions of others and then searching for optimized solutions to various problems which they face in their lives. These cognitive and motor-control processes, which take a wide variety of forms to survive in the modern world, are created by our body movements. An excellent example of these body movement dynamics in a complex, unpredictable interaction is observed in invasive ball sports, such as basketball and football, which are popular worldwide (e.g., 450 million people play basketball, as estimated by FIBA, 2007). Skilled players execute accurate, quick and strong decision making and motor control against their opponents, and the players' well-trained technique astonish and attract the audiences. The mechanism of these skillful techniques remains unclear because of the complexities of these processes; academic curiosity has recently been aroused, however, due to the development of various measuring instruments, such as motion capture systems (Esteves et al., 2011; Brault et al., 2012).

In an invasive ballgame, an attacker with the ball aims for the scoring point, and a defender stops the aim of the attacker. Based on these purposes, both of the players execute cognitive and motor skills beyond their ability. However, despite the inherence of coupling of perception and action in the performance of the task of interest in situ (Gibson, 1979), many researchers have separated cognitive and motor aspects in a laboratory-based, reductionism approach such as using functional magnetic resonance imaging (fMRI) (Aglioti, et al., 2008; Wright et al., 2012), or have only described 1-on-1 positional relationship (Passos et al., 2008; Cordovil et al., 2009; Esteves et al., 2012), and have neither focused on cognitive and motor skill actually executed by ballgame players nor given a feasible practical implication. Examining the cognitive and motor skills at the same time will provide the evidence of the unexplained mechanism for the expertise of these skills, therefore, this thesis simultaneously focused on cognitive and motor skill in defending an attacker, which is in common among various invasive ballgames.

Chapter 1 outlined the research background in cognitive and motor skill in ballgame 1-on-1 defending (Fig.1-1). In Chapter 2, in both cognitive and motor control perspective, defender's anticipation and reaction skill was quantified using choice reaction task with video clip (Study I). In Chapter 3, the defender's anticipatory mechanism was estimated using IPM simulation (Study II). In Chapter 4, basketball 1-on-1 defensive situation was categorized into three patterns (Study III). In Chapter 5, in motor control aspect, the importance of kinetic preparatory state for sidestepping was demonstrated in laboratory-controlled experiment (Study IV). Finally, in Chapter 6, under a basketball 1-on-1 dribble situation, the relationship between the kinetic preparatory state and the actual defensive performance was investigated (Study V).

The significance of this thesis is three-fold: (1) it developed the methods to simultaneously analyze cognitive and motor skill in the invasive ballgame. In Study I, in terms of visuo-motor delay, both cognitive and motor processes were evaluated. In Study III, the 1-on-1 defensive pattern was revealed by plotting the variables representing cognitive and motor control aspects in two-dimensional plane. In Study IV and V, the importance of kinetic preparatory state to react the opponent's movement was demonstrated by executing a laboratory-controlled sidestep experiment and a real-time 1-on-1 experiment. These findings of the studies would provide the evidence of the unexplained mechanism for the expertise of human cognitive and motor control. (2) It approached anticipatory mechanism for humans. Previously, researchers investigated anticipatory mechanism of movement of mass point (Zago et al., 2004; Zago et al., 2005) and behaviors during watching video of ballgame players (Williams & Davids, 1998; Brault et al., 2012); however, there has been no study of the mechanical model explaining the anticipatory mechanism of human movement. Study II applied the mechanical model used in standing and walking biomechanics to the cognitive model. This approach would develop the paradigm of anticipatory mechanism of human movement to more practical level with enhancing neurophysiological, mathematical background. (3) It contributed to the application to the field of ballgames. The studies in this thesis quantitatively and explicitly demonstrated the cognitive and motor skills which were sensuously or implicitly understood in the field. These evidences would be accumulated as scientific knowledge of the coaches, and would potentially improve the ballgame player's skills. Moreover, it could develop the invasive ballgames themselves because these findings can inform the potential or existing players and audiences about the enchantment and amusingness of the sport by explaining the superb cognitive and motor control techniques of the expert players.

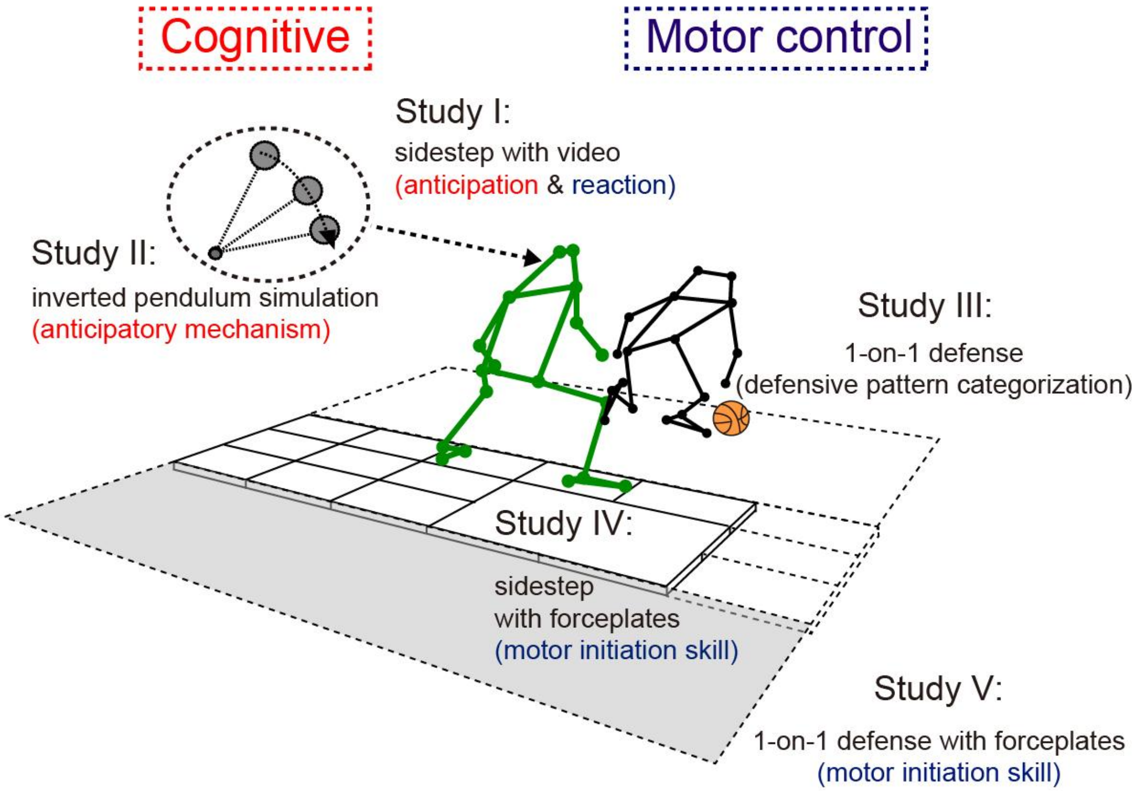

Fig. 1-1 Research approaches to investigate cognitive and motor mechanisms in basketball 1-on-1 defending.

Brief History of the Study

1.1. Cognitive perspective in defensive situation

For a successful defense in invasive ballgame situation, a skilled defender must anticipate his or her opponent's running direction based on visual information before the attacker actually changes running direction. Anticipating the motion of others is a challenging task for the central nervous system because it is based on current visual information and faces a severe time constraint. The early researchers, Allard et al. (1980) demonstrated that basketball players were superior to non-players in the recall of the slide, which shows the position of attacking and defensive players. The interpretation of the expert's ability to encode and recall structured information (e.g. basketball: Millsagle, 1998) is that skilled perception is dependent on an enhanced sport-specific knowledge base, which enables performers to encode the visual display into fewer, larger "chunks" of information that can be more easily remembered and then decoded to reproduce the original pattern (Allard & Burnett, 1985). Allard and Starks (1980) suggested that invasive team games such as basketball, rugby and soccer require skilled chunking, compared to the "focusing" which fast ball sports such as baseball and tennis required to ignore much of the game structure and to concentrate instead on detecting ball position. However, it is unlikely that sports can be classified discretely into "chunking" or "focusing" categories (Williams et al., 1999). Borgeaud and Abernethy (1987) revealed that expert volleyball players showed superior chunking *and* focusing ability compared with less skilled players. These studies have provided us insightful evidence about cognitive skill of athletes, however, there has been some criticisms regarding poor stimulus presentations (neither dynamic-evolving perceptual display nor making uses of contextual information) and unrealistic response (Williams et al., 1999).

To overcome the above problem, researchers have used video clip to simulate the visual display that observers confronted with during play. Jones and Miles (1978) initially used the temporal occlusion paradigm, which can externally control and constrain the duration and the nature of the display. If observers can correctly anticipate by watching a film clip which is temporally occluded, visual information during occluded period is not assumed to be necessary for the anticipation. According to Glencross and Cibich (1977), the extraction of key information from online visual information to predict the movement of others is called an “advanced cue”. Skilled ball players can extract advanced cues before a key event (Mann et al., 2010; Williams et al., 2009). For example, with respect to changes of running direction, Jackson et al. (2006) used the temporal occlusion approach and showed that skilled rugby players predict the correct running direction even when the video is occluded 360 ms before foot contact in the altered direction. In such a temporal occlusion experiment, however, decision making is not performed online (Williams et al., 1999). Researchers can replicate alternatively real-time situations in the laboratory through a reaction time paradigm

(Williams & Davids, 1998). Nevertheless, Williams and Davids (1998) analyzed only the frame when participants responded to video stimuli; hence, the timing of the response relative to the actual change in running direction could not be inferred. In study I, reference timing by synchronizing the film clip with foot contact timing was obtained. Then, Study I can estimate defender's video cue timing for the detection of relevant information in the correct running direction of attackers' cutting maneuvers, which was defined by subtracting a ready-go choice reaction time from the reaction time in the video task.

In biomechanical analysis for advanced cue, it is assumed that observers use the present kinematic information. For example, Brault et al. (2010) investigated body orientation/reorientation strategies in 1-on-1 situation in rugby. They analyzed relevant orientation/reorientation parameters, mediolateral displacement of CoM, foot, head, upper trunk roll, upper trunk and lower trunk rotation. They suggested that the player is using exaggerated shoulder movement and minimized foot and mediolateral CoM displacement in effective deceptive movements. In addition to the present position information, humans also have the visual system which automatically calculates or otherwise extrapolates the future position information of a moving object (Kelly & Freyd, 1987). For example, when a stimulus moves and vanishes abruptly, an observer's memory for the final position of the stimulus is shifted forward in the direction of motion (Freyd & Finke, 1984). Based on the findings of these studies, Study II introduced a cognitive model from the point of view that the prediction of the future movement outcome may be used in advanced cue utilization.

In biomechanics of human motion, a 3D IPM was widely used in the dynamics in standing (Gage et al., 2004), walking (Kuo, 2007) and running (Carver et al., 2009). In quick change of running direction, Suzuki and Enomoto (2009) used the 3D IPM to describe the relationship between the velocity of the CoM and the ground reaction forces. Most of 3D IPMs consist of a point-mass body connected to a single massless leg. Despite its simplicity, they can describe the dynamic requirements for these movements stability. Understanding mechanical constraints on these movements is important since they can help identify dynamic templates that musculoskeletal and motor control systems may be organized to achieve during movement (Jindrich & Qiao, 2009). Based on the evidences of these studies, Study II applied the 3D IPM to the prediction mechanism for the observers of quick change of running direction. The basic hypothesis of the study II was that the observers of quick change of running direction predict the final running direction by portraying the attacker as an inverted pendulum.

According to neurophysiological studies, humans are believed to maintain an internal forward model of the dynamic properties of the world in the central nervous system to help with anticipation (Wolpert et al, 1995; Zago et al., 2004; Berkes et al., 2011), such as in lateral cerebellum (Cerminara et al, 2009). Vestibular cortex (Indovina et al., 2005), vestibular nuclei and posterior cerebellar vermis (Miller et al., 2008) and right insula and left lingual gyrus (Maffei et al, 2010) specialized for processing visual motion of object accurately encoded the target velocity and direction. In more complex target such as human movement, the visuo-perceptual system uses a Gestalt-like perceptual grouping process to organize vast visual information into its simplest terms (Ward et al., 2002; Diaz & Fajen, 2012). Puce and Perret (2003) suggested that visual processing can enable the decoding of complex social signals through outputs to limbic, frontal and parietal systems (superior temporal sulcus) in a brain imaging study for both humans and non-human primates. In basketball free-throw anticipation, experts exhibited higher activation in the bilateral inferior frontal gyrus and in the right anterior insular cortex (awareness of errors) when producing errors whereas correct action prediction induced higher posterior insular cortex activity (body awareness) in experts and higher order, orbito-frontal activity in novices (Abreu et al., 2012). For decision making during perception and action, “vision for action” dorsal stream mediates the on-line visual control of selected actions (Milner & Goodale 1995; Cisek & Kalsaska, 2005; Cisek, 2007), and medial frontal cortex and basal ganglia evaluate reward and effort costs (Rushworth, 2008; Gold & Shadlen, 2007). These findings were also reviewed by Yarrow et al. (2009).

However, these fMRI and Transcranial magnetic stimulation (TMS) techniques invariably restrict the experimental task such as a recent study by Tomeo et al. (2013) who sought to examine responses to fooling actions by using TMS and video clips where bodily information was, and was not, linked to the action outcome, which consequently limit the degree to which the findings can be generalized (Mann et al., 2013). I agreed with their two particular concerns with this approach. First, the spliced video clips that show physically impossible actions are unlikely to simulate a fooling action. Second, it is difficult to make meaningful inferences about perceptual-motor expertise from experiments where participants cannot move (e.g., basketball free throw: Aglioti et al., 2008; badminton stroke: Wright et al., 2012). Taken together, wider generalizations based on these findings may provide a misunderstanding of the phenomenon such a study is designed to explore, therefore, this thesis did not use these fMRI and TMS approach in this thesis.

1.2. 1-on-1 competition in sport

Defenders should react to stop dribbler’s advance, whereas dribblers should also move to deceive defenders. Previously, researchers have focused on the anticipation aspect in replicated 1-on-1 subphase of the team sports involved using video clips in a laboratory-based approach (Jackson et al., 2006; Williams & Davids, 1998). This approach has successfully provided the experimenter with rigorous control over the test environment (Williams et al., 1999) and valuable insights into the anticipation skill of expert ball game players. However, to understand the defending-dribbler process using this approach, the dribbler-defender interaction has been a problematic (e.g., both players anticipating and reacting to their opponent).

To solve the problem, the motions of both of them were captured in the 1-on-1 subphase (Fajen et al., 2009; Headrick et al., 2012; Passos et al., 2008; Cordovil et al., 2009). In this situation, a dribbler and a defender interact with the opposite aims (i.e., the dribbler aims to penetrate, and the defender aims to stop the opponent). Because of the complexity of dribbler-defender dynamics, previous studies have described the dynamics using a dynamical system approach (Palut & Zanone, 2005; Lames, 2006; Araujo et al., 2002), which has comprehended the body movements including complex, unpredictable interactions of different elements in terms of non-linear dynamics (Davids et al., 2006; Passos, et al., 2008). For example, Palut and Zanone (2005) analyzed the displacement of the two tennis players as a system formed by two coupled non-linear oscillators, and suggested that rally in tennis may be studied as self-organizing complex system. In invasive team ball sports, each player's behavior can be regarded as a self-organizing system of spatiotemporal pattern (Schmidt et al., 1999). Also in basketball 1-on-1 subphase, defender-dribbler dynamics (Araujo et al., 2002), the dynamics varying with relative positioning (Esteves et al., 2012), with instruction and body-scaling (Cordovil et al., 2009), and the relationship between defender's posture and attacking direction (Esteves et al., 2011) were demonstrated. However, to investigate the defending-dribbler process, focusing on the defender's behavior using the traditional methods of sport psychology (Williams & Davids, 1998; Mori et al., 2002), including methods evaluating individual performance such as initiation time, movement speed, and response accuracy based on a stimulus-response paradigm (i.e., stimulus is attacker), excluding the attacker-defender interaction, should be primarily needed. Thus, Study III focused on and the spatiotemporal characteristics of the dribbler and the defender, such as when they begin moving and the speeds of their movements. The possibility of the dynamical systems approach is discussed in 7.4 (General discussion).

1.3. Motor control for defensive motion

In terms of anticipation in ballgame, there are information processing (reaction time) benefits and costs associated with correct and incorrect anticipation, respectively (i.e., incorrect anticipation results in a longer reaction time, according to Williams & Davids, 1998). However, even if the defender incorrectly anticipates the dribbler's motion, defenders can use quick movements after their movement initiation to compensate for their miscalculation. This is the very important point for the present 1-on-1 interactive task because the previous video-based approach without the interaction has not taken consideration into this defensive motion, not sidestepping (Williams & Davids, 1998). Hence, quick movements would also be an effective strategy to stop a dribbler. Then how can defenders create their quick movements?

Quick movement, or production of large power, generally needs to preparatory motion (e.g. countermovement). The preparatory motion, which is used before executing a movement to improve the motor performance, is executed in many sports activities such as jumping (Asmussen & Bondepet, 1974; Bosco & Komi, 1980; Komi & Bosco, 1978; Bobbert et al., 1996) or throwing (Perrin et al., 2000) to improve the quality of the movement (Uzu et al., 2009). In many ball sports, the players are subject to strict time-constraints, i.e., need to hasten their movement initiation after the visuo-motor delay (Tresilian, 1993; Benguigui et al., 2008). To overcome the strict time-constraint in speed ball sports such as tennis, a quick reaction technique called the split-step, which is a small vertical hop to prepare for a lateral step, is used (Uzu et al., 2009; Nieminen, et al., 2013). However, in invasive ball sports such as basketball and football, more strictly, the players are subject to strong motion-constraints, not to be allowed a small jump, in addition to time-constraints. Therefore, satisfying the requirements not only of a quick reaction movement (time-constraint) but also of preparation landing on both feet (motion-constraint) is necessary in invasive ball sports.

The mechanism of the preparatory motion in the previous studies, such as countermovement before jumping (Asmussen & Bondepet, 1974; Bosco & Komi, 1980) or a split-step (Uzu et al., 2009; Nieminen et al., 2013) was generally explained by the stretch-shortening cycle (SSC), which is a natural type of muscle function formed by the combination of eccentric and concentric actions (Norman & Komi, 1979; Komi, 1984). These preparatory motions change the movements themselves so greatly that kinetic parameters, such as mechanical force, energy and efficiency, are increased (Komi & Bosco, 1978; Uzu et al., 2009; Nieminen et al., 2013). However, in invasive ball sports, large countermovements are detrimental to the defense. Thus, under the strict spatiotemporal constraints, skilled players should minimize a preparatory motion while landing on both feet to improve their quality of movement.

The thesis then focused on the kinetic preparatory state as a base of the above preparatory motion and intended movement (i.e. defensive motion). For example, of the kinetic preparatory state, the unweighted state while landing on both feet is observed in the takeoff of a countermovement jump but not in squat jump without countermovement (Bosco and Komi, 1979; Bosco and Komi, 1980). This indicated that the unweighted state can be derived from an effective countermovement to improve the jumping height while both feet were on the ground. Thus, the thesis assumed that an effective preparatory motion during defense in contact ball sports, that meets the demands of the severe spatiotemporal constraints, would be accompanied by the optimal kinetic preparatory state. However, examining the effectiveness of the kinetic preparatory state involved several problems, such as the difficulty in the instruction of the movement and the great kinematic intra/interpersonal variability. Therefore, the voluntary but small continuous vertical body fluctuations as the preparatory motion for the sidestepping are artificially replicated by instruction of the participants in Study IV. Then, Study V investigated whether the kinetic preparatory state affects 1-on-1 outcome and defensive performance.

Chapter 2: STUDY I — Superior reaction to changing directions for skilled basketball defenders, but not linked with specialized anticipation.

2.1. Abstract

The purpose of the present study was to examine the timing for the detection of relevant information in the final running direction of attackers' cutting maneuvers. Skilled basketball players and novices performed sidestep and reach tasks in response to a ready-go choice stimuli using light emitting diode (LED task) and video stimuli (video task) wherein skilled ball players executed cutting maneuvers. The time at which the defenders first obtained relevant visual information was estimated by subtracting the visuo-motor processing time, acquired from the reaction time in the LED task, from the reaction time in the video task. Skilled basketball players reacted to and reached the target faster than novices, whereas the estimated video cue timings for the skilled players were not different from those for the novices. The results suggest that the anticipation of attacker's direction in this task would be a general visuo-motor skill, even without previous specialized perceptual training. Combined with the results from the reaction performance in the video task, I conclude that novices are afforded shorter times and more uncertain information before their stepping when they are in a 1-on-1 ballgame defensive scenario because their sidestepping takes a relatively long time.

2.2. Introduction

In many sports, such as basketball or football, defenders react to an attacker's cutting maneuver to stop them. For a successful defense, a skilled defender must anticipate his/her opponent's running direction based on visual information before the attacker actually changes running direction. Anticipating the motion of others is a challenging task for the central nervous system because it is based on current visual information (Runigo et al., 2010) and faces a severe time constraint (Williams et al., 1999). The unique experience of participating in sport itself could enhance players' anticipation, reaction and movement abilities because skilled athletes are habitually trained to anticipate and to react quickly to such changing situations. In fact, faster and more accurate anticipatory reaction in response to life-size film displays have been demonstrated among experienced football players (Williams & Davids, 1998) and karate athletes (Mori et al., 2002). These studies implicitly assume that novice ballgame players have not acquired the appropriate anticipation skills. However, we all face the need to anticipate the motion of others each day, such as when we avoid bumping into others on the street, regardless of our specific sport experiences. Thus, answering questions how anticipation, reaction and movement performance differ between skilled ballgame players and novices will address the development of anticipation skills, which are acquired by the specific training experiences of the skilled players.

Skilled ballgame athletes can extract relevant information from the visual stream and anticipate the outcome of an opponent's motion (Mann et al., 2010; Williams et al., 2009) before the attacker actually changes running direction. Jackson et al. (2006) investigated how this is accomplished using a temporal occlusion paradigm and showed that skilled rugby players predict the correct running direction even when the video is occluded 360 ms before foot contact in the altered direction. In such a temporal occlusion experiment, however, decision making is not performed online (Williams et al., 1999). Researchers can replicate alternatively real-time situations in the laboratory through a reaction time paradigm (Williams & Davids, 1998). Nevertheless, Williams and Davids (1998) analyzed only the frame when participants responded to video stimuli; hence, the timing of the response relative to the actual change in running direction could not be inferred. In this study, I obtained reference timing by synchronizing the film clip with foot contact timing from high-speed camera data. Then, for comparisons of the anticipatory performance of both groups, I estimated each defender’s video cue timing for the detection of relevant information in the correct running direction of attackers’ cutting maneuvers, which was defined by subtracting a ready-go choice reaction time from the reaction time in the video task. As mentioned above, anticipation skills within strict time constraints can be acquired by habitual specific sport training, such as that undertaken for basketball. Generally, more familiarity with a cognitive task drives differences in performance between expert athletes and novices (Williams & Davids, 1998). Thus, I hypothesized that the skilled basketball players would have faster video cue timing than the novices because of their familiarity with the video task.

To test this hypothesis, I examined differences in anticipation performance between skilled ballgame defenders and novices during detection of relevant information in an attacker’s cutting maneuver. In the present study, the participants performed a sidestep and reach task (Uzu et al., 2009) while watching a film clip on a life-size screen simulating basketball defense. I analyzed the reaction and movement performance of both groups by measuring reaction times and total reach times for sidestepping. Previous studies provide evidence for task specificity in a choice reaction task, of which results were inconsistent in the existence of sport expertise, i.e., the results of the previous studies indicates that trained athletes reacted faster than novices (Ando et al., 2001; Mori et al., 2002; Cojocariu, 2011), while revealing no difference between groups (Kimura et al., 2003; Helsen & Starkes, 1999; O'Donovan et al., 2006). However, sidestep and reach movements during the reaction task in the present study were more familiar to the skilled basketball players than a simple motor response, such as button pressing. Therefore, I assumed that skilled ballgame players would react and reach faster than novices.

2.3. Methods

2.3.1. Participants

Ten skilled basketball players (age = 19.5 ± 0.9 years [mean ± sd], height = 178.6 ± 4.2 cm, weight = 71.2 ± 3.8 kg) and ten novices (age = 23.8 ± 5.2 years, height = 171.6 ± 4.2 cm, weight = 59.6 ± 3.4 kg) participated as defenders, and seven different skilled ballgame players (five basketball players and two lacrosse players) participated as attackers (mean age = 20.9 ± 1.2 years). All participants had corrected-to-normal vision. I selected attackers with different sports background (e.g., participants who had also played football or handball in the past) because I wanted to obtain videos of cutting maneuvers of which movements were not specific to basketball. I confirmed that there was no difference in the effect of expertise on the defender's performance between the attacker's sport types. The skilled basketball players as the defenders and the skilled ballgame players as the attackers were members of their university's basketball or lacrosse teams where the players practiced for five to six days a week and had played competitively (defenders basketball experience = 7.2 ± 1.3 years; attackers ballgame experience = 11.3 ± 3.7 years). The novices were students at the same university who had only played ballgames in physical education classes and never competitively (not regularly exercised). The experimental procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Local Ethics Committee of the Graduate School of Human and Environmental Studies, Kyoto University (23-H-6).

2.3.2. Apparatus and protocol for the attackers

Seven participants performed quick sidestepping and crossover-cutting maneuvers to the left and right as “attackers”. The experimental setup is outlined in Fig. 2-1A. These participants were instructed to change their running direction by 45 degrees without a deceptive motion at their fifth step as quickly and unpredictably as possible. The attackers’ motions were recorded by one normal-speed (30 Hz) and four high-speed (300 Hz) cameras (both EXLIM PRO EX-F1; Casio Computer Co., LTD, Tokyo, Japan). The videos recorded by the high-speed cameras were used for detecting the attackers’ foot contact timing, and the videos recorded by the normal-speed camera were used to generate the video stimulus. High-speed cameras and a personal computer were synchronized by an LED signal, and the personal computer and the normal-speed camera were synchronized by a sound signal (Fig.2-1A).

2.3.3. Video stimulus

One session of the video stimulus included 28 maneuvers (right/left * sidestep/crossover * 7 attackers). A short version of the video stimulus was prepared as a practice film, which comprised 8 clips of an investigator (not included among the 7 participants). The video clips were filmed head-on at a height of 1.2 m and were edited using two software programs (Windows Movie Maker Version 2.1, Microsoft

Corporation, WA, USA and MPEG Streamclip for Windows Version 1.2, Squared 5, Italy).

2.3.4. Apparatus and protocol for the defenders

The defenders performed step-and-reach reactions (Uzu et al., 2009) with an LED (LED task) and the video stimulus (video task) as "defenders". The defenders were instructed to step laterally and reach target styrene forms (width: 45 cm, length: 10 cm, height: 45 cm and weight: 350 g). They were also instructed not to perform any preparatory steps or preliminary actions in which both feet were unweighted, such as a split step. The targets were placed 80 cm above the ground and at 80% of the participant's height, away from the participant's median line. The participants completed three sessions of the video task (28*3 reactions) and two sessions of the LED task (28*2 reactions). For the video task, the video stimulus was presented on a 1.7 m × 1.7 m screen and was viewed from a distance of 4.5 m (Fig. 2-1B). In the vertical direction, the ground reaction forces (GRFs) were measured to define the moment of reaction using two force platforms (OR6-7-2000, AMTI, Watertown, MA, USA; width: 46.4 cm, length: 50.8 and height: 8.25 cm).

To estimate the time when the defenders detected the relevant information in the video task (henceforth, termed the video cue timing), the visuo-motor processing time was subtracted from the moment of reaction to the video stimulus. I conducted the LED task to estimate each defender's visuo-motor processing time. To duplicate visuo-motor processing during the video task, I used a ready-go reaction task instead of a simple reaction task because in the video task, the defenders could predict the approximate moment when the sidestep or crossover cutting maneuver was performed. Two sets of LEDs (width: 46 cm and height: 30 cm), which were placed 15 cm apart, were set in front of the screen. The preparatory signals involved both sets of LEDs blinking four times at the attacker's foot contact interval during the video stimulus (mean intervals: lighting time = 292 ± 52 ms and lights-out time = 223 ± 34 ms). After the preparatory signals, either the left or right set of LEDs was illuminated as a direction signal. The test stimulus comprised 28 trials, and the practice stimulus comprised 7 trials with the same interval type as the test stimulus. The measurements included the LED stimulus output signal and the video stimulus sound signal. Measurements were sampled simultaneously at 1000 Hz using two 16-bit analogue-to-digital converters (PCI-6035E, National Instruments, Austin, TX, USA).

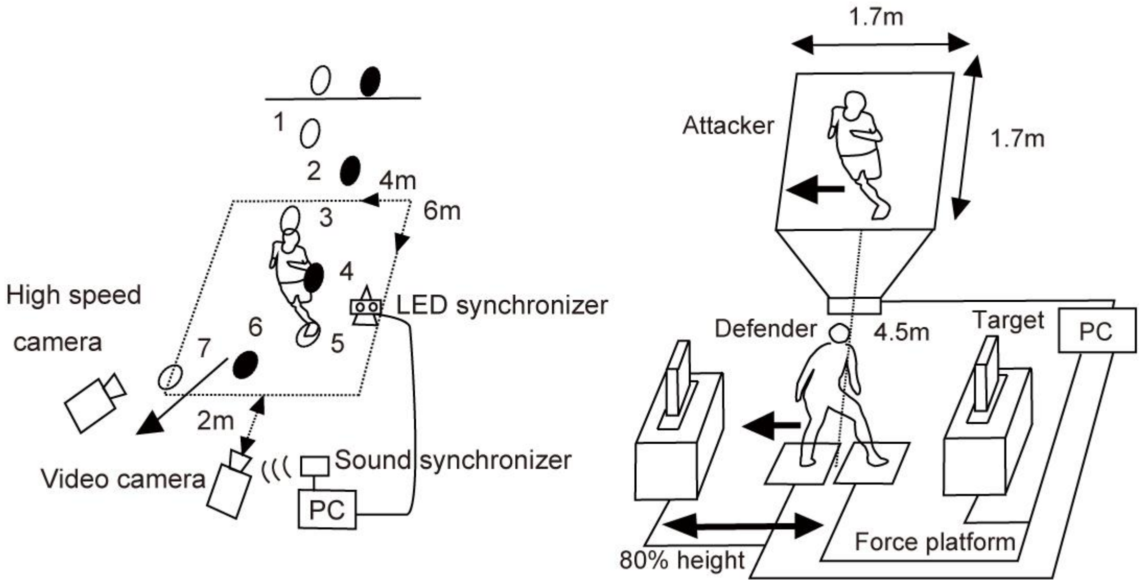

Fig. 2-1. Experimental setup for the attacker (A) and the defender (B). Motion analysis with a light-emitting diode (LED), sound signal synchronization (A) and the psychophysical experiment (B) enabled us to determine when the defenders perceived the relevant cue and reacted to the final running direction of the attackers.

