Third Person View And Guidance For More Natural Motor Behaviour In Immersive Basketball Playing

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Abstract

The use of Virtual Reality (VR) in sports training is now widely studied with the perspective to transfer motor skills learned in virtual environments (VEs) to real practice. However precision motor tasks that require high accuracy have been rarely studied in the context of VE, especially in Large Screen Image Display (LSID) platforms. An example of such a motor task is the basketball free throw, where the player has to throw a ball in a 46cm wide basket placed at 4.2m away from her. In order to determine the best VE training conditions for this type of skill, we proposed and compared three training paradigms. These training conditions were used to compare the combinations of different user perspectives: first (1PP) and third-person (3PP) perspectives, and the effectiveness of visual guidance. We analysed the performance of eleven amateur subjects who performed series of free throws in a real and immersive 1:1 scale environment under the proposed conditions. The results show that ball speed at the moment of the release in 1PP was significantly lower compared to real world, supporting the hypothesis that distance is underestimated in large screen VEs. However ball speed in 3PP condition was more similar to the real condition, especially if combined with guidance feedback. Moreover, when guidance information was proposed, the subjects released the ball at higher - and closer to optimal - position (5-7% higher compared to no-guidance conditions). This type of information contributes to better understand the impact of visual feedback on the motor performance of users who wish to train motor skills using immersive environments. Moreover, this information can be used by exergames designers who wish to develop coaching systems to transfer motor skills learned in VEs to real practice.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems — Artificial, augmented, and virtual realities;

Keywords: Visual feedback, performance, immersive room, basketball training, perception of distance in VR

1 Introduction

Over the last two decades, VR opened new perspectives for analysing and improving performance in various domains such as surgery [Waxberg et al. 2004] and sport [Bideau et al. 2010; Ruffaldi et al. 2012]. However, despite the technological progress, there are still many design challenges that need to be tackled to provide users with efficient technological and software facilities to improve motor skills and transfer them to real practice. Thus, exploring and evaluating the effects of different techniques or technologies in the area of sport simulators is still an unsolved issue [Sigrist 2011]. It involves characterising the VE according to both perceptual and functional fidelity [Gopher 2012]. While the perceptual fidelity is related to a realistic rendering and is evaluated in terms of questionnaires, functional fidelity requires an accurate physics model, real time response and a natural user interface [Miles et al. 2012]. Consequently, the user's experience in the VE has to be realistic, with parameters matching her behaviour in the real world.

In many sports, players have to throw or kick an object in a more or less accurate manner, such as passing a ball in soccer or football. Thus, in this paper we study precision tasks in the case of long distance constraints and focus on basketball free throw as an example. In a free throw, the player stands at the foul line 4.2m far from a 46cm wide and 3.05m high basket and needs to throw through it a 24cm wide ball. Under these constraints, even small variations in the throwing motion lead to failure. The goal of this paper is to explore how such a complex motor task can be altered by various immersive conditions in Cave Automatic Virtual Environments (CAVEs). Previous work has shown spatial underestimation in VEs especially if using Head Mounted Devices (HMDs) [Interrante et al. 2008; Knapp and Loomis 2004]. However, to our knowledge there is little research done on the study of distance perception in LSID environments or on training aiming tasks over long distances in VEs.

Hence, before developing an immersive training system with LSID, one has to consider perception issues, such as (1) the analysis of the perception of distance in VEs, (2) the quantification of the effects of exposure to various visual conditions, such as first person (1PP) and third person (3PP) views, and (3) the evaluation of the potential impact of additional feedbacks displayed to the user. Although it has been demonstrated that visual guidance has a positive impact on the early stage of learning [Chiviacowsky and Wulf 2007], to our knowledge, this type of feedback has never been studied in ball sports, as explained in [Miles et al. 2012]. Visual guidance should be designed to avoid cognitive overload that could affect its effectiveness. Consequently, in this paper we propose to analyse the effect of displaying the optimal trajectory of the ball on the player's shooting ability. This visual guidance is composed of a series of ellipses that interpolate the points belonging to the correct trajectories. These ellipses are displayed in a tubular structure centred around the optimal trajectory of the ball from the foul line to the basket. Thus, in addition to providing visual guidance, through this type of feedback we are able to display information closer to the user. Therefore, instead of aiming the basket, which is 4.2m far away, the user aims a closer target. We assume that adding visual depth cues diminishes the underestimation effect of egocentric distance.

