Using Virtual Reality to Analyze Sports Performance

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Scientists have developed many systems and methods to evaluate the most important parameters in sports performance—particularly in areas such as biomechanics, physiology, and behavioral neuroscience. Biomechanical analyses give trainers kinematic and dynamic data to help optimize particular movements or adopt new techniques through strength-and-conditioning training programs. Physiological analyses describe the energetic cost of human movement and how metabolism adapts to training. Behavioral neuroscience can explain the strategic choices that players make during competition, such as anticipating an opponent’s actions or optimally moving to intercept a ball. Biomechanical, physiological, and psychological phenomena occur concurrently during competition, making it difficult to study complex situations such as interaction between players. The ability to discern the most relevant perceptual information from an opponent’s movement is an essential component of anticipation skills in sports. The information a player uses must come from the kinematics or other dynamic variables (such as the body’s acceleration or the limbs’ orientation during the movement sequence) that are perceptible from the opponent’s movement. Because of technological limitations in both hardware and software, video playback has been the traditional method for exploring anticipatory behavior in different sporting scenarios. However, video playback is limited because the viewpoint is fixed to the camera position during recording. This prevents interactivity—something extremely important if the player wishes to move so as to better pick up key information. Moreover, video playback depends on which actions took place at a given time. Owing to improvements in technology and processing power, virtual reality (VR) can overcome these limitations by providing numerical simulations and immersive, interactive environments. (See the sidebar for more details concerning VR’s advantages over video playback.)

We use VR to study the perception-action loop in athletes: how perception influences choices about which action to perform, and how those choices influence subsequent perception. We investigate which perceptual information is important by asking players to predict what will happen in certain scenarios—for instance, where the ball will go when the end of the ball’s trajectory is cut off. Then, we introduce the action component to complete the loop. To perform such experiments, we designed a framework that uses video-game technology, including a sophisticated animation engine. We used this framework to conduct two case studies: The first was a perception-only task to evaluate rugby players’ ability to detect deceptive movement. The second concerned a perception-action task to analyze handball goalkeepers’ responses (action) when facing different ball trajectories (perception). These case studies demonstrate the advantages of using VR to better understand the perception-action loop and thus to analyze sports performance.

The Overall Process
Using VR technology to analyze sports perfor-
Performance involves a three-step process (see Figure 1). The first step involves capturing athletes’ actions in a given sport. These actions are not only useful for the virtual characters’ animation but also provide a way to compare the subject’s movements in real and immersed situations. The second step concerns animation of the virtual humanoids and their adaptation to specific constraints to modify only one part of the simulation. The third step involves the virtual environment’s presentation.

Although the first two steps are common for all the applications we present here, the third depends on the specific application because each immersive display system has its own advantages and disadvantages. For example, in our handball case study, the subject must act as if he is in a real-life setting and so must be free to move. So, we used a large cylindrical screen. For the rugby perception task, on the other hand, the subject only tries to identify his virtual opponent’s deceptive movements. So, we used a head-mounted display (HMD).

**Motion Capture of Sports Movements**

We used Oxford Metrics Group’s Vicon motion-capture system to record elite athletes’ movements in real situations. We captured these movements at 200 Hz using 12 infrared cameras. In each experiment, we equipped subjects with 43 markers, which we placed on anatomical landmarks to precisely reconstruct each body part’s 3D position and orientation.

For the rugby case study, we captured the motion of eight rugby players playing at the national level. For each motion-capture session, we simultaneously recorded the movements of two different players: an attacker and a defender. The attacker carried a ball and tried to beat the defender by performing a deceptive movement. The defender tried to stop the attacker from getting past him (see Figure 2). (Each player alternated between being the attacker and the defender.) Recording both players’ actions enables a retrospective in-depth biomechanical analysis of what the attacker does to successfully beat the defender.

For the handball case study, we captured the motion of 12 handball goalkeepers playing at the national level. All subjects had normal vision. We asked them to throw the ball 12 meters from the goal and aim at different specified target zones in the goal. We placed additional markers on the ball to obtain its trajectory. No goalkeeper was in the goal.