2.3.5. Analysis

The time when defenders first detected the relevant information in the video task, video cue timing, was estimated by subtracting their visuo-motor processing time (recorded in the LED task; LED initiation time) from their moment of reaction to the video stimulus (Video initiation time). The video cue timing can be of negative value if the participants anticipatorily react to the video clip before the foot contact of the direction change (fifth step).

The moment of reaction was defined as the initiation of the lateral step in the video task, which was the time when the lateral GRF under the supporting leg rose above 10% of the participant's weight. The defender's visuo-motor processing time (LED initiation time) was defined as the time from illumination of the direction signal to initiation of the lateral step in the LED task. The moment of reaction to the video stimulus was defined as the time from the foot contact of the attacker's fifth step (direction change step) to the defender's initiation of the lateral step. The defender's cue timing was expressed as a relative value with respect to the attackers' fifth foot contact (a negative value indicates cue timing is prior to the attacker's cutting maneuver).

The take-off time and total reach time were also obtained to examine the effect of expertise on reaction performance. The take-off time was defined as the time from the signal (i.e., LED illumination in LED task and direction change in video task) to the first time that the vertical force of the leading leg fell below 10% of the defender's weight. The total reach time was defined as the time from the signal to the instant at which the defender reached the target, when there was a marked signal in the force transducer. The thresholds for a marked signal of the force plate and for the force transducer were set by experimenter inspection. The time from the attacker's direction change was based on data from a high-speed camera (300 Hz). The attacker's foot take-off was visually judged from the camera data.

The peak lateral GRF, time to peak GRF and movement time for the defender's sidestepping movement were calculated. The peak lateral GRF and time to peak lateral

GRF were calculated from GRF data (Fig. 2-2). The movement time was obtained by subtracting the initiation time from the total reach time. I sampled 1120 trials in the LED task and 1680 trials in the video task. In the video task, film clips in which the mean video cue timing was too late (one film clip over 1000 ms) or too early (two film clips under -700 ms) were eliminated from the analysis. Thirty six LED trials (skilled: 18; novice: 18) of measurement failure or wrong decisions, 7 video trials (skilled: 3; novice: 4) of wrong decisions and 57 LED trials (skilled: 39; novice: 18) and 26 video trials (skilled: 22; novice: 4) judged as outliers were eliminated from analysis. In the outlier trials, the participants started to step too late (LED: over 600 ms), the take-off of the leading leg was too early (e.g., preparatory hop) or too late (LED: under 100 ms and over 600 ms, Video: under −500 ms and over 600 ms), and the participants reached the target too late (LED: over 1200 ms).

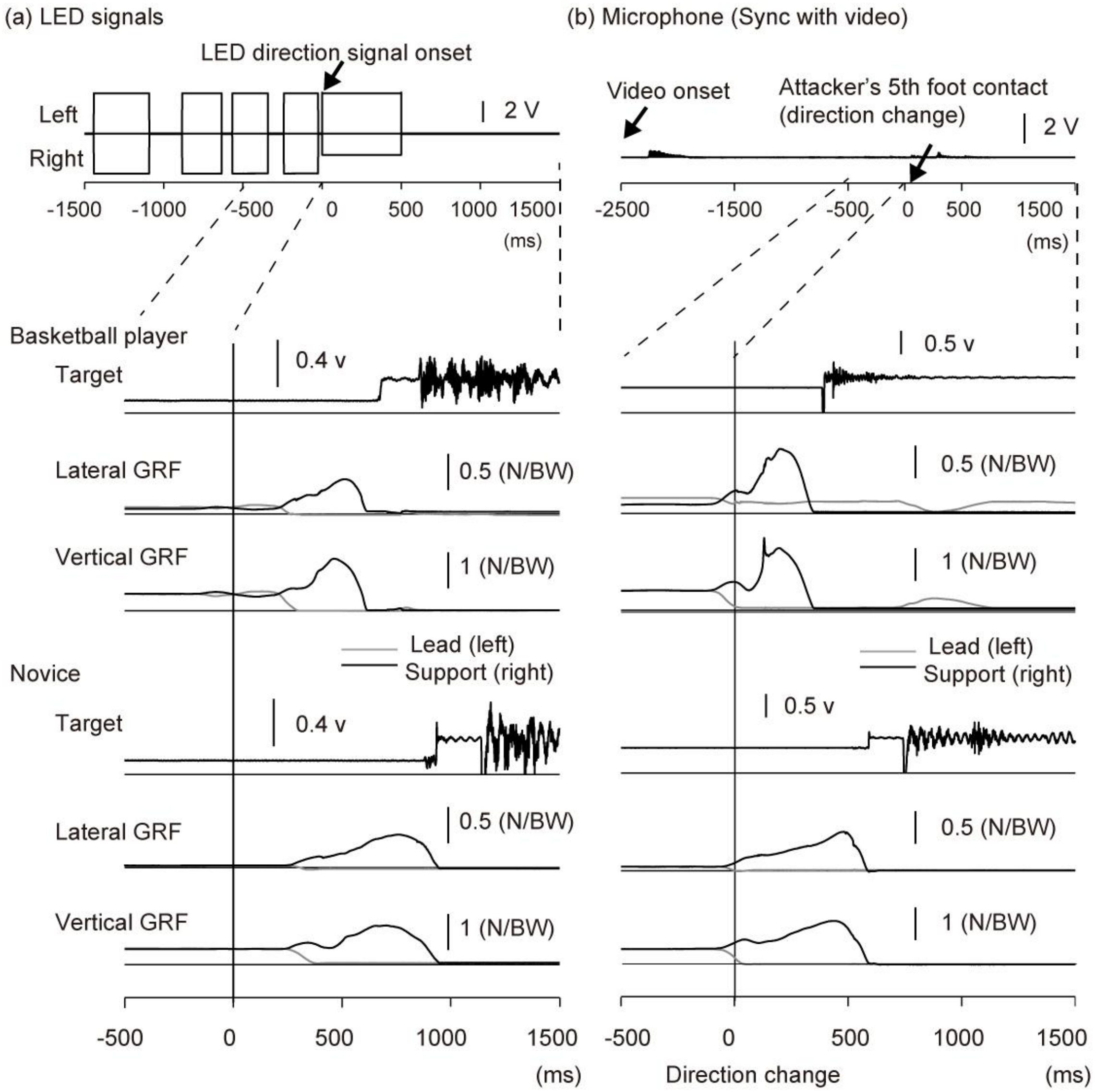

Fig. 2-2. A typical example of the LED signals, the synchronized signals, mechanical data, and ground reaction force (GRF) data from a skilled basketball player and a novice. Top (a): Traces of the voltages of the left and right LEDs signals that show the preparatory and direction signals. Preparatory signals were shown five times by both LEDs before the direction signal on one of the LEDs was presented (left in this trial). The number of preparatory signals and the interval of the signals simulated the foot contact of the attackers in the video task. Top (b): Traces of the voltages from the microphone for synchronized signals. The reference time of the reaction variables was

based on the instant of the foot contact of the attacker's fifth step (direction change step). Middle, lower: A typical trace for a skilled player and a novice in the LED task (left) and video task (right), respectively. The onset of a rising signal in the force transducer indicates the time when the participant reached the target. The participant's support leg (right in this trial; leading leg was left) produced both larger lateral and vertical GRF than their leading leg. For both the LED task and video task, although the amplitude of the peak GRFs was not different between the skilled players and novices, the time to peak GRF for the skilled players was shorter than that for the novices.

2.3.6. Statistical analysis

Comparisons of anticipation and reaction performance were performed with between-group paired *t* tests. To determine the independent and combined effects of movement performance, a two-way repeated measures ANOVA with an inter-group factor (skilled players vs. novices) and an intra-group factor (LED task vs. video task) was used. Cohen's *d* and partial eta-squared values (η_p^2) were reported as a measure of effect size. For all of the statistical calculations, $p<.05$ was accepted as significant. All of the statistical analyses were performed with MATLAB 2011a Statistical Toolbox (The MathWorks, Inc., MA, USA) and SPSS 16.0J for Windows (SPSS Inc., Chicago, IL, USA).

2.4. Results

2.4.1. Anticipation and reaction performance

Table 2-1 summarizes anticipation and reaction performance for both groups. For the LED task, the skilled basketball players initiated a step at 242 ± 20 ms, took off their leading step at 320 ± 34 ms and reached at 742 ± 43 ms after LED lightning; the novices initiated at 278 ± 14 ms, took off at 348 ± 13 ms and reached at 878 ± 66 ms. The skilled players had significantly lower values than did the novices on all three measures of reaction performance (Initiation time: $t_9 = -4.84$, $p = 1.3 \times 10^{-4}$, $d = -2.17$, Take-off time: $t_9 = -2.44$, $p = .025$, $d = -1.09$, Total reach time: $t_9 = -5.44$, $p = 3.6 \times 10^{-5}$, $d = -2.43$). For the video task, the skilled players initiated at −118 ± 33 ms, took off at −5 ± 33 ms and reached at 412 ± 45 ms for the attacker's direction change; the novices initiated at −45 ± 61 ms, took off at 52 ± 70 ms and reached at 562 ± 91 ms. Similar to the results of reaction performance in the LED task, the skilled players had significantly lower values than did the novices on all three measures of reaction performance (Initiation time: $t_9 = -3.32$, $p = .004$, $d = -1.48$, Take-off time: $t_9 = -2.31$, $p = .032$, $d = -1.03$, Total reach time: $t_9 = -4.68$, $p = 1.9 \times 10^{-4}$, $d = -2.09$). I then compared estimated video cue timing between both groups. The skilled players and novices perceived the relevant cue at 360 ± 37 ms and 323 ± 63 ms prior to the direction change, respectively. There were no significant differences in video cue timing between groups ($p = .13$).

Table 2-1. The anticipation and reaction performances in the LED (light-emitting diode) and video tasks and video cue timings for the skilled basketball players and novices (mean ± sd). The reference time for the video task was based on the instant of foot contact of the attacker's fifth step (direction change step).

	Basketball players			Novices		
LED initiation time (ms)	242	±	20	278	±	14
LED takeoff time (ms)	320	±	34	348	±	13
LED total reach time (ms)	742	±	43	878	±	66
Video initiation time (ms)	-118	±	33	-45	±	61
Video takeoff time (ms)	-5	±	33	52	±	70
Video total reach time (ms)	412	±	45	562	±	91
Video cue timing (ms)	-360	±	37	-323	±	63

2.4.2. Movement performance

I then analyzed movement performance in both the LED and the video task for both groups (Table 2-2). For the peak lateral GRF, there was no significant main effect and no significant interaction. There was a main effect on movement time. The skilled players had shorter movement times than the novices (significant main effect in expertise: $F_{1,18}$ = 13.9, p = .002, η_p^2 = .44). There were main effects of both expertise and condition for time to peak GRF (expertise: $F_{1,18}$ = 11.9, p = .003, η_p^2 = .40, condition: $F_{1,18}$ = 16.8, p = .001, η_p^2 = .48). The skilled players significantly obtained peak velocity earlier than the novices, and time to peak velocity was delayed in the video task relative to the LED task for both groups.

Table 2-2. The movement performance in the LED and the video task for the skilled basketball players and novices (mean ± sd). Movement time was defined as the time from initiation time to target reaching time (Table 2-1).

		Basketball players	Novices
Peak lateral GRF (N/BW)			
	LED	0.62 ± 0.07	0.61 ± 0.12
	Video	0.63 ± 0.08	0.63 ± 0.10
Time to peak GRF (ms)			
	LED	311 ± 30	381 ± 54
	Video	332 ± 46	409 ± 55
Movement time (ms)			
	LED	500 ± 28	600 ± 63
	Video	528 ± 56	607 ± 61

2.5. Discussion

2.5.1. Sidestepping performance for both groups

For the basketball players, the initiation time, take-off time and total reach time in both the LED and video tasks were significantly shorter than those for the novices. Choice reaction task studies with a simple light stimuli comparing experienced athletes and novices have revealed that trained athletes reacted faster than novices (Ando et al., 2001; Mori et al., 2002, Cojocariu, 2011), while the studies comparing among different types of ballgame experience revealed no difference between groups (Kimura et al., 2003; Helsen et al., 1999; O'Donovan et al., 2006). Generally, more familiarity with a cognitive task drives differences in performance between expert athletes and novices (Williams & Davids, 1998). In the present study, the novices had, not only, little experience with ballgames but also little experience with all competitive sport. Therefore, the LED task was more unfamiliar to the novices and was relatively familiar to the skilled players because the skilled players had habitually been trained to react to any visual stimulus, such as ball movements or their teammates' and opponents' behaviors. Previous studies have observed faster and more accurate reaction performances for experienced football players (Williams & Davids, 1998) and karate athletes (Mori et al., 2002) with a life-size film display. Similar to these previous studies, the results obtained from the present study imply that skilled basketball players are able to respond quickly compared to novices to the final running direction of an opponent's simple cutting maneuvers without deceptive movements.

The skilled basketball players were also better at sidestepping and reaching movements in reaction to both the LED and the video task. The skilled players had significantly shorter movement times and times to peak GRF in both the LED task and in the video task, whereas peak lateral GRFs for the skilled players were not different from those for the novices. These results are consistent with a previous study of skilled basketball players (Kimura et al., 2003) and skilled martial artists (O'Donovan et al., 2006). The skilled players in the present study acquired their faster movements and quicker responses by habitual training. The kinetic results indicate that the skilled players' faster reaction movements derived not from the amplitude of the lateral GRF but from the shorter time to peak GRF. Further investigations of kinematics (e.g., limb movements), muscle activity or muscle strength of the leg (Kimura et al., 2003) would shed light on crucial factors underlying the shorter time to peak GRF of the skilled athletes.

2.5.2. Anticipation performance for both groups

In contrast to their improved reaction performances, the skilled basketball players were estimated to detect relevant cues at almost the same time as novices. There were no differences in video cue timing between the experienced players and novices, suggesting that the anticipation of attacker's direction would be general visuo-motor skill, even without previous specialized training. There are three possible explanations for the difference between the finding in the present study and those in many studies on how expertise is related to pickup of relevant visual information (Abernethy et al., 2008; Sebanz & Shiffrar, 2009). One involves the estimation of video cue timing which reflects pure anticipatory performance by not considering reactive movement. Reaction time has been widely used to quantify anticipatory performance and has provided valuable insight into perception skill (Williams & Davids, 1998; Mori et al., 2002). The reaction time is defined as the moment of reaction to the video stimulus, including time required for anticipation and that for visuo-motor processing (I defined it as reactive performance). On the other hand, video cue timing in the present study, which was estimated by subtracting participant's visuo-motor processing time (LED initiation time in the present study) from the moment of reaction to the video stimulus. Therefore, the difference between the findings of the present study and those of the previous studies likely is a difference of the variable; actually, video initiation time for skilled players, which indicated reaction performance in the present study, was faster than that of the novices. Second explanation could be the higher familiarity in anticipation of other's movement direction than that in the specific task of the previous study requiring expertise (Abernethy et al., 2008; Chase & Simon, 1973; Sebanz & Shiffrar, 2009). In daily life, we encounter many opportunities to anticipate the motion of others, to avoid bumping into the one. This daily experience may underlie the similarity of both groups' relevant cue timing. This finding in the present study suggests that in anticipation skill, it would be necessary to distinguish between general visuo-motor skills, such as anticipation of other's movement direction in the present study, and sport-specific perception skill, such as anticipation of deceptive motion or another sport-specific motion (e.g., shoot or pass). Third is the lack of an extreme time pressure. The very few number of trials with wrong decision (skilled: 0.4 %; novice: 0.5 %) suggests that the participants took less risk for quick reaction than in the previous study, where 7.5 % and less than 10 % of error trials were reported, respectively (Williams & Davids, 1998; Mori et al, 2002). In such a risk-taking situation, the players were expected to execute higher anticipatory performance than in the reaction task to cutting maneuver without deceptive movement in the present study. In a real time-pressured ballgame situation, however, defenders must perform specific motions, such as sidestepping, tackling and slide tackling, at appropriate times. If novice players with long movement time were faced with such a time-pressured situation, they would have to initiate their stepping earlier than they actually did to complete their defensive motions on time. In this scenario, novices are afforded a shorter time and more uncertain information with which to anticipate attackers' running directions, which may result in incorrect responses. As a result, poor defensive performances by novices in ball sport should be ascribed not to their visuo-motor anticipation skills but to their poor physical abilities. This scenario was not the case with the present study possibly because of the lack of time pressure.

The experiments in Study I demonstrated that both skilled and novice defenders could detect relevant information and make a decision well in advance of an attacker’s change in running direction within real-time constraints. On average, I estimated that the skilled basketball players and novices could detect relevant information 360 ms and 323 ms, respectively, prior to the attacker’s direction change during the cutting maneuvers. This finding is comparable to previous results obtained from temporal occlusion research, wherein skilled rugby players could anticipate an attacker's running direction 360 ms prior to the direction change (Jackson et al., 2006). However, the previous result does not reflect a real-time process because the decision-making process included iconic memory in the temporal occlusion paradigm (Williams et al., 1999). The results for Study I were generated in a time-pressured situation and reveal a rapid real-time visuo-motor process in reaction to a change in an opponent's running direction.

The results also resolve another limitation from the previous study, which could not measure the timing of the participants' response relative to key events in the opponent's motion (Williams & Davids, 1998). In the present study, I synchronized the video clip with the kinematic data and estimated the defender's timing relative to the video clip by subtracting their visuo-motor processing time from their moment of reaction to the video stimuli. These methods enabled us to measure the moment that the defenders perceived the relevant cue and reacted to the attacker's final running direction.

Further studies are needed to understand which cues are relevant for the anticipatory strategies of skilled ballgame players and novices. One possible way is to abstract key kinematic parameters from various sources of attacker information (Brault et al., 2010). Another is to predict an attacker's final running direction within some parameters (e.g., constructing a model and forwardly simulating). Moreover, the present study did not demonstrate the enhancement of perception-action coupling by the expertise (Farrow & Abernethy, 2003), because an attacker and defender in basketball situation interact in the sense that the actions of the former influence the perceptions of the latter and vice versa. To identify any potential perception-action coupling in basketball, it is necessary to examine anticipation wherein attackers and defenders interact with more complicated movements, such as pass, shot or deceptive movements. These studies will reveal the mechanisms of skillful anticipation among experienced ballgame players.

2.5.2. Conclusion and practical implications

In conclusion, for both the LED task and the video of a typical cutting maneuver, the skilled basketball players reacted and reached the target faster than the novices. On the other hand, the skilled players and novices both perceived the relevant cue at almost the same time and anticipated the direction of a cutting maneuver without accompanying deceptive movement. The result suggests that the anticipation of attacker's direction in this task would be general visuo-motor skill, even without previous specialized perceptual training. From these results, I conclude that novices are afforded shorter times and more uncertain information before their stepping when they are in a 1-on-1 ballgame defensive scenario because their sidestepping takes a relatively long time.

As a practical implication for the unskilled basketball defender, novices should practice to be able to quickly move in the proper direction. The results demonstrate that the novices sidestepped more slowly in both the LED and the video task than did the skilled players. The anticipation of running direction (at least without faking movements) likely will not improve with ballgame experience. In contrast, basketball attackers or dribblers should practice faking movements because even novices can anticipate running directions when there are no such deceptive movements.

Chapter 3: STUDY II — Anticipation by basketball defenders: an explanation based on the 3D inverted pendulum model.

3.1. Abstract

I previously estimated the time when ballgame defenders detect relevant information through visual input for reacting to an attacker's running direction after a cutting maneuver, called cue timing. The purpose of this study was to investigate what specific information is relevant for defenders and how defenders process this information to decide on their opponents' running direction. In this study, I hypothesized that defenders extract information regarding the position and velocity of the attackers' CoM and the contact foot. I used a model which simulates the future trajectory of the opponent's CoM based upon an inverted pendulum movement. The hypothesis was tested by comparing observed defender's cue timing, model-estimated cue timing using the IPM (IPM cue timing) and cue timing using only the current CoM position (CoM cue timing). The IPM cue timing was defined as the time when the simulated pendulum falls leftward or rightward given the initial values for position and velocity of the CoM and the contact foot at the time. The model-estimated IPM cue timing and the empirically observed defender's cue timing were comparable in median value and were significantly correlated, whereas the CoM cue timing was significantly more delayed than the IPM and the defender's cue timings. Based on these results, I

discuss the possibility that defenders may be able to anticipate the future direction of an attacker by forwardly simulating inverted pendulum movement.

3.2. Introduction

Anticipating the motion of others using visual information is a challenging task for the central nervous system because it is based on current visual information (Runigo et al., 2010) under severe time constraints (Williams et al., 1999). For example, in invasive ball sports such as basketball and football, a skilled defender must anticipate his or her opponent's direction of movement based on visual information before the opponent actually starts to move laterally (Study I; Jackson et al., 2006). Regardless of our specific sport experience, we all need to anticipate the motion of others every day, to avoid bumping into each other on the street (Study I). More generally, an organism needs to anticipate the behavior of a predator or prey, and such anticipation could yield a selective advantage (Hubbard, 1998). In recent sports psychology, the process of anticipation has been investigated not only by analyzing the observer's response behaviors, such as reaction time (Study I; Williams et al., 1998; Mori et al., 2002), prediction accuracy (Farrow & Abernethy, 2003; Jackson et al., 2006) and visual search patterns (Williams & Davids, 1998; Ward et al., 2002), but also by abstracting the essence of the opponent's motion in various ways (Williams et al., 2009; Brault et al., 2010). Brault et al. (2012) further studied anticipation skill by examining the role of prospective, perceptual-based information (not task relevant visual experience) using a mathematical model. To better understand the mechanism for anticipating the motion of others, anticipation of a cutting maneuver in invasive ball sports is an excellent example or prototype (Brault et al., 2012). Thus, a comprehensive analysis of the biomechanics of an attacker's motion and a defender's psychophysical response is warranted.

According to Glencross and Cibich (1977), the extraction of key information from online visual information to predict the results from movement of others is an "advanced cue". Skilled ball players can extract advanced cues before a key event (Mann et al., 2010; Williams et al., 2009) such as a change in an attacker's running direction. Previously, I examined the timing with regard to detecting relevant information about the final running direction of the attacker (Study I). In that study I demonstrated that skilled basketball players perceived the relevant cue at a median of 360 ms prior to the direction change. What information, then, can be extracted as a cue to predict an opponent's motion? The first hypothesis was that the defender reacts to a change in the attacker's CoM trajectory, which is an 'honest' movement that is difficult to deceive a defender (Brault et al., 2012). Additionally, basketball coaches claim that defenders should always keep their eyes focused on the opponent's middle of the trunk (American Sport Education Program, 2007). However, under this hypothesis, a defender must follow an attacker's cutting maneuver, which may yield a delayed response. As an alternative, I hypothesized that defenders predict the future trajectory of the CoM to make decisions about their opponent's final running direction. Human motion, which is governed by Earth's gravity (Raichlen, 2008), can be expressed using a 3D IPM comprised of a point-mass body connected to a single mass-less leg (Fig. 3-1C). In the biomechanics of walking, the CoM trajectory is determined by the CoM state (i.e., its position and velocity) at toe-off (Kagawa & Uno, 2010). I thus assumed that defenders may estimate the future trajectory of attackers' CoM using the IPM, and I then examined the estimated cue timing based on the prediction model (Fig. 3-1).

I investigated the information relevant for defenders and how defenders process this information to decide on their opponents' running direction. The first hypothesis was that the cue timing based on the prediction model, which performs a forward dynamic simulation using the IPM is earlier than the timing based on only the current mediolateral CoM displacement information. The second hypothesis was that the model can predict an attacker's running direction as early as skilled defenders in the previous experiment (Study I). If the second hypothesis was incorrect, I would investigate the differences between the prediction model and real defenders using a kinematic analysis of the attackers' behavior.

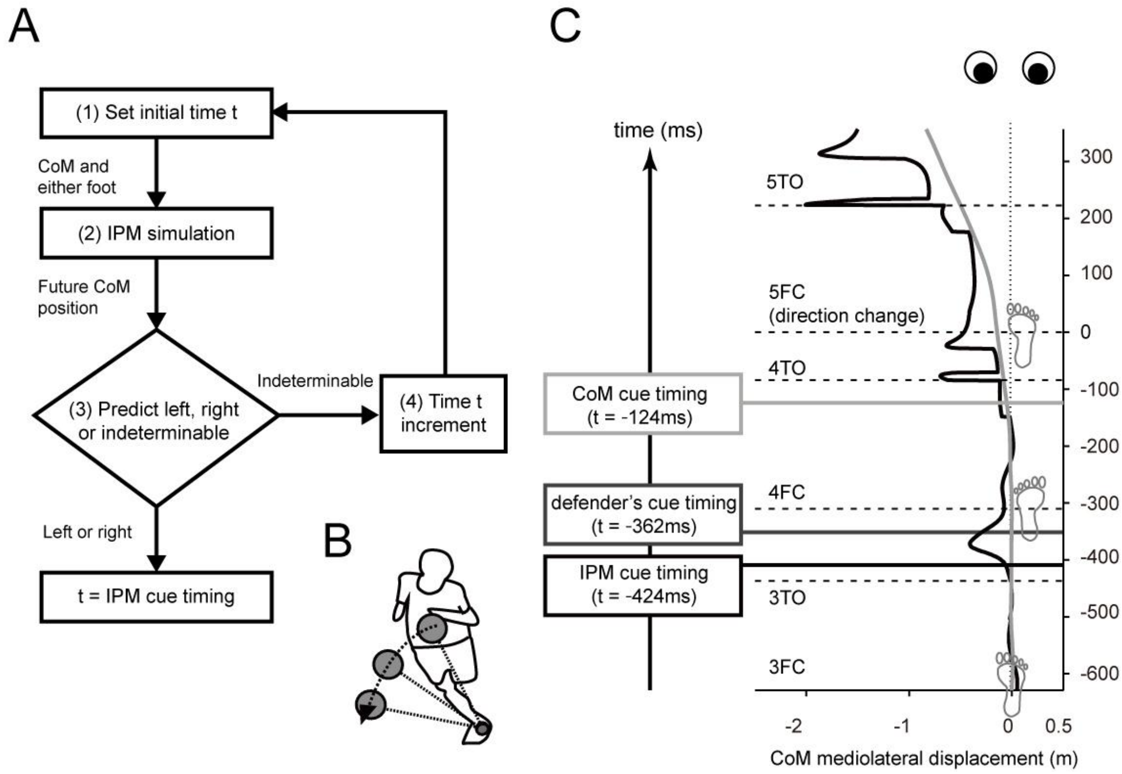

Fig. 3-1. (A) A schematic diagram of the prediction model of an attacker's running direction using an inverted pendulum. 1) The prediction model set an initial time t for the initial values in the forward IPM simulation. These initial values include the position and velocity of the CoM and the contact foot (the definition of the contact foot is described in the Methods). 2) The IPM simulation was performed to calculate the future mediolateral position of the CoM using the abovementioned initial values. 3) The model then predicted the IPM cue timing as time t if the simulated pendulum fell left or right. 4) If the pendulum did not fall left nor right, the model iterated the processes 1 to 3 using new initial values for time t+1 until an IPM cue timing was determined. (B) Illustration of the attacker and the 3D IPM. In this case, the 3D IPM predicted that the attacker was running to the left. (C) A representative example of the estimated mediolateral CoM displacement during sidestep cutting and the prediction of direction change in the IPM simulation (black). The gray line is the

measured mediolateral CoM displacement. The graduated horizontal gray lines are the IPM cue timing (most black), the averaged defender's cue timing among the defenders and the CoM cue timing. After the third foot takeoff (3TO), the prediction model using the inverted pendulum predicted that the attacker's final running direction would be to the left.

3.3. Methods

The participants, protocol and analysis used in the current psychophysical experiment were the same as in Study I. The experimental procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Local Ethics Committee in the Graduate School of Human and Environmental Studies, Kyoto University (22-H-22).

3.3.1. Apparatus and protocol for the attackers

Seven skilled ballgame players (age = 20.9 ± 1.2 years, experience = 11.3 ± 3.7 years) performed quick sidestepping and crossover cutting maneuvers to the left and right as attackers. The experimental setup is outlined in Fig. 3-2A. They were instructed to change their running direction by 45 degrees without a deceptive motion at their fifth step as quickly and unpredictably as possible. The attackers' movements were recorded head-on (the gaze of direction was instructed to be fixed) by one normal-speed camera (30 Hz) to create the video stimulus at a 1.2-m height and four high-speed (300 Hz) cameras (EXLIM PRO EX-F1; Casio Computer Co., LTD, Tokyo, Japan) for the model and biomechanical analyses. One video session included 28 maneuvers (right/left * sidestep/crossover * 7 attackers).

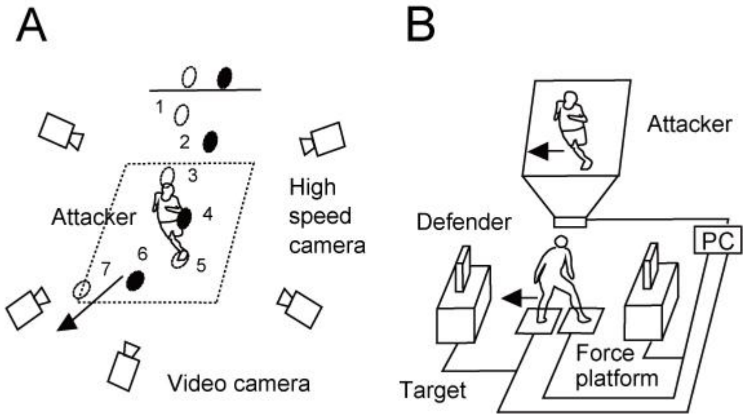

Fig. 3-2. Experimental setup for the attacker (A) and defender (B). Motion analysis and the psychophysical experiment enabled us to determine when the defenders perceived the relevant cue and reacted to the final running direction of the attackers.

3.3.2. Apparatus and protocol for the defenders

Ten skilled basketball players as defenders (age = 19.5 ± 0.9 years, experience = 7.2 ± 1.3 years) performed step-and-reach reactions with an LED (LED task) and the video stimulus (video task: Fig. 3-2B). The participants were instructed to step laterally and reach the target. The participants performed three sessions (using the same 28 videos but in different sequences) of the video task (28*3 reactions), and two sessions of the LED task (28*2 reactions). In the vertical direction, the ground reaction forces were measured to define the moment of reaction using two force platforms

(OR6-7-2000, AMTI, Watertown, MA, USA).

I conducted the LED task to estimate each participant's visuo-motor processing time. After the preparatory signals, which involved both sets of LEDs blinking four times simulating the attackers' foot contact interval during the video stimulus, either the left or right set of LEDs was illuminated as a direction signal. The test stimulus comprised 28 trials, and the practice stimulus comprised 7 trials with the same interval type as the test stimulus. The LED stimulus output signals and video stimulus using sound signals were sampled simultaneously at 1000 Hz.

