Chapter 13
Displacements in Virtual Reality for Sports Performance Analysis

Richard Kulpa, Benoit Bideau and Sébastien Brault

Abstract In real situations, analyzing the contribution of different parameters on sports performance is a difficult task. In a duel for example, an athlete needs to anticipate his opponent's actions to win. To evaluate the relationship between perception and action in such a duel, the parameters used to anticipate the opponent's action must then be determined. Only a fully standardized and controllable environment such as virtual reality can allow this analysis. Nevertheless, movement is inherent in sports and only a system providing a complete freedom of movements of the immersed subject (including displacements) would allow the study of the link between visual information uptake and action, that is related to performance. Two case studies are described to illustrate such use of virtual reality to better understand sports performance. Finally, we discuss how the introduction of new displacement devices can extend the range of applications in sports.

13.1 Introduction

Sport is gaining an increasing place in nowadays societies, not only as an entertainment but also as a socio-economical matter. There is now overwhelming evidence that regular physical activity has important and wide-ranging benefits on health [14]. Moreover, sport offers great pedagogical values for young people. It conveys moral values and requires appropriate behaviors in groups. As a consequence, studying sports becomes more and more important, not only to better understand performance

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F. Steinicke et al. (eds.), *Human Walking in Virtual Environments*,
DOI: 10.1007/978-1-4419-8432-6_13,

and improve it for high-level athletes but also to better train people and encourage them to practice more.

Sport is characterized by complex displacements and movements. These movements are dependent on visual information that the athlete gathers from his environment, including the opponent's actions. Perception is thus fundamental to the performance. Indeed, a sportive action, unique, complex and often limited in time, requires a selective gathering of information. While everyone is able to perform simple tasks, everyone cannot be top athlete and return service tennis reaching nearly 200 km/h, stop handball throw or prevent a rugby attacker to pass with a deceptive movement. For many sports, performance is dependent on the ability to correctly react under time pressure; everything being often played in a few milliseconds, it is important to be at the right place at the right time.

If we all access to the same information during the action, why do not we all react in the same way? The reason is probably that time constraint requires a selection of perceptual information, that is to say eliciting some information to get right to the point. This perception, often seen as a prerogative for action, takes the role of a passive collector of information. However, the perception-action relationship should not be considered uniquely but rather as a coupling: we perceive to act but we must act to perceive [27]. There would thus be laws of coupling between the informational variables available in the environment and the motor responses of a subject.

In sport, this framework has already inspired Farrow and Abernethy who preserved the perception-action coupling as close to the real situation as possible during a video-based experiment [24]. In this work, the authors tried to reproduce a realistic viewpoint by capturing video sequence from within the field of basketball. The authors tested two conditions: a coupled (perception and action) and uncoupled one. The results attest that participants were better in prediction accuracy when perception and action were coupled and when the ball flight was available. In other words, it is necessary that top athletes can act to better perceive the opportunities of action from the environment. Whichever school of thought considered, Virtual Reality offers new, more pertinent and more accurate perspectives to address these concepts.

13.1.1 Why Virtual Reality for Sports?

In sport, top athletes develop important skills and perceptual motor coordination adapted to the situation. As a consequence, many studies have focused on the analysis of perceptual information of athletes [61]. For example, in sports duel, it was shown that experts have better skills than novices in using visual information to guide their early response [6, 58]. However the analysis of duels is relatively complex. Indeed, the player's movement is modulated by his opponent's one. Understanding how and on which criteria players adjust their movements requires the development of specific methodologies. To better understand why Virtual Reality can be used for such studies, it is important to describe the limitations of previous approaches used to investigate sports performance, and to understand why it can overcome them.

One of the first methods used to analyze the visual information gathered by an athlete consists in interviewing him [21]. The use of questionnaires allows athletes to formalize and transcribe their impressions about the actions they performed and the perceptual information necessary for decision. Nevertheless, this methodology is based on the feelings of the subject after the experiment, without any time pressure. The relative importance of kinematic variables in the decision-making is then very difficult to quantify. In general, this technique, based on subjective measures of perception, does not accurately characterize the visual information gathered by the subject.

Methodologies based on video uses a video clip in which an opponent is currently conducting an action. In this setup, a camcorder is placed at subject's eye position during a real game situation. For example, to study the visual information gathered by a tennis player when his opponent serves, the sequence is performed by placing the camera on the bottom line of the short side of the court. If one is interested now in analyzing visual information of a football goalkeeper during a penalty kick, the video camera is positioned at the center of the goal line. Although it is not always respected during the experiments, the perspective of the athlete is fundamental for a realistic movie. Once the video is acquired, it is projected onto a screen and the subject has then to predict the final outcome of the action displayed. Two techniques can then be used to evaluate the visual information uptake: (i) the reaction time (ii) the temporal and spatial masking. The technique of the reaction time is based on the time taken by an observer to respond correctly to a task. In other words, when using this technique, the subject has as much time as he wants to perform his task. The duration of the response is then correlated with the accuracy of the response [1]. Studies using this method have demonstrated the superiority of experts over novices in the brevity and precision of the response [5, 59, 63]. But this technique does not know the precise time and location of the visual information gathered. The second technique based on occultation is more frequent. In this methodology, two procedures are used. The first one consists in using temporal occlusion and implies to cut the video at different times to get several key sequences, each with different visual information (motion shooting, ball flight, etc.) [2, 33, 34, 45]. The second procedure is a spatial occlusion where certain visual cues are masked in the video clip in order to see if they are used or not by the participant for performing the action. In both conditions (temporal or spatial occlusion) the instructions given to subjects viewing these sequences (repeated several times in random order) are then to predict the final outcome of the observed action [40, 47]. The way the subject responds may vary from one study to another: verbal responses [7, 45], written directions [17, 38, 39, 58] or button pressed [25, 26, 54]. Means of response do not modify the response once it has been given. More elaborated means were employed such as using a joystick to save the changes made by the subject during the experiment [46, 47]. The advantage of temporal occultation is to identify a relation between the perceptual processes involved and some key instants or visual cues of the video clip. It is thus possible to determine precisely at which key moment the subject effectively predicts the outcome of the action or which visual cues are used during the decision-making process. The visual information present at this key moment or in this visual area is then considered as

