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Teleoperators and Virtual Environments

Influence of the graphical levels of detail of a virtual thrower on the perception of the movement

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Abstract

Virtual reality has a number of advantages for analyzing sports interactions such as the standardization of experimental conditions, stereoscopic vision and complete control of animated humanoid movement. Nevertheless, in order to be useful for sports applications, accurate perception of simulated movement in the virtual sports environment is essential. This perception depends on parameters of the synthetic character such as the number of degrees of freedom of its skeleton or the levels of detail (LOD) of its graphical representation. This study focuses on the influence of this latter parameter on the perception of the movement. In order to evaluate it, this study analyzes the judgments of immersed handball goalkeepers that play against a graphically modified virtual thrower. Five graphical representations of the throwing action were defined: a textured reference level (L0), a non-textured level (L1), a wire-frame level (L2), a moving point light display (MLD) level with a normal-sized ball (L3) and a MLD level where the ball is represented by a point of light (L4). The results show that judgments made by goalkeepers in the L4 condition are significantly less accurate than in all the other conditions (p<0.001). This finding means that the goalkeepers' perception of the movement is influenced more by the size of the ball during the judgment task than the graphical LOD of the throwing action. The MLD representation of the movement thus appears to be sufficient for a sports duel analysis in virtual environments.

1. Introduction

Virtual reality is starting to be used more frequently as a means of understanding sports performance in athletes (Capin, Pandzic, Noser, Magnemat-Thalmann & Thalmann, 1997; Kelly & Hubbard, 2000; Bideau et al., 2003; Craig, Berton, Rao, Fernandez & Bootsma, 2006; Craig et al., 2009). Indeed, this tool offers several advantages over traditional methods for situational analysis in sports (Bideau et al., 2009): namely reproducibility between trials (Tarr & Warren, 2002), complete control of virtual environment and characters (Bideau et al., 2004) and presentation of the visual scene from the subject's view point (egocentric) and not that of an allocentrically positioned camera (e.g. spectator position) (Sheridan, 1992; Petit & Ripoll, 2008). In spite of these advantages, using virtual reality as a sports analysis tool does raise new questions. One of the most important is the perception of the movement of synthetic humanoids by the immersed athlete. This perception depends on parameters of the synthetic character such as the number of degrees of freedom of its skeleton or the levels of detail (LOD) of its graphical representation. This study focuses on the influence of this latter parameter on the perception of the movement. The final goal is to determine if there is a threshold on the graphical LOD that ensures that virtual reality can be used for sports applications.

2. Related Works

Several studies have been carried out on the visual LOD of a movement. In 1973 Johansson demonstrated that humans have the ability to accurately identify actions with limited visual information (Johansson, 1973). In these landmark experiments observers could only see points of light attached to strategic body parts as an actor performed an action and were subsequently named moving point light displays (MLD). The results from these experiments showed that in spite of the impoverished visual information, human observers were still able

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to accurately identify the action being performed. These findings suggest that the human visual system is highly sensitive to biological motion and is therefore capable of extracting relevant information from the dynamic spatiotemporal patterns of the moving point light displays (MLD). The perception of biological motion has since been thoroughly investigated and findings show that humans can reliably perceive gender (Kozlowski & Cutting, 1997), recognize individuals (Cutting & Kozlowski, 1977), categorize actions and motion types (Dittrich, Troscianko, Lea & Morgan, 1996) from moving point-light displays alone.

In sport it has also been demonstrated that biological motion information picked up from moving point light displays (MLD) plays an important role in anticipation (Williams & Elliot, 1999). For example, the MLD method has been used in different activities such as squash (Abernethy, Gill, Parks & Packer, 2001) and tennis (Shim, Carlton, Chow & Chae, 2005) in order to evaluate differences in perceptual anticipation between novices and experts. This kind of studies revealed that players are able to extract movement information in both video and point-light displays (Shim, Carlton & Kwon, 2006; Ward, Williams & Bennett, 2002). In computer animation, Hodgins and colleagues (1998) have also demonstrated that perception of motion is influenced by the geometric model (polygonal or stick) used for rendering (Hodgins, O'Brien & Tumblin, 1998). It should be noted however that all of these studies have been carried out only using two-dimensional displays. Carrying out complementary studies that use stereovision to assess the role of depth related visual information (Slater, Linakis, Usoh & Kooper, 1996) are however necessary.