3.3.3. Reaction time analysis for the defenders

I estimated the defender's cue timing by subtracting the visuo-motor processing time recorded during the LED task from the moment of reaction to the video stimulus. The moment of reaction was defined as the initiation of the lateral step in the video task, which is the time when the vertical ground reaction force under the stepping leg fell below 10% of the participant's weight. The participant's visuo-motor processing time was defined as the time from illumination of the direction signal to initiation of the lateral step in the LED task. The defender's cue timing was expressed as a relative value with respect to the attackers' fifth foot contact. The trials were eliminated from the analysis for the LED task when the reaction time deviated over 3 standard deviations from the mean. These criteria eliminated 22 trials (3.9%). In the video task, the film clips in which the mean defender's cue timing was too late (one film clip over 1000 ms) or too early (two film clips under -700 ms) and the trials in which the defender reacted in the opposite direction (3 trials: 0.4%) were eliminated from the analysis.

3.3.4. Motion analysis for the attackers

For each trial, the attacker's motion was recorded using four high-speed cameras (300 Hz) from the foot contact at the third step to foot takeoff at the fifth step (direction change). Three dimensional position data for ten body landmarks (right and left toes, heels, hips, shoulders and temples) were obtained by digitizing 2D camera data using software (Frame DIAS; DKH Co., LTD, Tokyo, Japan). The raw 3D data were smoothed using a third-order Butterworth digital filter with optimal cutoff frequencies (5-10 Hz) after a residual analysis with a wide range of cutoff frequencies (Yanai, 2004). The timing for each foot contact and takeoff was visually detected. The kinematic data were linearly interpolated from 300 to 1000 Hz for forward simulations. In calculating the future trajectory of the CoM, I used the attacker's CoM and center of the contact foot, as defined below, by calculating the position of the toes, heels, hips, shoulders and temples based on an estimation of body segment parameters (Ae et al., 1992).

For the kinematic analysis, the shoulder and hip rotation angles were calculated as described previously (Fujii et al., 2010). The shoulder and hip rotation angles were compared to the angles measured during a straight run (using the intra-attackers mean curve). The CoM displacements were arranged for comparison by fitting them to the final running direction (positive value). The foot displacements were categorized into the direction-change foot (fifth step) and the preparatory foot (fourth step).

3.3.5. Inverted pendulum simulation

To calculate the IPM cue timing, I generated a model that predicts the attacker's running direction using an IPM. For more detail, see Appendix. Here, I provide a brief explanation of the model (a conceptual diagram of this model is shown in Fig. 3-1A). The attackers' running directions were predicted via the following steps. 1) The prediction model set an initial time t (ms) for the initial values used in the forward IPM simulation (i.e., the position and velocity of the CoM and either foot at time t [ms], which is when the model want to predict the attacker's running direction). Assuming that each attacker's feet landed in an alternating pattern and actually not at the same time, the contact foot was defined as the foot grounded in the contact phase, and the foot that would land in the next step was in the flight phase. 2) The IPM simulation was performed to calculate the future mediolateral position of the CoM using the abovementioned initial values, until the pendulum fell down (Fig. 3-1C, black; after the third foot takeoff (3TO), the model predicted that the attacker's final running direction would be to the left). 3) The model then predicted the IPM cue timing as the time t if the simulated pendulum falls left or right (e.g., if the simulated inverted pendulum falls to the right, then the model predicted that the attacker would move to the right). 4) If the pendulum does neither fall leftward nor rightward, the model iterated the first three steps using new initial values for time t+1 until an IPM cue timing is determined.

The lateral thresholds between 5 and 20 cm (each 1 cm) that the IPM used for the direction of its falling, were determined for each trial using a grid search algorithm that could predict the earliest IPM cue timing without an error. The pendulum fall threshold (45 degrees) was confirmed to have little effect on the simulation results based on the grid search within the actual range of the fall angle (Fig. A1). To test the first hypothesis, the CoM cue timing was calculated using only the measured CoM mediolateral displacements (Fig. 3-1C, gray; the lateral thresholds were also determined using the same algorithm).

3.3.6. Statistical analysis

Kruskal-Wallis nonparametric tests were performed to compare the CoM, IPM and defender’s cue timings because the hypothesis of the homogeneity of variances between groups was rejected using Bartlett's test. For multiple comparisons following the Kruskal-Wallis tests, Scheffe's paired comparison test was performed. Eta-squared values (η^2) were reported as a measure of the effect size for the Kruskal-Wallis test. Because the data were not normally distributed (according to the Lilliefors test), Spearman's rank correlation was used for the IPM, CoM and defender's cue timings to test the validity of the IPM cue timing. Averaged defender's cue timing of the video was the mean values of the timing among ten defenders, which was the mean values of three trials (session). When the distribution was separated into two groups, paired *t*-tests were performed, and a Pearson's correlation coefficient was calculated for each group. For the statistical calculations, $p < .05$ was considered significant. All the statistical analyses and the numerical calculations, including the simulations, were performed using MATLAB 2011a (The MathWorks, Inc., MA, USA).

3.4. Results

In the previous study, the median value from the defender's cue timing was 358 ms (range from 173 to 429 ms) before the direction change (Study I). I then calculated the estimated CoM and IPM cue timing. Information based on the CoM predicted a change of direction at a median 41 ms (range from −163 to 124), and based on the IPM, the direction change was predicted at a median 287 ms (range from 116 to 665) before the direction change. A comparison among the IPM, CoM and defender's cue timings (Fig. 3-3A) revealed a significant difference ($\chi^2_2 = 37.8$, $p = 6.3 \times 10^{-9}$, $\eta^2 = .51$). Scheffe's paired comparison test revealed that the CoM cue timing was delayed compared with both the IPM and defender's cue timings ($p = < .05$). There were no significant differences for the remaining cue timing.

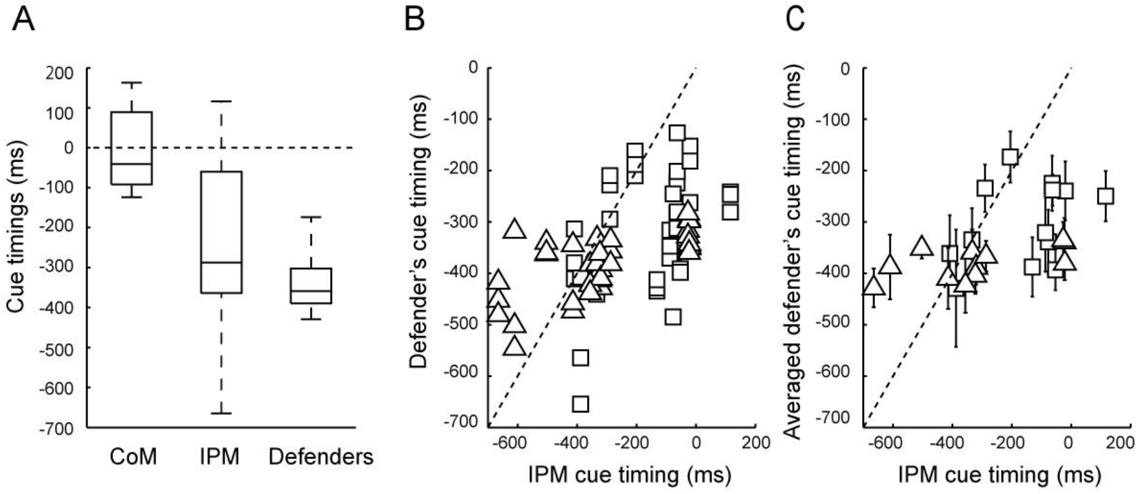

Fig. 3-3. (A) The CoM cue timing, IPM cue timing and defender's cue timing. The IPM cue timing was significantly earlier than the CoM cue timing and similar to the defender's cue timing. (B) An example of the scatter plot of one defender's cue timing and the IPM cue timing. Each square shows the sidestep maneuver and the triangle shows the crossover maneuver. The dashed line is the identification line where the IPM and defender's cue timings were the same value. (C) The relationship between the IPM cue timing and the averaged defender's cue timings among ten defenders in the sidestep (square) and the crossover (triangle) maneuver trials. The error bar indicates the standard deviation among ten defenders.

The IPM and defender's cue timings were then analyzed using Spearman's rank correlation analysis. For individual correlations, all ten defenders had significant positive correlations (median *Spearman's* ρ = .353 (range from .246 to .589), all $p < .05$). When the model based on IPM predicted the change of direction earlier, the real defenders perceived the relevant cue earlier. Figure 3-3B is a scatter plot that shows a typical example of this correlation. Significant positive correlations between the IPM and the averaged defender's cue timings and between CoM and the averaged defender's cue timings were also demonstrated (Fig. 3-3C, IPM and averaged defender' cue timing: *Spearman's* $\rho(24) = .536$, $p = 5.7 \times 10^{-3}$; CoM and averaged defender's cue timing: *Spearman's* $\rho(24) = .648$, $p = 4.6 \times 10^{-4}$). However, the distribution of the IPM cue timing in Fig. 3-3C was separated into two trial groups: 14 early-detection trials and 11 delayed-detection trials for the IPM cue timing. I divided two trial groups in such a way that the two groups were normally distributed and that the IPM and averaged defender's cue timing were correlated strongest in early-detection trials. The early-detection trials included five sidestep and nine crossover trials, whereas the delayed-detection trials included eight sidestep and three crossover trials. In the early-detection trials, no significant difference was observed (IPM: mean 388 ms and defender's cue timing: mean 361 ms prior to the direction change; $p > .05$), but in the early-detection trials, the IPM cue timing was delayed compared with the defender's cue timing (IPM: mean 41 ms and defender's cue timing: mean 313 ms prior to the direction change; $p = 1.7 \times 10^{-7}$). Furthermore, significant correlation with the defender's cue timing in early-detection trials was found ($r(13) = .541$, $p = .046$), but not in delayed-detection trials ($r(10) = -.103$, $p > .05$). The wide distribution of the IPM cue timing was caused by the delayed-detection trials.

Why can the IPM be predicted in the early-detection trials, but not in the delayed-detection trials? I then investigated shoulder and hip rotations as additional cues, and examined the mediolateral CoM and foot displacement (direction change and preparatory foot) as the kinematic parameters within the IPM. Fig. 3-4 shows the normalized time course for these variables from the attacker. For these variables, I did not use statistical analysis because of the smaller number of trials. For the IPM kinematic parameter, the preparatory foot displacement in the delayed-detection trials tended to be smaller than that in the early-detection trials for the sidestep maneuvers; whereas for the crossover maneuvers, the CoM fluctuation tended to be larger. For the other kinematic parameter, the shoulder and hip rotation angles in the delayed-detection trials were not larger than those in the early-detection trials.

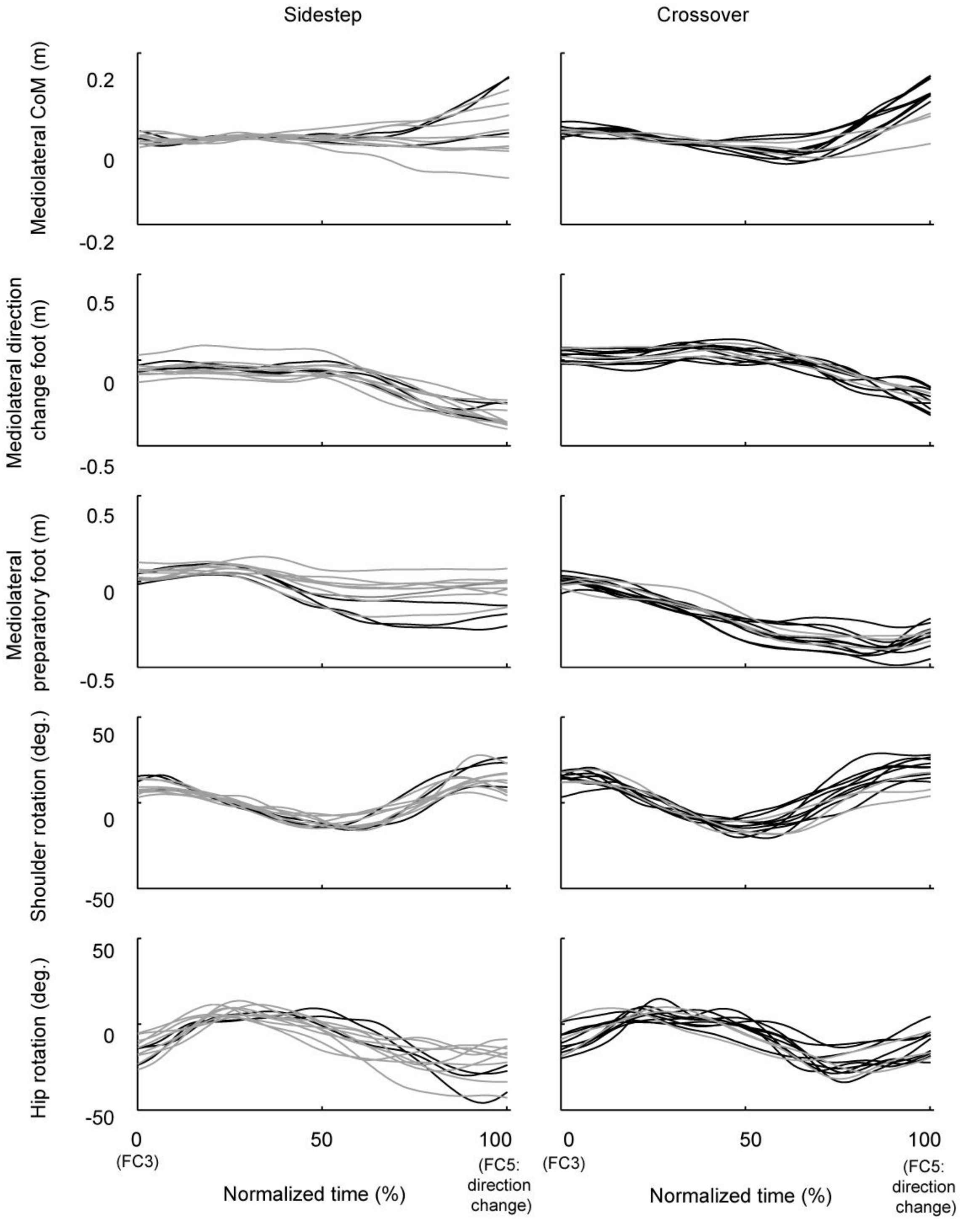

Fig. 3-4. Individual curves for the mediolateral CoM, direction-change foot, preparatory foot displacements, and shoulder and hip rotation angles during the sidestep (left) and crossover maneuvers (right) for the attackers from foot contact at the third step (FC3) to foot takeoff at the fifth

step (FC5, direction change). The black and gray lines indicate the delayed-detection trials and the early-detection trials for the IPM cue timing compared to the defender's cue timings (Fig. 3-3C), respectively. The positive values for the CoM and feet displacements represent the final running direction. For the sidestep maneuvers, the preparatory foot displacement in the delayed-detection trials tended to be smaller than those in the early-detection trials. For the crossover maneuvers, the CoM fluctuation in the delayed-detection trials tended to be smaller than in the early-detection trials. Positive values for the rotation angles represent a rotation to the right. The shoulder and hip rotation angles in the delayed-detection trials were not larger than those in the early-detection trials.

3.5. Discussion

The results in the present study demonstrated that the CoM cue timing was delayed compared with both the IPM and defender's cue timings, which suggests that defender's response would be too late if they reacted to a change in the CoM mediolateral displacement. In the previous study, the CoM was an 'honest' movement signal, which could not deceive the defender in a rugby cutting maneuver including deceptive motion (Brault et al, 2012). Additionally, basketball coaches claim that defenders should keep their eyes focused on the opponent's middle of the trunk (American Sport Education Program, 2007), which is assumed to be almost the same as the CoM. As an alternative, however, I hypothesized that defenders can predict the future CoM trajectory using a forward IPM simulation. This idea was partially supported by the results that the predicted attacker's running direction using the IPM in the earlier group in Fig. 3-3C (median 306 ms) was not significantly different from the psychophysical data (defender's cue timing: median 360 ms). Furthermore, the significant correlation between the IPM and defender's cue timing for all of the trials suggests a similarity between the defender's decision-making process and the IPM forward simulation. In the previous research, basketball dribblers drove to the side of the defender's advanced foot because it takes longer for the defender to recover position and protect the basket (Esteves et al., 2011). According to my model, the reason can be explained that the defender's advanced foot would be likely to move in a contralateral-backward and ipsilateral-forward direction, but not in an ipsilateral-backward direction, which was the direction the dribblers actually tended to drive. They also demonstrated that the better dribblers were able to conceal their postural information compared to the novices, which indicated that they can move in both directions mechanically in my model.

Is it plausible that the human central nervous system uses a forward IPM simulation to anticipate the motion of others? To answer this question, I need to discuss the rationale of the theoretical framework underlying the simulation process in terms of the representational structures of the brain. Humans are believed to maintain an internal forward model of the dynamic properties of the world in the central nervous system to help with anticipation (Wolpert et al., 1995; Zago et al., 2004; Cerminara et al., 2009). A neurophysiological study showed that cortical neurons specialized for processing visual motion accurately encoded the target velocity and direction but contained only partial information and a prior guess regarding acceleration (Merfeld et al., 1999; Indovina et al., 2005; Zago, & Lacquaniti, 2005; Miller et al., 2008; Maffei et al., 2010). With prior knowledge of acceleration from gravity and basic physics, a human can successfully extrapolate the trajectory for falling objects and anticipate the landing time as well as the location (Zago, Mclntyre et al., 2009; Zago et al., 2011; Nagai et al., 2002). Mah and Mussa-Ivaldi (2003) revealed that participants developed an internal model for the inverted pendulum during a task that required pointing at a moving target with the free end of an inverted pendulum object. The CoM trajectory during human locomotion can also be described as a simple IPM (Srinivasan & Ruina, 2006; Kagawa & Uno, 2010). The positive, significant correlation between the IPM and the CoM cue timings in the present study suggests that only the information on the CoM and the center of the contact foot assumed in the model contributed to estimating the attacker's future running direction. The visuoperceptual system uses a Gestalt-like perceptual grouping process to organize vast visual information into its simplest terms, according to researches on ballgame players (Ward et al., 2002; Diaz & Fajen, 2012), humans (Neri et al., 1998), and brain imaging for both humans' and non-human primates' (Puce & Perret, 2003). It is plausible that the human visuoperceptual system may extract information on the CoM and center of the contact foot from visual input of others' running. Based on the above discussion, I suggest that humans may be able to forwardly simulate the future trajectory of another person's CoM in reaction to a change in their running direction.

Notwithstanding, there were some trials in which the IPM could not predict the running direction as early as real defenders did. The failure of the model to completely predict the performance and the wide distribution of the IPM cue timing was observed in the delayed-detection trials. This result suggests that there could be cues other than the IPM (Brault et al., 2012). However, with regard to shoulder and hip rotation angles, I found no difference between the early- and delayed-detection trials. Another explanation was that the kinematic parameters within the IPM, such as the CoM and the foot displacements tended to be smaller in the delayed-detection trials compared with the early-detection trials. The slight difference in the initial values for the IPM forward simulation may underlie the different predictions obtained using the IPM in these two trial groups. Thus, the abovementioned possibilities may not account for the delayed-detection IPM cue timing. Therefore, factors other than the kinematic parameters within the IPM, such as viscoelastic properties (Full & Koditschek, 1999), are a possible cause for the difference between both the trial groups. Additionally, I can add the various sources of information technically by weighting and integrating this information at the decision making level (Fig. 3-1A (3)). However, I may gain little advantage from adding the various sources of information because the intrinsic information that cannot be concealed by the attackers is limited (Brault et al., 2012). Therefore, I would first like to propose my original model using only two simple sources of information. In this study, only simple sidestep and crossover cutting maneuvers were examined. As discussed above, the results of the present study which indicated that information on both the CoM and the contact foot was more useful than the CoM information alone, differed from the results of a previous study (Brault et al., 2012). One explanation of this difference might be the use of a cutting maneuver without deceptive motion in the present study. However, in a ballgame, there are situations when attackers perform the cutting maneuver without deceptive motion, e.g. because of a defender's understanding of the attacker's skill or tendencies. Outside of a specific situation in which the defenders were convinced of the attacker's cutting without deceptive motion, the defenders then should detect the other cues. The validity of the forward model in studies on anticipating others' motion should be tested in further experiments in which the participants can use deceptive movements or other techniques, such as a stop or an intentional change in stride frequency. The previous study (Study I) did not demonstrate any enhancement of perception-action coupling with expertise (Farrow & Abernethy, 2003; Aglioti et al., 2008). To identify any potential perception-action coupling in basketball, it is necessary to examine anticipatory mechanism wherein the attackers and the defenders interact with more complicated movements, such as passing, shooting or deceptive movements.

In a 1-on-1 ballgame scenario, the current study revealed that estimations of cue timing based on information about the CoM (almost equal to the trunk) and the contact foot occurred earlier than an estimation based on trunk information alone. This finding contrasts with the basketball coaching principle that defenders should always keep their eyes focused on the opponent's midsection (American Sport Education Program, 2007), i.e., the trunk. The present study suggests that trunk information alone is insufficient for effectively anticipating an attacker's final running direction. One possible recommendation in basketball coaching based on the present study is to emphasize seeing not only the attackers' trunk in the central vision but also the position of the contact foot in the peripheral vision to anticipate the attacker's movement. Seeing the attacker's entire body from the trunk to the contact foot without directing attention to any deceptive movements may enhance a defense against an attacker.

Chapter 4: STUDY III — Strategies for defending a dribbler: Categorization of three defensive patterns in 1-on-1 basketball.

4.1. Abstract

To clarify the defending-dribbler mechanism, the interaction between the dribbler and the defender should be investigated. The purposes of this study were to identify variables that explain the outcome (i.e., “penetrating” and “guarding”) and to understand how defenders stop dribblers by categorizing defensive patterns. Ten basketball players participated as 24 pairs of dribblers and defenders, who played a real-time, 1-on-1 subphase of the basketball. The trials were categorized into penetrating trials, where a dribbler invaded the defended area behind the defender, and guarding trials, where the defender stopped the dribbler’s advance. The results demonstrated that defenders in guarding trials initiated their movements earlier and moved quicker than the defenders in penetrating trials. Moreover, linear discriminant analysis revealed that the difference in initiation time and mediolateral peak velocity between the defenders and dribblers were critical parameters for explaining the difference between penetrating and guarding trials. Lastly, guarding trials were further categorized into three defensive patterns during 1-on-1 basketball (i.e., “early initiation” trials, “quick movement” trials and “dribbler’s stop” trials). The results suggest that there are three defending strategies and that one strategy would be insufficient to

explain the defending-dribbler mechanism, because both players' anticipation and reactive movement must be considered.

4.2. Introduction

In invasive ball sports, such as basketball or football, defenders should anticipate a dribbler's motion and react to stop his/her advance. Defenders perceive the relevant cues of the attacker's motion (Jackson et al., 2006; Williams & Davids, 1998), make a decision of their defensive action, and start to move in the direction the dribbler moves (Study I; Brault et al., 2012). Previously, researchers have focused on the anticipation aspect in replicated 1-on-1 subphase of the team sports using video clips in a laboratory-based approach (Study I; Jackson et al., 2006; Williams & Davids, 1998). This approach has successfully provided the experimenter with rigorous control over the test environment (Williams et al., 1999) and valuable insights into the anticipation skill of expert ballgame players.

However, to understand the defending-dribbler process using this approach, the dribbler-defender interaction has been a problem (e.g., both players anticipating and reacting to their opponent). To solve this problem, the motions of both of them were captured in the 1-on-1 subphase (Fajen et al., 2009; Passos et al., 2008). In this situation, dribbler-defender dynamics are a complex system (Davids et al., 2006; Passos et al., 2008), which are defined as the systems with non-linear, unpredictable interactions of different elements (i.e., the dribbler aims to penetrate, and the defender aims to stop the opponent). Because of this complexity, previous studies have described the attacker-defender dynamics using a dynamical system approach (Palut & Zanone, 2005; Araujo et al., 2002), in which the dynamics are analyzed as a system of pairs of attackers and defenders. However, it is unknown how the defender's performances actually affect the 1-on-1 subphase outcome (i.e., being penetrated or successfully guarding). To investigate the defending-dribbler process, focusing on the defender's behavior using the traditional methods of sport psychology should be primarily needed (Study I; Williams & Davids, 1998; Mori et al., 2002), including methods evaluating individual performance such as initiation time, movement speed, and response accuracy based on a stimulus-response paradigm (i.e., stimulus is attacker), excluding the attacker-defender interaction. Thus, I focused on the defensive step performance in basketball 1-on-1 subphase, set up the experimental environment with the defended area (Fig. 4-1), and analyzed the spatiotemporal characteristics of the dribbler and the defender, such as when they begin moving and the speeds of their movements.

The anticipation skill based on perceptual information helps the defender to initiate moving early in the direction of the dribbler. In rugby 1-on-1 subphase, CoM information is an "honest" movement signal because it is difficult to deceive a defender by the signal (Brault et al., 2012). If defenders use information on the dribbler's CoM as a cue for defending action, I assume that the defender's movement initiation time calculated from their CoM position will approach dribbler's initiation time, and vice versa, in the stimulus-response paradigm. In this paradigm, this time difference between the dribbler's initiation and defender's initiation can be considered as a visuo-motor delay, which defined as the time period between the pick up of information and its use in producing an adjustment in movement (Benguigui et al., 2008). I therefore examined the defender's initiation time relative to the dribbler's initiation time as the visuo-motor delay, and as one explanatory variable to separate the 1-on-1 outcomes.

In terms of anticipation, there are information processing (reaction time) benefits and costs associated with correct and incorrect anticipation, respectively (i.e., incorrect anticipation results in a longer reaction time, according to Williams & Davids, 1998). However, even if the defender incorrectly anticipates the dribbler's motion, defenders can use quick movements after their movement initiation to compensate for their miscalculation. This strategy is only applied to the 1-on-1 interactive task, but cannot be used in the previous video-based approach (Study I; Williams & Davids, 1998). Movement performance should be evaluated as the time or velocity from movement initiation to accomplishment of their aim of the movement. In the present study, I evaluated movement performance as the peak velocity or the time to peak velocity from the initiation time because quick movements would also be an effective strategy to stop a dribbler. Thus, I also evaluated the defender's and/or dribbler's mediolateral peak velocities as another explanatory variable because the 1-on-1 outcome would be changed by the dribbler's movement speed.

The purpose of this study was twofold: (1) to determine variables that explain the difference between penetrating and guarding trials, and (2) to understand how defenders stop dribblers by clarifying defensive patterns in the 1-on-1 ballgame subphase. I first classified the 1-on-1 outcomes in a real-time basketball situation, using spatiotemporal characteristics of the defenders and dribblers, such as initiation time and peak movement velocity. Second, I categorized the defensive patterns in guarding trials. Defenders can stop a dribbler using at least two strategies: their early initiation and quick movements. My description of these strategies enhances our understanding of how to defend a dribbler in a 1-on-1 basketball.

4.3. Methods

4.3.1. Participants and protocol

Ten skilled male members of a university basketball team (age = 20.2 ± 1.8 years, experience = 8.9 ± 3.2 years [mean ± SD]) participated in this study as 24 pairs of dribblers and defenders. The participants provided informed consent prior to the experiment. The experimental procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Local Ethics Committee in the Graduate School of Human and Environmental Studies, Kyoto University (23-H-6).

A dribbler with a basketball and a defender were instructed to play a real-time, 1-on-1 subphase within a 4×8 m (Fig. 4-1). The objective of the dribbler was to get past the defender and invade the defended area behind the defender. There was no basketball goal and scoring opportunity. The experimental task began with the dribbler's preferred timing after the experimenter's signal. As in a basketball game, the dribbler was not permitted to go across the sideline. The defender aimed to stop the dribbler according to the rules of basketball (FIBA, 2012), which allow the defender to stop the dribbler from a head-on position only. No additional instruction (such as time limit) was given to dribblers and defenders; all of the trials finished within 10 s.

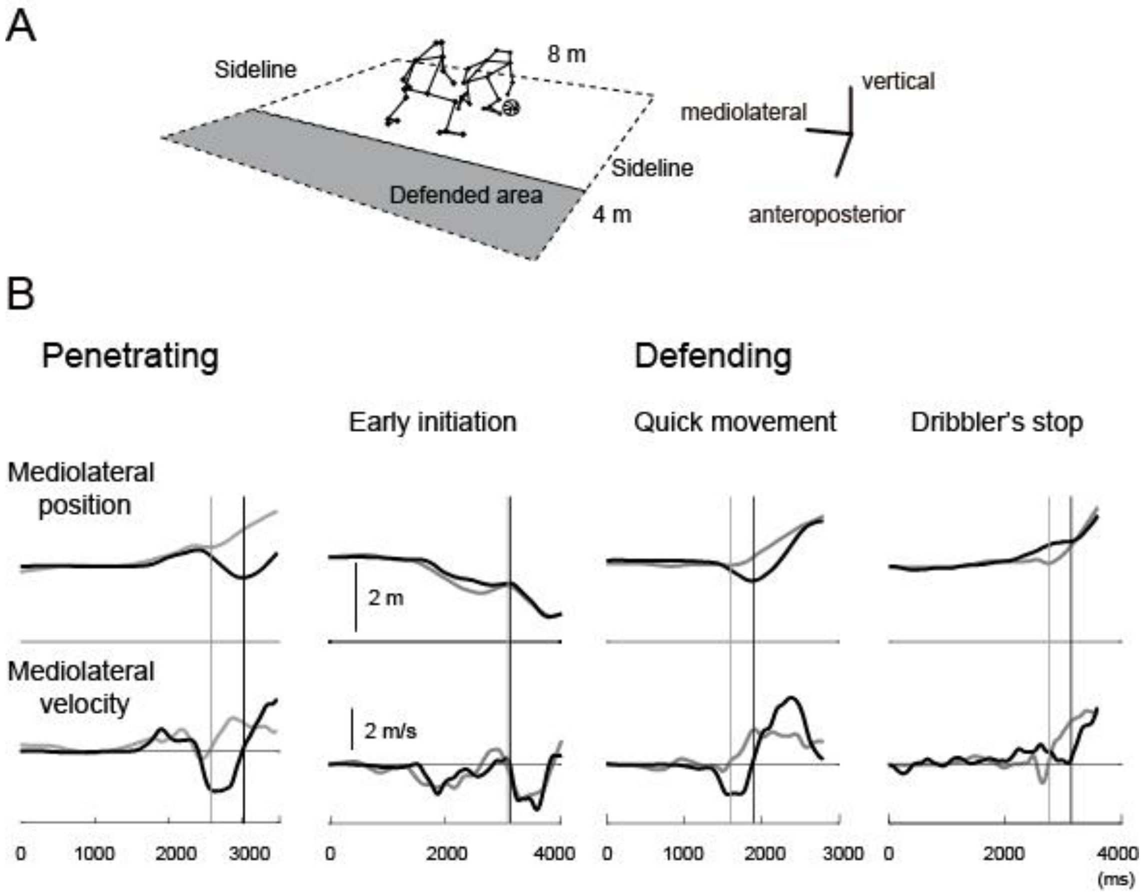

Fig. 4-1. (A) Schematic diagram of a defender and dribbler. The objective of the dribbler was to invade the defended area behind the defender. The defender aimed to stop the dribbler according to the rules of basketball, which allows the defender to stop the dribbler from a head-on position only. (B) A typical example of the mediolateral position and velocity of one dribbler (gray) and defender (black) for one penetrating and three guarding trial (early initiation, quick movement and dribbler's stop trial). Vertical lines represent the dribbler's (gray) and defender's (black) initiation time.