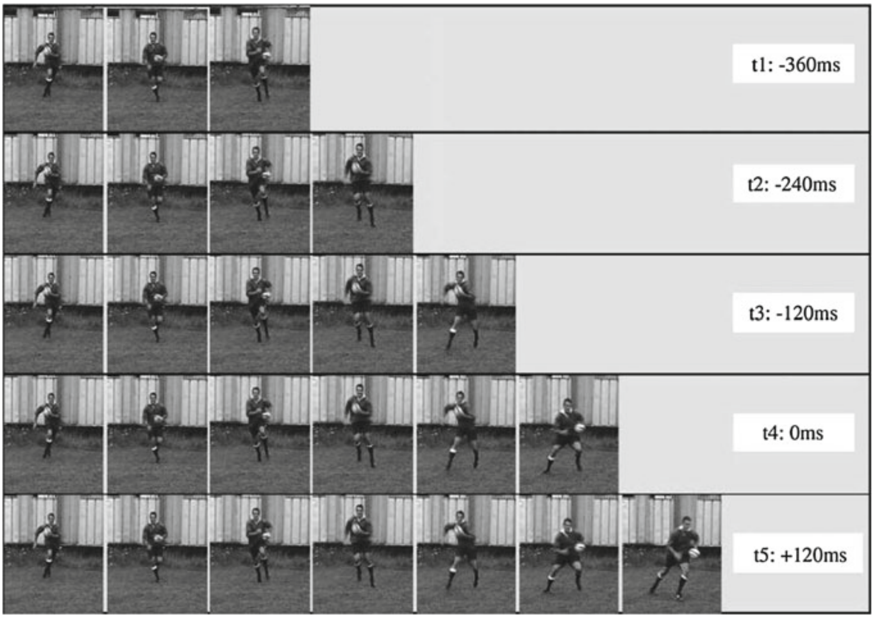

Fig. 13.1 Occlusion times used in the video-based work of Jackson et al. [33]

relevant for the subject. The occlusion-based methodology relies on the link between perceptual capabilities and performance of athletes [60] (Fig. 13.1).

However, some criticisms and drawbacks inherent to the use of video can be formulated:

- The video is a two-dimensional display. Therefore, it does not provide access to all the visual information of a real game situation [4, 61]. But the stereoscopic information can be critical to performance since it provides depth information [31, 37]. The three-dimensional video nevertheless allows to overcome this limitation.
- Another disadvantage of the video is that the viewpoint is fixed and the subject cannot change the way he sees the environment. Therefore, it is always the same information that is displayed. When an individual moves in reality, it can observe new visual information according to its viewpoint. By changing his angle of view, a soccer goalkeeper for example can obtain information about the orientation of the foot of the kicker or about the displacement of other player behind this kicker.
- The making of video clips can also be a problem. The presence of the camera indeed can force the players to adapt their behavior to avoid it. For example, as part of the study of deceptive movements in rugby, researchers filmed a player simulating this type of movement [33]. But it raises the question of the relevance of such a movement: would this deceptive movement have been effective in real one-against-one duel? Does his deceptive movement be the same if it has been done against a real opponent?

- The size of the screens can also be a problem. Sometimes, simple television screens were indeed used to view the video clips. The field of view is then limited and it reduces the access to depth information [21]. For example, in tennis, Fery and Crognier [25] have shown that the presentation of video clips on a TV screen lead to overestimation of the length of short ball trajectories and underestimation of long ball trajectories. These errors were not made in real situations.
- Video-based methodology mainly provides the instant when visual information are important but not the location of these information. This lack can be overcome by combining the technique of time occlusion with an occlusion of spatial visual information presented to subjects [1, 6]. However, few studies have used this coupling between time and space occlusions because the modification of the video is not an easy task. Other methods can be used to determine the position of pertinent visual information. The most used tool is the eye-tracker: this technique consists in analyzing the subject's point of gaze during an action. In duels for example, the subject must focus his attention on the most relevant sources of visual information on his opponent's gesture to react accordingly. It is therefore important to know where an athlete looks at [61]. It was indeed demonstrated that experts used specific visual search strategies during different actions [8]. This spatial dimension of the visual information gathered by athletes in front of a video clip has been analyzed with an eye-tracker [50]. The focus of the subject is then deduced from the position, the duration and the frequency of the fixations [47]. Many studies using this coupling between eye-tracking and video clips techniques have shown differences between expert and novice players, in soccer [29, 46, 47, 59, 63], tennis [28, 50], baseball [49], badminton [6] and combat sport [44, 62]. However, conflicting conclusions emerged about the visual strategies used by the same group level [61]. There are indeed several limitations to the use of eye-trackers. The main problem is that observing a visual fixation during an action does not necessarily mean that it is linked to pertinent information used to react [61]. Thus, the location of the gaze is not necessarily related to the visual information uptake [3, 22, 58].