Stereoscopic vision and head tracking are immersion factors commonly used in virtual reality (Hendrix & Barfield, 1996). These two elements are also associated to presence (Sanchez-Vives & Slater, 2005). In fact, the terms immersion and presence are often confused in the

literature. There are two main approaches to define these notions. In the traditional approach, the concept of immersion refers to the objective level of sensory fidelity a virtual reality system provides. In that sense, immersion is defined as "the technical capability of the system to deliver a surrounding and convincing environment with which the participant can interact" (Sanchez-Vives & Slater, 2005). Immersion is objective and measurable – one system can have a higher level of immersion of another. Consequently, the degree of immersion can be measured independently of the human experience that it engenders (Sanchez-Vives & Slater, 2005).

The traditional approach has also considered the concept of presence as the human response to the virtual reality system. More precisely, this phenomenon is defined as the subjective feeling of "being there" (Sanchez-Vives & Slater, 2005). Slater et al. (2009) said that "presence refers to how realistically participants respond to the environment as well as their subjective sense of being in the place depicted by the VE" (Slater, Khanna, Mortensen & Yu, 2009). The level of presence can be evaluated in different ways. The first methodology concerns the measure of presence using questionnaires (Witmer & Singer, 1998). As this kind of evaluation is subjective, an alternative methodology is to look for objective measures that quantify physiological, optical or physical changes in behaviour. Performance during a motor task can then be considered as one of these physical measures (Slater et al., 1996; Slater et al., 2009). This concept has been applied in sport. Indeed, Bideau et al. (2003) compared the movement of handball goalkeepers during the parry of the same throws made by real and virtual opponents. The results showed that the goalkeepers' gestures in both environments were similar. However, equivalent motor response does not imply the presence of the subject. Indeed, he can act the same way even if he feels far from being there. The objective evaluation is then correct while the subjective one obtained by questionnaire is not good. In

that case, Bowman and McMahan (2007) told about the evaluation of the "immersion's effects" instead of the evaluation of presence. Our study can then be considered as a contribution concerning the importance of an effect of immersion: the LOD of a virtual character.

The realism of the visual elements displayed in a virtual application is a key point for immersive systems. In the field of sport, Ma and Kaber (2006) have analyzed a range of synthetic environment design features suspected to influence athlete's perception in a virtual-reality-based basketball free-throw task (Ma & Kaber, 2006). Virtual viewpoint, auditory cue type and visual background were manipulated to see their relative influence. The results demonstrated that viewpoint and auditory cue type significantly impact actors' perception. The authors noticed that their results do not support those of Barfield et al. in which an increase in the degree of visual realism of a synthetic environment implies an increased level of presence (Barfield, Hendrix & Bjorneseth, 1995). On the whole, studies about the influence of the visual realism of the images on the perception did not found any consensus (Slater, Usoh & Chrysanthou, 1995; Welch, Blackmon, Liu, Mellers & Starcks, 1996; Usoh, Catena, Arman & Slater, 2000; Zimmons & Panter, 2003; Sanchez-Vives & Slater, 2005). Nevertheless, recent studies seem to demonstrate a positive relationship between the realism of the image and the phenomenon of presence (Khanna et al., 2006; Slater et al., 2009). Note that all these studies were focused on the visual realism of the background in a virtual environment whereas our study is interested in the influence of the LOD of a virtual handball thrower and the ball on perception.