4.3.2. Motion capture

For the kinematics, three-dimensional coordinates of the landmark points for both the dribbler and the defender were acquired using a 3D optical motion capture system with 16 cameras at 200 Hz (Raptor-EDigital Real Time System, Motion Analysis Corporation, Santa Rosa, CA, USA). Eighteen reflective markers were placed on each participant's body (right and left side of each of their heads, shoulders, elbows, wrists, hips, knees, ankles, heels and toes) to obtain CoM displacements (Ae et al., 1992). All raw coordinate data points were smoothed using a third-order Butterworth low-pass digital filter (lower than 10 Hz) with a residual analysis (Winter, 1990). The CoM displacements for the dribblers and defenders were linearly interpolated from 200 Hz to 1000 Hz for the analyses below.

4.3.4. Selection and categorization

Defending a dribbler is the outcome whereby the defender is able to deprive the dribbler of his free movement. The 1-on-1 finished only after the dribbler invaded the defended area (defined as penetrating trials), crossed the sideline, stopped dribbling (holding the ball) or was deprived of the ball by the defenders for any reason, e.g., the dribbler's poor ball handling. Guarding a dribbler is not a final determined outcome (unless the dribbler stops dribbling) but an instantaneous and fluctuating outcome where the dribbler and defender synchronize. Specifically, guarding a dribbler will indicate that the CoM positional difference between dribbler and defender and their movement velocity in mediolateral and anteroposterior directions approached zero (Fig. 4-1). The authors, a basketball coach (experience: 5 yrs. as coach, 16 yrs. as players), visually judged the penetrating and guarding trials based on the above criterion. The computational criterion was not used, because the reflective markers were occasionally invisible at the end of the trials, as the participants moved out of range of the cameras, particularly in the penetrating trials in the anteroposterior direction and due to contact with each other in the guarding trials. The total number of 1-on-1 games (trials) in the present study was 334: 140 penetrating trials, 78 guarding trials and 116 trials, in which the pair ran in parallel (69 trials) or the motion capture failed (47 trials). In these penetrating and guarding trials, I picked up 29 penetrating and 29 guarding trials including at least every pair (24 pairs). The analyzed trial numbers were selected because they provided adequate data for a creating scatter plot (Fig. 4-2). When determining the outcome, note that I did not use the assumed critical variables in the present study, such as the initiation time or peak velocity defined below.

4.3.5. Spatiotemporal variables

To describe the difference between both outcomes (i.e., penetrating and guarding trials), I first calculated the initiation time, peak velocity and time to peak velocity for both players. The peak velocity was defined as the local maximum of the mediolateral CoM velocity after the initiation time. The initiation time was defined as the time it took to reach 10 % peak velocity for the first time since the initial increase (sign change or a sign change of the derivative of the velocity when a sign change did not occur) in the mediolateral CoM velocity. This threshold allows the identification of the real initiation of the movement, not simply low oscillations in a 1-on-1 subphase (Brault et al., 2010). The time to peak velocity was expressed as the time from the initiation of movement to reaching mediolateral peak velocity. For offering an explanation of the dynamics of the process, the difference value between the dribbler and defender was calculated by subtracting the dribbler's value from the defender's. With consideration for another possibility, I calculated the interpersonal distance and both the defender's and dribbler's velocities at the dribbler's initiation time in the mediolateral and anteroposterior directions.

4.3.6. Statistical analysis

For investigating the defensive pattern in guarding trials, first, to compare the explanatory variables and spatiotemporal characteristics between the penetrating and guarding trials, an unpaired t-test was used. Effect size was estimated using Cohen's d. Second, to test that there is no relationship between these variables for a discriminant analysis below, Spearman's rank correlation coefficient was calculated to analyze the relationship between extracted explanatory variables because the whole data were not normally distributed. Third, linear discriminant analysis was used to find a classification boundary between the penetrating and guarding trials using explanatory variables or spatiotemporal characteristics in gait pattern classification (Lee et al., 2009; Boulgouris & Chi, 2007) and face recognition (Yu & Yang, 2001; Chen et al., 2000). The discriminant analysis was appropriate for the classification of the 1-on-1 outcome to statistically examine the best discriminating combination of variables that differed between the penetrating and guarding trials (Fig. 4-3). After equality of covariance was confirmed using Box's M-test, the best linear discriminant function and its accurate classification rate were calculated. Fourth, to categorize the various defensive processes, I performed quantitative categorization of the 1-on-1 defensive patterns with arbitrary thresholds in horizontal and vertical axes, respectively. Lastly, a quantitative comparison without statistical analysis between the categorized variables was performed due to the small sample size. For the statistical calculations, $p < .05$ was considered to be significant. All numerical calculations and statistical analyses were performed using the MATLAB 2011a Statistical Toolbox (The MathWorks, Inc., MA, USA) and SPSS 16.0J for Windows (SPSS Inc., Chicago, IL, USA).

4.4. Results

Figure 4-1 displays a typical example of the mediolateral position and mediolateral velocity. In the penetrating trial, the dribbler's mediolateral position and velocity were rapidly increased, and the defender's mediolateral position and velocity were decreased after the dribbler's initiation time. Alternatively, in the guarding trial, the dribbler's and defender's mediolateral positions and velocities were similar, respectively. Table 4-1 presents spatiotemporal variables in both penetrating and guarding trials. The difference in the initiation time between the defender and the dribbler in the guarding trials was significantly less than that in the penetrating trials (t_{57} = 4.0, p = < 0.001, d = 1.1). The peak velocity difference between the defender and the dribbler in the guarding trials was greater (i.e., the defender was faster than the dribbler) than that in the penetrating trials (t_{57} = –3.4, p =.001, d = – .90). These two findings were expected because I compared them after the data were categorized, but it is important that I first quantified these fundamental performance variables. However, the difference in the time to peak velocity between the defender and the dribbler in the guarding trials was not significantly different from that in the penetrating trials (t_{57} = –.32, p = .74, d = –0.08). The mediolateral distance for the guarding trials was less than that for the penetrating trials (t_{57} = 2.0, p = .041, d = .54). The mediolateral velocity of the defender in the guarding trials was lower and in a negative direction compared to the penetrating trials (t_{57} = –2.9, p = .006, d = –.75). The anteroposterior velocity of the dribblers in the guarding trials was smaller compared to the penetrating trials (t_{57} = –2.1, p = .037, d = –.56).

Variable	Penetrating (N = 29) M	SE	Defending (N = 29) M	SE	p value
Initiation time difference (ms)	318	28	172	25	<0.001
ML peak velocity difference (m/s)	-0.38	0.15	0.31	0.14	0.001
Time to peak velocity difference (ms)	7	35	22	33	n.s.
ML distance (m)	0.22	0.03	0.14	0.02	0.041
AP distance (m)	1.40	0.04	1.43	0.07	n.s.
ML velocity (m/s)					
Dribbler	0.23	0.02	0.23	0.03	n.s.
Defender	-0.97	0.15	-0.38	0.14	0.006
AP velocity (m/s)					
Dribbler	-1.65	0.12	-1.24	0.15	0.037
Defender	-0.58	0.14	-0.65	0.17	n.s.

Table 4-1. The descriptive variables and spatiotemporal characteristics at the initiation time difference for the penetrating and defending trials. The results of the *t*-test were described. ML: mediolateral direction. AP: anteroposterior direction. The difference values were calculated by subtracting dribbler's values from defender's values.

Before the discriminant analysis, correlation analyses between pairs of the five variables significantly different variables (Table 4-1) demonstrated that there was no significant correlation between them (all $p > .05$). Next, a linear discriminant analysis using the initiation time and mediolateral peak velocity difference (according to my hypothesis) achieved an accurate classification rate of 79.3 % (Fig. 4-2; 46 of 58 trials).

Notably, 27 of the 29 guarding trials were correctly classified (93.1 %). Combinations of other variables, such as interpersonal mediolateral distance, the defender's mediolateral velocity and the dribbler's anteroposterior velocity, did not improve the classification of the 1-on-1 outcome (all had less than a 75 % classification rate in all trials). The result indicated that these variables had relatively smaller effect on the outcome compared to the initiation time and mediolateral peak velocity difference. There were two guarding trials in which the defender neither moved early nor reacted quickly relative to the dribbler, and they were not classified by the discriminant analysis (near the center of Fig. 4-2). To interpret the presence of these trials, I then performed a quantitative categorization using the defender's initiation time and peak velocity difference.

A quantitative categorization of the 1-on-1 defensive patterns identified the "early initiation" trials, "quick movement" trials and "dribbler's stop" trials (Fig. 4-1 and 2). Early movement initiation occurred prior to the movement, and I thus categorized these trials irrespective of movement velocity (threshold in horizontal axis: 200 ms). In the remaining area, as shown by the linear discriminant analysis, I separated trials with relatively quick defender movements and slower defender movement (threshold in vertical axis: 0.5 m/s). The visuo-motor delay (initiation time) occurred approximately 200 ms slower than expected based on the timing of the relevant information (Uzu et al., 2009). A peak velocity difference threshold of 0.5 m/s (the vertical axis intercept in Fig. 4-2) suggests that a defender with a 200 ms delay can catch up with a dribbler after 600 ms if the dribbler moves laterally at 1 m/s and the defender moves at an average rate of 1.5 m/s. Table 4-2 presents the spatiotemporal variables for each trial. Early initiation indicated that the defender had sufficient time to move properly. In the quick movement trials, the defenders moved much faster than the dribblers, whereas the defenders were delayed compared the dribblers. A dribbler's stop indicated that he stopped on his own even if there was sufficient time and movement velocity to penetrate the defender.

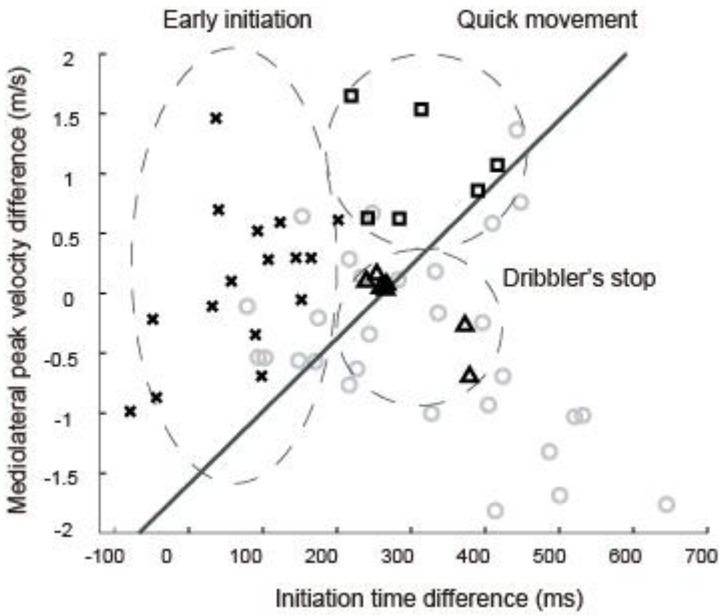

Fig. 4-2. A scatter plot of the initiation time difference and mediolateral peak velocity difference between dribbler and defender for all trials, and schematic illustration after quantitative categorization of the guarding trials. The gray "O" and black three different marks represent penetrating trials and guarding trials, respectively. Linear discriminant analysis using these variables

achieved an accurate classification rate of 79.3 %. The boundary line equation can be written as follows: [0.005 × defender's initiation time] + [−0.855 × mediolateral peak velocity difference] −1.359 = 0. Three different symbols and dashed boundary ellipses represent the three different strategies in the guarding trials.

	Early initiation (N = 16)		Quick movement (N = 6)		Dribbler's stop (N = 7)	
Variable	M	SE	M	SE	M	SE
Initiation time difference (ms)	69	19	302	32	283	22
ML peak velocity difference (m/s)	0.08	0.16	1.02	0.19	-0.10	0.11
Time to peak velocity difference (ms)	-8	24	84	78	-25	95
ML distance (m)	0.11	0.10	0.16	0.08	0.18	0.17
AP distance (m)	1.47	0.15	1.58	0.19	1.29	0.23
ML velocity (m/s)						
Dribbler	0.25	0.22	0.18	0.02	0.22	0.04
Defender	-1.60	0.63	-1.01	0.82	-0.93	0.75
AP velocity (m/s)						
Dribbler	-0.15	0.46	-0.87	1.01	-0.52	0.99
Defender	-0.64	0.79	-0.46	0.53	-1.18	0.93

Table 4-2. The descriptive variables and spatiotemporal characteristics at the dribbler's initiation time for early initiation, quick movement and dribbler's stop trials in the defending trials. Because of the small sample size, statistical analysis was not performed.

4.5. Discussion

4.5.1. Penetrating and guarding trials

The defender's initiation time in the guarding trials was less compared to the penetrating trials, which supported my hypothesis. This is "early initiation" trials for defending a dribbler. CoM information, which was used to calculate the initiation time in the present study, is an "honest" movement signal (Brault et al., 2012). If defenders use information on the absolute and relative position and velocity of the dribbler's CoM (almost equal to information on the dribbler's trunk) as a cue for defending action, the dribbler's initiation time is assumed to be the defender's visuo-motor delay. The delay is a task-dependent variable that ranges from 50 ms to 300 ms (Lee et al., 1983; Benguigui et al., 2008). In the present study, in 6 of the 30 guarding trials, the difference in the initiation time was less than 50 ms, and in three trials, the defender started to move earlier than the dribbler. This result suggested that, at least in these three trials, the defenders anticipated the dribblers' direction of movement by detecting relevant information aside from that provided by the dribbler's trunk because the defenders began moving before the dribblers' trunks moved in the future moving direction. This anticipation ability is very important for taking advantage of the opponents in a ballgame (Jackson et al., 2006; Williams et al., 2009). To further understand the mechanism of the anticipation skills, the relevant cue should be identified by detailed kinematic analysis (Brault et al., 2012), visual search analysis (Williams & Davids, 1998) or simulation analysis in real-time 1-on-1 subphase.

In the penetrating trials, the mean initiation time difference (317 ms) was presumably caused by factors such as a defender's incorrect anticipation and a defender's loss of balance (e.g., reacting to a dribbler's deceptive movement). These may be caused by dribbler's deceptive movement, such as head and shoulder rotation (Brault et al., 2010), and a basketball movement by the dribbler's handling. The initiation time difference varied widely (SD = 160 ms, from −100 ms to 700 ms) compared to empirical data collected in a more laboratory-like environment (e.g., SD = 33 ms from the study of Study I). This indicates that the defender and dribbler interaction can increase the initiation time variation, which has importance in influencing the 1-on-1 outcome.

According to my hypothesis, the mediolateral peak velocity difference between the dribbler and defender in the guarding trials was also less than that in the penetrating trials. In the guarding trials, the defender's peak velocity was greater than the dribbler's, whereas the opposite was true in the penetrating trials. Intriguingly, however, the correlation analysis revealed that the initiation time and mediolateral peak velocity difference were not significantly correlated. The defender's anticipation, reflected by the defender's initiation time, had little to do with the movement performance reflected in the peak velocity difference in the 1-on-1 basketball. Thus, my data suggested that the anticipation and movement performance should be analyzed separately, also in the subsequent analysis.

4.5.2. Linear discriminant analysis and quantitational categorization

The results of the linear discriminant analysis using the two critical variables achieved a highly accurate classification rate (28 of 30 trials) for the guarding trials, suggesting that the difference between the penetrating and guarding trials can be described by these two variables. The boundary line provides insightful information. The slowest peak velocity of the defenders was –1.00 m/s, and the estimated defender's initiation time on the boundary line was 94 ms. Visuo-motor delay can be as short as 100 ms when information is used in a continuous mode, such as a smooth start to the movement or no important correction of that movement (Benguigui et al., 2008). In the present study, the relevant cue would be found in a movement of human body, such as the CoM or foot, head, shoulder, hip rotation (Brault et al., 2010), or a basketball movement; thus, the visual cue would not be a discrete cue such as an unexpected ball bounce or light illumination. The results also indicated that the most delayed initiation time difference was 407 ms and that the estimated peak velocity difference on the boundary line was 1.01 m/s. Even if the defender starts to react slowly relative to the dribbler (200-400 ms), the defender can stop the dribbler by moving 1 m/s faster than the dribbler. This is the "quick movement" trials, which the quantitative categorization analysis also revealed that in the trials the defenders moved 1.06 m/s on average faster laterally than the dribblers and were able to catch up with the dribblers. This quick movement can help defenders stop a dribbler even if they incorrectly anticipate the future direction of the dribbler. For example, the unweighted state shortens the defender's step initiation (Study IV) or a split step reduces the movement time in a "know when, not where" choice reaction task (Uzu et al., 2009). Also in 1-on-1 subphase, to confirm the presence of the split step or another preparatory kinetic state, ground reaction force pattern should be analyzed.

4.5.3. Three process patterns in the guarding trials

Another goal of this study was to reveal how defenders stop dribblers in 1-on-1 basketball. The results of the quantitative categorization in the guarding trials demonstrated the presence of third defensive patterns: "dribbler's stop" trials. Defenders can successfully defend a dribbler by stopping the dribbler on his/her own. As mentioned above, the defender-dribbler interaction occurred in a real-time 1-on-1 subphase. The video approach cannot reveal the existence of the dribbler's stop trials; however, in the trials in which the defender stopped the dribbler, the results demonstrated that the defender's initiation time was delayed and that the peak movement velocity was nearly the same as the dribbler's values. My analysis based on the stimulus-response (dribbler-defender) paradigm, which excluded the possibility of defender's action changes dribbler's action (Esteves et al., 2011). Then, I should further assume that dribbler-defender dynamics are a complex system (Davids et al., 2006; Passos et al., 2008) and analyze using a dynamical system approach (Kijima et al., 2012; Okumura et al, 2012). Another possibilities were the dribbler's poor ball handling, incorrect anticipation of the defender's movement or less confidence to successfully penetrate towards the actual moving direction. Practically, because the "dribbler's stop" would rely less upon the defender's action, defenders in l-on-1 basketball should do their best to execute "early initiation" or "quick movement" decision making and leave the rest to the dribbler. The optimal combination and method of utilization of these strategies should also be further investigated.

4.5.4. Other variables

Mediolateral interplayer distance and the dribbler's advancing velocity were other possible critical variables influencing the 1-on-1 outcome. However, a linear discriminant analysis demonstrated that these variables did not improve the classification of the 1-on-1 outcome (less than a 75% classification rate). This result suggests that these variables would not always affect the 1-on-1 outcome and may only be involved as critical variables in some trials, such as middle initiation time and peak velocity difference (Fig. 4-2). Other variables that were not considered in this analysis, such as posture or arm movements of the dribbler or the defender, may also influence the 1-on-1 outcome. However, I assumed that these specific kinematic variables may have large individual variability, and therefore, the variables might not be common variables. The present study is meaningful as it demonstrated that only a few global variables, such as the initiation time and mediolateral peak velocity difference, influenced the 1-on-1 outcome.

Chapter 5: STUDY IV — Unweighted state as a sidestep preparation improve the initiation and reaching performance for basketball players.

5.1. Abstract

The preparatory motion of a defensive motion in contact sport such as basketball should be small and involve landing on both feet for strict time and motion constraints. I thus proposed the movement creating an unweighted state. Ten basketball players performed a choice reaction sidestepping task with and without the voluntary, continuous vertical fluctuation movement. The results indicated that the preparatory movement shortened the time of their sidestep initiation (301 vs. 314 ms, $p = 0.011$) and reaching performance (883 vs. 910 ms, $p = 0.018$) but did not increase their peak ground reaction force or movement velocity. The mechanism of the improvement was estimated to be the following: in the preparation phase, the vertical body fluctuation created the force fluctuation; after the direction signal, the unweighted state can shorten the time required to initiate the sidestepping (Unweighted: 279 ms; Weighted: 322 ms, $p = 0.002$); around the initiation phase, the dropping down of the body and weighted state can contribute to the reaching performance. I conducted additional experiment investigating muscle-tendon-complex dynamics and muscle activity using ultrasound device and electromyography. The result suggests that the building up of active state of muscle might explain the improvement of sidestepping performance.

5.2. Introduction

The preparatory motion, which is used before executing a movement to improve the motor performance, is executed in many sports activities such as jumping (Asmussen & Bondepet, 1974; Bosco & Komi, 1980; Komi & Bosco, 1978; Bobbert et al., 1996) or throwing (Perrin et al., 2000) to improve the quality of the sidestep (Uzu et al., 2009). However, in many ball sports, the players are subject to strict time-constraints, i.e., need to hasten their movement initiation after the visuo-motor delay. The delay is defined as the time period between the pick-up of information and its use in producing an adjustment in movement (Tresilian, 1993; Benguigui et al., 2008), and could be longer than 100 ms (McLeod, 1987; Benguigui, et al., 2003). To overcome the strict time-constraint in speed ball sports such as tennis, a quick reaction technique called the split-step is used, which is a small vertical hop to prepare for a lateral step (Aviles et al., 2002; Uzu et al., 2009; Nieminen et al., 2013). In contact ball sport such as basketball and football, more strictly, the players are subject to strong motion-constraints in addition to time-constraints. To intercept the ball and the opponent's body, only a small jump by the defender will allow time for the attacker to change the direction of their initially intended movement. Therefore, satisfying the requirements not only of a quick reaction movement (time-constraint) but also of preparation without jumping or hopping (motion-constraint) is necessary in contact ball sports.

The mechanism of the preparatory motion in the previous studies, such as countermovement before jumping (Asmussen & Bondepet, 1974; Bosco & Komi, 1980) or a split-step (Uzu et al., 2009; Nieminen et al., 2013) was generally explained by the SSC, which is a natural type of muscle function formed by the combination of eccentric and concentric actions (Norman & Komi, 1979; Komi, 1984). These preparatory motions change the movements themselves so greatly that kinetic parameters, such as mechanical force, energy and efficiency, are increased (Komi & Bosco, 1978; Uzu et al., 2009; Nieminen et al., 2013). However, in contact ball sports, large countermovements are detrimental to the defense. Thus, for both strict time and motion constraints, a different preparatory motion while landing on both feet should be used by skilled players to improve their quality of movement.

The unweighted state while landing on both feet is observed in the takeoff of a countermovement jump but not in squat jump without countermovement (Bosco & Komi, 1979; Bosco & Komi, 1980). The unweighted was indicated to be derived from an effective countermovement to improve the jumping height while both feet were on the ground. Thus, I assumed that an effective preparatory motion during defense in contact ball sports, that meets the demands of the severe time and motion constraints, would be accompanied by the unweighted state. However, examining the effectiveness of the creating of unweighted state involved several problems, such as the difficulty in the instruction of the movement and the great kinematic intra/interpersonal variability. Therefore, the voluntary but small continuous vertical body fluctuation as the preparatory motion for the sidestepping, is artificially replicated by instruction of the participants in the present study. The motion easily enables the participants to create the unweighted state while landing on and not moving both legs and is also assumed to minimize the individual movement variability.

The purpose of this study was to clarify the effect of creating the unweighted state on the sidestepping performance. First, I hypothesized that the defender's preparatory motion, which was instructed to continuously and vertically fluctuate in a voluntary way, improves the sidestepping performance. Second, I hypothesized that the unweighted state within the specified time is a critical factor for the sidestepping performance. I used the same visual stimulus as Uzu et al. (2009) but changed the reaction movement into a defense-like two step task simulated in a basketball 1-on-1 situation.

5.3. Methods

5.3.1. Participants

Ten skilled basketball players who were members of a university basketball team (age = 19.7 ± 1.4 yrs., experience = 7.3 ± 1.5 yrs. [mean ± *SD*]) participated in this study. The experimental procedures were conducted in accordance with the Declaration of Helsinki and approved by the Local Ethics Committee in the Graduate School of Human and Environmental Studies, Kyoto University (24-H-7).

5.3.2. Protocol and apparatus

The participants performed a two-alternative forced choice, sidestepping reaction task. Although players in contact ball sport move also forward and backward, I selected the common step task in only lateral direction which allows us to compare the results of the previous study (Uzu et al., 2009). They were instructed to take two steps laterally towards the illumination of one of two LEDs and reach the target with their leading foot at a distance equal to their body height from the initial midline (Fig. 5-1A). However, the reaching performance was calculated based on the lateral torso displacement described below, according to the rules of basketball, in which the defenders are allowed to stop the attacker by contact on their torso (FIBA, 2012).

Two conditions were considered in the LED tasks: a preparatory condition and a no preparatory condition. In the preparatory condition, the participants were instructed to perform a voluntary, continuous vertical fluctuation movement while landing on both feet as a preparatory motion before taking the lateral step and to maintain their weight in the center of their body in the mediolateral direction. The participants performed the preparatory movement for a self-selected frequency and amplitude. In the no preparatory condition, the participants did not perform any preparatory motions before the direction was indicated. Two sets of LEDs were placed 2 m apart from the participants and set at eye level. After the preparatory signals for both sets of LEDs blinking three times, either the left or right set of LEDs was illuminated as a direction signal (Fig. 5-1). After at least five familiarization trials, the participants completed two sessions of ten reaction task for both conditions. The orders of the conditions and the stimulus were counterbalanced among all participants. To eliminate the effect of fatigue, participants were given more than 2 minutes to rest between sessions.

Three-dimensional coordinates of the landmark points were acquired using a 3D optical motion capture system with 16 cameras at 200 Hz (Raptor-EDigital Real Time System, Motion Analysis Corporation, Santa Rosa, CA, USA). Eighteen reflective markers were placed on each participant's body (right and left side of their heads, shoulders, elbows, wrists, hips, knees, ankles, heels and toes, according to Ae et al. [1992]). All raw coordinate data points were smoothed using a fourth-order Butterworth low-pass digital filter (8-12 Hz) using residual analysis (Winter, 1990). The torso and CoM displacements calculated based on an estimation of body segment parameters (Ae et al., 1992), were linearly interpolated from 200 Hz to 1000 Hz for the analyses below. To measure the participants' GRFs at the initial position and first step, four force platforms were used (TF-4060-B, Tec Gihan, Japan). All numerical calculations including the analyses below were performed using MATLAB 2011a (The MathWorks, Inc., MA, USA).

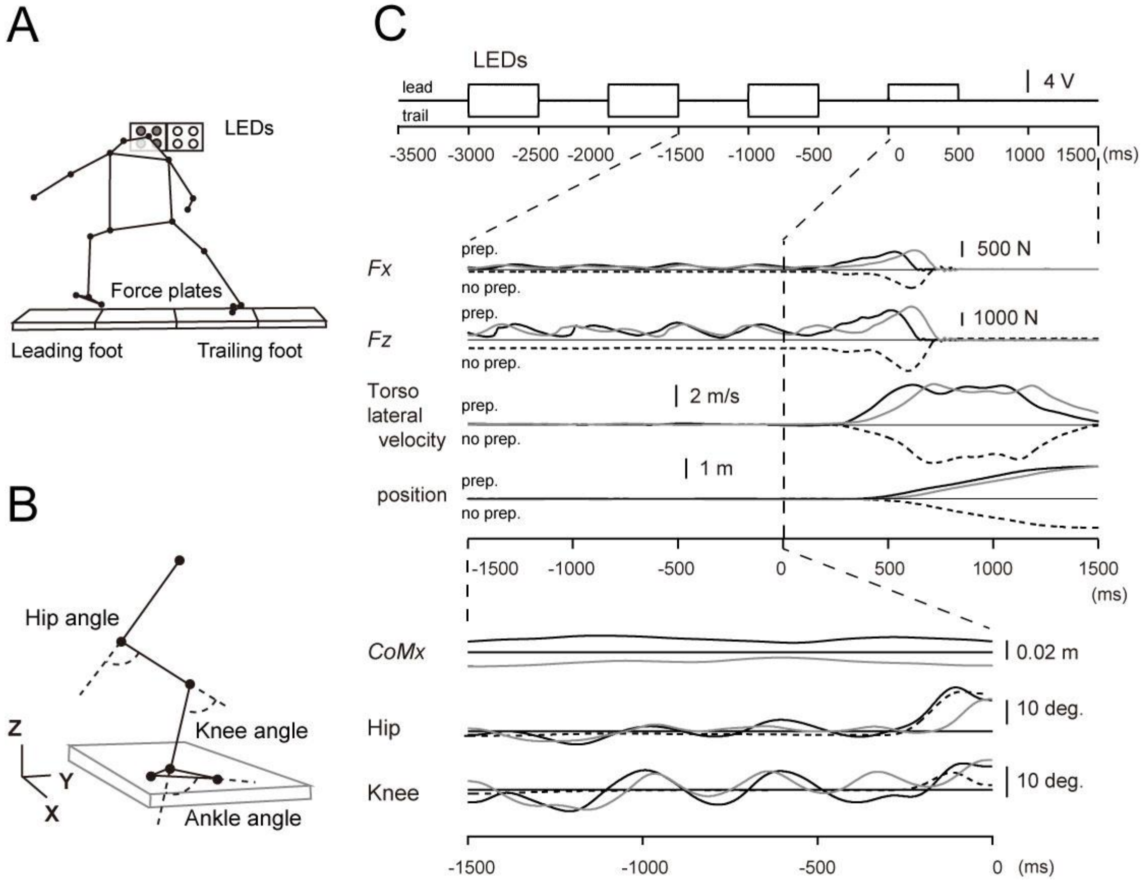

Fig. 5-1. (A) Experimental setup. Two LED sets and four forceplates were used in the present study. Three dimensional marker displacements were also calculated using a 3D optical motion capture system with 16 cameras. (B) Definition of the hip and knee angles for describing the vertical fluctuation of the preparatory motion. (C) A typical example of the LED signals, GRF, lateral torso displacement and velocity, and fluctuation in the no preparatory condition (dash line), unweighted trials (black solid) and weighted trials (gray solid). Traces of the voltages of the left and right LED signals show the preparatory and direction signals. The preparatory signals were shown three times

by both LEDs before the direction signal on one of the LEDs was presented (left in this trial). *Fx* and *Fz* indicate the total lateral and vertical GRF for both legs, respectively. The unweighted trial was defined as the trial when the *Fz* decreased more than 20% of the body weight at 100 ms after the signal illumination (the weighted trials was the opposite). The variables including the torso lateral velocity and displacement for the unweighted trials increased earlier than those in the weighted trial and the no preparatory condition, whereas the maximums of these variables were similar among the trials and conditions. *Fz,* vertical CoM displacement (*CoMz*), and the hip and knee angle were used to describe the voluntary continuous vertical fluctuation (preparatory motion). The *CoMz* fluctuation in the preparatory phase was too small to observe in the scale. All variables fluctuated in the preparatory condition (all values were reconfigured to fluctuate around zero).

5.3.3. Analysis

Temporal performance in sidestepping.

The temporal performances in sidestepping for both conditions from the direction signal illumination (0 ms) were defined as follows: (1) *Fx* (Lateral GRF) rising time, the time to *Fx* rising for both legs, exceeding 10% of the body weight; (2) torso initiation time, the time to the lateral torso velocity rising, exceeding 10% of the peak velocity; (3) takeoff time, the time to the takeoff of each leg below 10% of the body weight; and (4) torso reach time, the time to the lateral torso displacement reaching 60% of the body height.