The paper is organised as follows. Section 2 reports related work about sports training in VEs and the associated problem of distance perception in such an environment. Section 3 describes the basketball free throw simulator developed in this work. The model was

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tested and calibrated with real world data to ensure that the ball motion is coherent to the user's performance. In Section 4, we expose the three VE setups and protocols used in evaluating the three visual feedback types tested in this work: 1PP, 3PP 3PP+guidance. Results are given in section 5 before conclusion.

2 Related work

Building learning accelerators for sport related skills implies dealing with several heterogeneous problems ranging from psychological questions to technological issues. In this section we firstly discuss the relevant previous work in sport analysis and training based on VEs. Then we focus our attention on different types of feedback delivered in such VEs for sports training, especially visual feedback. Finally we discuss the underestimation of distance in a VE, which is a key issue in the specific context of aiming tasks over a long distance.

2.1 Analysis and training of sport skills in VE

VR offers clear advantages as it enables: 1) the design of standardised scenarios, 2) the guidance of user performance by providing additional information, and 3) a fast adaptation to various competitive situations. All these features have the potential to create a significant change in traditional training practices. For instance, the success rate of free throws in NBA competitions has remained constant over the last decades (approximately 70%), although more than a quarter of wins are usually decided at the free throw line [Whitehead et al. 1996]. Thus, the development of an innovative training method meant to improve the free throw skill is crucial, and VEs seem to provide a promising complementary approach. Traditional training can be alternated with a virtual coach, in an environment where the trainee could perform a larger number of repetitions, in a wider range of situations, while being automatically evaluated for each trial. Moreover, it is well known that immersive environments enhance motivation, which is also a key factor in training [Eyck et al. 2006].

In the literature, the training of ball throwing or catching skills have been widely studied. Typical examples exist in rugby [Brault et al. 2009; Brault et al. 2010; Miles et al. 2013], handball [Vignais et al. 2009; Vignais et al. 2010], baseball [Fink et al. 2009] or tennis [Xu et al. 2009]. Most of these studies aimed at analysing the perception-action coupling without considering the accuracy with which the tasks were performed by the subjects. For instance, in [Fink et al. 2009] ball trajectories are flat and unrealistic because of the limited size of the screen leading to a permitted error up to one meter. When training accurate motor skills, such as the basketball free throw, such an error would be incompatible with a relevant evaluation of the user's performance. For a basketball simulator, accuracy is a key point in displaying a ball trajectory that is perceived as coherent with the user's action.

2.2 Telepresence and performance in sport related VEs

There are many design features that could be considered in building training paradigms in VEs, and there is no universally accepted method in assessing the performance/relevance of such a VE according to the desired objective. Simulators which are designed to analyse or train a specific skill should consider the impact of affordances and feedback, to trigger a realistic behaviour of the user. Hence, the assessment of such a training system should take the user's perspective and feedback into account.

The perspective from which the user interacts with the VE plays a crucial role in her behaviour [Kallinen et al. 2007]. In the development of a precision task simulator, in which the target is placed at a significant height, using 1:1 scale environments is not always feasible. An alternative consists of using 3PP instead of 1PP so that the virtual environment could be displayed on smaller screens. This technique is widely used in video games. On the one hand, we could expect that 1PP has the advantage of immersing participants with a better presence sensation. On the other hand, screens which are limited in size may be unable to display all the relevant information and may disturb the users, for example if the ball disappears during part of its trajectory. On the contrary, 3PP allows the display of a wider field of view as the camera could be shifted at a convenient position, so that the whole trajectory could be viewed by the user. It has been shown that 1PP is often preferred in navigation tasks, while 3PP is more suitable for tasks that need global knowledge [Salamin et al. 2010]. In ball catching tasks, the same authors [Salamin et al. 2010] have shown that 3PP leads to better distance evaluation than other displays when using a HMD. We consider necessary to evaluate if 3PP actually leads to a better estimation of the distance in the VE also when a precision aiming task like the basketball free throw is considered.