If these two methodologies can be used to define the relationship between the decision of the player and his level of expertise, or to define the moment when the player makes his decision, it seems very difficult to differentiate the influence of one kinematic parameter compared to another. In the case of sports without human interactions, it is easier to standardize situations and to control their modifications, even in the field by the means of throwing machines for example. But in the case of human interactive sports, it becomes very difficult to standardize situations since the athlete cannot perform twice the same movement and further less modify only one part of his motion without modifying the other parameters. For example in the case of duel between a goalkeeper and a thrower in handball, it is very difficult to demonstrate the influence of the wrist of the thrower on the reaction of the goalkeeper. Indeed, the thrower cannot change the position of his wrist at ball release without modifying the rest of his movement. The experimental conditions are thus not controlled. To understand and determine the weight of each kinematical parameter of the movement of an opponent in the decision of a player, it is necessary to control all these parameters. Virtual reality meets the requirements of standardization of the situation through the control of synthetic humanoids. All the motion editing techniques can indeed be applied to modify only one part of the motion up to completely control the virtual character to react differently, such as by modifying the direction of his run, change his stances, etc. [36, 41]. Moreover, it overcomes the limitations of previous methodologies. It indeed allows three-dimensional display, viewpoint adaptations, and modifications of the visual information provided to the immersed subject.

13.1.2 Requirements for Using Virtual Reality for Sports

13.1.2.1 A Sufficient Level of Presence

Using virtual reality for sports analysis must nevertheless be done with caution. Some requirements must indeed be observed. The most important is to provide an environment that generates a high level of presence, the subject then has the feeling of being in the virtual environment [10]. The sense of presence is related to various factors. Slater and Usoh [53] distinguish two types of factors: external factors related to technology and internal factors related to psychological aspects. Internal factors are the way to internalize the experience of an individual. External factors are the types of technologies and materials used to display and interact with the virtual environment. Evaluation of presence is thus fundamental to consider that a virtual environment can be used to study physical activity and sports performance.

Measuring presence is very complex since it results from a set of parameters difficult to control. Hendrix divides this measurement into objective and subjective evaluations [30]. Objective evaluation depends on several categories of indicators [9]. These indicators are physiological, they are function of muscle tension, eye and cardiovascular responses to virtual events. They are also linked to the achievement of one or more tasks in the synthetic world, the precision of movement and speed of response [52]. Subjective measures correspond to a psychological evaluation, usually conducted using questionnaires [51, 55, 64]. Given the intrinsic nature and complexity of the presence, validate subjective measures of presence is not obvious. As Hendrix highlighted [30], "Evaluation of the presence requires both the use of subjective and objective measures. This is the most appropriate measure.". In the case of physical activities, it is necessary that the subject can reproduce gestures as close as possible to reality. This requirement is in addition to other constraints that determine the presence. To assess the degree of presence of an athlete, it seems necessary to use an objective method in connection with the completion of the task in a virtual environment. This achievement must be compared to that encountered in the real world. Comparison of the kinematics of athletes between a real and a virtual situation is then an additional quantitative assessment of presence.

This kind of objective kinematical validation of the presence has been done by Bideau et al. [11]. They focused on the duel between a handball goalkeeper and a thrower. To this end, they defined an experiment divided into two steps: a motion capture of duels in real situation and an experiment of the same duels in virtual environment between a real goalkeeper and a virtual thrower. At last, they compared the goalkeeper's gestures in the real and in the virtual experiments to determine if virtual reality engendered the same movements in reaction to the same throws. Their results showed that these movements were similar between the real and virtual environments.

13.1.2.2 Displacements and Freedom of Movements

In the case of this last work, the high level of presence is also due to the freedom of movements of the immersed subjects. The freedom of movement is indeed an important requirement for the use of virtual reality for sport applications since it is inherent in the physical activities. However it is not the only requirement. The displacement of the immersed player is also important. In the example of duel between attacker and defender in rugby (first case study), the displacement of the immersed player is limited comparatively to other situations. The second case study shows an example of such a situation: the soccer goalkeeper's action in front of a free kick.

In real sport situation the displacement of a player influences the displacement of his opponent. In virtual reality, the coupling of the virtual and real environments should be done to handle the interaction between the immersed subject and his virtual opponent. A real time motion capture system should then be used. Moreover, it can be used to concurrently handle the viewpoint of the subject. As mentioned before, having an egocentric viewpoint is important to gather all the visual information. Moreover, the motion capture of the immersed subject allows the biomechanical analysis necessary to evaluate his reactions.

13.1.3 Some Applications of Virtual Reality for Sports

Virtual reality is more and more used for sports applications. In 1997, Noser et al. already proposed an interactive situation in tennis [42]. If this study highlighted the technological tool, the situation was not standardized: two real players confronted each other through two virtual reality systems. Each real player then played against the avatar of the other player. Since the situation was not standardized, no link can be done between the decision made by one player and the actions of the other. Many other simulators in virtual environments have been developed such as for rowing [66], bobsleigh [35], etc.

