Virtual Reality for Research and Training in Sport: an Illustration with CoPeFoot

Chapter · January 2009

Cyril Bossard
Université de Bretagne Occidentale
46 PUBLICATIONS 246 CITATIONS
SEE PROFILE

Gilles Kermarrec
Research Center for Education, Didactics & Learning
73 PUBLICATIONS 345 CITATIONS
SEE PROFILE

Romain Bénard
Thales Group
15 PUBLICATIONS 59 CITATIONS
SEE PROFILE

Pierre De Loor
Laboratory of Science and Technology of Information, Communication and Know…
98 PUBLICATIONS 444 CITATIONS
SEE PROFILE

Virtual Reality for Research and Training in Sport: an Illustration with CoPeFoot

Bossard, Cyril (**), Kermarrec, Gilles (**), Bénard, Romain (*), De Loor Pierre (*), & Tisseau Jacques (*).

(*) Laboratoire d'Informatique des Systèmes Complexes, European University of Brittany, University of Brest, France.
European Centre for Virtual Reality, 25 rue Claude Chappe, 29 280 Plouzané.
E-mail: gilles.kermarrec@univ-brest.fr; {bossard ; benard ; deloor ; tisseau}@enib.fr

(**) University of Sport and Physical Education.

Abstract

New possibilities for research and training in sport could be offered thanks to virtual reality simulations. The literature is examined, analysing the advantages and properties of current simulators. This paper aims to present an original experiment in virtual reality simulation design based on autonomy, interaction and evolving concepts. Our main suggestion is that believability of simulation for the user needs both regularity and surprises (in terms of virtual agents' behaviour). A naturalistic approach was used to study experts' decision-making processes in soccer settings. The decision-making model represented a guideline for choosing and implementing computational models. The advantages of virtual reality simulation are discussed in relation to training and research in sports science.

Key-words: Simulation, Virtual Reality, Sport, Design.

Introduction

The benefits of new technologies have led many researchers to develop research programmes relating to simulation design. Although simulations in the fields of driving, aviation and military or medical interventions is no longer questioned (Sebrechts et al., 2003), similar interest in the field of sport is much more recent (Ripoll, 2004). There is therefore very little information available about the benefits of simulations for research and training in high-level sports. Simulation, that is to say pretending, imagining or performing an action outside of its regular context, can serve many purposes in the context of high-level sports: preparing oneself for action, acquiring new technical skills, or studying particular techniques. In order to interact with a virtual environment, the validity of the simulation relies on the design approach and on the models of the virtual agents involved (Cobb et al., 2002).

Virtual environments (VE) can be used to immerse an individual or a team within a believable and interactive computer-generated environment. Users must be able to interact with autonomous agents and/or other human users. In order for the interaction to be effective, the virtual agents must also be able to influence the user, and be altered by the user's actions. The VE must be able to evolve due to these interactions. If the agents' behaviour evolves, it must be neither totally predictable, nor completely random. By making the virtual agents autonomous, we could expect more believable behaviours.

With a view to immersing high-level football players in a simulation, designing this believability depends on a balance between predictability and surprise in order to allow users to construct meaning in terms of their interaction with the VE. The aim of this paper is to present a multidisciplinary approach to designing simulations dedicated to sport. We will examine the methodological and scientific choices made in designing the CoPeFoot (Collective Perception in Football) virtual environment.

We will introduce our suggestion by a brief review of the simulators put forward up until now in the field of sports. We will show that these simulators respond poorly to the demands of autonomy, evolution and interaction. In our experiment, we will present four stages of a collaborative approach between sports science and computer science, with the aim of developing a believable simulation application for football. Finally, we will discuss the advantages of the simulation using virtual reality apparatus for sports research and training.

1. Sport simulation: a brief overview

According to Alessi (2004), three main aims can be associated with simulation for sports research and training: improving cognitive aspects of performance, improving the physical aspects of performance, and improving the affective aspects of performance (emotion and attitudes). Two main approaches are linked to these objectives and can be used to facilitate them: virtual reality simulation and realistic physical simulators. Within the approaches that use virtual reality simulations, we can identify the uses of simulations for strategic analysis of sports situations, and those relating to user-player immersion. The aim of the training in question imposes, or at least suggests the use of one or other of these approaches.