As explained above, one of the main advantages of using VEs to train motor skills is the possibility to add feedback and guidance information. Designing an efficient training simulator is strongly connected to delivering the significant information, but there is no universally accepted method to validate a VE. Therefore, in the development of a VE for training motor skills we need to carefully consider the affordances and feedback which are provided [Sigrist 2011]. It has been shown that both informative and guidance feedback are essential in different moments of the learning process and they have the potential to diminish the skill acquisition duration [Salmoni et al. 1984]. However, guidance feedback methods have not been studied yet in training systems for high precisions skills over long distances. The result of a basketball free throw depends on the user's ability to make the ball follow a trajectory that goes through the basket. Thus, in this paper we aim at evaluating if displaying the optimal ball trajectory (according to literature in sports science and the anthropometric data of the user) would improve the experience in the VE: more natural motor behaviours and better performance.

2.3 Distance perception in LSIDs

The free throw in basketball is a high precision aiming task, therefore it demands an accurate perception of distances. In the review of literature on VEs for ball sports training, Miles et al. [2012] highlighted several challenges that need to be addressed but the topic of spatial perception was not discussed. Thus, the perception of distances in sport related VEs remains an open question and its effects need to be quantified.

Previous work investigated the differences between sensory information and user's perception and action in real and virtual environments [Slater et al. 2009]. Spatial perception has been identified as one of the main differences between the two environments, with an underestimation of the distances in the virtual world up to 50% [Loomis and Knapp 2003].

Studies on egocentric distance perception have been mostly carried-out with HMD devices because of the difficulty to analyse this parameter with classical methods within LSID platforms. The consensus is that distance perception is distorted in VE as compared to real environments when using HMD [Knapp and Loomis 2004]. The results are not so clear when considering how people perceive distances in LSID environments such as CAVEs. In [Plumert et al. 2004] users estimated the time to walk to a target in a real world and a non-stereoscopic LSID system. Participants used timed imagined walking to estimate distance judgments of an action space larger than 6m. Results indicated that participants underestimated distances in both environments, but the errors in the imagined time to walk were significant higher in LSID. Interestingly, Riecke et al. found that blind walking is not affected when using several dimensions of the display (HMD, 24 or 50 inch display) [Riecke et al. 2009]. These results showed a similar spatial perception for both virtual and real world, but they are not consistent with previous investigations. Because of space limitations, verbal estimation of the distance to the target or timed walking were usually chosen as evaluation methods for LSID immersive environments [Plumert et al. 2004; Piryankova et al. 2013]. However, blind walking requires a large amount of space between the target and any solid object. On the other hand, the verbal estimation has the disadvantage that the observer's perception of the distance can not be directly inferred from the action.

In this paper, we evaluate a fully configurable system with a focus on spatial perception in the VE, especially for aiming tasks over long distances. This type of evaluation is necessary in developing a VE that should not leave gaps nor create dependencies in the user's training process.

3 Free-throw simulator

The basketball free throw simulator developed for this work is a configurable multimodal platform composed of motion capture facilities and visualisation systems. The goal of this system is to assist in the training of basketball free throw skills. Through the experiments we present in this paper we investigate the quality of the perception of distance in the simulator for various types of visual feedback.

The success of a free throw requires a perfect combination between a set of launching parameters (mainly height, and velocity vector at ball release). As we showed in Section 2, there are various technical and technological limitations that need to be considered and evaluated when designing such a VE: the tracking of the user's action; the display of the VE; the latency; the accuracy of the physical model of ball; the efficiency of multi-sensory feedback when throwing the ball. In this section we describe how we have addressed these problems in the process of developing the free throw simulator. We focused on: (1) the design of the training platform and the validation of the physical model of ball, and (2) the design of the information exchange with the users and the setup of three visual conditions (1PP, 3PP, 3PP+guidance).

3.1 Development of the basketball free throw simulator

Building a free throw simulator that provides a real time estimation of the result tackled challenges related to maintaining the balance between the complexity of the model, the latency level and the amount of permitted error. Our proposed system estimates a swish (a successful throw without a previous contact with backboard or rim) based on the initial velocity vector applied to the ball by the user. In the case of a swish, previous authors in biomechanics have shown that spin between 2 and 4Hz leaded to similar probability to succeed [Okubo and Hubbard 2006]. Thus, the Magnus force seems to have little effect on the result, which enabled us to simplify the model. We developed a ballistic model of the ball for basketball free throws, as suggested in [Gablonsky and Lang 2005]. Although the most of the parameters are known, the drag coefficient depends on the characteristics of the ball. Consequently, in order to have an accurate estimation of the result we determined experimentally the value of the drag coefficient for the ball we used in the experiments.