Other studies have used virtual reality to study decision making of sports athletes. For example, Craig et al. [19, 23] used virtual reality to study the perception of soccer goalkeepers depending on the effects of ball. Their study demonstrated that the Magnus effect was hard to perceive by goalkeepers, even experts. Others have studied baseball [43], rugby [57] or handball [12, 56] to analyze the decision-making of sports players.

Two case studies are presented below to illustrate this kind of studies but implying moreover large displacements of the immersed subject. The first example shows a duel between a real rugby defender and a virtual attacker who makes deceptive movements (case study 1). The defender must thus perform medio-lateral displacements to intercept the attacker. This study is based on an HMD technology to allow the defender to move. The second case study examines the performance of a soccer goalkeeper against a free kick depending on the configuration of the wall (case study 2). The goalkeeper has to dive as in real situation to intercept the ball.

13.2 Case Study 1: Deceptive Movements in Rugby

In rugby, the aim is to progress with a ball, toward the opposite team for scoring a try after the goal-line. In order to win, each team must thus develop individual and collective displacements to avoid being intercepted by opponents. The main difficulty for the defender is to intercept a human and not an object (such as a ball) that could follow a predefined trajectory. Indeed, a rugby attacker has the opportunity to suddenly change his running direction at every moment. This is precisely what happens during a deceptive movement of an attacker. If such motor strategies are very used during sports interaction, few studies investigated them [18, 33, 48].

The wealth of the rugby duel is this opportunity for an attacker to play with deceptive and non-deceptive movements to take the advantage over a defender. The goal of this case study is to explore this complex interaction and more precisely how a defender expert, compared to a novice one, reacts to a deceptive movement of an attacker? For analyzing such strategies, a controllable and repeatable stimuli (attacker movement) as well as a system allowing free displacements of the real defender is necessary. Virtual reality is the solution.

13.2.1 Setup

In this experiment, deceptive (DM) and non-deceptive (NDM) movements were presented to novice and expert defenders. The goal of the immersed defender is to stop the attacker. The virtual reality system described in this section allows the displacement and freedom of movement of the defender to achieve his task (Fig. 13.2).

Real 1 attacker versus 1 defender actions were recorded using the optoelectronic motion capture Vicon MX system. Eight rugby players (age 21.38 ± 1.18 years) who played in the French national league took part in the motion capture session. The aim for the attacking player was the same as in the game of rugby: the attacker had to try to beat the defender whilst the defender had to try to stop the attacker. Both deceptive (DM—changing running direction to beat the defender) and non-deceptive (NDM—not changing running direction to beat the defender) were recorded [15]. These captured movements were then used to animate a virtual rugby player by using

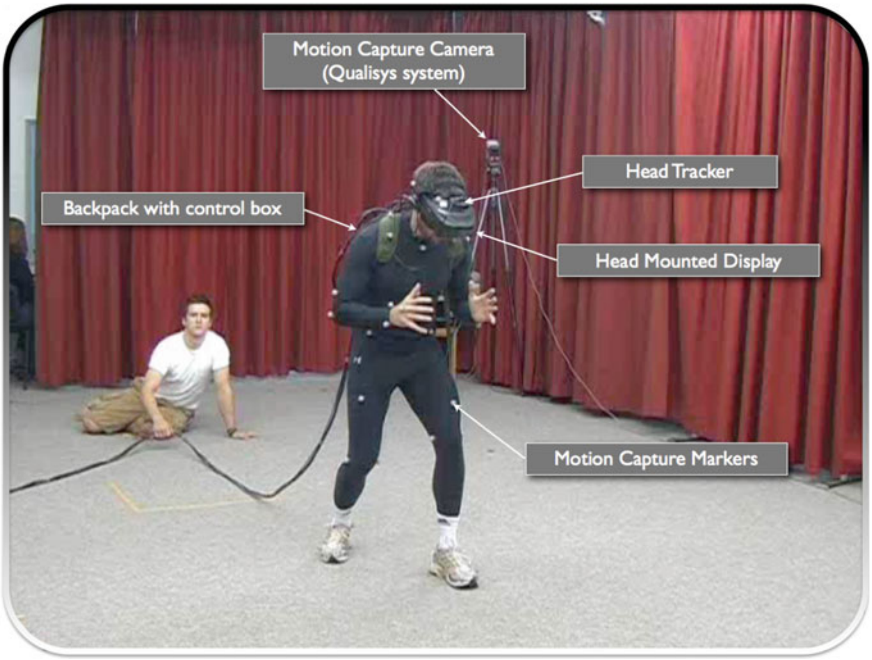

Fig. 13.2 Setup of the experiment

the animation engine MKM (Manageable Kinematic Motion) [36, 41]. MKM has already been used and validated in other experiments involving different sporting duels [11, 13]. The 3D development software Virtools manages the final virtual reality solution and integrates all the developed components (3D rugby pitch, humanoid animation, management of the interface).

13.2.2 Method

12 expert rugby players (age 23.9 ± 2.9 years) from the professional club of Ulster rugby (Belfast, UK) and 12 non-rugby players (age 22.6 ± 2.6 years) took part in the study. 12 attacking runs were selected from the real 1 vs 1 motion capture session: four in which the attacker passed to the left of the defender by performing an effective DM to the right and four in which he passed to the right of the defender by performing an effective DM to the left. The other four attacking runs did not involve any DMs and were made up of two simple changes in running direction (NDM): two to the left and two to the right of the defender.