Realistic physical simulators for studying technical movements

In physical simulators designed for studying technical movements, the aim is to recreate a more believable environment with regards to senses; mainly relating to sight, balance, touch and sound. The physical interaction between the user and the machine is an essential part of believability. In order to enhance the user's impression of immersion in these simulators, we use different mechanical systems to recreate the vibrations inherent to sports such as skiing or mountain biking, for example (Mester, 1999). Immersion through physical interaction is also linked to the scale (1/1) of the simulator. These very characteristics can be observed in *Peloton*, an environment which recreates virtual cycle races (Ensor *et al.*, 2000). Similarly, Bideau *et al.* (2003) suggest immersing handball goalkeepers by confronting them with virtual players; Huffman & Hubbard (1996), and Kelly & Hubbard (2000) also presented a virtual training environment for piloting Bobsleighs. One of the issues raised by these simulators is the evaluation of their value for completing the exercise in real-life situations. For example, Todorov *et al.* (1997) present a study based on the acquisition of technical moves in table tennis in a VE. They studied the transfer of these moves to real-life settings. Studies examining the transfer of acquisitions from the virtual to reality (Bossard *et al.*, 2008) show the need to think both about the alternation between real and virtual training sessions, and about the content of the desired acquisitions and the information provided by the virtual environment in response to the users' actions.

Finally, simulations for technical movements aim to optimize believability by focusing primarily on the physical interaction. Although these systems are tightly controlled, lacking autonomy and evolution, this type of simulation can be used to improve the physical aspects of performance.

Virtual reality simulation for analysis and strategic assistance.

The advantage of virtual reality simulations is that it is possible to conduct risk-free experiments and to be able to analyse the consequences of choices made by the players in different situations. The aim is not to use simulations to put the player in the thick of the action, but, on the contrary, to enable the player to take a step back from the action. In much the same way as for analysing parts of a game from video footage, the idea is to offer the player a number of different viewpoints. From a technical point of view; in order to generate a believable environment, this tool uses image processing and synthesis. For example, Ziane (2004) suggests that basketball coaches could be trained to analyse their team's actions. A model recreating scenes from the game based on a film was used to identify specific movements of both the players and the ball. A kinematic study of the action enables the coaches to graphically represent and to accurately interpret the different ways the teams positioned themselves on the court, the surface area occupied by each team, the distance between the players, the ball and the hoop, and the speed of the players and the ball. Other models (Bayesian networks) can be used in order to identify the most relevant viewpoint amongst all the possible points of view in order to study the correlations between the players' movement, the teams, and the ball. This tool has the advantage of being able to alter the view of the action and to identify the phenomena which are difficult to perceive through spontaneous observation. Metoyer & Hodgins (2000) also suggest a simulator with the aim of analysing the results of different combinations of movements in American football. These combinations are played by virtual agents. According to the authors, there is no point in modelling the virtual players to look realistic, as the illusion of reality is more likely to be lost if their *behaviour* is unnatural. Therefore, believability depends less on the appearance of the players than on their behaviour (their movements) in context. The aim is to test different movement strategies in order to evaluate the results before applying them to real-life settings. This type of simulation is therefore a useful tool in training high-level players.

Here, the believability of behaviours relies essentially on "visual" return from the images, or the conformity of the behaviours in the simulation compared to those from the knowledge base created by experts in the field. These approaches can be used to improve the strategic analysis of sports situations either outside of, or at a distance from the action. Furthermore, this type of simulator does not require the user to participate in the action but is rather concerned with the graphical quality of the environments or the conformity of the produced behaviours. The autonomy of the agents and the evolution of this kind of simulation are limited.