As the sidestepping characteristics, five variables were calculated: (1) peak *Fx* and *Fz* (vertical GRF); (2) time to peak *Fx*, the time from the *Fx* rising time to the instant at which the *Fx* reached the peak; (3) lateral peak velocity; and (4) time to peak velocity, the time from the torso initiation time to the instant at which the lateral torso velocity reached its peak.

Preparatory state and motion characteristics.

The *Fz,* vertical CoM displacement (*CoMz*), three-dimensional joint angle of the hip and knee of the trailing leg (Fig. 5-1B) were used to describe preparatory state and motion characteristics. The mean value for these variables in the interval from 1500ms before the direction signal illumination to the illumination (preparatory phase) showed the initial state in no preparatory condition (hardly moving) and average state in preparatory condition. The standard deviations (*SD*s) for these variables were used for evaluating preparatory motion characteristics. In addition, the time delay for the two time series of the four variables was calculated using cross correlation analysis. The time delay of the two series was defined as the time delay when the maximum correlation coefficient was recorded between the two series in the range of ± 200 ms.

Unweighted and weighted state.

After demonstrating the importance of the vertical ground reaction force fluctuation in sidestepping, I categorized the preparation trials into the unweighted and weighted trials at the specified time (from 0 ms to 400 ms after the direction signal), in order to investigate the relationship between weighted state and temporal performance in sidestepping. The unweighted state was defined as the state that *Fz* of the participant was less than 80% of the body weight. The threshold was based on the value not exceeded during the preparatory phase in the no preparatory condition. Similarly, the weighted state was defined as the state the *Fz* was above 120% of the body weight.

Error trials.

Trials were eliminated from the analysis when the participants moved oppositely or their torsos did not reach the target distance. These criteria eliminated 5 trials (no preparation: 1, preparation: 4). Based on the *Fx* rising time, the trials in which the participants launched too late (more than 350 ms; no preparation: 2, preparation: 2) or too early (less than 10 ms; preparation: 5) were also regarded to be error trials.

Additional experiment.

Two male basketball players were participated in the additional experiment (age = 26 and 21 yrs.; experience: 16 and 11 yrs.). They performed the same choice reaction sidestep task for both no preparatory and preparation conditions (each 10 trials). I analyzed three trials for both participants: no preparation trial, unweighted trial and weighted trial at the direction signal illumination in the preparation trials. The fascicle and tendinous tissue length of their right lower leg (trailing leg) in each trial was calculated for three steps. First, the muscle-tendon-complex length (L_{MTC}) was calculated using the ankle and knee joint angles (Fig. 5-1B) according to Hawkins and Hull (1990). The three-dimensional ankle and knee joint angles were obtained using two high-speed video cameras (Fujii et al., 2010). Second, the fascicle length of the MG was calculated using the data obtained from a real time B-mode computerized ultrasonic apparatus (α-6, Aloka, Tokyo, Japan). The fascicle length, fascicle angle and deep aponeurosis angle of the MG (Fig. 5-4A) were measured from the ultrasonic movie recorded at 51 Hz using digitizing software (ImageJ 1.45, National Institutes of Health, Bethesda, MD, USA). The fascicle length (L_{Fa}) and pennation angle (α) were calculated using the variables (Kawakami et al., 2002). Third, the tendinous tissue length (L_T) was calculated (Fig. 5-4B) according to Allinger & Herzog (1992). The surface EMG signals (Biometrics SX230, Gwent, U.K.) of their right MG, which were full-wave rectified, and GRF (OR6-7-2000, AMTI, MA, U.S.A.) were also recorded.

5.3.4. Statistical analysis

To compare the variables between in the preparatory and no preparatory conditions, a paired *t*-test within participants (mean value among twenty trials in each condition) was used. Pearson's correlation coefficient was calculated to analyze the relationship between the instantaneous GRF values and temporal performances subtracted by their mean values. An unpaired t-test was also used to compare the temporal performance between in the unweighted and weighted state in the specified time. For the statistical calculations, $p < .05$ was considered significant. The statistical analyses were performed using the MATLAB 2011a Statistical Toolbox (The MathWorks, Inc., MA, USA).

5.4. Results

Figure 5-1 displays a typical example of the kinetic and kinematic variables during the choice reaction task with and without the preparatory motion. Table 4-1 presents the temporal performances and movement characteristics in sidestepping. The temporal performances showed significant improvement with the preparatory motion. For example, except for the Fx rising time (p = 0.103), the torso initiation time (p = 0.011, t_9 = 3.20, d = 0.37), the takeoff time (leading leg: p = 0.028, t_9 = 2.62, d = 0.57; trailing leg: $p = 5.1 \times 10^{-3}$, t_9 = 3.68, d = 0.62) and torso reach time (p = 0.018, t_9 = 2.88, d = 0.32) were shortened by executing the preparatory motion compared with those without the preparatory motion. For the movement characteristics, the time to peak Fx was shortened with the preparatory motion ($p = 2.3 \times 10^{-4}$, t_9 = 5.88, d = 0.41), whereas the other movement characteristics, such as the time to peak velocity, peak velocity, and peak *Fz*, were not increased after the preparatory motion (all $p > 0.05$).

Variable		no preparation (n = 10) *M*	*SD*	preparation (n = 10) *M*	*SD*	Significance	Cohens'*d*
Temproal performance in sidestepping							
Fx rising time (ms)		190	31	179	29	n.s.	0.37
Torso initiation time (ms)		314	37	301	33	*	0.37
Takeoff time (ms)							
	Leading leg	294	42	268	48	*	0.57
	Trailing leg	617	68	570	82	**	0.62
Torso reach time (ms)		910	90	883	76	*	0.32
Sidestepping characteristics							
Initial movement time (ms)		125	10	124	17	n.s.	0.05
Peak *Fx* (N / BW)		1.13	0.08	1.17	0.09	n.s.	-0.46
Peak *Fz* (N / BW)		2.19	0.53	2.27	0.40	n.s.	-0.18
Time to peak *Fx* (ms)		311	56	288	60	***	0.41
Lateral peak velocity (m/s)		2.75	0.24	2.77	0.24	n.s.	-0.08
Time to peak lateral velocity (ms)		552	133	529	109	n.s.	0.19
Preparatory state and motion characteristics							
Fz (N / BW)							
	M	1.00	0.00	1.00	0.03	n.s.	-0.11
	SD	0.02	0.01	0.26	0.11	***	-3.01
CoMz (cm)							
	M	82.1	8.3	83.5	6.1	n.s.	-0.19
	SD	0.5	0.6	1.1	0.5	*	-1.02
Hip (deg.)							
	M	78.8	20.7	73.8	13.4	n.s.	0.29
	SD	0.9	0.6	1.6	0.6	*	-1.08
Knee (deg.)							
	M	59.0	19.0	57.0	14.4	n.s.	0.12
	SD	0.8	0.5	2.7	0.9	***	-2.55

Table 5-1. Temporal performances in sidestepping, sidestepping characteristics, initial state and preparation characteristics. Statistical significances of the difference between the two conditions: *$p < 0.05$; **$p < 0.01$, ***$p < 0.001$.

Figure 5-1 and Table 5-1 also present a typical example and the results of the statistical analyses for the preparatory state and motion characteristics. The mean values of the four variables (i.e., initial state in no preparatory condition and average state in preparatory condition) were not significantly different between conditions ($p < 0.05$, $d < 0.50$). The initial or average states, which may influence sidestepping performance, were similar in the preparatory and no preparatory conditions. On the other hand, the mean *SD*s of the four variables were all increased with the preparatory motion (*Fz*: $p = 7.9\times 10^{-5}$, $t_9 = -6.80$, $d = -3.00$; *CoMz*: $p = 0.039$, $t_9 = -2.41$, $d = -1.01$; hip: $p = 0.017$, $t_9 = -2.90$, $d = -1.08$; knee: $p = 1.7\times 10^{-4}$, $t_9 = -6.11$, $d = -2.55$). The *CoMz* fluctuation range was significantly increased with the preparatory movement, and the difference in the mean *SD* values (approximately 11 mm) was visually small.

To determine the most important factor in the fluctuation variables for the performance improvement, I conducted a correlation analysis between the performance and the value of the fluctuation variables in specified times. Fig. 5-2 shows scatter plots of the relationship and Table 5-2 shows the correlation coefficients. The smaller the *Fz* values were at 100 ms after the direction signal, the better the torso initiation time were shortened with preparatory motion ($r_{188} = 0.26$, $p = 3.1\times 10^{-4}$). On the other hand, the larger the *Fz* values were at 300 ms and 400 ms after the signal illumination, the more the torso initiation times were shortened (300 ms: $r_{188} = -0.44$, $p = 3.0\times 10^{-10}$; 400 ms: $r_{188} = -0.3$, $p = 3.6\times 10^{-5}$). At 200 ms after the signal, the *CoMz* and instantaneous *Fz* value were positively correlated ($p < 0.05$). The improvement effect by the unweighted was also verified on the results that the unweighted state (20% body weight decrease) at 100 ms improved temporal performance in sidestepping compared with the weighted state (279 ± 7 vs. 322 ± 14 ms, p = 0.002, t_{61} = 3.24, d = 0.66).

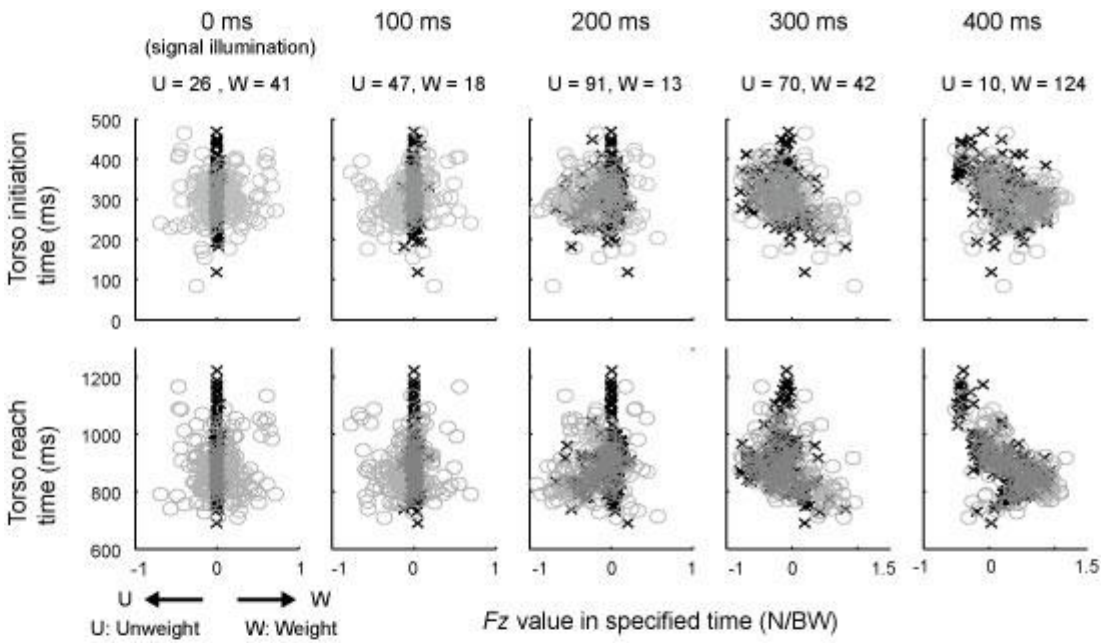

Fig. 5-2. Scatter plots of the relationship of the sidestepping performance and vertical ground reaction force (*Fz*) values at the specified times (0 ms, 100ms, 200 ms, 300 ms, and 400 ms after the signal illumination) with two temporal performances in the no preparatory condition (black x) and preparatory condition (gray o). U and W are number of trials in unweighted and weighted state which were less than 80% and more than 120% of the body weight, respectively. At 100 ms after the illumination, the torso initiation time was weakly but positively correlated with the *Fz* value (also, the torso reach time at 200 ms). On the other hand, all two variables were moderately and negatively correlated with the *Fz* at 300 and 400 ms.

Table 5-2. Pearson's correlation coefficient between the sidestepping performance and the instantaneous vertical ground reaction force (*Fz*) and the CoM displacement (*CoMz*) at specified times (0 ms, 100 ms, 200 ms, 300 ms, 400 ms after the direction signal illumination). Statistical significances of the difference between the two conditions: *$p < 0.05$; **$p < 0.01$, ***$p < 0.001$.

Pearson's correlation coefficent	0 ms	100ms	200 ms	300ms	400 ms
Fz in preparation condition					
vs. Torso initiation time (ms)	0.07	0.26 ***	0.04	-0.44 ***	-0.30 ***
vs. Torso reach time (ms)	0.02	0.14	0.16 **	-0.41 ***	-0.55 ***
CoMz in preparation condition					
vs. Torso initiation time (ms)	-0.07	-0.10	0.24 ***	0.30 ***	-0.12
vs. Torso reach time (ms)	-0.05	-0.01	0.21 **	0.32 ***	-0.07

Fig. 5-3C presents a typical example of the *Fz*, muscle activity, the length of MTC, fascicle and tendinous tissue of the MG in the additional experiments. From a qualitative viewpoint, the additional experiment demonstrated that the unweighted state shortened the timing to activate the muscle, stretch the tendinous tissue and shorten the fascicle without changing the dynamics (the other participants also showed the same trend). The initial rise of *Fz*, fascicle shortening and tendinous tissue lengthening of the MG in the unweighted state after the signal were visually shorter than that in the weighted state and without the preparatory motion (Fig. 5-3C). In contrast, the MTC length was constant after the signal. These MTC dynamics were similar to those during jump without countermovement (Kawakami et al., 2002). In the previous study, the SSC occurred in the countermovement jump accompanied by the prestretching of the muscle and tendon and the preactivation of the muscle. The results suggested that SSC in MG would not occur in the sidestepping for either condition because neither prestretching nor preactivation was observed.

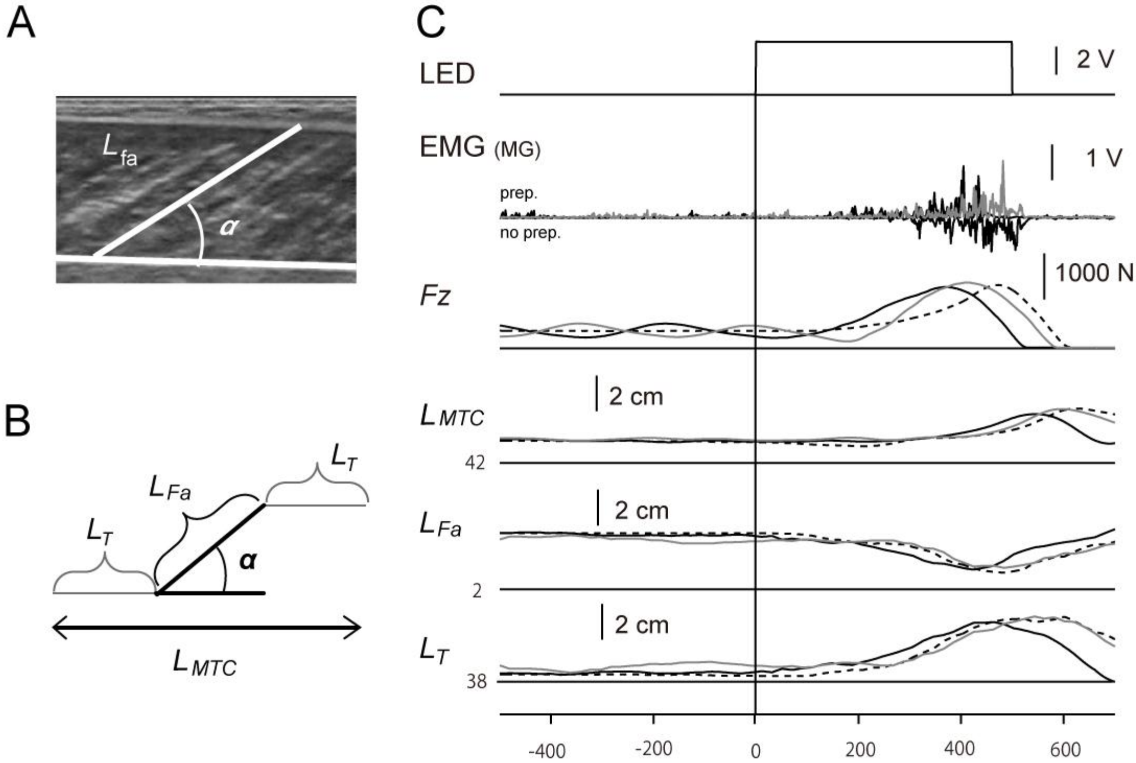

Fig. 5-3. (A) Typical example of the ultrasonic image of the gastrocnemius medialis (MG) of the right leg (trailing leg). I obtained the fascicle length (L_{Fa}) and pennation angle (α) by digitizing the images. (B) A diagram of the muscle-tendon-complex (MTC), fascicle and tendinous tissue. The tendinous tissue length (L_T) was obtained from the MTC length (L_{MTC}) and L_{Fa}. (C) A typical example of the LED signals, electromyography (EMG) of the MG, vertical ground reaction force (*Fz*), muscle and tendinous tissue fluctuation of the right (trailing) leg in the no preparation condition (dashed line), unweighted trial (black solid line) and weighted trial (gray solid line). The LED signals and *Fz* were the same in Fig. 5-1 (only the preparatory phase was shown). The unweighted

and weighted definitions were also the same in Fig. 5-1. The time to the initial rise and reaching a peak of the EMG of the MG, *Fz*, fascicle activity, L_{MTC}, L_{Fa} and L_T were earlier following the order of unweighted, weighted and no preparation trial. In particular, L_{Fa} and L_T began to shorten or lengthen, respectively, after the LED illumination.

5.5. Discussion

Preparatory motion

In the present study, the preparatory motion before sidestepping improved the performance of the sidestepping choice-reaction task (sidestep initiation: 301 vs. 314 ms; reaching: 883 vs. 910 ms). The preparatory motion, which was defined as a voluntary continuous vertical fluctuation movement, was smaller but confirmed by the observation of the increase in the *SDs* for *Fz*, *CoMz*, the lower joint angles. Although the preparatory motions in the previous study, such as a countermovement before a jump (Asmussen & Bondepet, 1974; Bosco & Komi, 1980) or a split-step in tennis (Uzu et al., 2009; Nieminen et al., 2013) were obviously different from the movement without preparatory motion, the preparatory movement in the present study was kinetically large (*SD* of *Fz*: 0.26 N/BW) but kinematically small (e.g., *SD* of *CoMz*: 1.1 cm). This motion constraint is crucial for contact sports, in order not to indicate the intention of the player because the attackers can easily change their motions after the defender's movement. The participants in the present study elected to improve the performance parameters with a higher priority rather than increase the kinetic and kinematic variables within the relatively limited preparatory movement. The result showed that only the time to peak *Fx* with the preparatory motion was improved with a preparatory motion in the sidestepping characteristics, which suggests that the temporal kinetic parameters could be adopted to be improved as discussed below.

Unweighted state as preparatory movement

In the sidestepping choice-reaction, the GRF would be the critical factor to determine the initiation and reaching performance. I used vertical GRF values in correlation analysis because the baseline of lateral GRF (Fig. 5-1C) cannot identified due to their lateral force during quiet standing (the baseline of the vertical GRF was their body weight). However, because the lateral and vertical GRF was strongly associated (Fig. 5-1C), I assumed that the change of vertical GRF, which indicates unweighted/weighted state, equals to that of the lateral GRF, which directly contributed the sidestepping performance.

I showed the importance of the unweighted state immediately after the signal illumination in the preparatory motion. The results indicate that there were weak but significant correlations between the movement initiation and the instantaneous *Fz* values at 100 ms after the direction signal. The unweighted state at 100 ms shortened the initiation in sidestepping compared with the weighted state (279 vs. 322 ms). In the preparatory hop in sidestepping, the time to land after the signal had a strong effect on the sidestepping reach time (Uzu et al., 2009). The ability to choose the timing of the unstable kinetic state in the preparatory phase may be an important skill in ball sports, particularly in the "*know when not where*" situation. To explore the ability of timing for the contact ball sports players, a more complex choice reaction task for more skilled players needs to be performed.

After the movement initiation, both the *Fz* and *CoMz* were important factors for the reaching performance. The results suggest that the greater *Fz* around the movement initiation was accompanied by early movement initiation and caused a better reaching performance. Good timing of unweighted immediately after the signal and weighted after the movement initiation would improve the performance. In contrast, the larger decrease in the *CoMz* would improve the sidestepping performance around the movement initiation. Combined with all the above results, the mechanism involved in the improvement of the sidestepping performance by the unweighted state is the following: (1) in the preparation phase, the continuous knee and hip flexion creates *Fz* fluctuation, because we can operate the kinematic parameters in our body but cannot control the *Fz* without a kinematic change; (2) after the direction signal, the unweighted state can shorten the sidestepping initiation; (3) around the initiation phase, the decrease in the *CoMz* and weighted state can contribute to the performance of the sidestepping reaching motion. Generally in basketball coaching, the kinematics of the player's body, such as knee and hip (trunk) angles have been focused (American Sport Education Program, 2007). However, I emphasized the importance of controlling the kinetic state (*Fz*) in the sidestepping movement. Especially, in losing-balance (i.e., extremely larger or smaller *Fz*) situation like a real 1-on-1 defense, I speculated the defender more benefit from the unweighted state than in the experimental situation of the present study if the defender can anticipate the timing of the attacker's movement initiation. To confirm this idea, the kinetic and kinematic analysis for the defensive player in a real-time l-on-1 ballgame situation should be examined. In practical implications, creating the unweighted state was difficult to detect visually and, thus, is difficult to teach. Repetitive practice of creating the unweighing state will enable the execution of "*small preparation, quick initiation*" sidestepping to defend in 1-on-1 contact ball sports.

Potential mechanism of the improvement with unweighted state

Why unweighted state improved sidestepping performance, biomechanically? Because the visuomotor delay (i.e. the time from the trigger to the arrival of motor commands at the muscles) is assumed to be not affected by the preparatory movement, the improvement of the motor performance with the preparation equals to muscle output forces. The rate of force increase after the arrival of motor commands depends on excitation dynamics and contraction dynamics in strict time and motion constraints. Excitation dynamics refers to building up active state of muscles by such as release of calcium from the sarcoplasmic reticulum, whereas contraction dynamics refers to the interaction between the force-velocity relationship of muscles and series elastic elements (van Zandwijk et al., 2000). I then conducted supplementary experiment investigating muscle-tendon-complex dynamics and muscle activity and showed that SSC in MG muscle would not occur in the sidestepping for either condition because neither prestretching nor preactivation of muscle was observed (Ishikawa & Komi, 2004; Kawakami et al., 2002; Komi, 2000). On the other hand, due to early stretching the series elastic components (i.e., tendinous tissue) and muscle activity, the calcium concentration of the defender's muscle might be hastened during the unweighted state. The similarity in these amplitudes between with and without the preparatory motion showed a low potential for larger neural input such as spinal excitability with the preparatory motion. Thus, I speculated after the unweighted state, the muscle is able to build up force more quickly. The important contribution seems to be the building up of active state, because this process seems to be much slower than the stretching of series elastic elements (Bobbert and Casius, 2005). The vertical fluctuation movement would be too small to change the muscle-tendon-complex dynamics due to the motion constraint, but the building up of active state of muscles and utilization of the elastic energy of the tendoneous tissue in ankle joint might explain the improvement of sidestepping performance. However, there is another possibility that other muscle dynamics contributes this improvement, such as knee and hip joint muscles. Further investigation for the contribution of these muscle activity and joint torque should be needed.

Chapter 6: STUDY V — The role of kinetic preparatory state in defending a dribbler in a basketball 1-on-1 dribble subphase.

6.1. Abstract

I investigated how the outcome of 1-on-1 subphase of team sports determines. Previously, I focused on the kinetic preparatory state (i.e., ground reaction forces) and demonstrated improved sidestepping performance. The purpose of this study was to clarify the effect of the kinetic preparatory state on 1-on-1 basketball outcome and performance. Ten basketball players participated in this study as 10 pairs of dribblers and defenders who played a real-time, 1-on-1 subphase of basketball. The outcomes (penetrating and guarding) and the kinetic preparatory state (non-weighted and weighted states) were assessed by separating the phases in determination level. The results demonstrated that the non-weighted state made guarding in 78.8% probability, whereas the weighted state did so in 29.6%. The defenders would adopt the non-weighted strategy to prevent delaying the step before the time to peak velocity of the player in the determination phase. In the one-previous phase (prior to the determination phase), both the non-weighted and weighted state were likely to transition to the weighted state, at which time the phase-transition of the defender’s kinetic state determined the outcome of a 1-on-1 subphase. Consequently, these results suggest that a defender’s creation of a non-weighted state before the defender’s initiation of the

determination phase would enable a quick defensive step and successful guarding of the dribbler in a 1-on-1 basketball subphase.

6.2. Introduction

Humans in a group interact with each other using their bodies by changing their actions, perceiving the actions of others and then searching for optimized solutions to various problems which they face in their lives (Wolpert et al., 1995). These cognitive and motor-control processes, which take a wide variety of forms to survive in the modern world, are created by our body movements. An excellent example of these body movement dynamics in a complex, unpredictable interaction is observed in invasive ball sports, such as basketball and football, which are popular worldwide (e.g., 450 million people play basketball, as estimated by FIBA, 2007). Skilled players execute accurate, quick and strong decision making and motor control against their opponents, and the players' well-trained techniques astonish and attract the audiences. The mechanism of these skillful techniques remain unclear because of the complexities of these processes; academic curiosity has recently been aroused, however, due to the development of various measuring instruments, such as motion capture systems (Study III; Esteves et al., 2011; Brault et al., 2012).

In invasive ball sports, defenders should anticipate a dribbler's motion and react to stop his/her advance. Defenders perceive the relevant cues of the attacker's motion (Jackson et al., 2006; Williams & Davids, 1998), make a decision regarding their defensive action (Study II), and start to move in the direction the dribbler moves (Study I; Brault et al., 2012). The question remains: how can defenders stop the dribbler? Previously, researchers have focused on aspects of the defender's anticipation aspect in a replicated game subphase using video clips in a laboratory-based approach (Study I; Jackson et al., 2006; Williams & Davids, 1998). However, with regard to understanding the defending-dribbler process using this approach, the dribbler-defender interaction has been problematic (e.g., both players anticipating and reacting to their opponent). To solve this problem, the motions of both players were captured in a 1-on-1 subphase of the team sports with the least number of players' interaction (Study III; Esteves et al., 2011). In my previous study, successful defensive trials in basketball 1-on-1 subphases were determined by the initiation time and peak velocity difference between the dribbler and defender (Study III); however, how the defender can hasten movement initiation or increase peak velocity remains unclear.

In many ball sports, the players are subject to strict time-constraints, i.e., they need to hasten their movement initiation after the visuo-motor delay (Tresilian, 1993; Benguigui et al., 2008). To overcome the strict time-constraints in speed ball sports such as tennis, a quick reaction technique called the split-step, which is a small vertical hop to prepare for a lateral step, is used (Uzu et al., 2009; Nieminen et al., 2013). However, in invasive ball sports such as basketball and football, more strictly, the players are subject to strong motion-constraints, not to inform the opponents of their motion such as by only a small jump in addition to time-constraints (Study IV). Therefore, satisfying the requirements not only of a quick reaction movement (time-constraint) but also of a preparation landing on both feet (motion-constraint) is necessary in contact ball sports.

In my previous sidestepping study (Study IV), I focused on the kinetic preparatory state (i.e., GRFs) for quick sidestepping and demonstrated that the unweighted state after the direction signal can shorten the sidestepping initiation time, while the weighted state after the initiation can contribute to the performance improvement. From these results, I assumed that the kinetic preparatory state before the execution of a defensive step (e.g., before the defender's initiation) would be critical for the successful defensive step in a basketball 1-on-1 subphase. In that study, I defined the unweighted state as the kinetic state below 80% body weight, and the weighted state as the state above 120% body weight (Study IV). However, in a basketball 1-on-1 defensive situation, I need to redefine the kinetic state for two main reasons. First, I raised the force threshold, which is the non-weighted state under 120% body weight because the defender's kinetics state would be greatly disturbed by the dribbler's feigning movement. In 1-on-1 competition, players minimize their loss (i.e., slow initiation in the present study) rather than maximize the benefit (i.e., quick initiation), which is called a mini-max strategy (Kijima et al., 2012). I therefore assume that the defender adopts this mini-max strategy to create the non-weighted state. The second reason is that the analysis interval should be adequate before the defender's initiation unless the defender took two or three actions (e.g., move left, right and left) because the defender's movement initiation time also had large variability relative to the dribbler's, compared with the LED stimulus (Study I; Study IV). Thus, I redefined the effective kinetic preparatory state for a quick defensive step as the non-weighted state before the defender's initiation.

The purpose of this study was to clarify the effect of the kinetic preparatory state on basketball 1-on-1 defending performance. First, I categorized the basketball 1-on-1 outcomes (penetrating and guarding, according to Study III) and the kinetic preparatory state (non-weighted and weighted state) by separating the phases in the determination level. The analysis will reveal the dynamics of a defender's kinetic state in a 1-on-1 dribble subphase and provide a determining mechanism for the outcome of the sport subphase. Second, I investigated the effect of the kinetic preparatory state on defensive stepping performance variables (Study IV). The present study provides evidence for the importance of the kinetic preparatory state and enhances our understanding of how to defend a dribbler in a 1-on-1 basketball situation.

6.3. Methods

6.3.1. Participants

Ten skilled male members of a university basketball team (age = 19.7 ± 1.4 yrs., experience = 7.3 ± 1.5 yrs. [mean ± SD]) participated in this study as 10 pairs of dribblers and defenders. The experimental procedures were conducted in accordance with the Declaration of Helsinki and approved by the Local Ethics Committee in the Graduate School of Human and Environmental Studies, Kyoto University (24-H-7).

6.3.2. Protocol

A dribbler with a basketball and a defender were instructed to play a real-time, 1-on-1 game (Study III) within a 2.4 ×3.6 m square (mediolateral × anteroposterior, Fig. 6-1). To obtain the defender's GRFs, the dribbler started to move while holding the ball. According to the rule in basketball, the dribbler was allowed to move while pivoting (movement while keeping grounded on either foot) and dribbling but was not allowed to initiate dribbling again after he stopped dribbling and was holding the ball. The objective of the dribbler was to get past the defender and invade the defended area behind the defender. There was no basketball goal or scoring opportunity. The experimental task began with the dribbler's preferred timing after the experimenter's signal. As in a basketball game, the dribbler was not permitted to go across the sideline.

The defender aimed to stop the dribbler according to the rules of basketball (FIBA, 2012), which allow the defender to stop the dribbler from a head-on position only. No additional instruction (such as time limit) was given to dribblers and defenders; all of the trials finished within 10 s.