The virtual attacking movements (8 DM, 4 NDM) were pseudo-randomly presented five times (total of 60 trials). Participants were asked to act as in a real match situation by stopping the virtual attacker. Defenders' movements were recorded with a Qualisys ProReflex motion capture cameras. Thirty-eight reflective markers were placed on key anatomical landmarks on the defenders' body. The external markers attached to the body of the participants were used to compute the 3D positions of the joint centers and then to obtain the 3D position of the global center of mass [65]. This latter was used to determine if the defender initiated his action by an early movement bias in the wrong direction. The initiation of the displacement was taken as effective when the COM mediolateral linear velocity get over a 0.5 m.s-1 threshold. Four parameters were then calculated to compare novices and experts: (i) movement initiation time (ms) of the defending action, (ii) percentage of early movement bias, (iii) displacement amplitude (cm) of the early bias, and (iv) the minimal distance (cm) observed between the defender and the attacker during the duel.

The real defender is also equipped with a head mounted display (Cybermind Visette pro, 45deg field of view, resolution 1280 * 1024) to have stereoscopic vision. His viewpoint is changed in real time (120 Hz) thanks to an Intersense head tracker sensor mounted on the front of the headset.

13.2.3 Results

The different results illustrate the defending strategies differences between experts and novices. Firstly, results show that experts wait significantly longer before initiating movement (Experts 267.74 ± 36.18 ms vs. Novices 192.71 ± 63.82 ms; $t(22) = 3.54$, $p = .002$) (Fig. 13.3). Secondly, regarding the percentage of early bias, authors note that novices initiates more often in the wrong direction (Novices 41.9 ± 20.5% vs. Experts 14.62 ± 9.8%; $t(12) = -4.219$, $p = .01$). These two results can be logically linked. The third parameter, namely the amplitude of the early bias, has significantly greater values for novices (14.99 ± 2.68 cm) compared to experts (11.74 ± 3.81 cm) ($t(22) = 2.41$; $p = .025$, $d = .98$) (Fig. 13.3). Finally, the minimal distance between defender and attacker in front of DM, which highlights the real performance of the defender, appears to be logically smaller for experts compared to novices (Novices 70.8 ± 7.6 cm; Experts 49.2 ± 11.4 cm, $p < .001$).

13.2.4 Discussion

The aim of this study was to explore the differences of displacement strategies between novices and experts defender in front of DM. The results highlight the fact that experts, compared to novices, wait much longer before initiating a displacement to intercept the virtual attacker. Consequently, experts are able to make a significantly lower number of early bias movement in the wrong direction as well as a significantly lower amplitude in the wrong direction during an early bias. This type of results has already been observed in the literature [23]. Dessing and Craig

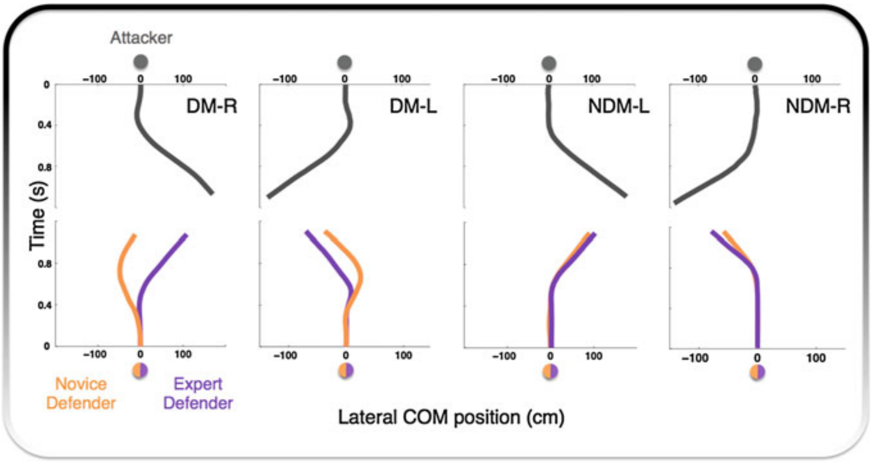

Fig. 13.3 Effects of expertise on movement initiation and displacement. Four examples of the virtual attacker's movements: *dark grey*—DM-R (deceptive movement *right*), DM-L (deceptive movement left), NDM-L (non-deceptive movement *left*) and NDM-R (non-deceptive movement *right*) and the corresponding influence on movements of an expert (*purple*) and a novice (*orange*) defender. Displacements represent the lateral movement (cm) of the COM (center of mass) over time (s) [15]

have indeed immersed soccer goalkeepers (10 novices and 2 experts) in a virtual environment and observed their motor strategies in front of different conditions of free kicks. Their results have demonstrated that the most experienced goalkeepers wait longer before initiating movement. This allows him to observe the ball trajectory during a longer period and thus allows him to better interpret the curvature of the trajectory before initiating movement. In our case, waiting longer would also allow the defender to obtain more reliable information about the true direction of the attacker and finally be closer for intercepting him.

Such an exploration is very interesting for understanding novices vs. experts differences in terms of displacement strategies. For researchers, a permanent difficulty is to be able to explore performance during a situation that is as close as possible to the real and complex situation and that keeps a high level of perception-action coupling. In this case study, virtual reality presents the opportunity to recreate a situation in which the defender can move freely as in a real game situation. It allows researchers and coaches to access to quality and pertinent knowledges about expert strategies. Indeed, the results previously presented can be used on the field for training attacker's ability to perform deceptive movements and attacker's ability to intercept them.