Virtual reality simulation for immersion in sports settings

When the aim is to immerse the human user within a believable virtual environment, simulators attempt to produce virtual agents with a certain degree of autonomy. Video games can therefore provide very effective simulations. The TeamVision system from Konami, for example, is an adaptive artificially intelligent system for Pro Evolution Soccer 2008. The creators of the game FIFA 2008 (*Fédération Internationale de Football Association*) refer to a system evaluating up to thirty action options at any given time as an opportunity map. In the current state of affairs, the achieved behaviours are realistic, as they are due to the relative autonomy of the virtual players. The choices are made by each agent independently of a metamodel. However, these simulations often lack evolution in terms of behaviours, and interactions can be limited by the options programmed into the system. Sanza *et al.* (1999) present a football simulator called ***NeViS*** (*Networked Virtual Soccer)* enabling interaction between humans and virtual agents. The agents' behaviour is guided by a classifier system. The virtual agents can practice their interactions together in order to learn (to select) new winning strategies. The classifier system implements reinforcement learning from an "action-condition" set of rules. Each rule can be evaluated according to the quality of its attributes. The system inspects the environment, selects one of the applicable rules, and carries out an action as a result of these rules. The chosen rule may be reinforced, depending on the result (compensation). The rules can be combined using genetic algorithms to create new laws. This computational modelling allows for a good deal of evolution in the agents' behaviours. However, Sanza *et al.* (1999) highlight the fact that, as the new rules are generated randomly, they create valuable behaviours, but sometimes, these behaviours which are absurd in terms of suitability in sports settings. Research into the believability of behaviours is essential if these simulations are to be considered significant by experts in the field. Indeed, this requirement is crucial for players to be able to transfer real skills to virtual situations (Bossard *et al.,* 2008). Walls *et al.* (1998) present an experiment with a sailing simulator. The simulator reproduces the bridge of a boat, held up by two supports and dynamically controlled by the computer. The visual elements of the manoeuvres such as steering, or adjusting the sails, are extremely realistic. Having familiarized themselves with the simulator, competent sailors complete a 1km race into a headwind, aiming to complete the race in the fastest time possible. The ranking of each subject on the simulator was then compared to their ranking in other competitions. The results confirmed the possibility of transferring decisional skills from reality to the virtual and, as a consequence, they reinforce the believability of the environment.

Simulations aiming to immerse users in sports settings thus require autonomous agents whose behaviour evolves, in order to produce believable virtual situations.

2. A User-centered Virtual Reality Simulation: the CoPeFoot project

We here present a user-centered design approach to virtual environments which is unique in that it is based on close collaboration between computer science researchers and researchers in sports science. This collaboration is founded on four stages, explained separately here, but which constitute an interactive process: 1) an analysis of the experts' activity is conducted in a naturalistic football setting (reality); 2) this analysis fuels the choice and implementation of computational models to improve the virtual agents' behavioural believability; 3) the result obtained, the VE, is used to engage in simulations (pairing subjects with the environment) and to improve the implemented computational model; 4) the believability of the virtual agents' behaviour and the simulator are evaluated using the simulation itself.

Modelling tactical decisions in naturalistic settings.

Unlike "anthropomorphic" simulations (Burkhardt, 2007), the aim of our design approach to virtual environments is not to reproduce reality but to make the situation as believable as possible. In order for the simulation to be considered believable, agents need to be relatively autonomous, and the designer therefore needs a model for this autonomy. Each virtual entity must be able to make choices according to its past experience, its state, its perceptions and the possible actions it can execute, so that its behaviour appears coherent and unique. The role of the sports science researcher would be to participate in making these choices while this agent model is being defined. Although knowledge acquired from analyzing actions is starting to be utilized in the context of training settings (Ria *et al.*, 2006), their use in simulation settings making the most of virtual reality techniques remains largely unexplored. In order to simulate a counter attack in football, we wanted to model the tactical decision of players from a naturalistic study.

Using the NDM (Naturalistic Decision Making) approach, which examines the relationship between user and context, we considered the tactical decision to be a process of recognition of spatiotemporal configuration (Klein, 2008). This link can be described as a "cognitive package" (Ross *et al.*, 2006, p. 406), a set of elements relevant to the user. These elements are recognized as relevant and represent significant relationships as they are perceived from a background structure deriving from experience. From our hypothesis, this functional structure for recognizing and reacting seems to refer back to the concept of schemata (Piegorsch *et al.*, 2006).

In order to contribute to the empirical validation of this approach within the context of team sports, we tested a counter attack situation in football. Behavioural data was recorded from 12 national level football players (under 16s) supplemented by verbal data collected during self-confrontation interviews. Analyzing decision-making activity allows us to define activities and the most likely sequences (i.e. possible scenarios) of 16 schemata from experts in situations with tight time constraints. These schemata represent underlying structures which link perceptive and cognitive elements, and facilitate the recognition of situations during a counter attack.