**Animation of Sporting Actions**

After recording the movements in the real situations, we animated the virtual characters using the MKM (Manageable Kinematic Motions) animation technique.
Virtual Reality’s Advantages over Video Playback

Much of the research on anticipatory behavior in sporting scenarios has employed *temporal occlusion*, which controls the amount of visual information presented to participants. This method displays a video of a prerecorded sporting event and stops at key moments such as racquet and ball contact for tennis, or foot and ball contact for soccer. Participants then must predict what would happen next on the basis of the information they saw. Although this method is common, observing a video differs considerably from observing the same information in a game-like scenario. For example, Jaeho Shim and Les Carlton observed a progressive decrease in expert performance in tennis when participants reacted to video images, compared to real-life situations. In this study, the performance deterioration could be due to the lack of presence (the feeling of being in a realistic environment) that participants might have felt because of the absence of interactivity and of a 3D display of the sport scenario.

Players must see other players’ key body parts and the ball, so some researchers also use portable eye-tracking systems to analyze players’ visual search behavior when performing anticipatory skills. Such systems can identify where a player’s eyes are looking to determine which visual-information sources that player uses to make anticipatory judgments about where a ball will go. Although this approach is useful, determining each information source’s relative weight and role in providing pertinent prospective information for the player still remains difficult.

Virtual reality (VR) can overcome many of these limitations and has several advantages over video presentation. First, in a virtual environment, subjects and simulated opponents can interact with one another while the experimenter carefully controls and modifies the type of information the immersed player can see at any time. Second, VR lets researchers systematically control and tune all factors affecting the player’s judgment, ensuring reproducibility between trials. Monitoring this tuning’s effects on the player’s behavior in real time can ensure ecological validity. Third, by tracking head movements in real time, researchers can update the player’s viewpoint in the virtual environment in real time, which helps enhance the player’s feeling of presence. Finally, VR displays are stereoscopic, giving the player vital depth information—something severely lacking in 2D video displays. Because of these advantages, the players’ perspective and behavior in a virtual environment correspond far more closely to their perspective and behavior in real-life environments.

For example, Benoit Bideau and his colleagues recently showed that an interactive, immersive virtual handball court with a realistically animated handball goalkeeper player throwing the ball toward the goal elicited expert handball goalkeeper responses similar to real-world responses. This important study helps validate VR technology as a way to examine anticipatory responses in elite players, with the researchers observing a high level of behavioral presence.

Other research has used VR technology to study curved free kicks in soccer. The researchers wanted to know engine. MKM is suitable for interactive applications because it enables the motion adaptation of hundreds of characters in real time.

MKM represents motion independently of morphology, leading to efficient motion retargeting. Using MKM, we can automatically adapt motions to any kind of virtual humanoids, even if their morphologies differ from the captured athletes’ anthropometric data.

Moreover, this representation is based on both Cartesian and angular data, allowing fast motion adaptation to constraints. This feature facilitates realistic character animation—for instance, by ensuring that feet contact the ground without the usual sliding effects. MKM offers an inverse-kinematics and kinetics solver based on intuitive constraints. This solver allows for easily changing any body point’s position and orientation, even on the skin. Moreover, we can combine these constraints by using priorities (MKM verifies the most important constraints first) or weighting (the resulting animation combines all constraints according to their relative importance).

This fast motion adaptation is also important for studying performance. It allows for modifying only one of a movement’s parameters at a time (for instance, the player’s wrist position at ball release). We can then determine each parameter’s importance by comparing the immersed athlete’s judgment or action when he is in front of the animation with and without this modified parameter.

**VR Experiments**

The technology used to analyze sports actions from a behavioral perspective depends on players performing movements as realistically as possible.

**Rugby Case Study (Perception Task)**

In this experiment, we tested expert and novice rugby players’ ability to detect deceptive movements in an attacking player’s approaching run. Detection involves inferring intentions from others’ actions.

**Apparatus.** The participants made simple perceptual judgments and thus didn’t need to move much. So, we used a Cybermind Visette Pro HMD, comprising two screens of 1,280 × 1,024 pixels with a 45°
whether the side spin that causes the ball to bend on its way to the goal would influence expert soccer goalkeepers’ judgments about whether the ball would end up in the back of the net. By using VR technology, the experimenters simulated realistic free kicks, varying only the spin’s direction (and hence the ball’s trajectory), while keeping all other variables such as ball speed constant. So, they could draw conclusions regarding players’ ability to incorporate information about spin and then use this information to accurately predict where the ball would end up.