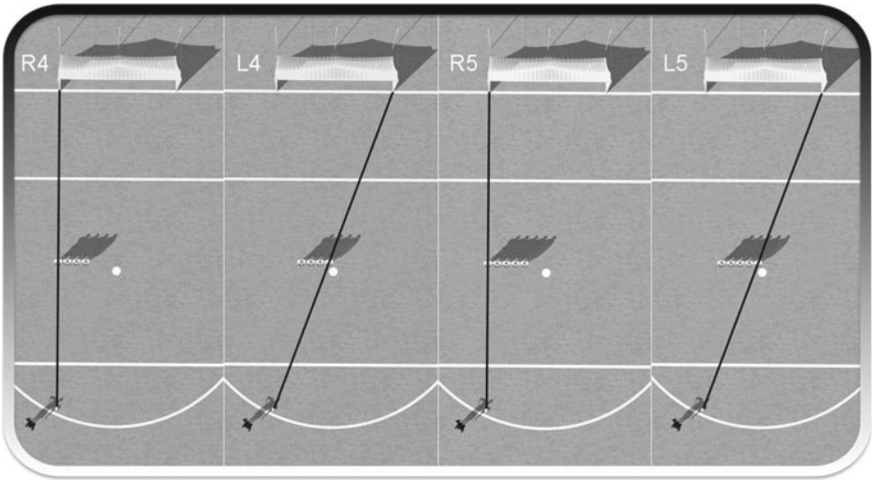

Fig. 13.4 Wall configurations: 4 or 5 players, aligned on right or left

13.3 Case Study 2: Wall Configuration for Soccer Free Kicks

During a soccer match, when a foul is committed near the penalty area and when the attacking team has a free kick, the defending team has the opportunity to set up a defensive wall between the kicker and the goalkeeper. The way this wall is configured is basically based on two parameters: its position and the numbers of players composing it. Concerning the position of the wall, one of the two external players is placed between the ball and the goalpost (Fig. 13.4). This ensures that at least one side of the goal is protected by the wall. Commonly, if the kick comes from the right and if the kicker is right-hander, the external player of the right side of the wall will be aligned with the ball and the right goalpost. As pointed out by Hugues [32], the aim for the goalkeeper is to cover two-thirds of the goal with the wall. To help covering the goal, the goalkeeper can also change the numbers of players composing the wall, usually 4 or 5. If the wall is composed of 5 players then the goal is well covered by the wall and the free zone (not covered by the wall) is then reduced. Nevertheless, the goalkeeper that is covering the free zone of the goal is far from the opposite goalpost. If the ball is kicked over the wall (it is not unusual to observe such a kick and a goal scored on the side normally covered by the wall), the goalkeeper has only a few chance to intercept the ball. On the opposite, 4 players in the wall means a larger free zone. It means it is easier to score a goal. But it also allows a better placement of the goalkeeper. Indeed, he generally places himself in the alignment of the external player of the wall and the ball. He is then closer to the middle of the goal and can thus be more efficient if the ball is kicked over the wall. The configuration of the wall is then a dilemma for the goalkeepers. The aim of this study is precisely to analyze the influence of different wall configurations on the goalkeeper performance.

13.3.1 Setup

As described in the introduction of this chapter, virtual reality systems are the only way to control all the parameters of the displayed situation. Indeed, the animation of the kicker as well as the trajectory of the ball must be completely controlled to change only one parameter at a time. Nevertheless, in that study, the displacements of the goalkeeper must be the core of the Virtual Reality system designed for this experiment. Indeed, the goalkeeper must be able to see the situation from different viewpoints going from the two goalposts to any position in the goal. Moreover, when the ball is kicked, the system must allow the goalkeeper to dive to intercept the ball and to evaluate his performance.

13.3.1.1 Hardware Setup

To allow a complete freedom of movement of the goalkeeper, the stereoscopic vision was ensured by the Nvidia 3D vision system at 120 Hz. This system is composed of wireless glasses and USB infrared emitter. These glasses are similar to normal ones and are maintained with a headband attached to the arms of the glasses. Thus, participants are fully free of their movements. In addition, contrary to HMD devices for example, the goalkeepers can also see their body segments such as their arms that are really important for such intercepting tasks. These glasses are synchronized with an Acer high frequency H5360 video projector. Rear projection was done to avoid shadows since the goalkeeper was placed near the screen to have a very large field of view. In front of this screen, a real goal was placed on synthetic grass to allow the immersed goalkeeper to feel the pitch and to dive as realistically as possible (Fig. 13.5).

The viewpoint used in the simulation was modified according to the head movement. Five markers were indeed placed on a hair band to record the head's position via the Vicon MX motion capture system. This latter was coupled with the Autodesk Motionbuilder software in order to update in real time the player's viewpoint as well as handling the stereoscopic vision.

13.3.1.2 Virtual Kicker and Ball Animations

Kicker animation was based on captured motions (see [16] for detailed information on the motion capture session). Real free kick situations were captured using the optoelectronic motion capture Vicon MX camera system at 300 Hz. The participants were mid-level football players. They had to kick the ball in a zone of 1.7 m * 1 m in the top corner of the net avoiding a plastic wall of five players. The ball was positioned at 20 meters from the goal and aligned with the left goal post (Fig. 13.4). Successful motions were kept for animation.