Nevertheless it is important to consider the "uncanny valley" concept when studying the influence of graphical LOD of humanoids in a virtual environment. This concept shows that

in any type of human-like object, the graphical representation of the character generates an unpleasant impression for the viewer if this representation is excessively close to the human appearance but not realistic enough (Seyama & Nagayama, 2007). It is then important to determine the minimal LOD of humanoids that provides all the needed information about its movement. And even with the increase of computer capabilities, going beyond the "uncanny valley" is a challenging task and before this goal can be reached, all the future level of details of characters must be compared to simpler ones that are before the gap of the "uncanny valley". To this end, in this paper we investigate the effects that different graphical LODs of a throwing movement can have on the performance of immersed handball goalkeepers.

3. Overview

In order to evaluate the influence of the graphical LOD of character and ball on the handball goalkeepers' perception, we developed a three-step process (see Figure 1):
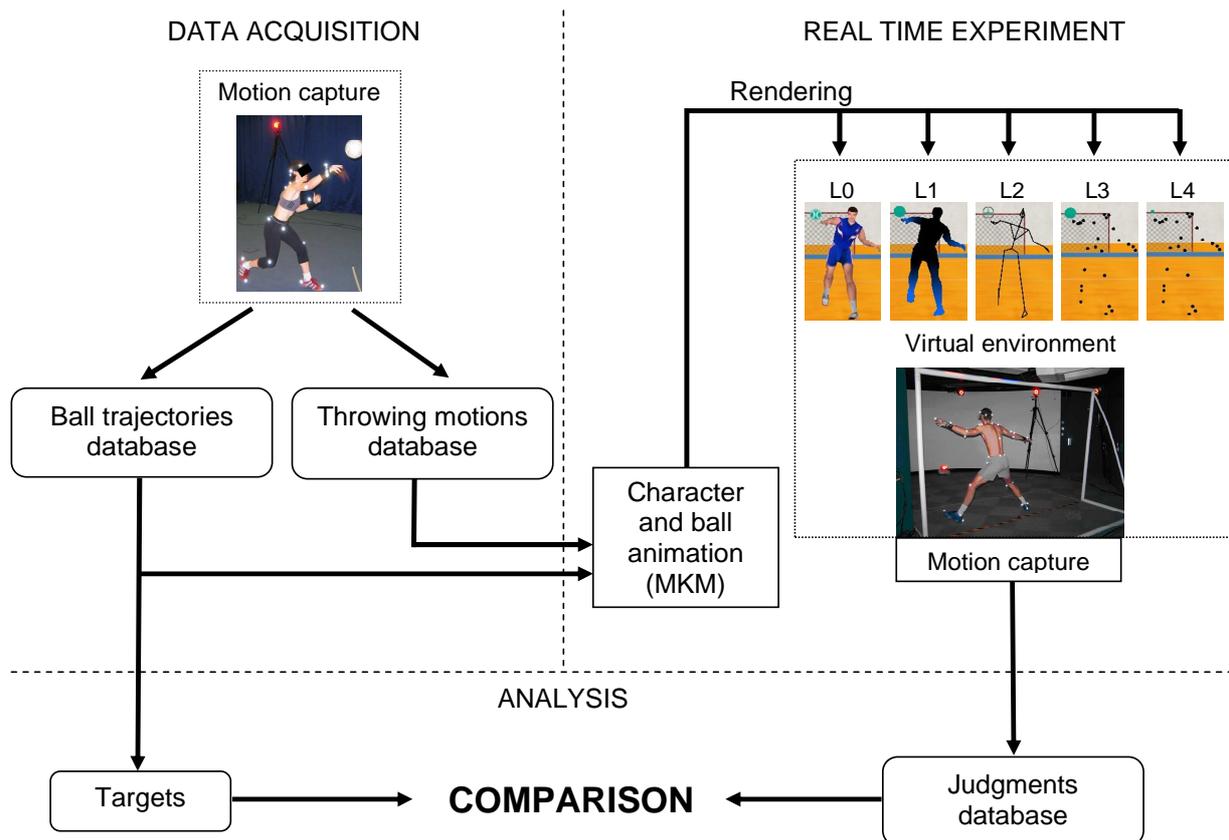
Figure 1: Three-step process: data acquisition; real time experiment that includes motion animation, motion degradation and motion capture; performance comparisons.