Choosing and implementing computational models

The second stage of the design process consisted of working on narrowing the gap between the decision-making model for tactical recognition of relevant configurations (Bossard, 2008) and computational models. In fact, two computational models were required in order to obtain what we refer to as a simplified analogy: a problem-solving model (Case Based Reasoning; Aamodt & Plaza, 1994) and a context representation model (Kokinov, 1995).

The CBR (Case Based Reasoning) model is based on the hypothesis that a perceived problem (development) can be solved successfully by referring to past experience. Finding a solution depends on identifying the experience which best fits the current situation, within all the cases encountered in the past (recall). Each case thus represents an action potential which is defined according to its context (adaptation). This ability to adapt is one of CBR's most encouraging features as the solutions found in the base are not applied directly but are rather adapted to fit a specific context. The base set of cases acts as a guide and does not dictate the responses. This model stems from frames theory (Minsky, 1975), which are similar to schemata concepts. The schemata can be adapted due to contextual representation.

Contextual representation originates from the model developed by Kokinov (1995). According to the dynamic theory of context, if the context of a decision is always general, we can distinguish its component dimensions through analysis and representation. He thus identifies internal and external context. External context refers to the physical properties of the situation, the elements that could be said to be objective from an exocentric point of view. Internal context is defined as the active state of an agent's cognitive system at a given moment *t*. These are the elements to which the agent will refer in order to make a decision: the context as perceived from an egocentric point perspective. From this initial distinction, the context of a CoPeFoot agent is then divided into a number of sub-contexts. The external, or environmental, context groups together all of the physical elements of the situation. Internal context is a representation of the agent's skills, or a representation of the agent's state, i.e. fatigue. Each sub-context is made up of a set of perceptions which, once assembled, form the context of the agent within the situation. This context-free representation has two roles. The first is to facilitate contextualised decision-making (figure 1); for each agent, the context is thus an active filter which generates the situation in progress. The second role is to authorise the graphical visualisation of each perception and context.

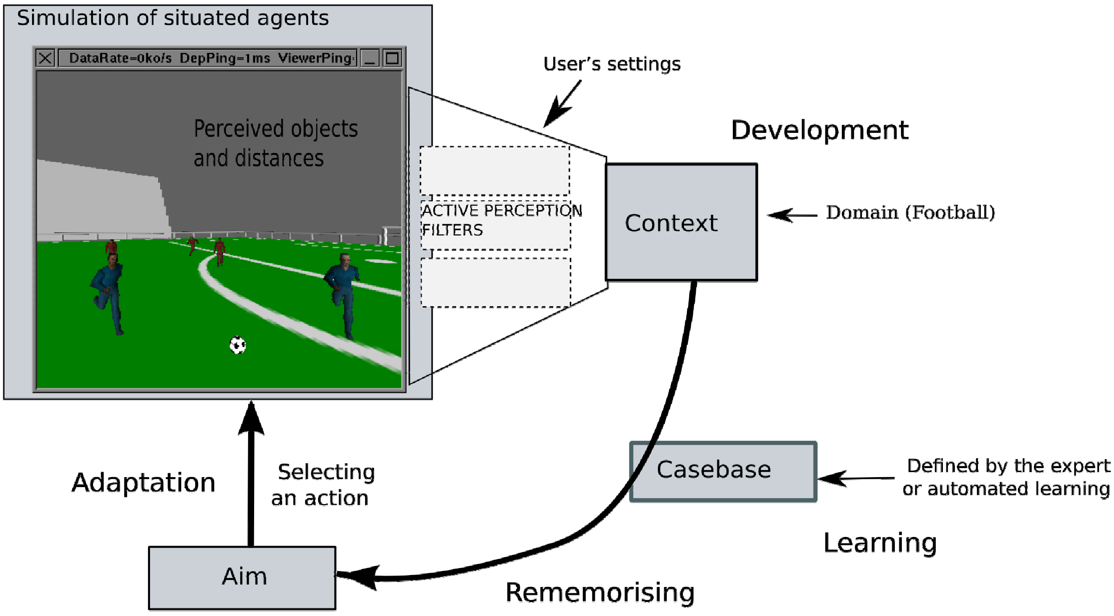

Figure 1. The computer-generated CBR and Context model (Bénard, 2007)

Using these two computational models, we can conduct a simplified analogy between a representation of the tactical decision, from a social-science perspective, and that of the autonomous virtual agents' decision-making, from a computer science perspective. Above all, we are trying to avoid contradiction between a tactical decision model in football and an autonomous virtual agent model.