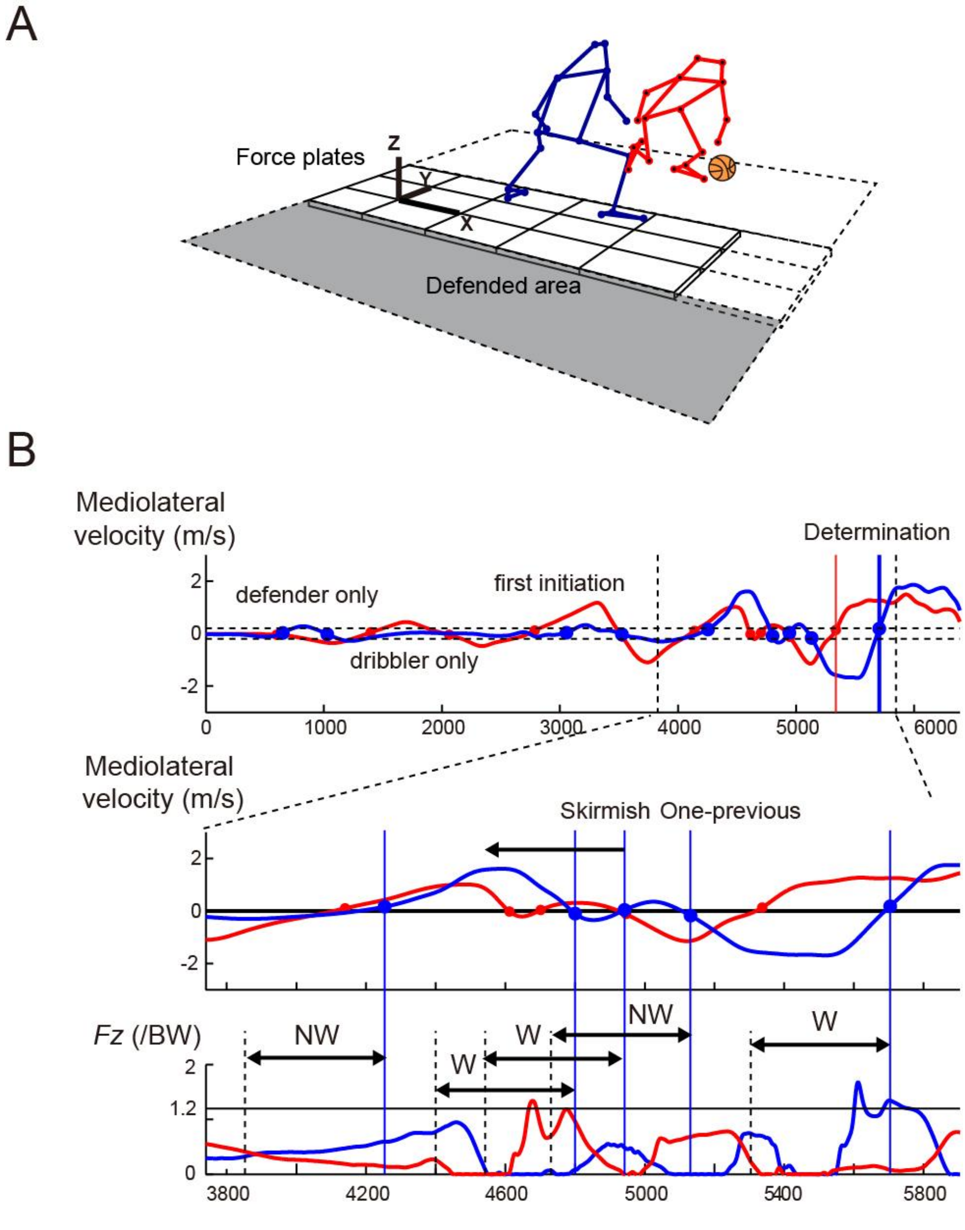

Fig. 6-1. (A) Experimental setup and schematic diagram of a basketball defender and dribbler. The objective of the dribbler was to get past the defender and invade the defended area behind the

defender. According to the rules of basketball, the dribbler was not permitted to cross the sideline and the defender was allowed to stop the dribbler from a head-on position only. (B) Time series of defender's (blue) and dribbler's (red) mediolateral velocity and vertical GRFs (*Fz*) of defender's leading foot (red) and trailing foot (blue). I separated three phases (determination, one-previous, and skirmish) based on the defender's initiation (blue dot), defined as the initial rise in velocity. In these phases, I categorized into two kinetic states (non-weighted and weighted), based on a threshold of 120% body weight.

6.3.3. Motion capture

For the kinematics, three-dimensional coordinates of the landmark points were acquired using a 3D optical motion capture system with 16 cameras at 200 Hz (Raptor-EDigital Real Time System, Motion Analysis Corporation, Santa Rosa, CA, USA). Reflective markers were placed on each participant's body to obtain CoM displacements (Study IV). All raw coordinate data points were smoothed using a fourth-order Butterworth low-pass digital filter (8-12 Hz) using residual analysis (Winter, 1990). The torso and CoM displacements that were calculated based on an estimation of body segment parameters (Ae et al., 1992) were linearly interpolated from 200 Hz to 1000 Hz for the analyses below. To measure the defenders' GRF, fifteen force platforms were used (TF-4060-B, Tec Gihan, Japan).

6.3.4. Selection and categorization into penetrating and guarding trials

Definitions of guarding a dribbler and penetrating a defender were described in the previous study (Study III). The author, who is a basketball coach (experience: 5 yrs. as a coach, 16 yrs. as a player), judged the penetrating and guarding trials visually because the reflective markers were occasionally invisible at the end of the trials (Study III). In the present study, compared with the previous study, I constrained the dribbler's movement by starting with holding the ball and limiting the size of the movement area (previous: 4×8 m), which simulates a narrowly-spaced basketball 5-on-5 situation. The experimental setup allowed me to select the penetrating and guarding trials easily because the dribbler's movement variation (e.g., movement distance and total duration of the game) became smaller. The total number of 1-on-1 games (trials) in the present study was 120 (57 penetrating trials, 48 guarding trials). In the remaining 15 trials, the recordings of the kinematics or ground reaction forces failed.

6.3.5. Analysis

Three temporal phases and kinetic state transitions.

To investigate the kinetic state transitions (Fig. 6-2), I defined three temporal phases: (1) the determination phase, in which the dribbler's and defender's initiation - defined as the time to the rising of each mediolateral torso velocity exceeding 10% of the peak velocity - determined the outcome of 1-on-1 subphase; (2) the one-previous phase, the one-directly previous phase to the determination phase; and (3) the skirmish phase, or the remaining all phases other than the determination and one-previous phases (Fig. 6-1B). To establish the beginning of 1-on-1 subphases, I assume an imaginary non-initiation state to define a first-initiation trial (Fig. 6-2), in which there was no prior initiation of dribbler and defender, to differentiate from the trials which transitioned from a kinetic state defined below (transition trials). In these analyses, the trials in which only either the defender or dribbler initiated (neither player's peak velocity reached 0.2 m/s) were excluded (Fig. 6-1B). These trials were distributed randomly in the outcome (Fig. 6-3), except that in defender-only-moving situation, the possibility of being penetrated was slightly higher than that of guarding.

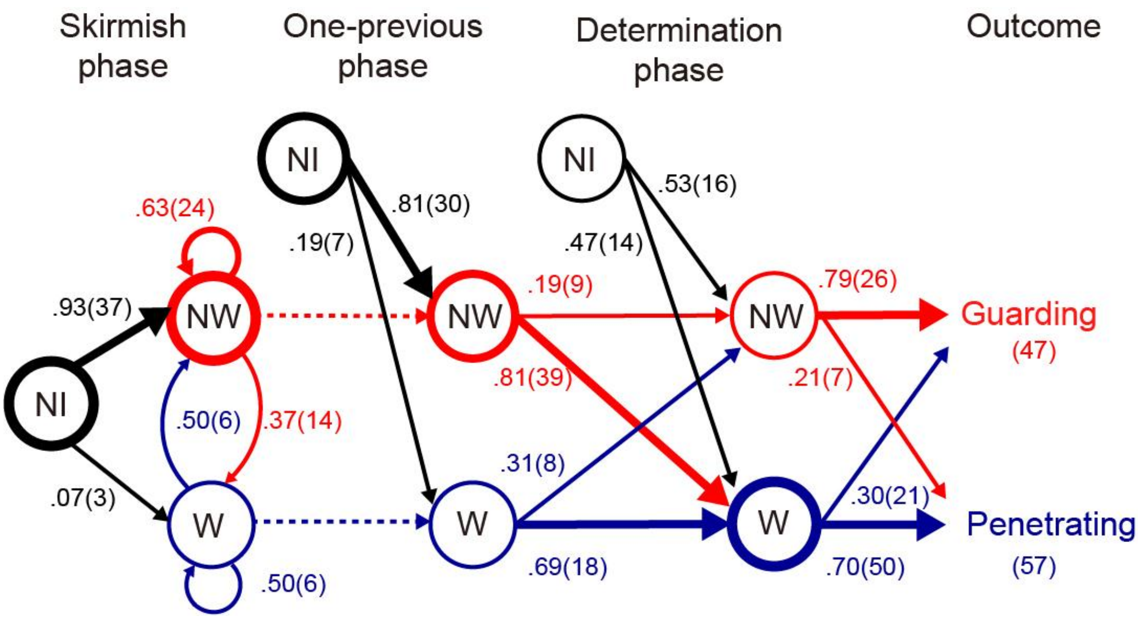

Fig. 6-2. State transition diagrams with the probabilities of non-weighted (NW), weighted (W) and imaginary no-initiation state (NI) on the outcome of 1-on-1 subphase (guarding and penetrating trials). The thickness of arrows represents higher probabilities, and thickness of circles indicate

larger numbers of trials.

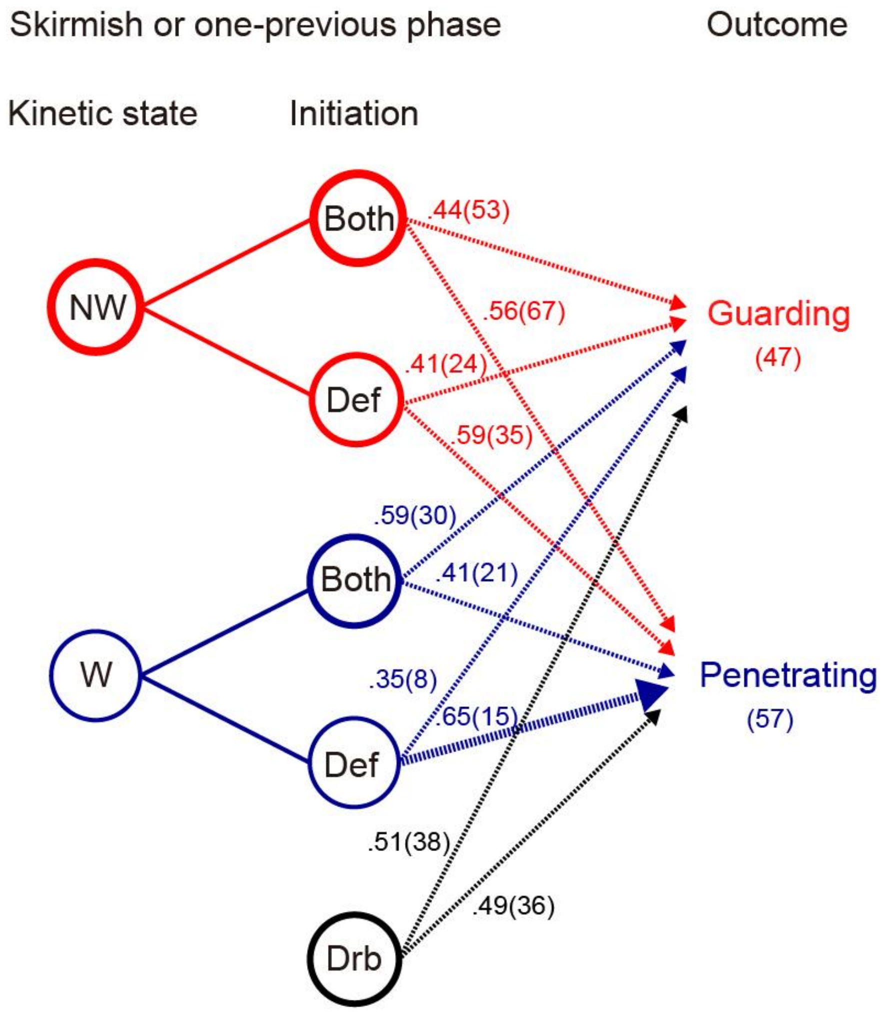

Fig. 6-3. State transition diagrams with the probabilities of the existence of both defender's and dribbler's initiation (Both), only defender's (Def) and only dribbler's (Drb) in non-weighted (NW) and weighted (W) states on the outcome of 1-on-1 subphases (guarding and penetrating trials). Thicker arrows represent higher probabilities, and thicker circles represent larger numbers of trials. The trials in which only either the defender or dribbler initiated in one-previous phase or skirmish

phase were excluded from the analysis.

Kinetic state and contact state.

I then categorized the kinetic state of the defender in the penetrating and guarding trials into non-weighted and weighted trials. The non-weighted trial was defined as the state that vertical GRFs (*Fz*) of both of the defender's feet were less than 120% of the body weight, during 400 ms before the defender's initiation time. The force threshold should be higher than that of the laboratory-controlled sidestep experiment (Study IV) because the defender's kinetic state would be greatly disturbed by the dribbler's feigning movement, compared with the LED stimulus. In the present study, I defined the force threshold (120% body weight) based on the value within the slow step initiation of the previous study (Study IV). The analysis interval (400 ms) should be adequate unless the defender did not take two or three actions (e.g., move left, right and left) because the defender's movement initiation time also had large variability relative to the dribbler's, compared with the LED stimulus (Study I; Study IV). The weighted trial was defined as the state the *Fz* was above 120% of the body weight. To investigate the presence of the preparatory hop (Uzu et al., 2009) or airborne phase of either foot, the trial in which the either of the defender's feet was in the air more than 100 ms (i.e., GRFs of both feet were under 10% body weight) during the 400 ms was defined as the airborne trial and the other was defined as the grounded trial. The threshold was based on the flight time (180 ± 89 ms) of the preparatory hop in the previous study (Uzu et al., 2009). Furthermore, I investigated the possibility of no preparatory motion for the defender, in which the *Fz* of the defender's trailing foot was 40-60 % of the body weight. These were defined as stuck trials (if quietly standing, the value was 50 %).

Temporal performance and movement characteristics.

I analyzed the motion of defenders and dribblers in the aforementioned three phases. The temporal performances for the defender were defined as follows: (1) initiation time difference, the defender's mediolateral torso velocity defined above, relative to the dribbler's initiation time; (2) time to peak velocity, the time from the defender's initiation time to the instant at which the defender's mediolateral torso velocity reached its peak, and (3) time to peak *Fx*, the time from the defender's initiation time to the instant at which the *Fx* reached the peak. The *Fx* was recorded from the trailing leg, which was defined as the remaining foot after the defender's initiation time. The trailing leg was always the foot opposite to the dribbler's final moving direction (the other foot was defined as the leading foot). Three variables of movement characteristics were calculated: (1) the peak *Fx* for the trailing leg during contact time from 100 ms before the defender's initiation time to the takeoff (100 ms was based on impossibility of anticipation according to Study III), which needs to initiate the defender's movement, and (2) the defender's and (3) the dribbler's mediolateral peak torso velocity from their initiation time.

6.3.6. Statistical analysis

Chi-squared (χ^2) test was performed to measure the relationship among various kinetic state transitions in three phases. To assess the independent and combined effects of the temporal performance and movement characteristics, three two-way ANOVAs were used with (1) the two outcomes (penetrating and guarding) and the two kinetic states (non-weighted and weighted), (2) the two outcomes and the two landing states (airborne and grounded) in the determination phase, and (3) the two phases (determination and one-previous) and the two kinetic states excluding first initiation trials, if the hypothesis of homogeneity of variances between groups was accepted with Levene's test. If rejected, Kruskal-Wallis nonparametric tests were performed to compare these variables. An unpaired *t*-test or Mann-Whitney *U*-test was used to compare the variables within the factor where a significant interaction in ANOVA or a significant effect in Kruskal-Wallis test was found, respectively. The effect size was estimated using Cohen's *d* for *t*-test, Cramér's *V* for Chi-squared test (Cramér, 1999) and eta-squared value (η^2) for ANOVA. In the analyses of the first initiation trial and skirmish phase, I did not use statistical analysis because of small number of trials. For the statistical calculations, $p < .05$ was considered significant. All numerical calculations including these statistical analyses were performed using the MATLAB

2011a Statistical Toolbox (The MathWorks, Inc., MA, USA).

6.4. Results

Figure 6-2 presents the results of the categorization into non-weighted and weighted trials for both penetrating and guarding trials. In the determination phase, when defenders were in the non-weighted state for both feet, they guarded in 78.8 % of the trials (26 out of 33), while in the weighted state this percentage dropped down to 29.6 % (21 out of 71; χ^2 (1) = 22.9, p = 1.8 × 10^{-6}, V = .47). I then investigated whether the non-weighted state was derived from the state in which either foot was in the air. As a result, the non-weighted and weighted trials consisted largely of the grounded trials for both feet (81.8%, 27 out of 33) and the airborne trials (77.5%, 55 out of 71), respectively (χ^2 (1) = 34.8, p = 3.7 × 10^{-9}, V = .58). When defenders were in the airborne state, they guarded in only 29.5% of the trials (18 out of 61; χ^2(1) = 17.2, p = 3.3 × 10^{-5}, V = .41). Figure 6-4 illustrates the detailed probability with respect to the contact state, the kinetic state and the outcome.

Additionally, the defender became stuck in only two of the penetrating trials (3.6%) and four of the guarding trials (9.3%).

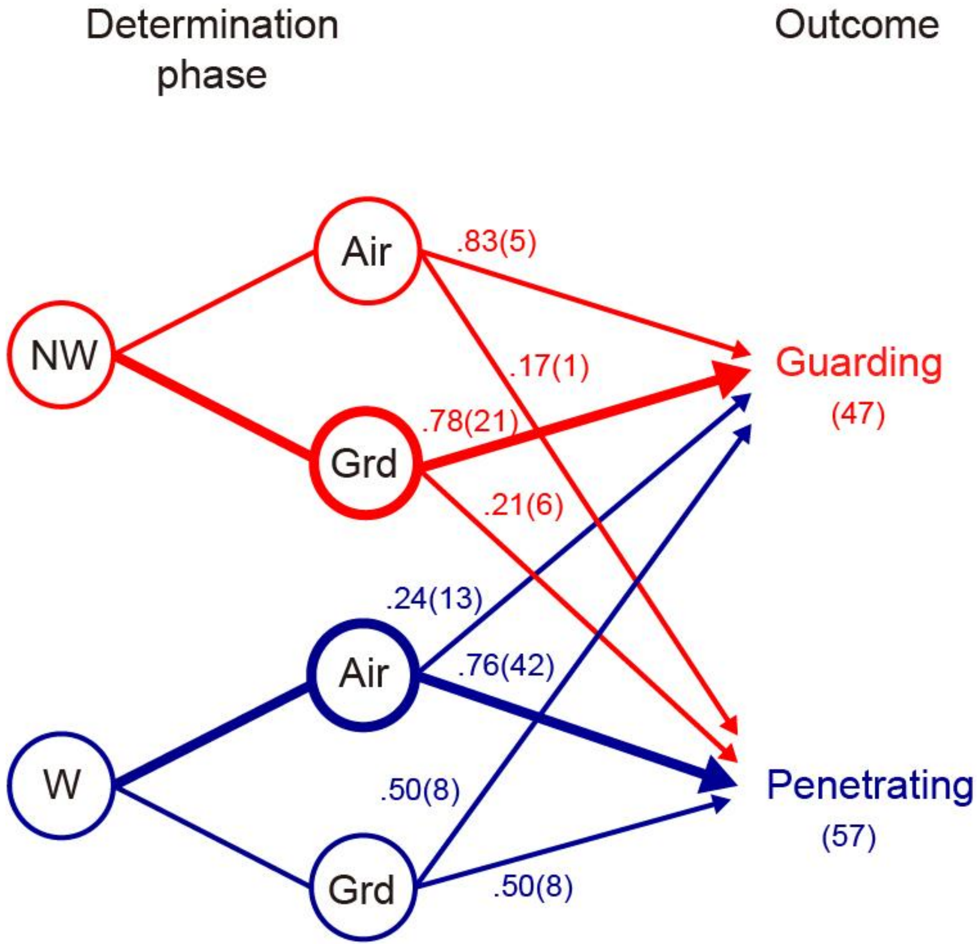

Fig. 6-4. State transition diagrams with the probabilities of the airborne (Air) and grounded (Grd) trials in non-weighted (NW) and weighted (W) states to the outcome on 1-on-1 subphases (guarding and penetrating trials). The thickness of the circles indicates larger numbers of trials, and the thickness of the arrows represent higher probabilities and larger numbers of trials.

For the temporal performances and movement characteristics between the kinetic states in the determination phase, two significant main effects and an interaction were found in initiation time difference (Table 6-1 left, outcome: $F_{1,100} = 5.3$, $p = .024$, $\eta^2 = .36$; kinetics: $F_{1,100} = 5.1$, $p = .026$, $\eta^2 = .35$; interaction: $F_{1,100} = 4.2$, $p = .044$, η^2

= .29). The initiation time for the weighted state in penetrating trials was longer than the trials in the remaining categories, respectively (all p = < .01). Taking the successful guarding possibilities into consideration, the difference in weighted trials between penetrating and guarding trials showed a high risk for slow initiation. Counterintuitively, the time to peak *Fx* for weighted and penetrating trials was shorter than that in the non-weighted and guarding trials, respectively (outcome: $F_{1,100}$ = 5.8, p = .018, η^2 = .21; kinetics: $F_{1,100}$ = 20.9, p = 1.4×10^{-5}, η^2 = .76). In the non-weighted state, the peak *Fx* and the defender's mediolateral peak velocity in penetrating trials were significantly lower than those in guarding trials (peak *Fx*: p = .013; peak velocity: p = .003). Regardless of the kinetic state, in guarding trials, time to peak mediolateral velocity was longer than that in penetrating trials ($F_{1,100}$ = 5.2, p = .025, η^2 = .75), and there was no significant difference in the dribbler's peak velocity (all p > .05).

Similar to the results for the kinetic state, for the variables between the contact states (Table 6-1 right, see the ANOVA results), the initiation time for airborne in penetrating trials was longer and that in guarding trials was shorter than the trials in the remaining categories, respectively (all p = < .01). The difference in airborne trials between penetrating and guarding trials also showed a high risk for slow initiation considering the possibilities. For time to peak *Fx*, conversely, the trials for airborne in penetrating trials were shorter and those in guarding trials were longer than the trials in the remaining categories, respectively (all p = < .01). The results for the peak *Fx*, the time to the peak velocity and the defender's and dribbler's peak velocities were similar to those in the kinetic state categorization. Figure 6-5 illustrates examples of one defender's GRFs and the defender's and dribbler's mediolateral velocities in non-weighted, weighted and airborne trials for both penetrating and guarding trials.

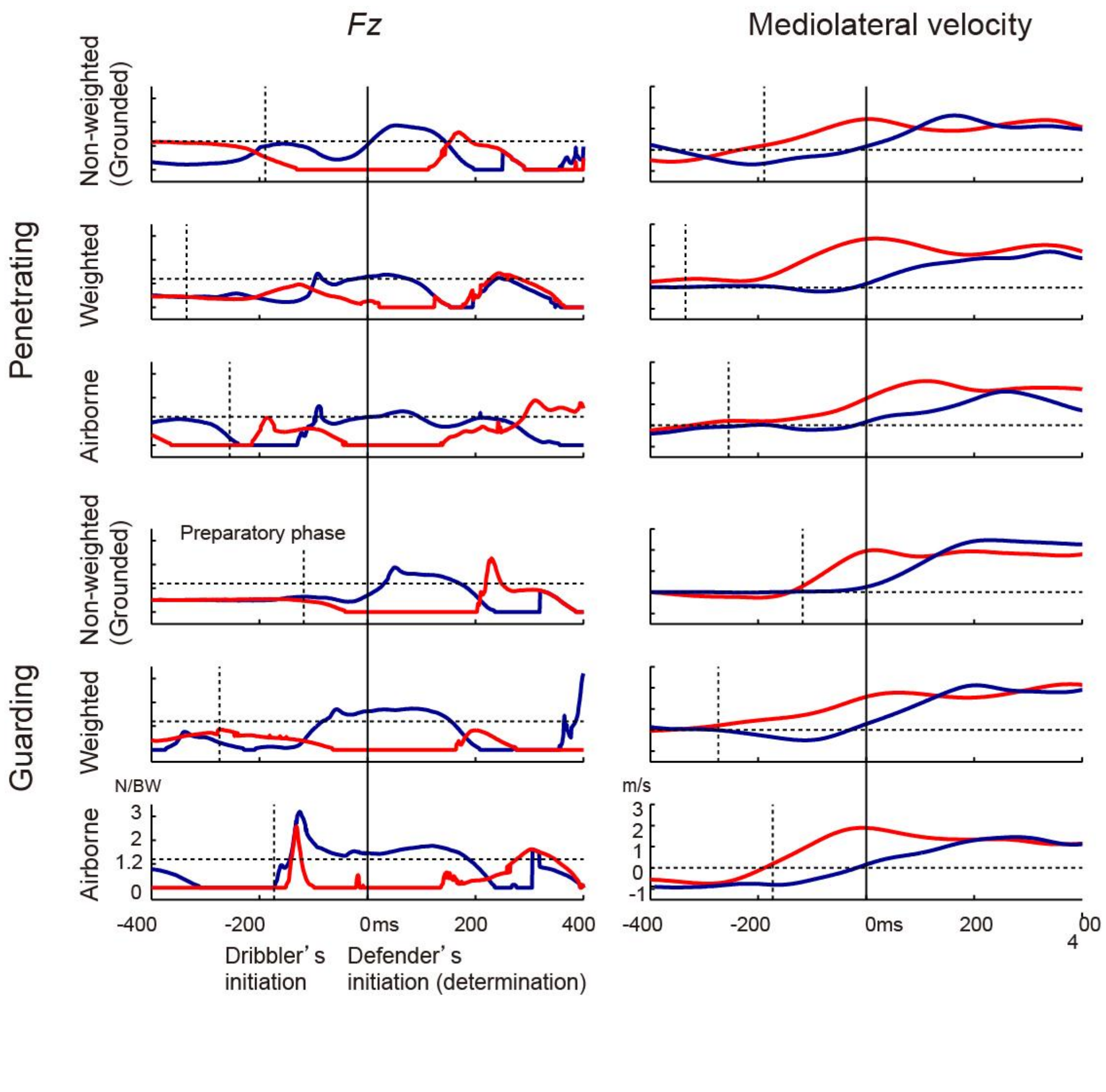

Fig. 6-5. A typical example of one defender's GRFs (left) and the defender's and dribbler's mediolateral velocities (right) in non-weighted, weighted and airborne trials for both penetrating and

guarding trials. Grounded trials were included in the non-weighted trials. *Fz* for trailing (blue) and leading (red) foot and the mediolateral velocity for defender (blue) and dribbler (red) are presented. The vertical solid and dashed lines are defender's (0 ms) and dribbler's initiation times, respectively. The horizontal dashed line for *Fz* is the criterion for determining non-weighted trials (120% body weight). For the weighted in penetrating trial, the defender's peak *Fx* after movement initiation was smaller and the defender's initiation time was slower than those of the remaining non-weighted and weighted trials. For the airborne state in penetrating trial, the peak *Fx* was smaller, and the defender's initiation time was slower than those of the remaining grounded and airborne trials.

Table 6-1. Temporal performances and movement characteristics in penetrating and guarding trials, in kinetic states (non-weighted and weighted) and landing states (airborne and grounded). O: outcome (penetrating and defending), K: kinetic state, L: landing state. Statistical significance: $*p < 0.05$; $**p < 0.01$, $***p < 0.001$.

	Non-weight (0-120 % BW)		Weight (>120 % BW)		Two-way ANOVA			Airborne (100 ms~ flight)		Grounded (~100 ms flight)		Two-way ANOVA		
Variable	M	SE	M	SE	O	K	O × W	M	SE	M	SE	O	L	O × L
Temporal performance														
Initiation time difference (ms)														
Penetrating	144	28	264	18	*	*	*	276	20	167	16	***		**
Guarding	137	17	143	26				125	22	148	19			
Time to peak velocity (m/s)														
Penetrating	243	52	246	13	*			246	14	243	33	*		
Guarding	326	23	279	21				265	22	330	21			
Time to peak *Fx* (ms)														
Penetrating	124	33	48	6	***	*		46	7	93	19	***		*
Guarding	145	12	94	14				129	16	118	12			
Movement characteristics														
Peak *Fx* (N/BW)														
Penetrating	0.88	0.08	1.16	0.04			*	1.17	0.04	0.99	0.07			*
Guarding	1.05	0.04	1.04	0.09				0.98	0.08	1.09	0.05			
Mediolateral peak velocity (m/s)														
Defender														
Penetrating	1.28	0.18	1.66	0.07	**		*	1.66	0.07	1.45	0.13	**		*
Guarding	2.02	0.11	1.87	0.13				1.78	0.14	2.06	0.10			
Dribbler														
Penetrating	1.85	0.20	1.91	0.05				1.85	0.06	2.06	0.10			
Guarding	1.81	0.11	1.77	0.10				1.80	0.12	1.79	0.09			

With respect to the kinetic state transitions from the one-previous to the determination phase (excluding first initiation trials), both the non-weighted and weighted trials likely transitioned to the weighted trials (Fig. 6-2, 81.3% and 69.2%; χ^2 (1) = 22.6, p = 2.0 × 10^{-6}, V = .47). In weighted trials, the initiation time in the one-previous phase was shorter than that in the determination phase (Table 6-2, interaction: $F_{1,107}$ = 12.5, p = 6.0 × 10^{-4}, η^2 = .94, *t*-test: p = 6.0 × 10^{-4}). Taking the outcome into consideration, in non-weighted trials in the one-previous phase, the initiation time in guarding trials (127 ± 53 ms [mean ± SE]) was shorter than that in penetrating trials (309 ± 65 ms; t_{16} = 2.2, p = .042, d = 1.04). Similarly, in the weighted trials in the one-previous phase, the initiation time in guarding trials (44 ± 45 ms) was shorter than that in penetrating trials (188 ± 52 ms; $t_{17} = 2.1$, $p = .049$, $d = .97$). The time to peak velocity, defender's and dribbler's mediolateral peak velocity and peak *Fx* in the one-previous phase were shorter and lower than those in determination phase (all $p < .001$). The results of time to peak *Fx* were similar to the above results, regardless of the phases.

Table 6-2. Temporal performances and movement characteristics in four kinetic states (transition and no-initiation, non-weighted and weighted) and three phases (determination, one-previous and skirmish).