- First of all, to realistically animate the synthetic thrower and the ball in the virtual environment, we captured real throwing actions. This led to the creation of a large motion database with throws to various places in the goal.

- Secondly, these captured throws were used by the MKM animation engine (Kulpa, Multon & Arnaldi, 2005; Multon et al., 2008) in order to realistically animate the virtual characters. The rendering of these animations was done with five different LODs.

- Finally, the movements of the goalkeepers were captured in real time. These data were then analyzed to determine which responses were successful.

4. Motion capture and animation process

Throwing movements of top-level handball players were recorded using a VICON motion capture system (Oxford Metrics). The participant and ball movements were captured at 200Hz using 12 infrared cameras. Thirty reflective markers were placed on key anatomical landmarks on each participant. The players were asked to throw the ball 12 meters from the goal aiming at different pre-specified target zones within the goal (no goalkeeper was present).

These captured motions were then used to animate the virtual thrower using the animation engine MKM (Manageable Kinematic Motions) (Kulpa et al., 2005; Multon et al., 2008). This engine has already been used and validated for the animation of movements during a sporting duel (Bideau et al., 2004) and it offers the following capabilities: motion synchronization, blending, retargeting, and adaptation thanks to an enhanced inverse kinematics and kinetics solver (Multon et al., 2008).

5. Evaluation of the perception of movement

After animating the handball throwing actions, 12 handball goalkeepers (playing in first division and at national level) were placed in the virtual environment (see Figure 2).

Figure 2: A handball goalkeeper immersed in the virtual environment.

They all gave their informed consent before participating in the experiment. Mean participant age, height and hand length were 23.2 years (± 4.2 years), 1.85 m (± 0.06 m) and 20 cm (± 0.8 cm) respectively. All participants had normal vision. Three synchronized video projectors (Barco 1208S) driven by an SGI Onyx2 Infinite Reality system were used to project the 3D sports hall environment onto a large cylindrical screen (3.80m radius, 2.38m height and 135° field of vision). Stereoscopic glasses were activated at 60 Hz (30 Hz for the right eye and 30 Hz for the left eye) and synchronized with the system in order to give stereovision. The VICON motion capture system was used to record the goalkeeper's movement during the experiment and also to automatically change his point of view (head-tracking). In order to enhance the feeling of presence, a real goal was placed behind the goalkeeper at the corresponding position of the virtual goal in the virtual handball stadium.

Five graphical LODs of a virtual thrower were tested (see Figure 3):

- L0: a first LOD that defines the reference textured level as presented in (Bideau et al. 2004) (see Supplementary material video0.mpg),

- L1: a second LOD similar to L0 but without texture on the synthetic thrower and ball (see Supplementary material video1.mpg),

- L2: a third LOD based on a wire-frame representation (see Supplementary material video2.mpg),

- L3: a fourth LOD using a MLD representation with 25 points of light (see Supplementary material video3.mpg),

- and L4: a fifth LOD similar to L3 but where the size of the ball was significantly reduced. In this latter condition the size of the ball corresponded to the size of a point of light (cf. video4.mpg).

It can be noticed that the reference textured level provides a sufficient degree of presence as suggested in Bideau et al.'s study (Bideau et al., 2003). In that way, if the performance in a level is similar to the performance in the L0 level, the former level can be rated as a sufficient level of graphical representation in terms of the degree of presence and behavioral realism.
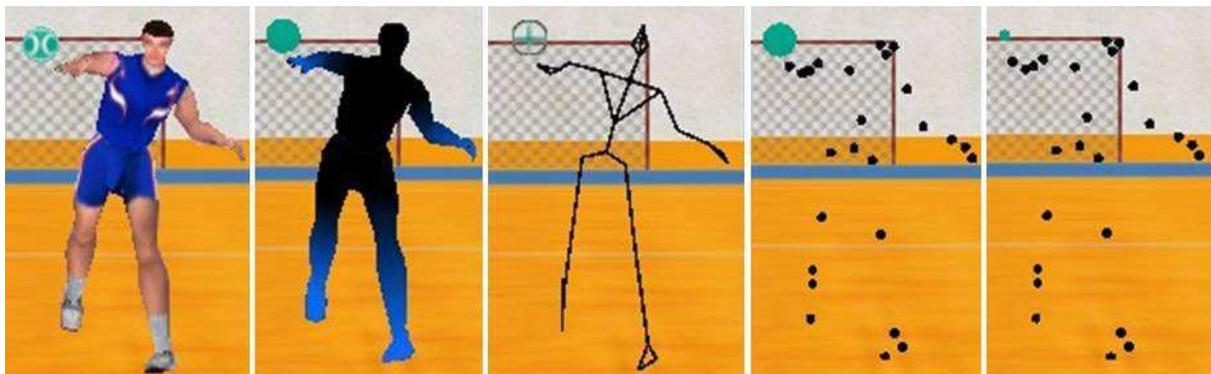
Figure 3: Graphical LOD of the thrower/ball representation. From left to right, conditions L0, L1, L2, L3 and L4 are represented.