A 4th order Runge Kutta integrator was used to estimate an accurate real time trajectory of the ball based on a set of initial parameters when ball is released: position of the ball, horizontal and lateral angle of the velocity vector, and speed.

We determine the release moment of the ball as the moment with a maximal value of ball speed followed by a decreasing tendency. Real world recordings confirmed the assumption that immediately after release, the ball speed is decreasing under the effect of friction forces. After detecting of ball release, the simulator computes the trajectory of the ball estimating the result of the throw. To this end, the reference frames of the real and virtual world are aligned and calibrated. Hence, successful throws can be identified with this method. The validation of the model is provided in the next section by comparing results obtained in the real world with those produced by the simulator.

3.2 Validation of the basketball free throw simulator

3.2.1 Experimental setup

To validate the physical model of ball, we have carried-out a set of experiments on a basketball FIBA court. Seven expert basketball players and 20 naive players volunteered to participate in this study. Participants were asked to exercise 30 free throws using a 0.59kg-weight and a 0.24m-diameter ball. Before starting the shooting trial, they received a set of instructions: the ball should go through the basket without touching the rim, the ball should be shot with both hands and the feet should be kept in contact with the ground in order to avoid differences resulting from the jump height. The players provided written informed consent.

To facilitate the placement of the markers, participants wore close fitting clothes and their normal athletic shoes. A total of 45 reflective spherical markers (9mm diameter) were placed on standardised anatomical landmarks. Other 14 flat markers were placed all over the ball surface, to give a good estimation of its volume.

The 3D position of the markers placed on the player and on the ball were recorded at 120Hz using a Vicon-MX motion capture system (product of Oxford Metrics) composed of 12 infrared cameras. The volume of the captured data was 4m high, 4.5m in the direction of the shooting and 6m wide. The cameras were able to capture a throw with sufficient accuracy and precision.

The professional players had a competitive basketball experience of more than 7 years and were playing at a professional level. Their success rate for swishes was measured as $53.8\% \pm 10.79\%$. Beginners did not have any club experience in basketball free throwing and their success rate was $15.45\% \pm 11.76\%$.

3.2.2 Data analysis

We developed a C++ module to reject motion capture data artefacts, such as occlusions or inversions. Let us recall that the goal of this analysis was to validate the physical model of ball by comparing simulations to actual data in similar conditions (i.e. initial velocity vector at ball release). Based on the cleaned data, we computed the centre of the ball position using a geometrical method: finding the centre of a bounding sphere circumscribing the cloud of points composed of the surface markers.

One of the factors considered in the implementation of the physical engine is the drag coefficient. Its value depends on a set of elements like: the size and shape of the object and the surface type. In order to obtain an accurate representation of actual basketball shots, it was necessary to estimate the experimental value of this coefficient. The chosen method computes this coefficient using the final phase of a swish: the vertical fall of the ball from the rim level to the ground. We compared the computed vertical displacement with the actual recorded data for values of drag coefficient situated in the interval [0.3, 0.6], using a method proposed in [Okubo and Hubbard 2006]. We found that the difference between computed and recorded height was minimal for a drag coefficient equal to 0.4 (see Figure 1).

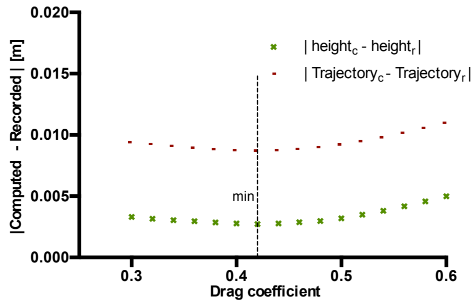

Figure 1: *Difference between computed and recorded data (height and trajectory) depending on drag coefficient.*

Next, we checked the influence of the drag coefficient value on the whole trajectory, from ball release to the rim. Figure 2 illustrates the comparison of two trajectories: one corresponding to the recorded data and one computed by the simulator based on the release parameters and the drag coefficient obtained as described above. Because the capture volume covered by the tracking cameras did not include the highest part of the trajectory, we do not present complete information about the highest recorded path of the ball. The ball was accurately detected for the first 40 frames after release, and also before entering the basket.