Variable	Transition: Non-weight (0-120 % BW) M	SE	Transition: Weight (>120 % BW) M	SE	No initiation: Non-weight (0-120 % BW) M	SE	No initiation: Weight (>120 % BW) M	SE
Temporal performance								
Initiation time difference (ms)								
Determination	124	19	244	17	153	21	165	37
One-previous	208	45	113	37	224	27	263	47
Skirmish	146	37	172	27	235	29	296	54
Time to peak velocity (m/s)								
Determination	276	31	260	13	344	29	235	19
One-previous	184	18	170	15	203	10	175	43
Skirmish	213	25	141	19	212	15	107	24
Time to peak *Fx* (ms)								
Determination	135	17	59	7	146	15	70	15
One-previous	181	43	58	31	122	18	29	18
Skirmish	135	33	51	27	147	35	4	20
Movement characteristics								
Peak *Fx* (N/BW)								
Determination	1.00	0.06	1.15	0.04	1.03	0.04	1.03	0.10
One-previous	0.69	0.08	0.63	0.07	0.65	0.06	0.87	0.22
Skirmish	0.49	0.05	0.62	0.08	0.43	0.03	0.68	0.06
Lateral peak velocity (m/s)								
Defender								
Determination	1.72	0.16	1.79	0.06	2.02	0.14	1.45	0.17
One-previous	0.87	0.14	0.74	0.09	0.83	0.09	0.60	0.08
Skirmish	0.66	0.09	0.52	0.07	0.51	0.06	0.50	0.08
Dribbler								
Determination	1.61	0.16	1.88	0.05	2.03	0.06	1.80	0.14
One-previous	0.75	0.12	0.69	0.13	0.54	0.07	0.52	0.08
Skirmish	0.59	0.08	0.63	0.07	0.65	0.05	0.48	0.18

In relation to the first-initiation trials, although first initiation in the skirmish and one-previous phases likely transitioned to the non-weighted state (92.5 % and 81.1 %), the first-initiation trials in determination phase transitioned in an unbiased way (53.3 %). Averaging the first initiation trial in one-previous and skirmish phase, the dribbler's and defender's peak velocities were under 1.0 m/s and the initiation time difference was over 200 ms, indicating that both players moved without maximal speed and earliest timing.

6.5. Discussion

Defender's kinetic preparatory state in determination phase

When defenders were in the non-weighted state for both feet, they guarded in 78.8% of the trials, while in the weighted state for either foot this percentage dropped down to 29.6%. These results suggest that the weighted state for either foot could destabilize the kinetic preparatory state for a defensive step and increase the risk for being penetrated. For the weighted trials, the initiation time in penetrating trials was slower than that for the remaining categories, which coincided with my previous laboratory-controlled study (Study IV). In the previous study, I demonstrated that the timing of peak force, not its value, was important for sidestepping performance. This was supported by the present findings that an early time to peak *Fx* and the value of peak *Fx* did not result in better defensive performance. Taking the successful guarding possibilities into consideration, the initiation time delay for the weighted state in penetrating trials showed a high risk for slow initiation. In real-time 1-on-1 subphases of basketball because of the temporal and movement variability of the dribbler, defenders would adopt the mini-max (Kijima et al., 2012), non-weighted strategy not to delay the defensive step, rather than the max-min, unweighted strategy to hasten the step.

The results also showed that most of the non-weighted trials for both feet were grounded trials (81.8%). In contrast, when defenders were in the airborne state for either foot, they guarded in only 29.5% of the trials, which suggests that the defender's airborne state for either foot could also destabilize the kinetic preparatory state and increase the risk for being penetrated. Actually, the results of the initiation time difference and time to peak *Fx* in airborne trials were similar to those in the weighted state, compared to its counterpart (grounded and non-weighted state). In fast ball sports such as tennis, researchers demonstrated that the split-step (preparatory hop) strategy is effective in increasing GRFs and the players' movement speed because they knows when but not where the ball will move (Uzu et al., 2009). However, in invasive contact ball sports, the airborne phase did not increase defender's peak *Fx* and velocity, which was congruent with the previous study that claimed the airborne phase allows the opponent to accelerate or change direction at the same time, and is undesirable (Study VI). Therefore, before the defender's initiation, the results suggest that it is necessary for both of the defender's feet to land on the ground. The improvement mechanism by creating a non-weighted state is, however, still unknown. Further investigation of muscle activity (Study IV; Uzu et al, 2009; Nieminen et al., 2013) in the defender's lower limbs and joint torque analysis of the contribution of gravity or multi-joint interaction torque (Hirashima et al., 2003; Furuya et al., 2009) are needed.

Irrespective of the kinetic and contact state, variables related to peak velocity (i.e., defender's mediolateral peak velocity, mediolateral peak velocity difference, and time to peak mediolateral velocity) affected only the 1-on-1 outcome. One reason is because of the defender's prediction ability in the 1-on-1 outcome. When a defender anticipates guarding a dribbler, the defender can increase his movement speed. However, when the defender anticipates being penetrated by the dribbler, the defender decreases his movement speed to avoid bumping into the dribbler because increasing the movement speed leads to bumping, which is dangerous and also constitutes a foul in basketball rules. Therefore, variables related to peak velocity would be the effect, rather than the cause, of the 1-on-1 outcome. In other words, the 1-on-1 outcome should be determined before the time to peak velocity of the defender.

Additionally, the analysis of whether the non-weighted state was equal to quiet standing indicated that the defender became stuck in fewer trials (two penetrating trials and four guarding trials); this suggests that the defender's non-weighted state is not simply quiet standing. The defender's GRF is always changing to predict and respond to the dribbler's behavior (e.g., dribbler's eyes, shoulders, ball and legs), which cannot be fully explained by the present study. The simultaneous kinetic and kinematic analysis of the dribbler and defender (Study II; Brault et al., 2012) should be further investigated to understand which of the dribbler's actions affects the defender's kinetic state.

One-previous and skirmish phase

In time series of all trials, in non-critical phases for determining the outcome in a 1-on-1 subphase such as the skirmish phase, the kinetic state was attracted to the non-weigthed state. Also for the first initiation trials in the one-previous phase, the number of the non-weighted trials exceeded the weighted trials. In these trials, the dribbler's and defender's movement velocities were slow and the defender's initiation was delayed, suggesting that both players may wait to observe their opponents feigning without maximal speed or quickest response. These interpersonal competitive coordination dynamics have been observed in activities such as in kendo (Okumura et al, 2012; Yamamoto et al., 2013) and play-tag (Kijima et al., 2012). The coordination would likely occur in a kinetically stable state, such as the non-weighted state in the basketball 1-on-1 subphase. To take advantage of the opponents, however, this coordination needs to be broken (Passos et al., 2008; Cordovil et al., 2009). From the one-previous to the determination phase, both the non-weighted and weighted trials likely transitioned to the weighted trials. This moment may be the time at which the coordination-breaking phase transition occurs. In the non-weighted state in the one-previous phase, unlike in the determination phase, the initiation time difference was larger than that in the weighted state. I assumed the non-weighted trials were kinetically stable states to initiate the defender's step (Study IV); however, perceptual (dribbler's) factors such as feigning movement may cause the initiation delay, especially in the penetrating trial. This suggests that dribblers continuously launched an attack in real-time 1-on-1 subphase. My results revealed the phase-transition dynamics of the defender's kinetic state in determining the outcome of a 1-on-1 dribble, such as how dribblers penetrate a defender or how defenders guard a dribbler.

Other factors

With regard to defending in contact ball sports such as basketball, a player's kinematic variables (e.g., foot position, knee and hip joint angle) are generally considered (American Sports Education Program, 2007; Esteves et al., 2011). The previous study indicated that a dribbler changed his or her penetrating direction depending on the defender's both feet position (Esteves et al., 2011), suggesting that the defender's feet position is not an effective strategy for defending the dribbler. With regard to the knee and hip angles, my previous results demonstrated that a good kinetic preparatory state (i.e., unweighted state in the previous study) before the kinematic variable (e.g., knee and hip angle) affects performance and would be important for the defensive step. Finally, my analysis based on the stimulus-response (dribbler-defender) paradigm excluded the possibility that a defender's action changes the dribbler's action (Study III; Esteves et al., 2011). I should assume that dribbler-defender dynamics are a complex system and analyze them using a dynamical systems approach (Kijima et al., 2012; Okumura et al, 2012; Yamamoto et al., 2013).

Practical implications

As discussed above, although basketball coaches pay attention to player's kinematic variables such as foot position and knee and hip angle (American Sports Education Program, 2007), the results suggest that the importance of the kinetic preparatory state before the defender's initiation should be emphasized. The non-weighted state in the determination phase made guarding in 78.8% probability, whereas the weighted state did in 29.6%. In the penetrating trial, the defender's initiation time in the non-weighted state was faster than that in the weighted state by more than 100 ms on average. Because the kinetic state is difficult to detect visually, it is challenging to know how to play (or coach) to create a non-weighted state for both feet on the ground before the defender's initiation. One example is preventing increasing GRFs by attenuating impact using knee and hip joint flexibility against the dribbler's movement, including feigning. Another example is shuffling the feet to decrease the airborne phase for either foot. The results in Study V suggest that executing these techniques and creating a good kinetic preparatory state in the determination phase would enable a stable, quick defensive movement in a 1-on-1 subphase of basketball.

Chapter 7: General Discussion

7.1. Motor control and cognitive mechanism of defending a dribbler

In Study V, I demonstrated that defender's initiation time relative to the dribbler would be critical for the outcome of basketball 1-on-1 dribble task, and suggested that defender's movement velocity was not important because the 1-on-1 outcome would be determined before the time to peak velocity. When were defenders estimated to perceive the relevant cue for their anticipation? Similarly in Study I, I estimated the defender's cue timing by subtracting initiation time in Study IV (LED task) with preparatory motion as visuo-motor delay from the defender's initiation time in Study V. Figure 7-1 shows the comparison between defender's cue timings in video task (Study I, basketball players only) and in real-time 1-on-1 dribble task (Study IV and V, non-weighted and weighted state). The modes of defender's cue timing in video task and that in non-weighted state during 1-on-1 task were similar (approximately 200 ms before the attacker's initiation), which suggests that in non-weighted state, basketball defenders can anticipate and react at the similar level in laboratory (in weighted state, defender's cue timing would be invalid because the defender's visuo-motor delay would be prolonged by the perturbation by the dribbler's action). However, these two histograms are observed like mirror-reversed distribution (note that the definitions of defender's initiation were different: force initial falling in Study I and velocity initial rise in Study IV and V). This difference would be derived from task-specificities with (Study V) and without (Study I) deceptive motion. In real-time 1-on-1 task with deceptive motion, too early action would have a disadvantage for defender as well as too delayed action, because the dribbler can change his or her action after watching the defender's too early action. Therefore, it suggests that basketball defenders can anticipate the attacker's motion and move quickly to appropriate direction, irrespective of task difficulties in laboratory and real-time 1-on-1 task.

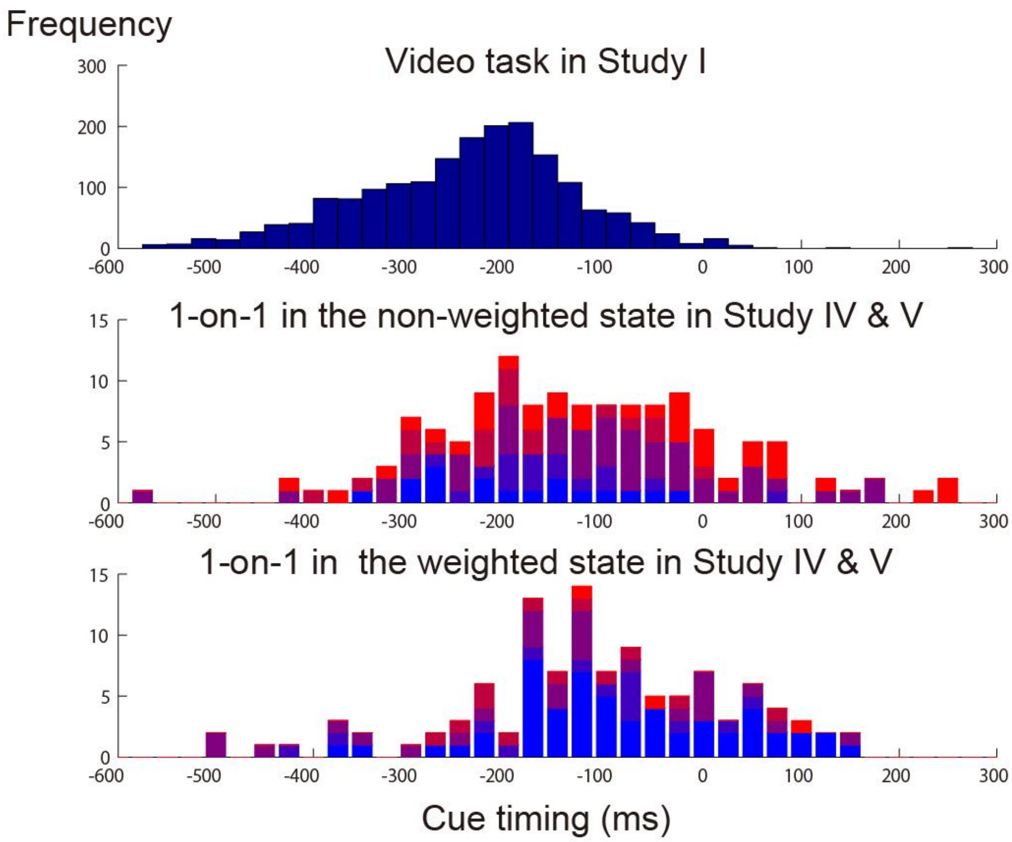

Figure 7-1. Histograms of three cue timings: defender's cue timings in video task (Study I, basketball players only) and the cue timings in real-time 1-on-1 dribble task (Study IV and V, non-weighted and weighted state). These cue timings were estimated by subtracting initiation time in

LED task (Study I and IV with preparatory motion) as visuo-motor delay from the initiation time in realistic task (video task in Study I and 1-on-1 task in Study V).

Taken together in all of discussion in this thesis, defending-dribbler mechanism in basketball 1-on-1 dribble subphase was explained by the following both cognitive and motor control strategies. First, in motor control before defender's initiation, defender should create kinetically stable state for defending dribbler, which indicates that the ground reaction force of the defender is not too high (i.e., non-weighted state). This is a mini-max strategy, in which players minimize their own possible maximum deficit (i.e., slow initiation due to the weighted state in Study IV) rather than maximize the benefit (i.e., quick initiation due to the unweighted state in Study IV). For a deceptive movement of the dribbler such as one-previous of determination phase (Study V), the defender's initiation time would be delayed relative to the dribbler's initiation despite of the non-weighted state. In this severe situation for defenders, second, cognitive strategy before the defender's initiation should be critical for defending a dribbler. In the previous study, mediolateral CoM information was an "honest" movement signal, which could not deceive the defender in a rugby cutting maneuver including deceptive motion (Brault et al., 2012). They also suggest that other body movements were "deceptive" signals (e.g. head yaw, upper trunk yaw and out-foot mediolateral displacement). Study II showed that in case of no possibility of attacker's deceptive movement with very high movement velocity, contact foot and CoM information predict the attacker's final running direction, however, the IPM cannot explain 1-on-1 outcome with real-time player's interaction (undisclosed data). The more realistic, forward musculoskeletal model should be developed to predict the attacker's final running direction. To sum up, skilled dribblers have a variety of deceptive movement, thus, defenders should also take a mini-max strategy which minimize their loss (i.e., slow initiation by directly watching and following specific body parts including deceptive signals) rather than maximize their benefit (i.e., quick initiation by correct anticipation due to directly watching the specific body parts) in cognitive strategy. Third, after the dribbler and defender initiation, defenders should modulate their movement velocity by predicting the 1-on-1 outcome, which was confirmed in Study V. If the velocity modulation mechanism will be clarified, forward simulation model, which can predict a dribbler's final running direction and velocity, can be created and applied to virtual interpersonal training to improve the invasive-ballgame-specific skill.

7.2. Other factors of defending a dribbler

This thesis provided a meaningful insight as it demonstrated that only a few global variables, such as the initiation time and mediolateral peak velocity difference, and vertical ground reaction force influenced the 1-on-1 outcome (Study III and V), assuming that these specific kinematic variables may have large individual variability and the variables might not be common variables. However, other factors that were not considered in this thesis, such as arm movements or posture of the dribbler or the defender, may also have the possibility to influence the 1-on-1 outcome. For example, “up and active” hand movement is important technical skill in basketball defending to pressure the opponent (American Sport Education Program, 2007). In Study III and IV, defenders can use their hands according the rule of the task (equal to the rule of the basketball). However, they seldom used their hands effectively, because if they use hands to deprive of the ball, they could lose their balance, destabilize their kinetic state (i.e., weighted state), and delay their initiation in the moment. In the task with basketball goal, scoring and pass opportunity, the hand movement skill can be investigated. Second, “proper posture” in basketball defending such as stance width, hip and knee angle is also not considered in this thesis. These variables and ground reaction forces are mechanically related to the force output and movement kinematics (Inaba et al., 2013), which is discussed in 7.3 below. Finally, in this thesis, I assumed stimulus-response paradigm, which exclude the phenomena that defender did not react to the dribbler or reacted more than two times (the same as dribblers) or defender launched attacks the dribbler as research matters. This would be theoretical limitation in this thesis; therefore, the alternative approach should be needed (discussed in 7.4).

7.3. Skilled maneuvers of ballgame players

For both a dribbler and a defender, the ability of quick initiation (reaction) as a part of skilled maneuvers would be important in invasive ballgame sports, because they take an advantage of the opponents by quick initiation (i.e., penetrating for dribbler and defending for defender), whereas they should take care of too early initiation which will result in being outmaneuvered. In study V, I succeeded to confirm the presence of the quick initiation skill of invasive ballgame defenders. The mechanical cause of this skill should further be investigated, thus, rigid-body segment model will be constructed and muscle activity and three-dimensional joint torque analysis decomposing contribution of gravity, multi-joint interaction torque (Hirashima et al., 2003; Furuya et al., 2009) will be investigated.

Attackers-specific skill in invasive ballgame other than the above common skill should then be discussed. The most different point from defenders' skill is that the attackers almost cannot take the mini-max strategy like defenders, because they cannot penetrate the defender unless the attackers launch attacks with and without deceptive movements. Hence, they should attack many times using a variety of techniques (e.g., crossover, inside-out, and leg-through in basketball dribbling) and lose the defender's balance, destabilize the defender's kinetic state (i.e., weighted state), and delay the defender's initiation. In this process, the attacker sometimes intentionally attracts the defenders to the dribbler's movements. In one previous determination phase in Study V, the dribbler moved at submaximal speed (less than 1 m/s), which delayed the defender in non-weighted state and hastened the defender in weighted state. For the attacker's cognitive skill, they should make a decision whether they should move to leftward or rightward by watching the defender's kinematic cue. In more closely to the ballgame situation, the attackers have more options such as shooting or passing. It emerges complex interaction in this situation due to many options for each player; therefore, alternative approach discussed below is expected.

7.4. Non-linear dribbler-defender dynamics as a complex system

In this thesis, I adopted reductionist approach to analyze ballgame 1-on-1 defending (i.e., stimulus-response paradigm) and provide theoretical and practical knowledge about how to defend a dribbler. However, it would be difficult to reveal team offense and defense dynamics using the same approach, because each player has huge amount of cognitive information processing and diverse body movements are emerged due to the interaction by each player. To discover mechanisms of emergence of such complex systems, it would be needed to select a dynamical approach which comprehends changing state of order in a game (Palut & Zanone, 2005; Araujo et al., 2002), not a static approach that assumes a skill which has a unique solution. Dynamical systems theory, which describes time evolution of the order state along a certain rule (Abraham & Shaw, 1984; Combs, 1993), is the most effective method to reveal a regularity underpinning complex systems. For example, dynamical systems theory has elucidated mechanisms of emergence not only of collective behavior of schooling fish (Couzin et al., 2002; Tunstrøm et al., 2013) and insects (Garnier et al., 2007), but also of motor coordination (synergy) of individual behavior in humans (Tanabe et al., in revision; Miura et al., 2011) and synchronization of multiple humans (Richardson et al., 2007; Varlet et al., 2011). In group dynamics of human sport behavior, although this theory has been applied to synchronization (Kijima et al., 2012), joint action (Yokoyama et al., 2011) and competition such as kendo (Okumura et al., 2012; Yamamoto et al., 2013), it has never been explained phenomena of breaking an equilibrium state, getting a score and winning a game in invasive group ballgame such as basketball. These bifurcation phenomena (Scheffer et al., 2009; Drake et al., 2010), in which one stable state expressed by order parameter transits to another state as control parameters change, should further be investigated during near-basketball game situation with basketball goal, alternate offense and defense, and scoring and pass opportunity.

7.5. Conclusion of the thesis

In this thesis, first, anticipatory (cognitive) mechanism in replicated 1-on-1 defensive situation was investigated using video-based approach. In study I, the timing for the detection of relevant information in the final running direction of attackers' cutting maneuvers was examined. In Study II, using the prediction model with the IPM, I discussed that defenders may be able to anticipate the future direction of an attacker by forwardly simulating inverted pendulum movement. In Study III, to clarify the defending-dribbler mechanism, a real-time, 1-on-1 subphase of the basketball was investigated. The guarding trials were categorized into three defensive patterns including defender's early movement initiation and quick movement. Then, the defender's motor control mechanism of the earlier and quicker movement was investigated using force plates. In Study IV, the movement creating an unweighted state was proposed. After the direction signal, I demonstrated that the unweighted state can shorten the time required to initiate the sidestepping than the weighted state. In Study V, the effect of this kinetic preparatory state in 1-on-1 subphase of the basketball was investigated. The defenders would adopt the non-weighted strategy to prevent delaying the step before the time to peak velocity of the player in the determination phase.

In conclusion, in both cognitive and motor control strategies, the thesis suggests that because skilled dribblers have a variety of deceptive movement, defenders should take strategies to prevent slow step initiation due to the weighted state and being deceived by the dribbler's deceptive signals other than the information of CoM, rather than strategies to achieve quick step initiation by the unweighted state and excessive anticipation using specific body parts.

Chapter 8: Practical implications

In this thesis, defending-dribbler mechanism in basketball 1-on-1 dribble subphase was estimated in cognitive and motor control perspectives. In Study I, skilled basketball players sidestepped more quickly in both the LED and the video task than did the novice players, whereas the anticipation of running direction (at least without faking movements) likely will not improve with ballgame experience. In Study V, the kinetically stable state, in which the defender’s vertical ground reaction forces were not too high (i.e., the non-weighted state) during the determination phase, made guarding in 78.8% probability, whereas it was 29.6% in the unstable weighted state. Taken together, this thesis suggests that the motor control strategy for defensive movement is relatively higher priority for defensive performance than the cognitive strategy.

In practical implication, first, defender should create the kinetically stable non-weighted state for the motor control before defender’s movement initiation. As the kinetic state is difficult to detect visually, however, it is challenging to know how to play (or coach) to create a non-weighted state for both feet on the ground before the defender’s initiation. One example is to prevent increasing GRFs by attenuating impact using knee and hip joint flexibility against the dribbler’s movement, including feigning. Another example is shuffling the feet (e.g., glide step or stutter step in basketball) to decrease the airborne phase for either foot. It suggest that executing these techniques and creating a good kinetic preparatory state before the defender’s initiation would enable a stable and quick defensive movement, whereas after the step initiation, the outcome would be likely to determine even if the defender makes efforts to produce higher movement velocity.

Second, in this severe situation for defenders such as one-previous of determination phase, cognitive strategy before the defender's initiation should be critical for defending a dribbler (Study V). As skilled dribblers have a variety of deceptive movement, defenders should watch the opponent's trunk information (dribbler's unhidden information) in their central vision and should not directly watch (i.e., watching in their peripheral vision) and follow specific body parts including deceptive signals (e.g., head, shoulder, foot and ball movements), rather than correctly anticipate for a quick initiation by directly watching the specific body parts. However, in case of little possibility of dribbler's deceptive movement with very high movement velocity, contact foot and CoM information predict the attacker's final running direction (Study II).

Dribblers (attackers) can also apply the findings to their play. The most different point from defenders' skill is that the dribblers should attack many times using a variety of techniques (e.g., crossover, inside-out, and leg-through in basketball dribbling), lose the defender's balance by destabilizing the defender's kinetic state (i.e., weighted state), and delay the defender's initiation. In this process, the attacker sometimes intentionally attracts the defender to the dribbler's movements. In one previous determination phase, the dribbler moved at submaximal speed (less than 1 m/s), which delayed the defender in non-weighted state and hastened the defender in weighted state (Study V). Dribblers should practice faking movements because even novices can anticipate running directions when there are no such deceptive movements (Study I). For the attacker's cognitive skill, they should make a decision whether they should move to leftward or rightward by watching the defender's kinematic cue. In more closely to the ballgame situation, the attackers have more options such as shooting or passing, thus, the decision making skill would be of growing importance. For example, a dribbler should see the kinematic of on-ball defender to shoot and of off-ball defender to pass his or her teammate.

Acknowledgements

I would like to express my gratitude to many people who have supported and helped to make my research.

First, I would especially like to express sincere appreciation to my supervisor, Dr. Motoki Kouzaki for his regularly kind support. He gave me constructive comments and warm encouragement, and taught me about philosophy of enjoying an intensive research life. I really had good time and have made many memories.

I would especially like to thank to Dr. Isaka, Dr. Yoshioka, and Dr. Otsuka of Ritsumeikan University for use of sports performance laboratory facilities. Without their guidance, this thesis would not have possible.

I would like to extend special thanks to Dr. Oda and Dr. Shinya for their valuable, kind, and earnest suggestions about my experiments. I have learned a lot of precious things from their attitude to the research in my undergraduate and master course.

Many thanks to Daichi Yamashita, Hiroko Tanabe and Shota Hagio and other Neurophysiology Lab members, then-Motor control Lab members and other many researchers for their helpful support and suggestions for my research.

Special thanks go to the member of Kyoto University Basketball Team (Badbears), who were willing to participate in my experiments and played basketball with me for nine years.

I would also thanks to my parents and younger sister. They were always supporting and encouraging me with their best wishes for twenty seven years.

Finally, I would like to thank my fiancée, Yurie Ban, who was always watching me and cheering me up through the good times and bad.

Appendix

Study II was designed to generate testable predictions for the direction of CoM positions during quick direction changes based on a few easily measured parameters. My approach was based on forward dynamic simulation of the inverted pendulum with the attacker's kinematics and generation a model that predicts the attacker's running direction with the simulation.

Study II used a mechanichal, 3D IPM for quick changes in running direction. Several aspects of the mechanical model were simplified to derive algebraic expressions that were clear and provided the most intuitive embodiment possible. First, when the contact foot position was in the flight phase, both the CoM and the contact foot were assumed to be in parabolic motion. The CoM and the contact foot were given by the position and velocity (x, y, z, $\dot{x}, \dot{y}, \dot{z}$). The equation for the CoM and contact foot motions in the flight phase is given by the following second-order differential equation:

$$\frac{d}{dt}\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -g \end{bmatrix} \quad \textbf{(A1)}$$

where g is acceleration of gravity. Second, the impulse at the foot contact and impulse attenuation were neglected. Third, in the stance phase, the leg length (the leg was defined as the segment comprising the distance from the CoM to the center of the contact foot) was not assumed to change. The leg length was constant and defined as the value at the foot contact.

With above assumptions, in stance phase the CoM was modeled as the motion for an inverted pendulum in the foot-centered polar coordinate system. The corresponding relationship between an absolute Cartesian coordinate system and the foot-centered polar coordinate system is given by the following equation:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} l\sin\theta\sin\phi \\ l\sin\theta\cos\phi \\ l\cos\theta \end{bmatrix} \quad \textbf{(A2)}$$

where l is the leg length. The derivative values for the foot-centered polar coordinate system are given by the following expressions using Jacobian matrix *J*.

$$\begin{bmatrix} \dot{l} \\ \dot{\theta} \\ \dot{\theta} \end{bmatrix} = J^{-1}\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix},$$

$$J = \begin{bmatrix} \sin\theta\sin\phi & l\cos\theta\sin\phi & l\sin\theta\cos\phi \\ \sin\theta\cos\phi & l\cos\theta\cos\phi & -l\sin\theta\sin\phi \\ \cos\theta & -l\sin\phi & 0 \end{bmatrix}. \quad \textbf{(A3)}$$

When det (*J*) is zero, the transformation into polar coordinate is impossible because J^{-1} is not defined. We then stopped the simulation when det (*J*) > .995 and eliminated the outcome for the initial time value.

Next, the initial values for CoM position and velocity were substituted into the equation for motion. The Lagrangian L is given by the following equations:

$$L = \frac{1}{2}ml^2(\dot{\theta}^2 + \sin^2\theta\cdot\dot{\phi}^2) - V,$$

$$V = mgl\cos\theta, \quad \textbf{(A4)}$$

where V is potential energy. The Lagrangian L was inserted into the following Euler-Lagrange equation (6), and the second-order differential equations (7) were generated. The above differential equations were solved by the 4th order Runge-Kutta method (Press et al., 1992).

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}}\right)-\frac{\partial L}{\partial \theta}=0,$$
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\phi}}\right)-\frac{\partial L}{\partial \phi}=0. \qquad \textbf{(A5)}$$

$$\ddot{\theta}=\sin\theta\cos\theta\cdot\dot{\phi}^2+\frac{g}{l}\sin\theta$$
$$\ddot{\phi}=-2\frac{\cos\theta}{\sin\theta}\cdot\dot{\theta}\cdot\dot{\phi}\,. \qquad \textbf{(A6)}$$

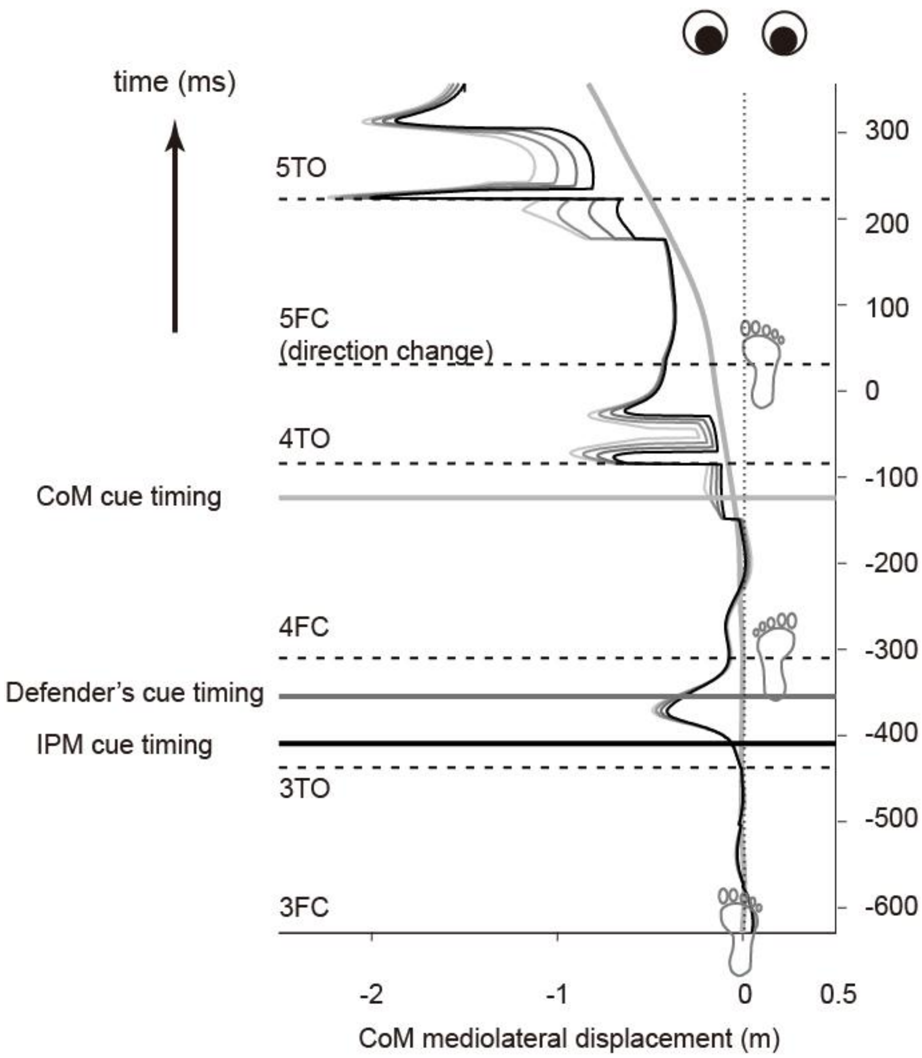

Fig. A1. Typical time series for the measured CoM (gray) and the estimated CoM using the IPM prediction with four different fall thretholds. The graduated graylines were 45 (most black), 50, 55 and 60 degrees for the fall thresholds in the IPM simulation. The fall threshold had little influence on the IPM cue timing (i.e. the estimated CoM initial rise), whereas the threshold amplified the estimated CoM displacement. During the airborne phase for all of the predictions, from foot takeoff (TO) to foot contact (FC), the prediction model using the inverted pendulum tended to predict larger a movement. The depression in the prediction during the airborne phase (e.g. 4TO-5FC) could reflect countermovement for the cutting maneuver (i.e., the CoM and the contact foot deceleration before acceleration to the final running direction).