Simulations and enhancing computational models.

In order to improve the behavioural believability of the virtual agents, the computational model can be assigned evolution possibilities. We considered the evolution of the agents' behaviour according to three categories which can be positioned on three levels:

1) First level: the empirical model stemming from the analysis of human activity is used (applied) in order to enhance the set of cases and to define the agents' perceptions in context. In this respect, the description of expert footballers' typical schemata constitutes an information base for computer science researchers. The computer program limits actions: there is explicit learning or learning through instructions.

2) Second level: the computational model is enhanced through use. Within CoPeFoot, an interaction is proposed: the users click on the zones of the context they find relevant. Contextual information is reified by symbols indicating distance from the target, teammates and opposition players; symbols indicate whether or not teammates are marked or open.

Figure 2: Representation of an agent's perceptions in context: exocentric perspective.

Thanks to the benefits offered by augmented virtuality, the user defines the action's significant elements. The information provided by the users, when they click on these elements, is used to revise the weighting associated with each contextual element according to an algorithm described in Bénard (2007). The computer program has only partial control of actions: learning is linked to the agents' imitation of the users' perceived behaviours.

3) Third level: enhancement is a result of the simulation. The computational model records the new cases which occur during interaction. The “case tree” expands in order to offer the virtual agents new possibilities in terms of actions. The computer program has very little control of actions: learning is implicit.

This stage of the design process of an interactive simulation demonstrates the importance of the models’ evolution, which in turn enables the behaviours arising from that simulation to evolve.

Experimentation and simulation validation

The believability of a simulation is not easy to evaluate. Some simulators are tested in terms of skills transfer (for a complete review of these tests, see Bossard *et al.,* 2008). The transfer of skills from the virtual to reality is considered as a measure of the VE’s success as a training tool. Some experimental studies have shown effective skills transfer (Rose *et al.*, 2000), while others have shown less significant results (Kozak *et al.*, 1993). These evaluations, which are carried out after the study, do not participate in designing the virtual environment and therefore are not used to modify the computational model. In order to rectify this shortcoming, we implemented an exploratory *in virtuo* study which aimed to evaluate the behavioural believability of CoPeFoot during the design process. Inspired by the Turing test (1950), this experimentation tested the ability of a user to distinguish between players controlled by humans and autonomous virtual players. This “decoy effect” was studied by comparing two groups of subjects (experts and novices) during three consecutive measurements. Results show a more marked decoy effect for novices when compared to experts, and an improvement for both groups over time. These results show that our virtual agents seem to demonstrate acceptable believability. They also show a reduction of this believability over time, and highlight the importance of the evolutionary nature of computational models in ensuring these simulations remain believable.

3. Advantages of virtual reality simulation for training and research in sports sciences

Today, virtual reality provides a conceptual, methodological and experimental framework which is well adapted to imagining, modelling and experimenting complexity. Virtual reality simulations therefore allow real interaction with the modelled system. These simulations let us observe phenomena as if we had a virtual microscope which could be moved and oriented as we wish, with a choice of focal points. User can test the resistance of the implemented model (reactivity and adaptability). They become spectator-actor-creators as they can focus on observing a specific type of behaviour, a subsystem's activity or the overall activity of the system. The user can also interrupt the phenomenon at any time, accurately focus on the bodies present and the interactions underway, and then restart the simulation where it was stopped. This new kind of experiment is called *in virtuo* experimentation. Simulations in virtual reality allow the user to evolve with other users and/or virtual autonomous agents. Finally, users are "in situ" and "in action". Virtual reality fully involves the user in the simulation, which is closely akin to the participatory design approach preferring to consider users as human actors rather than human factors. Within this type of virtual environment, users must interact with autonomous agents and/or human team members. Various combinations of multiple human or virtual learners may be brought together for practice exercises.