The goalkeeper viewed all throws with different graphical LODs in a randomized order. The ball was released when the virtual thrower was 12 meters from the goalkeeper and a cut-off was applied in order to make the ball disappear at 6 meters from the goal. Ball velocities were similar for the three trajectories (20 ± 0.2 m.s^{-1}). The goalkeeper was asked to predict where

he thought the ball would end up by placing his hand at the correct position in the goal. We encouraged the goalkeeper to make his decision as quickly as possible. The goalkeeper's final hand position was recorded using the VICON motion capture system for each trial. The goalkeepers were equipped with 11 optoelectronic markers: four on their head for head tracking, three on their right hand and four on their left hand (including a dissymmetrical marker needed for the right-left hand distinction). The markers were placed on the hands in such a way that the central position of the hand could be easily calculated.

A total of three different trajectories were presented for the five LODs: upper left, mid right and lower left of the goalkeeper. The goalie hand considered for the error evaluation was respectively the left hand for throws at upper left and lower left and the right hand for throws at mid right. The three different ball trajectories were randomly repeated five times for each LOD. A total of 75 throws (3 trajectories × 5 repetitions × 5 LODs) were displayed. We also randomly included 10 other throws to different target locations in the goal to avoid goalkeepers becoming habituated to the arrival position of the ball in the goal. Each participant had a training period to allow them to become familiar with the environment and the task. During this time the participants were randomly presented with four new throws for each of the displays depicting the various graphical LODs. Trials in the training period were not included in the subsequent analysis.

6. Results

Data were analyzed using analyses of variance on dependent variables after examination of normality distribution (Kolmogorov–Smirnov test) and equal variances (Levene's test). Post-hoc comparisons were conducted with Tukey's HSD test. The limit of significance was set to $p < 0.05$.

The first part of the analysis looks at how the different graphical LODs influenced the participants' prediction about the final position of the ball in the goal. To estimate successful judgments, the hand and the ball were both represented by spheres (see Figure 4) for the purposes of analysis. A judgment was considered successful if the sphere around the hand made contact with the ball at its arrival position in the goal.
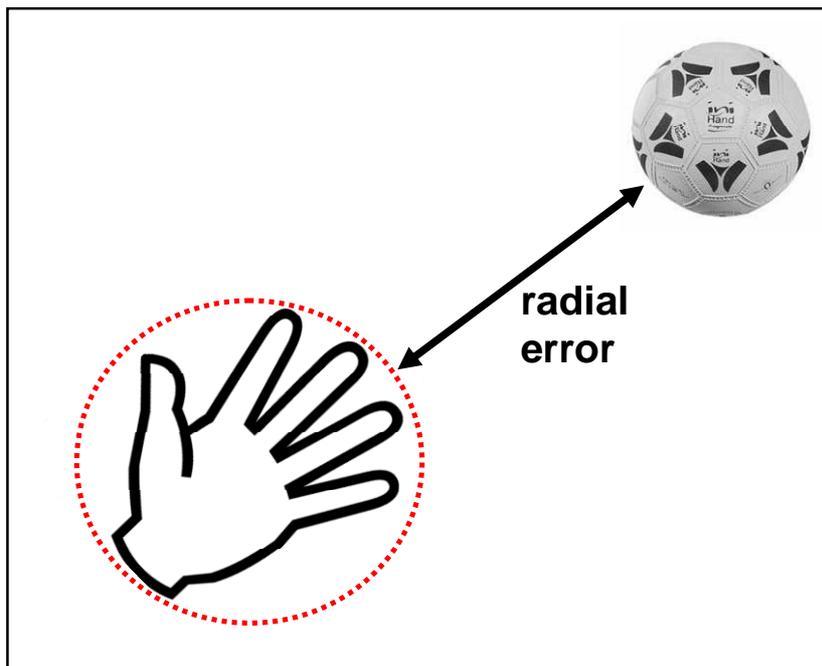