In light of these examples, applying VR technology to understand and analyze sports performance can be considered a serious game (a computer-based application that draws on entertainment game approaches and technologies but is intended primarily for nonentertainment purposes). Many fields, including learning and training, have used serious games. In the field of sports, Guido Brunnett and his colleagues have developed V-pong, an immersive table tennis simulation that lets players interact in real time with a ball. For this simulation, they integrated a physics engine with three major aspects: ball movement, collision modeling, and game strategy. Sidney Fels and his colleagues created an interface to enhance learning how to swim. Although this interface could improve learning, the technology isn’t yet suitable for high-level swimmers. In our research, we hope to promote interest in serious games as a way to understand sports performance from a behavioral-neuroscience viewpoint.

References

Figure 3. The apparatus used for the rugby case study: (a) the head-mounted display (HMD) and (b) the virtual rugby environment. The combination of these hardware and software technologies allows a full immersion of players in the virtual rugby pitch.

field of view (see Figure 3). The display was still interactive because we used the Vicon motion-capture system to record the head’s position and orientation using five markers placed atop the HMD. This information updated in real time the player’s viewpoint of the unfolding action on the virtual pitch.

Procedure. To study a rugby player’s ability to detect deceptive movements, we used temporal occlusion. We cut off the displays at the penultimate step (T0), which occurred before the direction change (see Figure 4). The other cutoffs were 100 ms (T1), 200 ms (T2), and 300 ms (T3) after T0. For each movement and for each cutoff, the expert...
and novice rugby players had to define the virtual player’s final direction. To do this, they pressed one of two buttons on a Microsoft SideWinder game controller (left button for a player going left, right button for player going right). We recorded their responses about player direction along with the time they took to make those responses. We used this information to evaluate the differences between expert and novice rugby players and their ability to pick up advanced perceptual information regarding which direction the player is going to run.

**Data analysis.** We tested eight novice and eight expert rugby players. The total number of correct answers (see Figure 5a) was significantly greater for the experts (76.4 percent ± 1.82) than the novices (68.3 percent ± 1.88) \[t(14) = -4.046, p < 0.01\]. Moreover, most experts defined the final direction of the rugby player’s movements more quickly than the novices did. Figure 5b shows a significant greater percentage of successful trials for experts at \(T_0\) and \(T_1\) \([t(14) = -2.366, p < 0.05\) at \(T_0\); \(t(14) = -4.894, p < 0.001\) at \(T_1\)].

**Handball Case Study (Perception-Action Task)**

Here, our main goal was to evaluate anticipatory skill and see how it relates to performance. The ability to anticipate an opponent’s movement has proved to be a reliable discriminator between expert and novice performers in many sports having tight temporal constraints. We define performance here as the goalkeeper’s ability to intercept the ball when facing different throwing actions and ball trajectories.

In this experiment, standardizing the throw and providing real-time interaction between the goalkeeper’s movements and the ball trajectory are imperative for evaluating successful interception. So, analyzing anticipation and performance in a real-life setting or by using video wouldn’t be adequate. In either case, a real person would have to
throw the ball, which would be inherently variable, making it impossible to exactly reproduce or standardize the throwing action and the resulting ball trajectory. Moreover, although a video system could present the same action repeatedly, it couldn’t detect collisions between the ball and the goalkeeper’s limbs because it couldn’t show the ball trajectory in 3D. VR lets us overcome these limitations by providing an environment with standardized throws and real-time interaction between the handball goalkeeper and the ball trajectory.

Apparatus. To ensure that the goalkeeper can move freely, we used an immersive system provided by the Bunraku team at IRISA (Institut de Recherche en Informatique et Systèmes Aléatoires) in Rennes, France. This system includes three Barco 1208s synchronized video projectors, driven by Silicon Graphics’ Onyx2 InfiniteReality, projecting the 3D sports hall shown in Figure 6 onto a large cylindrical screen (3.80-m radius, 2.38-m height, and 135° field of view). We attained 3D vision using stereoscopic glasses activated at 60 Hz (30 Hz for each eye), and we interactively updated the viewpoint by using four Vicon markers to track in real time the head’s changing position.