Advances in virtual reality technologies can be used to enhance the acquisition of cognitive skills. As an example, to become progressively effective in a sport situation, the athlete must learn by acting. Putting the athlete into action can be expensive (in material terms) or risky (in human terms). This is the case when the aim is to learn how to act and react when faced with unpredictable events (like in team sports) or malfunctioning (material difficulties or psychological breakdown during competition). These problem-solving skills in dynamic situations are particularly difficult to deal with (uncertain, progressive and with strong time constraints) using the classical training approach of case studies, establishing general rules or instructions related to expected scenarios. On the contrary computer simulation makes it possible to immerse athletes in a VE where they can try things, choose, take initiatives, fail and try again. In virtual reality simulations, users can reconsider all previous research in order to study the operations induced by the sporting situation through the simulation. By confronting the athlete with more realistic environments than those traditionally used (i.e. pictures or videos), virtual reality allows, for example, to go from a mode of external or exocentric presentation to a mode of internal or egocentric presentation (Petit & Ripoll, 2008).

In conclusion, virtual reality simulations, as we developed them, allow the creation of game situations, which radically change the environments commonly used, in the perspective of both research and training. Of course, there is an obvious need for further investigation to acquire better and deeper understanding of the benefit of virtual reality simulations in sport. Loomis *et al.* (1999) have already highlighted the value of virtual reality technologies as a tool with high ecological validity that will greatly serve psychological research. We hope that, in view of this, sports science researchers will also be tempted by the new opportunities that virtual reality has to offer.

References

Aamodt, A. & Plaza, E. (1994). Case-Based Reasoning: Foundational Issues, Methodological Variations and System Approaches. *AI Commun*, *7*(1), 39-59

Alessi, S. (2004). Five keys to successful simulations. In Third International Sport Sciences Days, The analysis of elite performance in its contextual environment (pp. 141-143). Paris, INSEP.

Bénard, R. (2007). *Raisonnement en contexte pour la simulation participative et l'étude des situations dynamiques collaboratives. Une application au sport collectif*. [Reasoning in Context for Participatory Simulations and Studying Dynamic Collaborative Situations: An Application for Team Sports. (Doctoral thesis)] Thèse de doctorat, Université de Bretagne Occidentale.

Bideau, B., Kulpa, R., Ménardais, S., Fradet, L., Multon, F., Delamarche, P. & Arnaldi, B. (2003). Real Handball Goalkeeper vs. Virtual Handball Thrower. *Presence: Teleoperators & Virtual Environments*, 12(4), 411-421.

Bossard, C., Kermarrec, G., Buche, C. & Tisseau, J. (2008). Transfer of learning in virtual environments: A new challenge? *Virtual Reality*, 12, 151-161.

Burkhardt, J. M. (2007). Immersion, Representation and Collaboration in Virtual Reality: discussion and empirical perspectives in cognitive ergonomics. *Intellectica*, 45(1), 59–87.

Cobb, S. V. G., Neale, H. R., Crosier, J. K., & Wilson, J. R. (2002). Development and evaluation of virtual environments in education. In K. Stanney (Ed.), *Virtual environment technology handbook (pp 911-936)*: Lawrence Erlbaum Associates Inc.

Ensor, J. R., Carraro, G. U., & Edmark, J. T. (2000). Accommodating performance limitations in distributed virtual reality systems. *Computer Communications*, 23(3), 199–204.

Huffman, R. K. & Hubbard, M. (1996). A motion based virtual reality training simulator for bobsled drivers. Dans Haake, S., (Eds), *The Engineering of Sport*, pages 195–203.

Kelly, A. & Hubbard, M. (2000). Design and construction of a bobsled driver training simulator. *Sports Engineering*, 3(1):13–24.

Klein, G. (2008). Naturalistic Decision Making, *Human Factors*, 50(3), 456-460.

Kokinov, B. (1995). A Dynamic Approach to Context Modeling, *IJCAI'95 Workshop on Modeling Context in Knowledge Representations and Reasoning*, IBP, LAFORIA 95/11, Paris.