Figure 4: A schematic representation of the radial error (i.e. the distance between the virtual ball and the real goalkeeper's hand).

The mean percentage of correct trials shows that there is no statistical difference between the different graphical LODs (see
Figure 5). The only noticeable difference lies between L4 and the other four LODs

(L0=22.2%±4.7; L1=22.8%±5.2; L2=20.4%±5.7; L3=20%±3.3; L4=12.5%±5.6).

Nevertheless, this difference was not found to be significant according to a two-way repeated measures analysis of variance ($F_{(4,88)}=2.368$; $p=0.067$). Moreover, there was no significant

influence of the LOD on the mean percentage of correct trials into each of the three zones aimed.
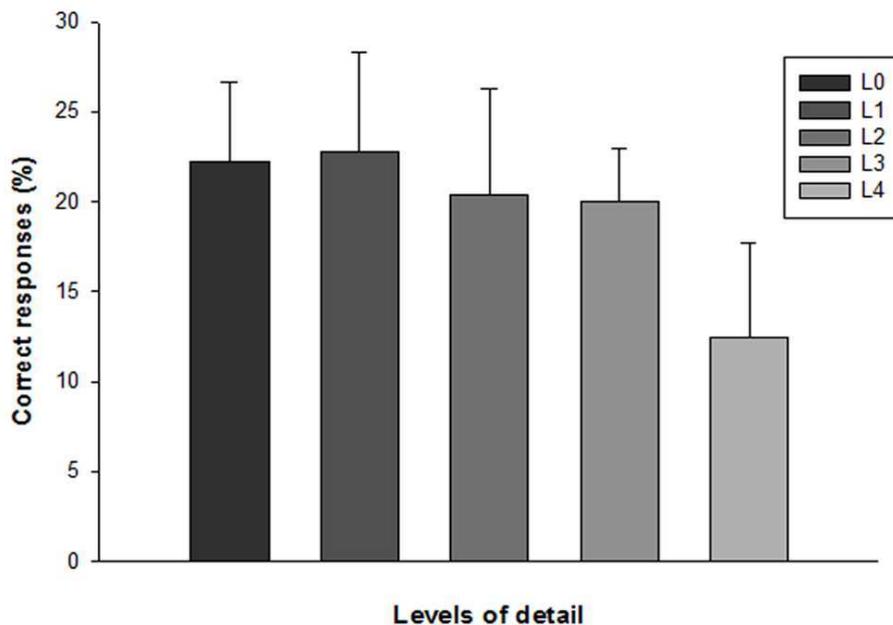

Figure 5: Mean percentage of correct responses for all goalkeepers and for each of the different graphical LOD. The error bars represent the standard deviations for each of the conditions.

In the second part of the analysis, a repeated measures analysis of variance revealed however a significant difference for the radial error between the different graphical LODs ($F(4,84)=12.187$; $p<0.001$). A Tukey HSD post-hoc analysis shows that the radial error for L4 was significantly greater than all the other conditions (L0=36.1cm±2.5; L1=33.9cm±2.7; L2=35.2cm±3.4; L3=35cm±2.9; L4=54.2cm±2.9) (see Figure 6). Besides, there was a significant influence of the LOD on the radial error into the mid right zone (L0=39.6cm±2.8; L1=37.9cm±3.3; L2=41.1cm±2.9; L3=38.5cm±2.6; L4=61.7cm±3.1) and into the lower left zone (L0=35.7cm±2.5; L1=30.3cm±3.1; L2=32.8cm±2.7; L3=30.3cm±2.9; L4=63.4cm±3.2).