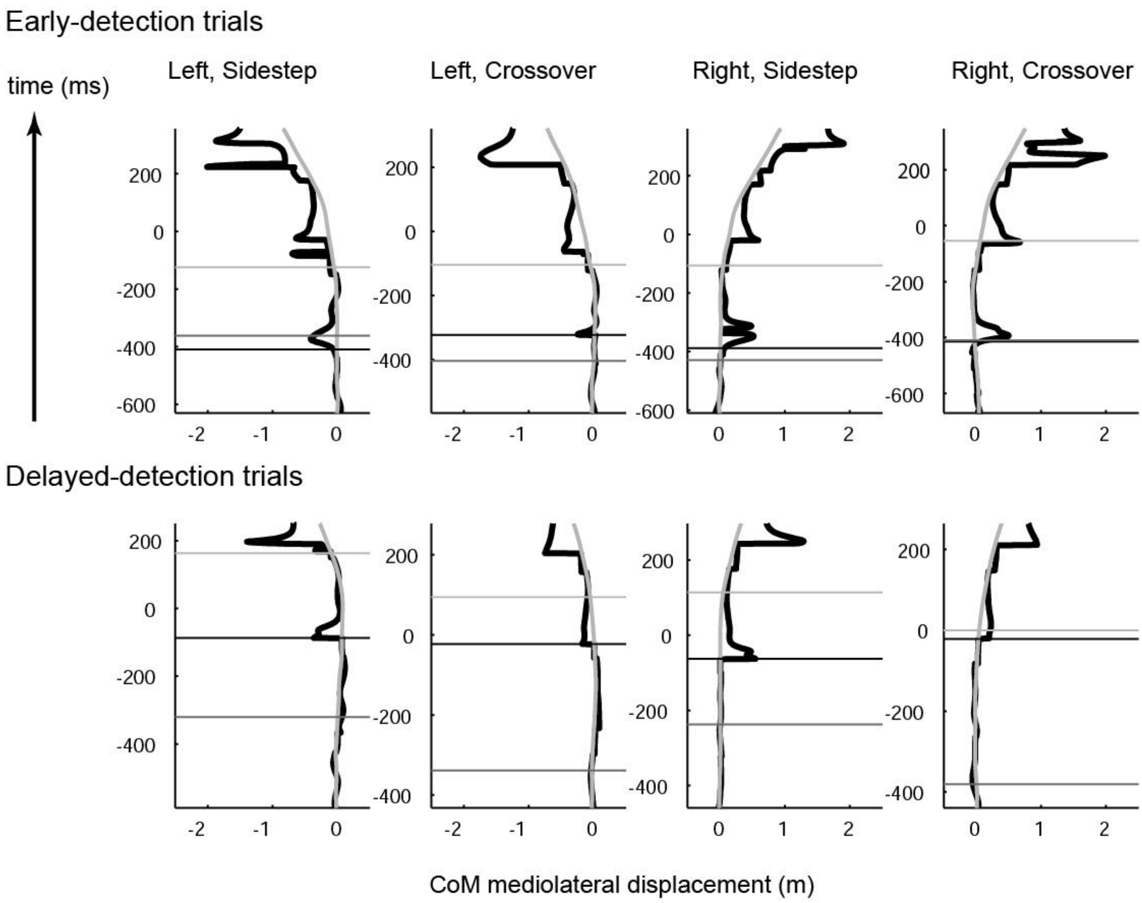

Fig. A2. Typical time series for the measured CoM (gray) and the estimated CoM (black) by the IPM in the early-detection and delayed-detection trials for IPM prediction. Four types of cutting maneuvers are shown (left and right sidestep and crossover). The graduated horizontal gray lines are the IPM (most black), defender's and CoM cue timings.

References

Abernethy, B., Zawi, K., & Jackson, R. C. (2008). Expertise and attunement to kinematic constraints.*Perception, 37*(6), 931-948.

Abraham, A.H., & Shaw, C.D. (1984). *Dynamics-the geometry of behavior; Part I: Periodic behavior*. Santa Cruz, CA: Aerial Press.

Abreu, A. M., Macaluso, E., Azevedo, R. T., Cesari, P., Urgesi, C., & Aglioti, S. M. (2012). Action anticipation beyond the action observation network: a functional magnetic resonance imaging study in expert basketball players. *European Journal of Neuroscience, 35*(10), 1646-1654.

Ae, M., Tang H., & Yokoi. T. (1992). Estimation of inertia properties of the body segments in Japanese athletes, *Biomechanism, 11*, 23–33.

Aglioti, S. M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience, 11*(9), 1109-1116.

Allard, F., & Burnett, N. (1985). Skill in sport. *Canadian Journal of Psychology, 39,* 294–312.

Allard, F., Graham, S., & Paarsalu M.L. (1980). Perception in sport: basketball, *Journal of Sport Psychology 2*, 14-21.

Allard, F., & Starkes, J. L. (1980). Perception in sport: Volleyball. *Journal of Sport Psychology, 2,* 22–33.

Allinger, T., & Herzog, W. (1992). Calculated fiber lengths in cat gastrocnemius muscle during walking. *In Proceedings of NACOB II*. Chicago, IL: The Second North American Congress on Biomechanics: 81-2

American Sport Education Program. (2007). *Coaching Basketball Technical and Tactical Skills.* Illinois: Human Kinetics.

Asmussen, E., & Bondepet.F. (1974). Storage of elastic energy in skeletal-muscles in man. *Acta Physiologica Scandinavica, 91*(3), 385-392.

Ando, S., Kida, N., & Oda, S. (2001). Central and peripheral visual reaction time of soccer players and nonathletes. *Perceptual and Motor Skills, 92*(3), 786-794.

Araujo, D., Davids, K., Sainhas, J., & Fernandes, O. (2002). Emergent decision-making in sport: A constraints-led approach. *In L. Toussaint, & P. Boulinguez (Eds.), International congress "Movement, attention & perception"*. Poitiers, France: Universite de Poitiers: 77.

Aviles, C., Benguigui, N., Beaudoin, E., & Godart, F. (2002). Developing early perception and getting ready for action on the return of serve. *ITF Coaching and Sport Science Review,* 28: 6–8.

Benguigui, N., Baure`s, R., & Le Runigo, C. (2008). Visuomotor delay in interceptive actions. Open peer commentary. *Behavioral and Brain Sciences, 31,* 200–201.

Benguigui, N., Ripoll, H., & Broderick, M. P. (2003). Time-to-contact estimation of accelerated stimuli is based on first-order information. *Journal of Experimental Psychology-Human Perception and Performance, 29*(6), 1083-1101.

Berkes, P., Orban, G., Lengyel, M., & Fiser, J. (2011). Spontaneous cortical activity reveals hallmarks of an optimal internal model of the environment. *Science, 331*(6013), 83-87.

Bobbert, M. F., & Casius, L. J. R. (2005). Is the effect of a countermovement on jump height due to active state development? *Medicine and Science in Sports and Exercise, 37*(3), 440-446.

Bobbert, M. F., Gerritsen, K. G. M., Litjens, M. C. A., & VanSoest, A. J. (1996). Why is countermovement jump height greater than squat jump height? *Medicine and Science in Sports and Exercise, 28*(11), 1402-1412.

Borgeaud, P., & Abernethy, B. (1987). Skilled perception in volleyball defense. *Journal of Sport Psychology, 9*(4), 400-406.

Bosco, C., & Komi, P. V. (1979). Potentiation of the mechanical-behavior of the human skeletal-muscle through prestretching. *Acta Physiologica Scandinavica, 106*(4), 467-472.

Bosco, C., & Komi, P. V. (1980). Influence of aging on the mechanical-behavior of leg extensor muscles. *European Journal of Applied Physiology and Occupational Physiology, 45*(2-3), 209-219.

Boulgouris, N. V., & Chi, Z. X. (2007). Human gait recognition based on matching of body components.*Pattern Recognition, 40*(6), 1763-1770.

Brault, S., Bideau, B., Craig, C., & Kulpa, R. (2010). Balancing deceit and disguise: How to successfully fool the defender in a 1 vs. 1 situation in rugby. *Human Movement Science, 29*(3), 412-425.

Brault, S., Bideau, B., Kulpa, R., & Craig, C. M. (2012). Detecting Deception in Movement: The Case of the Side-Step in Rugby. *Plos One, 7*(6).

Carver, S. G., Cowan, N. J., & Guckenheimer, J. M. (2009). Lateral stability of the spring-mass hopper suggests a two-step control strategy for running. *Chaos, 19*(2).

Cerminara, N. L., Apps, R., & Marple-Horvat, D. E. (2009). An internal model of a moving visual target in the lateral cerebellum. *Journal of Physiology-London, 587*(2), 429-442.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology, 4*(1), 55-81.

Chen, L. F., Liao, H. Y. M., Ko, M. T., Lin, J. C., & Yu, G. J. (2000). A new LDA-based face recognition system which can solve the small sample size problem. *Pattern Recognition, 33*(10), 1713-1726.

Cisek, P. (2007). Cortical mechanisms of action selection: the affordance competition hypothesis.*Philosophical Transactions of the Royal Society B-Biological Sciences, 362*(1485), 1585-1599.

Cisek, P., & Kalaska, J. F. (2005). Neural correlates of reaching decisions in dorsal premotor cortex: Specification of multiple direction choices and final selection of action. *Neuron, 45*(5), 801-814.

Cojocariu, A. (2011). Measurement of reaction time in qwan ki do. *Bilology of Sport, 28(2),* 139-143.

Combs, A. (1993). The evolution of consciousness: A theory of historical and personal transformation. *World Futures: The Journal of General Evolution,* 38, 43- 62.

Cordovil, R., Araujo, D., Davids, K., Gouveia, L., Barreiros, J., Fernandes, O., et al. (2009). The influence of instructions and body-scaling as constraints on decision-making processes in team sports. *European Journal of Sport Science, 9*(3), 169-179.

Couzin, I. D., Krause, J., James, R., Ruxton, G. D., & Franks, N. R. (2002). Collective memory and spatial sorting in animal groups. *Journal of Theoretical Biology, 218*(1), 1-11.

Cramér, H. (1999). *Mathematical Methods of Statistics,* Princeton, NJ: Princeton University Press.

Davids, K., Button, C., Araujo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behavior in human movement systems. *Adaptive Behavior, 14*(1), 73-95.

Diaz, G. J., Fajen, B. R., & Phillips, F. (2012). Anticipation from biological motion: the goalkeeper problem. *Journal of Experimental Psychology-Human Perception and Performance, 38*(4), 848-864.

Drake, J. M., & Griffen, B. D. (2010). Early warning signals of extinction in deteriorating environments. *Nature, 467*(7314), 456-459.

Esteves, P. T., Araujo, D., Davids, K., Vilar, L., Travassos, B., & Esteves, C. (2012). Interpersonal dynamics and relative positioning to scoring target of performers in 1 vs. 1 sub-phases of team sports. *Journal of Sports Sciences, 30*(12), 1285-1293.

Esteves, P. T., de Oliveira, R. F., & Araujo, D. (2011). Posture-related affordances guide attacks in basketball. *Psychology of Sport and Exercise, 12*(6), 639-644.

Fajen, B. R., Riley, M. A., & Turvey, M. T. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*(1), 79-107.

Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception - action coupling affect natural anticipatory performance? *Perception, 32*(9), 1127-1139.

FIBA. (2007). Key numbers. *FIBA: International Basketball Federation.* Retrieved October 23, 2013, from http://www.fiba.com/pages/eng/fc/FIBA/quicFact/p/openNodeIDs/889/selNodeID/889/quicFacts.html

FIBA. (2012) Official Basketball Rules 2012. *FIBA: International Basketball Federation,* 33-6. Retrieved October 23, 2013, from http://www.fiba.com/downloads/Rules/2012/OfficialBasketballRules2012.pdf

Fujii, K., Yamada, Y., & Oda, S. (2010). Skilled basketball players rotate their shoulders more during running while dribbling. *Perceptual and Motor Skills, 110*(3), 983-994.

Freyd, J. J., & Finke, R. A. (1984). REPRESENTATIONAL MOMENTUM. *Journal of Experimental Psychology-Learning Memory and Cognition, 10*(1), 126-132.

Full, R. J., & Koditschek, D. E. (1999). Templates and anchors: Neuromechanical hypotheses of legged locomotion on land. *Journal of Experimental Biology, 202*(23), 3325-3332.

Furuya, S., Osu, R., & Kinoshita, H. (2009). Effective utilization of gravity during arm downswing in keystrokes by expert pianists. *Neuroscience, 164*(2), 822-831.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception,* Boston, MA: Houghton Mifflin

Gage, W. H., Winter, D. A., Frank, J. S., & Adkin, A. L. (2004). Kinematic and kinetic validity of the inverted pendulum model in quiet standing. *Gait & Posture, 19*(2), 124-132.

Garnier, S., Gautrais, J., & Theraulaz, G. (2007). The biological principles of swarm intelligence. *SwarmIntelligence, 1(1),* 3–31

Glencross, D. J., & Cibich, B. J. (1977). A decision analysis of games skills. *Australian Journal of Sports Medicine, 9,* 72–75.

Gold, J. I., & Shadlen, M. N. (2007). The neural basis of decision making. *Annual Review of Neuroscience, 30,* 535-574.

Hawkins, D., & Hull, M. L. (1990). A method for determining lower-extremity muscle tendon lengths during flexion extension movements. *Journal of Biomechanics, 23*(5), 487-494.

Headrick, J., Davids, K., Renshaw, I., Araujo, D., Passos, P., & Fernandes, O. (2012). Proximity-to-goal as a constraint on patterns of behaviour in attacker-defender dyads in team games. *Journal of Sports Sciences, 30*(3), 247-253.

Helsen, W. F., & Starkes, J. L. (1999). A multidimensional approach to skilled perception and performance in sport. *Applied Cognitive Psychology, 13*(1), 1-27.

Hirashima, M., Kudo, K., & Ohtsuki, T. (2003). Utilization and compensation of interaction torques during ball-throwing movements. *Journal of Neurophysiology, 89*(4), 1784-1796.

Hubbard, T. L. (1998). Some effects of representational friction, target size, and memory averaging on memory for vertically moving targets. *Canadian Journal of Experimental Psychology-Revue Canadienne De Psychologie Experimentale, 52*(1), 44-49.

Inaba, Y., Yoshioka, S., Lida, Y., Hay, D. C., & Fukashiro, S. (2013). A Biomechanical Study of Side Steps at Different Distances. *Journal of Applied Biomechanics, 29*(3), 336-345.

Indovina, I., Maffei, V., Bosco, G., Zago, M., Macaluso, E., & Lacquaniti, F. (2005). Representation of visual gravitational motion in the human vestibular cortex. *Science, 308*(5720), 416-419.

Ishikawa, M., & Komi, P. V. (2004). Effects of different dropping intensities on fascicle and tendinous tissue behavior during stretch-shortening cycle exercise. *Journal of Applied Physiology, 96*(3), 848-852.

Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica, 123*(3), 355-371.

Jindrich, D. L., Besier, T. F., & Lloyd, D. G. (2006). A hypothesis for the function of braking forces during running turns. *Journal of Biomechanics, 39*(9), 1611-1620.

Jones, C. M., & Miles, T. R. (1978). Use of advance cues in predicting the flight of a lawn tennis ball. *Journal of Human Movement Studies, 4,* 231-235.

Kagawa, T., & Uno, Y. (2010). Necessary condition for forward progression in ballistic walking. *Human Movement Science*, *29*(6), 964-976.

Kawakami, Y., Muraoka, T., Ito, S., Kanehisa, H., & Fukunaga, T. (2002). In vivo muscle fibre behaviour during counter-movement exercise in humans reveals a significant role for tendon elasticity.*Journal of Physiology-London, 540*(2), 635-646.

Kelly, M. H., & Freyd, J. J. (1987). Explorations of representational momentum. *Cognitive Psychology, 19*(3), 369-401.

Kijima, A., Kadota, K., Yokoyama, K., Okumura, M., Suzuki, H., Schmidt, R. C., et al. (2012). Switching Dynamics in an Interpersonal Competition Brings about "Deadlock" Synchronization of Players. *Plos One, 7*(11).

Kimura, M., Takeuchi, T., Azumane, A., & Yamamoto, M. (2003). Ability of side step speed under reaction time task in basketball players. *Japanese Journal of Sport Methodology, 16(1)*, 129-135.

Komi, P. V. (1984). Physiological and biomechanical correlates of muscle function: effects of muscle structure and stretch-shortening cycle on force and speed. *Exercise and sport sciences reviews, 12*, 81-121.

Komi, P. V. (2000). Stretch-shortening cycle: a powerful model to study normal and fatigued muscle.*Journal of Biomechanics, 33*(10), 1197-1206.

Komi, P. V., & Bosco, C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. *Medicine and Science in Sports and Exercise, 10*(4), 261-265.

Kuo, A. D. (2007). The six determinants of gait and the inverted pendulum analogy: A dynamic walking perspective. *Human Movement Science, 26*(4), 617-656.

Lames, M. (2006). Modelling the interaction in game sports - Relative phase and moving correlations.*Journal of Sports Science and Medicine, 5*(4), 556-560.

Lee, C. R., & Farley, C. T. (1998). Determinants of the center of mass trajectory in human walking and running. *Journal of Experimental Biology, 201*(21), 2935-2944.

Lee, D. N., Young, D. S., Reddish, P. E., Lough, S., & Clayton, T. M. H. (1983). VIsual timing in hitting an accelerating ball. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology, 35*(MAY), 333-346.

Lee, M., Roan, M., Smith, B., & Lockhart, T. E. (2009). Gait analysis to classify external load conditions using linear discriminant analysis. *Human Movement Science, 28*(2), 226-235.

Maffei, V., Macaluso, E., Indovina, I., Orban, G., & Lacquaniti, F. (2010). Processing of Targets in Smooth or Apparent Motion Along the Vertical in the Human Brain: An fMRI Study. *Journal of Neurophysiology, 103*(1), 360-370.

Mah, C. D., & Mussa-Ivaldi, F. A. (2003). Evidence for a specific internal representation of motion-force relationships during object manipulation. *Biological Cybernetics, 88*(1), 60-72.

Mann, D. L., Abernethy, B., & Farrow, D. (2010). Visual information underpinning skilled anticipation: The effect of blur on a coupled and uncoupled in situ anticipatory response. *Attention Perception & Psychophysics, 72*(5), 1317-1326.

Mann, D., Dicks, M., Cañal-Bruland, R., van der Kamp, J., (2013). Neurophysiological studies may provide a misleading picture of how perceptual-motor interactions are coordinated. *i-Perception, 4(1),* 78–80.

McLeod, P. (1987). Visual reaction-time and high-speed ball games. *Perception, 16*(1), 49-59.

Merfeld, D. M., Zupan, L., & Peterka, R. J. (1999). Humans use internal models to estimate gravity and linear acceleration. *Nature, 398*(6728), 615-618.

Millsagle, D.G. (1988). Visual perception, recognition recall and mode of visual search control in basketball involving novice and experienced basketball players. *Journal of Sports Behavior, 11,* 32–44.

Miller, W. L., Maffei, V., Bosco, G., Iosa, M., Zago, M., Macaluso, E., et al. (2008). Vestibular nuclei and cerebellum put visual gravitational motion in context. *Journal of Neurophysiology, 99*(4), 1969-1982.

Milner, D. A., Goodale, M. A., (1995). *The Visual Brain in Action,* Oxford, UK: Oxford University Press.

Miura, A., Kudo, K., Ohtsuki, T., & Kanehisa, H. (2011). Coordination modes in sensorimotor synchronization of whole-body movement: A study of street dancers and non-dancers. *Human Movement Science, 30*(6), 1260-1271.

Mori, S., Ohtani, Y., & Imanaka, K. (2002). Reaction times and anticipatory skills of karate athletes.*Human Movement Science, 21*(2), 213-230.

Nagai, M., Kazai, K., & Yagi, A. (2002). Larger forward memory displacement in the direction of gravity.*Visual Cognition, 9*(1-2), 28-40.

Neri, P., Morrone, M. C., & Burr, D. C. (1998). Seeing biological motion. *Nature, 395*(6705), 894-896.

Nieminen, M. J. J., Piirainen, J. M., Salmi, J. A., & Linnamo, V. (2013). Effects of neuromuscular function and split step on reaction speed in simulated tennis response. *European Journal of Sport Science*, *in press,* doi:10.1080/17461391.2013.785598

Norman, R. W., & Komi, P. V. (1979). Electro-mechanical delay in skeletal-muscle under normal movement conditions. *Acta Physiologica Scandinavica, 106*(3), 241-248.

O'Donovan, O., Cheung, J., Catley, M., McGregor, A. H., & Strutton, P. H. (2006). An investigation of leg and trunk strength and reaction times of hard-style martial arts practitioners. *Journal* *of Sports Science and Medicine, 5,* 5-12.

Okumura, M., Kijima, A., Kadota, K., Yokoyama, K., Suzuki, H., & Yamamoto, Y. (2012). A Critical Interpersonal Distance Switches between Two Coordination Modes in Kendo Matches. *Plos One*, *7*(12).

Palut, Y., & Zanone, P. G. (2005). A dynamical analysis of tennis: Concepts and data. *Journal of Sports Sciences, 23*(10), 1021-1032.

Passos, P., Araujo, D., Davids, K., Gouveia, L., Milho, J., & Serpa, S. (2008). Information-governing dynamics of attacker-defender interactions in youth rugby union. *Journal of Sports Sciences, 26*(13), 1421-1429.

Press, W. H., Flannery, B. P., Teukolsky, S. A., & Vetterling, W. T. (1992). “Runge-Kutta Method” and “Adaptive Step Size Control for Runge-Kutta”. *Numerical Recipes in FORTRAN: The Art of Scientific Computing (2nd ed.).* Cambridge: Cambridge University Press: 704-716.

Perrin, P., Perrot, C., Deviterne, D., Ragaru, B., & Kingma, H. (2000). Dizziness in discus throwers is related to motion sickness generated while spinning. *Acta Oto-Laryngologica, 120*(3), 390-395.

Puce, A., & Perrett, D. (2003). Electrophysiology and brain imaging of biological motion. *Philosophical Transactions of the Royal Society B-Biological Sciences*, *358*(1431), 435-445.

Raichlen, D. A. (2008). The effects of gravity on human walking: a new test of the dynamic similarity hypothesis using a predictive model. *Journal of Experimental Biology, 211*(17), 2767-2772.

Richardson, M. J., Marsh, K. L., Isenhower, R. W., Goodman, J. R. L., & Schmidt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science, 26*(6), 867-891.

Runigo, C., Benguigui, N., & Bardy, B. G. (2010). Visuo-motor delay, information-movement coupling, and expertise in ball sports. *Journal of Sports Sciences, 28*(3), 327-337.

Rushworth, M. F. S. (2008). Intention, choice, and the medial frontal cortex. *Year in Cognitive Neuroscience 2008, 1124,* 181-207.

Scheffer, M., Bascompte, J., Brock, W. A., Brovkin, V., Carpenter, S. R., Dakos, V., et al. (2009). Early-warning signals for critical transitions. *Nature, 461*(7260), 53-59.

Schmidt, R. C., O'Brien, B., & Sysko, R. (1999). Self-organization of between-persons cooperative tasks and possible applications to sport. *International Journal of Sport Psychology, 30*(4), 558-579.

Sebanz, N., & Shiffrar, M. (2009). Detecting deception in a bluffing body: The role of expertise.*Psychonomic Bulletin & Review, 16*(1), 170-175.

Srinivasan, M., & Ruina, A. (2006). Computer optimization of a minimal biped model discovers walking and running. *Nature, 439*(7072), 72-75.

Suzuki, Y., Enomoto, Y. (2009). Relationships between the velocity of center of gravity and the reaction force in side step and cross step cutting, *Kyoto Journal of Physical Education, Health and Sport Sciences*, 24, 1-11.

Tanabe, H., Fujii, K., & Kouzaki, M. (2013). Inter- and intra- joint coordination in the lower limb joints of classical ballet dancers during tiptoe standing. *Human Movement Science, in revision*.

Tomeo, E., Cesari, P., Aglioti, S. M., & Urgesi, C. (2013). Fooling the Kickers but not the Goalkeepers: Behavioral and Neurophysiological Correlates of Fake Action Detection in Soccer. *Cerebral Cortex, 23*(11), 2765-2778.

Tresilian, J. R. (1993). 4 questions of time to contact - a critical-examination of research on interceptive timing. *Perception, 22*(6), 653-680.

Tunstrom, K., Katz, Y., Ioannou, C. C., Huepe, C., Lutz, M. J., & Couzin, I. D. (2013). Collective States, Multistability and Transitional Behavior in Schooling Fish. *Plos Computational Biology, 9*(2).

Uzu, R., Shinya, M., & Oda, S. (2009). A split-step shortens the time to perform a choice reaction step-and-reach movement in a simulated tennis task. *Journal of Sports Sciences, 27*(12), 1233-1240.

van Zandwijk, J. P., Bobbert, M. F., Munneke, M., & Pas, P. (2000). Control of maximal and submaximal vertical jumps. *Medicine and Science in Sports and Exercise, 32*(2), 477-485.

Varlet, M., Marin, L., Lagarde, J., & Bardy, B. G. (2011). Social Postural Coordination. *Journal of Experimental Psychology-Human Perception and Performance, 37*(2), 473-483.

Ward, P., Williams, A. M., & Bennett, S. J. (2002). Visual search and biological motion perception in tennis. *Research Quarterly for Exercise and Sport, 73*(1), 107-112.

Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer.*Research Quarterly for Exercise and Sport, 69*(2), 111-128.

Williams, A. M., Davids, K., Burwitz, L., & Williams, J. G. (1994). Visual-search strategies in experienced and inexperienced soccer players. *Research Quarterly for Exercise and Sport, 65*(2), 127-135.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception & action in sport.* London: Taylor & Francis.

Williams, A. M., Huys, R., Canal-Bruland, R., & Hagemann, N. (2009). The dynamical information underpinning anticipation skill. *Human Movement Science, 28*(3), 362-370.

Winter, D. A. (1990). *Biomechanics and Motor Control of Human Movement Second edition.* New York: A Wiley-Interscience Publication.

Wolpert, D. M., Ghahramani, Z., & Jordan, M. I. (1995). An internal model for sensorimotor integration. *Science, 269*(5232), 1880-1882.

Wright, D. J., Holmes, P. S., Di Russo, F., Loporto, M., & Smith, D. (2012). Differences in cortical activity related to motor planning between experienced guitarists and non-musicians during guitar playing. *Human Movement Science, 31*(3), 567-577.

Yamamoto, Y., Yokoyama, K., Okumura, M., Kijima, A., Kadota, K., & Gohara, K. (2013). Joint Action Syntax in Japanese Martial Arts. *Plos One, 8*(9).

Yanai, T. (2004). Buoyancy is the primary source of generating bodyroll in front-crawl swimming. *Journal of Biomechanics, 37*(5), 605-612.

Yarrow, K., Brown, P., & Krakauer, J. W. (2009). Inside the brain of an elite athlete: the neural processes that support high achievement in sports. *Nature Reviews Neuroscience, 10*(8), 585-596.

Yokoyama, K., & Yamamoto, Y. (2011). Three People Can Synchronize as Coupled Oscillators during Sports Activities. *Plos Computational Biology, 7*(10).

Yu, H., & Yang, H. (2001). A direct LDA algorithm for high-dimensional data - with application to face recognition. *Pattern Recognition, 34*(10), 2067-2070.

Zago, M., Bosco, G., Maffei, V., Iosa, M., Ivanenko, Y. P., & Lacquaniti, F. (2004). Internal models of target motion: Expected dynamics overrides measured kinematics in timing manual interceptions. *Journal of Neurophysiology, 91*(4), 1620-1634.

Zago, M., La Scaleia, B., Miller, W. L., & Lacquaniti, F. (2011). Observing human movements helps decoding environmental forces. *Experimental Brain Research, 215*(1), 53-63.

Zago, M., & Lacquaniti, F. (2005). Visual perception and interception of falling objects: a review of evidence for an internal model of gravity. *Journal of Neural Engineering, 2*(3) 198-208.

Zago, M., McIntyre, J., Senot, P., & Lacquaniti, F. (2009). Visuo-motor coordination and internal models for object interception. *Experimental Brain Research, 192*(4), 571-604.

List of articles

This dissertation is based on the following articles.

1. Fujii, K., Shinya, M., Yamashita, D., Kouzaki, M., & Oda, S. in press. Superior reaction to changing directions for skilled basketball defenders, but not linked with specialized anticipation, Journal of European Sport Science, doi: 10.1080/17461391.2013.780098
2. Fujii, K., Shinya, M., Yamashita, D., Kouzaki, M., & Oda, S. in press. Anticipation by basketball defenders: an explanation based on the 3D inverted pendulum model, Journal of European Sport Science, doi: 10.1080/17461391.2013.876104
3. Fujii, K., Yoshioka, S., Isaka, T., & Kouzaki, M. (2013). Unweighted state as a sidestep preparation improve the initiation and reaching performance for basketball players. Journal of Electromyography and Kinesiology, 23(6), 1480-1484.