Concurrently, the initial linear and angular velocities of the ball at kick were captured by using reflective tapes on the ball. In addition to the final position of

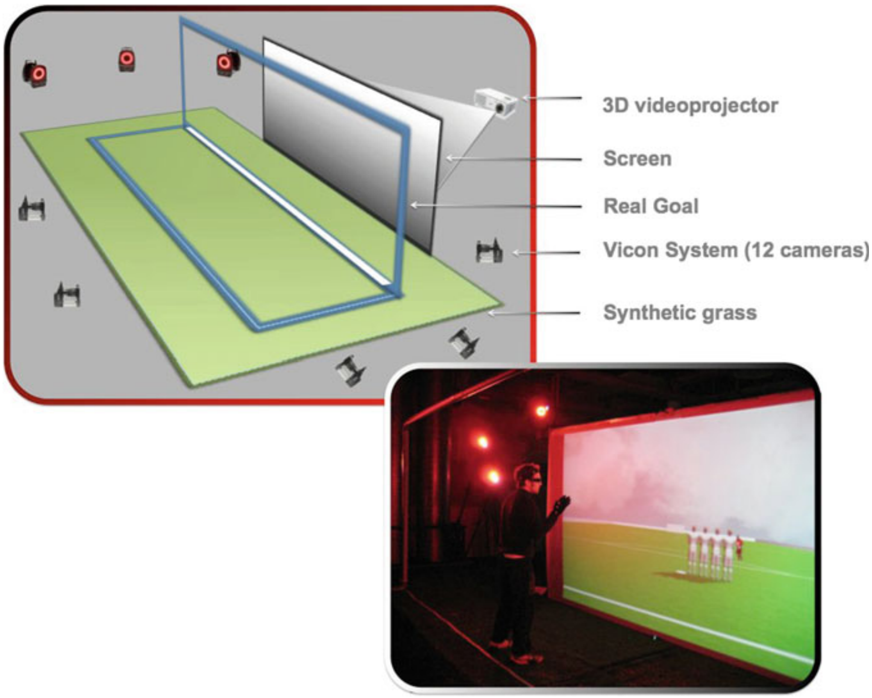

Fig. 13.5 Setup of the experiment

the ball in the goal, these velocities allowed the definition of the full ball trajectory thanks to a dynamic ball model (Fig. 13.6 and [16] for details).

All the developed components of the final virtual reality solution were integrated in the 3D development software Motionbuilder (3D soccer pitch, humanoid animation, ball animation, management of the interface).

13.3.2 Methods

11 mid-level goalkeepers who play at a departmental or regional level (mean age 26.1 $\pm$ 4.1 years) volunteered to take part in the experiment. The mean playing experience for these experts was 16.4 $\pm$ 5.4 years.Participants had to intercept different free kick conditions as in a real situation. These following conditions were mixed: 2 free kicks (in the top left and right corners), 2 wall positions (aligned with the right or left goalpost) and 2 numbers of players in the wall (4 or 5). Moreover, four other free kicks were added in order to keep a sufficient level of uncertainty. Note that all the left and right sides refer to the kicker's viewpoint. The 48 experimental trials were presented in four randomized blocks of 12 trials (2 free kicks * 2 wall positions * 2 numbers of players + 4 random free kicks). The participants then saw 8 different free

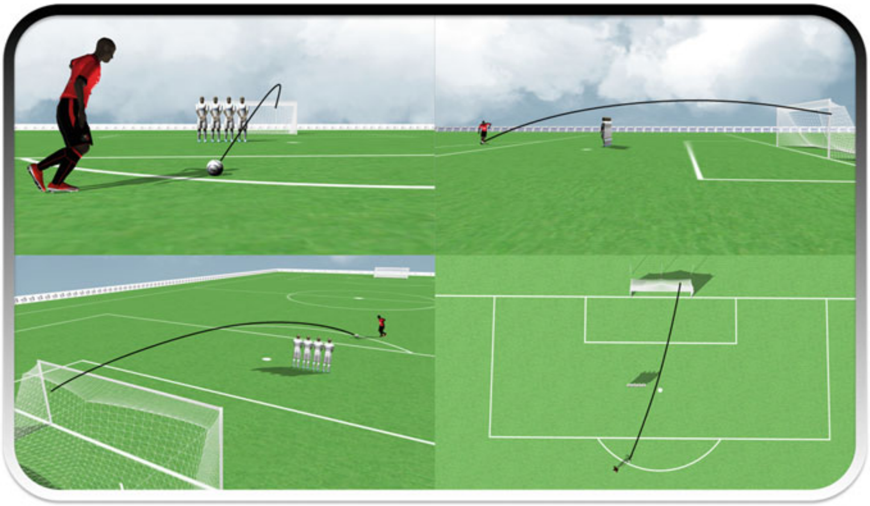

Fig. 13.6 Virtual environment

kick conditions (noted i.e. fkL_4_wL with fkL: freekick to the Left, 4: 4 players in the wall, and wL: wall aligned with the Left goalpost). A training period was carried out before the experiment to familiarize subjects with the virtual environment and the task. Five situations were randomly selected and presented to participants that had to react as in the real experiment.