This influence was also characterized by a significant difference between L4 and all the other LOD in both zones ($p<0.001$). However there was no significant influence of the LOD on the radial error into the upper left zone (L0=32.9cm±2.5; L1=33.4cm±3.1; L2=31.5cm±2.6; L3=36cm±2.8; L4=37.5cm±3.2)
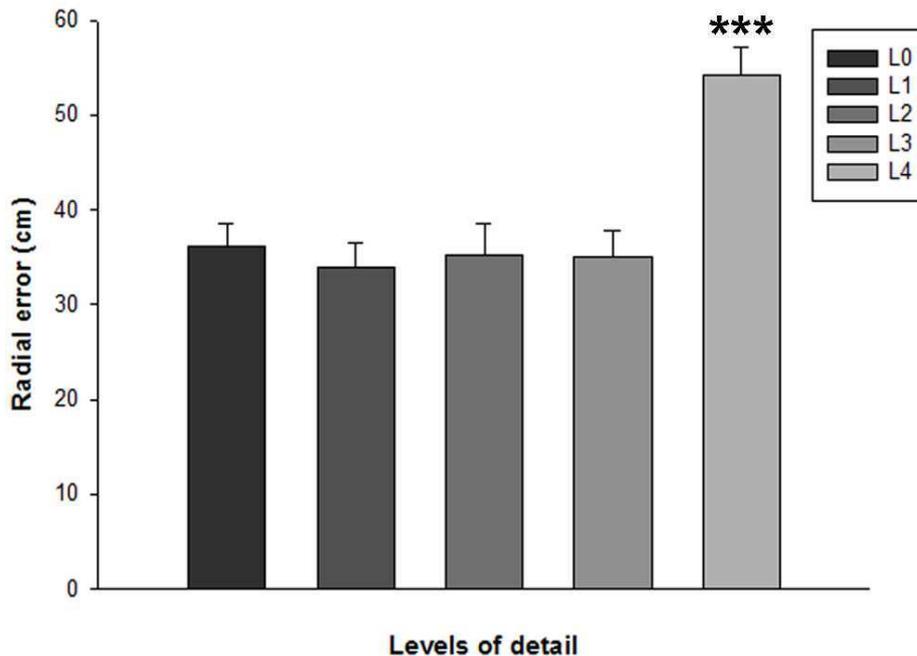
Figure 6: Mean radial errors for all goalkeepers and for each graphical LOD. L4 was found to be significantly greater than all the other LODs (***p<0.001).

Discussion

This paper aims at studying the influence graphical LOD of a virtual thrower and ball have on a goalkeeper's perception of the realism of a simulated movement. Perception in this case was evaluated by quantifying the goalkeeper's judgments about the final position of the ball in the goal.

The results show that the first four graphical LOD (L0, L1, L2 and L3) do not significantly affect the goalkeepers' judgments. As the first graphical level L0 corresponds to a sufficient-for-presence LOD for the handball goalkeeper (Bideau et al., 2003), we can conclude that the

impoverished graphical levels L1, L2 and L3 are able to induce a sufficient level of presence. This statement agrees with Ma and Kaber (2006) who showed that a streamlined visual background does not significantly influence the level of presence. As L3 is the simplest of the four LODs, it means that an MLD representation of the movement can induce a sufficient level of presence in this virtual environment.