Kozak, J.J., Hancock, P.A., Arthur, E.J., & Chrysler, S.T. (1993). Transfer of training from virtual reality. *Ergonomics*, 36(7), 777–784.

Loomis, J. M., Blascovich, J. J. & Beall, A. C. (1999). Immersive virtual environment technology as a basic research tool in psychology, *Behavior Research Methods, Instruments, & Computers, 31*(4), 557-564.

Mester, J. (1999). Biological response to vibration load. *Abstract of the XVIIth congress of international society of Biomechanics*, p32. Calgary,Alberta: ISB.

Metoyer, R. & Hodgins, J. (2000). Animating athletic motion planning by example. *Graphics Interface*, pp 61–68.

Minsky, M. (1975). A framework for representing knowledge. In Winston, P.H. (Eds), *The Psychology of Computer Vision*, pages 211–277. McGraw-Hill, New York.

Petit, J-P. & Ripoll, H. (2008). Scene perception and decision-making in sport simulation: A masked priming investigation. International Journal of Sport Psychology, 39(1), 1-19.

Piegorsch, K.M., Watkins, K.W., Piegorsch, W.W., Reininger, B., Corwin, S.J., & Valois, R.F. (2006). Ergonomic decision-making: A conceptual framework for experienced practitioners from backgrounds in industrial engineering and physical therapy. *Applied Ergonomics*, 37, 587–598.

Ria, L., Leblanc, S., Serres, G. & Durand, M. (2006). Recherche et formation en « analyse des pratiques » : un exemple d'articulation. [Research and Training in "practical analysis": an example of articulation.] *Recherche et Formation*, 51, 43–56.

Ripoll, H. , Le Troter, A., Baratgin, J., Mavromatis, S., Faissolle, M., Zmilsony, F., Poplu, G., Petit, J.P., & Sequeira, J. (2004). The interest of simulation for research and training in sport: the exemple of football. Third International Sport Sciences Days*, The analysis of elite performance in its contextual environment*, Paris, INSEP, pp. 147-148.

Rose, F.D., Atree, E.A., Perslow, D.M., Penn, P.R., & Ambihaipahan, N. (2000). Training in virtual environments: transfer to real world tasks and equivalence to real task training. *Ergonomics*, 43(4), 494–511.

Ross, K. G., Shafer, J. L. & Klein, G. (2006). Professional judgments and "naturalistic decision making". In Ericsson, K. A., Charness, N., Hoffman, R. R. & Feltovich, P. J. (Eds): The Cambridge Handbook of Expertise and Expert Performance (pp 403–419). Cambridge University Press, Cambridge.

Sanza, C., Panatier, C., & Duthen, Y. (1999). Adaptive behavior for cooperation: a virtual reality application. In USA, I., Ed, RO-MAN'99, 8th *IEEE International Workshop on Robot and Human Interaction*, Pise, Italie, pages 76–81.

Sebrechts, M. M., Lathan, C., Clawson, D. M., Miller, M. S., & Trepagnier, C. (2003). Transfer of Training in Virtual Environments: Issues for Human Performance. In Hettinger, L. J. & Haas, M. W. (Eds), *Virtual and Adaptive Environments: Applications, Implications and Human Performance Issues* (pp 67-90). Lawrence Erlbaum Associates, Mahwah: NJ.

Todorov, E., Shadmehr, R., & Bizzi, E. (1997). Augmented feedback presented in a virtual environment accelerates learning of a difficult motor task. *Journal of Motor Behaviour*, 29(2), 147–158.

Turing, A.M. (1950). Computing machinery and intelligence. *Mind*, 59, 433–460.

Walls, J., Bertrand, L., Gale, T., & Saunders, N. (1998). Assessment of upwind dinghy sailing performance using a virtual reality dinghy sailing simulator. *Journal of science and medicine in sport,* 1(2), 61–71.

Ziane, R. (2004). *Contribution à la formation des entraineurs sportifs, caractérisation et représentation des actions de jeu : l'exemple du basket-ball.* [A Contribution to Training Sports Coaches, and to Characterising and Representing Actions from Sports: The Example of Basketball. (Doctoral Thesis)] Thèse de doctorat, ENS Cachan.