To improve the subject’s presence (how closely the virtual environment “feels” like the real environment to the subject), goalkeepers stood in a real goal in front of a screen, which was in the same position it would be in the virtual stadium (see Figure 7).

To record the goalkeeper’s movements as the virtual player threw the ball, we placed 36 passive Vicon markers on anatomical landmarks on the body. The different body parts’ captured movements provided vital information for a full behavioral analysis of how players responded (action) to the changing visual information (perception).

Procedure. The goalkeeper had to stop the virtual ball by moving to the interception point. To do this, he stood in the real goal, which corresponded in size and position to the virtual goal. We asked the goalkeeper to move as if he were stopping a ball in a real match situation, and we recorded his movements during each trial. We gave each participant a training period to become familiar with the environment and task. After this period, he had to stop 50 virtual throws, presented in random order.

Figure 6. The virtual environment for the handball case study. As with the rugby case study, the environment was enhanced to improve the immersion of the subjects.

Figure 7. A real goalkeeper facing a virtual thrower in the handball case study. The global setup enables immersion and recording of the goalkeeper’s real motor action in responding to the virtual thrower.
We evaluated anticipation skill through success rates and response times. We considered a movement successful when, according to motion-capture data, at least one part of the goalkeeper’s body collided with the virtual ball—giving an overall success rate for each throw in each zone. We calculated response times as the time from ball release from the virtual thrower’s hand to the peak acceleration of the goalkeeper’s interceptive limb.

On the basis of the results, we can relate the performance level (successful movement) to the response time. In other words, successful movements are characterized by faster response times. For example, subject S1 had a response time of 398 (±10) ms, for 15 (±9) percent successful movements, whereas subject S2 had a response time of 287 (±7) ms, for 40 (±7) percent successful movements (see Figure 8).

The results show that response time and the percentage of successful movements differed for the two subjects. So, we conducted further studies to determine whether the visual information the players used to control their interceptive actions was based on body posture, ball trajectory, or both. We used VR to dissociate this visual information concerning player movements from the visual information relating to the ball trajectory. We presented three different conditions: only the attacking player’s throwing action (T), only the resulting ball trajectory (B), and both (TB). For these two subjects, preliminary results (B: 70 percent, TB: 77 percent, and T: 21 percent) show that the two case studies involving the ball trajectory provided a higher percentage of successful responses. The ball trajectory is thus important. Moreover, the throwing action seemed to increase overall performance.

The sophistication of MKM lets experimenters precisely control the avatar’s movement, eliminating movement variability between trials as a potential source of variance in the results. In another handball study, Benoit Bideau and his colleagues presented exactly the same movement of a virtual player during repeated trials, while changing only the position and orientation of the virtual player’s wrist. This fostered an evaluation of how these body position changes affected expert goalkeeper’s judgments about where they thought the ball would go.

So, a computer-generated visual environment lets experimenters control factors that would otherwise be extremely difficult, if not impossible, to control in the real world. Such systematic variation of one parameter at a time allows for determining how a particular factor might influence player behavior. Furthermore, VR’s immersive, interactive nature facilitates high-speed recordings of player movements and responses. This data lets researchers perform a full behavioral analysis on how the unfolding event’s dynamics in the virtual environment (perception) inform the players’ choices about which movements to perform and how to execute them (action). Being able to close the perception-action loop while observing different components can greatly enhance our understanding of why players do what they do.

Once researchers better understand how perceptual information informs action, the next step is to develop the technology to create a virtual-sports-training tool. By exploiting this technology’s advantages over video playback, coaches can put themselves in their players’ shoes and experience the same patterns of visual images those players experience in a game setting. They can then better guide their players in the decision-making process by experiencing the action together and provide real-time feedback as the game scenario unfolds.

Further applications might include training players to be attentive to pertinent perceptual in-
formation so that they can make advanced, more accurate judgments about where a ball is heading. Researchers could also harness the powerful combination of animation and simulation to develop training scenarios in which players who have never confronted, say, a David Beckham free kick will be able to see for themselves what it looks like and respond in real time. So, VR technology’s future looks bright, and effective virtual sports trainers could be just around the corner.

References


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