These results are very relevant when considered in light of other research in this area. Indeed previous studies that have looked at the effects of the graphical LOD in motion recognition tasks (Bobick & Davis, 1996) have shown that poor motion representations are still sufficient to accurately recognize actions. For example, Ahlström et al. have shown that it was easier to identify a walker in an MLD representation than in a blurred video representation (Ahlström, Blake & Ahlström, 1997). Other studies have also shown how personal characteristics pertaining to individuals can also be picked up through MLD representations, such as Stevenage et al. (1999) who have demonstrated how gait patterns represented in a MLD display can be used to reliably predict identity of the walker (Stevenage, Nixon, & Vince, 1999). In other words, the spatiotemporal pattern of the movement of point of lights attached to the body parts reliably reproduces the key informational elements necessary to determine identity. All these studies used only 2D displays and usually involved action recognition. Using 2D displays instead of 3D displays may introduce a methodological bias particularly in studies interested in perception (Hendrix & Barfield, 1996). Moreover, other studies have shown how the additional motion-in-depth information provided by 3D displays improves perception of action (Beintema, Oleksiak & Van Wezel, 2006; Mazyn, Lenoir, Montagne & Savelsbergh, 2004). This study shows that an MLD representation can be sufficient to perceive movements even in stereoscopic virtual environments.

In this paper, both thrower and ball representations were modified to correspond to different graphical LODs. The only significant difference was found between level 4 (L4) and all the

others. Indeed, we observed a significantly greater radial error for the L4 level when compared to the other four levels and yet the only difference between L3 and L4 levels is the size of the ball (respectively equal to 15cm and 5cm). This means that the reduction of the size of the ball affects the accuracy of the goalkeeper's judgment. This result can be explained by the phenomenon of expansion: an object moving in depth in the visual field causes the size of the image projected on the human retina to increase or decrease (Clifford, Beardsley & Vaina, 1999). In this study, the expansion rate of the ball is the same between L3 and L4 so it seems that there is a threshold on the size of the ball below which the visual information of the ball are not sufficient to predict its final position in the goal. Our results in virtual environments are in accordance with Berthier et al.'s study carried out in real situations (Berthier, Clifton, Gullapalli, McCall & Robin, 1996). Indeed, these authors have shown that hand speed profiles change when the size of the object they are trying to catch decreases. In both studies, the size of the object has an influence on the response of the participant.

7. Conclusion

To conclude, the results presented in this study help to clarify the influence different LODs of a virtual thrower and ball have on the goalkeepers' perception of movement. The goalkeepers were equipped with stereoscopic glasses in order to have the in-depth information of the 3D virtual environment. Their perception was evaluated by quantifying their judgments about the final position of the ball in the goal. This study shows that a simplification of the graphical representation of the virtual thrower and ball up to an MLD model does not influence goalkeepers' judgments. So, the graphical model of the thrower does not seem to be the most important parameter for perceiving movement. Moreover, this study demonstrates that a reduction of the size of the ball in the MLD level influences goalkeepers' responses. Consequently it seems that the objects that gets close to the participant (such as the ball)

influences the perception of the throwing action. In future studies, it will be interesting to analyze the influence of the reduction of the ball size on the perception of the movement of a throwing action in the other LODs from the fully textured one (L0) to the wire-frame one (L2). It could also be interesting to compare these results with the same experiment carried out with only 2D projections.

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Figures Captions

Figure 1: Three-step process: data acquisition; real time experiment that includes motion animation, motion degradation and motion capture; performance comparisons.

Figure 2: A handball goalkeeper immersed in the virtual environment.

Figure 3: Graphical LOD of the thrower/ball representation. From left to right, conditions L0, L1, L2, L3 and L4 are presented.

Figure 4: Representation of the radial error. It is the distance between the virtual ball and the real goalkeeper's hand.

Figure 5: Mean percentage of correct responses for all goalkeepers and for each of the different graphical LOD. The error bars represent the standard deviations around the mean scores.

Figure 6: Mean radial errors for all goalkeepers and for each graphical LOD. L4 was found to be significantly greater than all the other LODs (***$p<0.001$).

Supplementary Material Captions

Video0: View of the reference textured level (L0)

Video1: View of the first-level degradation without texture on the synthetic thrower (L1)

Video2: View of the second-level degradation using a wire-frame representation (L2)

Video3: View of the third-level degradation using a point light display representation (L3)

Video4: View of the fourth-level degradation condition (L4)