13.3.3 Results

The distance between the center of the ball and the center of the closest goalkeeper's hand was calculated in real time and its minimal value is kept for each trial. A three-way analysis of variance (2 free kicks (right, left) × 2 walls (right, left) × 2 numbers of players (4, 5)) allows us to highlight significant differences. One can indeed observe a significant main effect of the number of players in the wall ($F(1,352) = 11.05$, $p < .001$, $\eta^2 = 1069.49$) with a significant better performance for situations with 5 players in the wall (minimal distance ball/hand for 5 players = 14.39 ± 11.14; for 4 players = 17.88 ± 10.01). Another main effect concerns the wall position condition ($F(1,352) = 11.05$, $p < .001$, $\eta^2 = 1069.49$) with a significant better performance for situations with a wall aligned with the right post (minimal distance ball/hand for right wall = 14.9 ± 10.21; for left wall = 17.35 ± 11.09). No difference appeared between the free kick kicked to the right or the left of the goal.

About the pairwise comparison post-hoc test (Tuckey HSD test), results highlight two conditions with a significantly lower performance, namely, "fkR_4_wL": free kick to the right, 4 players in the wall, wall on the left ($p < 0.001$ except for fkR_5_wL, $p < 0.01$) and "fkL_4_wR": free kick to the left, 4 players in the wall, wall on the right ($p < 0.01$ except for fkR_5_wL, $p = 0.175$). These two situations present a small wall (4 players) and a free kick kicked in the free zone of the goal. In other terms, the lower performance can be explained, here, by the fact that a small wall involves a large free area to cover by the goalkeeper. It is consequently much more difficult for the goalkeeper to stop it.

13.3.4 Discussion

The main goal of this case study is to analyze the influence of different wall positioning strategies on the goalkeeper performance. Results show that goalkeepers were significantly less efficient in two situations: a wall of 4 players and a ball kicked in the free zone of the goal. With 4 players in the wall, the free zone is wider and the position of the goalkeeper is closer to the center of the goal. This situation is thus very difficult for goalkeepers. Nevertheless, in the opposite case (5 players in the wall and a ball kicked over it), the results of the goalkeepers are not that bad. This result is startling since the free zone is smaller and the goalkeeper is farthest from the center of the goal and even more from the opposite goalpost. Finally, looking at all the situations, it thus seems that the goalkeeper should choose to place 5 players in the wall. Notice that the side where the wall is aligned does not influence the ability of the goalkeeper to intercept the ball.

Such an analysis of the goalkeeper's performance in front of different wall configurations would not be possible without a Virtual Reality system that ensures a complete freedom of movement of the goalkeeper. If a lot of studies have already investigated this very popular sport, the large space of the pitch and the complexity of the interaction make the experimentations difficult. If numerous studies have explored the goalkeeper's performance during penalties [46, 47], very few have analyzed the goalkeeper performance during free kick. Some interesting studies such as those of Craig et al. [19, 20] were focused on free kick in order to explore the perceptual skills of goalkeeper and to identify the optical variables that underlie judgments. In these studies, the aim was to evaluate the influence of ball's effect on perception. In the case study presented here, the goal is to evaluate the goalkeeper's performance on the perception-action coupling. His movements are thus fundamental, to intercept the ball of course but also to place the wall. The goalkeeper indeed must change his viewpoint from one goalpost to the other to be able to align the wall depending on the number of players in the wall and the position of the kicker. This kind of studies can then not be done if no displacement in the virtual reality system is provided.

13.4 Conclusion

The two case studies presented in this chapter show how virtual reality can be used to analyze the visual information uptake in sports duel. The first example deals with the interception of a virtual attacker doing deceptive movements, by a real defender in rugby. The second one concerns the influence of the wall configuration during free kick in soccer on the goalkeeper's performance. Both examples emphasize the importance of freedom of movements and displacements for the analysis of the performance of the immersed athletes. These features are indeed fundamental when studying sports. It allows the immersed subject to react realistically without constraints, to act as in real situation.

Thus, as we have illustrated, virtual reality is a fundamental tool for sports applications. It indeed offers standardized and fully controlled situations. The influence of one parameter on the performance of an athlete can then be analyzed by only modifying it and by observing the reaction of the immersed subject. Virtual reality thus offers a new way to understand performance and to increase the knowledge on sports. Another important application of the use of virtual reality for sports concerns the training. These simulators can indeed also be used to train the athletes. It offers an environment that controls exactly the information provided and allows the training of specific situations. Moreover, information can be added to the virtual environment to focus the attention of the athlete on important features of the opponents' movement for example. Indeed it is possible to use the knowledge obtained in virtual reality experiments on sports to create a new generation of training systems.

Nevertheless, in this kind of studies in virtual reality, the situations are always chosen with limited displacements. Having displacement devices would largely extend the range of studies that can be done. In the duel of the first case study for example, the defender is real and the attacker virtual. In the opposite duel between a virtual defender and a real attacker, the displacements are mainly done toward the screen. The use of a locomotion device is then necessary to handle these displacements. A specific device should obviously be developed nevertheless because the displacements are fast and jerky. In the same way, in soccer, some studies [19, 20] worked on the perception of aerial balls with effects (such as the Magnus one). To go further and study the interception of these aerial balls (for example lobs in soccer, fly balls in baseball), it is then necessary to have a displacement device that allows to move at least forward and backward. Indeed, having a large CAVE for example is not a solution since the immersed subject must be near the screen to see the balls that can be very high. When the subject is too far from the screen, the vertical field of view is then too limited and the subject looses the ball. A displacement device is then necessary to walk around the virtual field while staying near the screen of the virtual reality system.

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