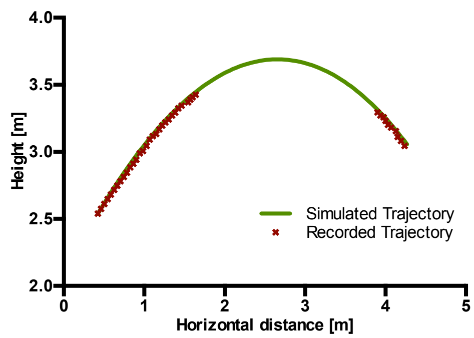

Figure 2: *Simulated and recorded trajectory for a random selected throw*

The accuracy of the model was verified in two ways. Firstly, we checked the correspondence between real and simulated results: does a success with the simulated ball correspond to an actual success in the real experiment . The input data consisted of 575 trials and the results showed that 510 of them were correctly estimated (success throw or failure) by the simulator. The remaining 65 trials (41 successes and 24 failures) were misclassified by our proposed model. These differences might have appeared because tracking errors could have affected the value of the initial parameters of the ball, especially the velocity vector at ball release.

Secondly, we quantified the mean differences between the real and simulated trajectories for each trial using the Root Mean Square Error (RMSE). We have sorted each trial according to the amount of RMSE and the results are summarised in Figure 3. Most of the trials (almost 80% of the trials) leaded to a RMSE which was smaller than 30mm along the 4m-long trajectory.

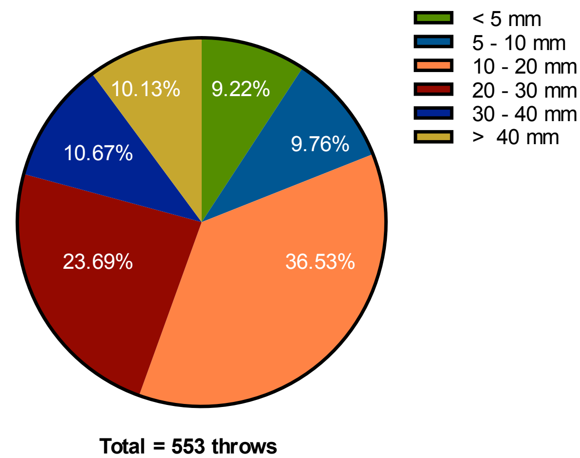

Figure 3: *Evaluation of mean differences between simulated and recorded trajectory for all throws using RMSE, for the 575 trials.*

4 VE experiments

In this section, we describe the experiments carried-out with three different display setups in immersive environments. The goal is to evaluate if these different setups change the way the users perform the task in immersive environment.

4.1 VE training conditions

Regardless of the used visual condition, our VE system aims at computing coherent feedback, such as an accurate trajectory of the ball and at providing the user with useful information about his performance. Informative feedback, that describes the user's performance is very important in helping him to adjust his motion for the next trial. The user needs to be informed about the result of his throw or about the values of the performance parameters. In real world, this information can be naturally observed. In VEs, where performance can be influenced by visual feedback conditions, it is necessary to provide quantitative information in addition to the concurrent guidance information. Hence, in our proposed simulator we provided the user with offline feedback at the end of each throw (see Figure 4). This offline feedback consists of information about: the release parameters of the ball; the optimal parameters depending on his height; and the quantification of the result: success/failure and precision of the shot evaluated as the distance to the centre of the rim.

Concurrent to user's performance, we also provide online feedbacks. One of our aims is to evaluate the effects of various pieces of feedback conditions (1PP, 3PP, 3PP + guidance) on user's behaviour. In the latter condition, visual guidance is a concurrent visual cue meant to guide the users towards performing a successful free throw (see Figure 5). In the protocol, we considered a user standing at the foul line who wants to perform a swish. In normal circumstances, to perform this throw, the user needs to control the motion of her limbs and make the ball fly directly through the rim, which is a complex task. Under these circumstances, we designed the guidance feedback to simplify the given task. Moreover, given the fact that aiming at long distances could be altered by spatial

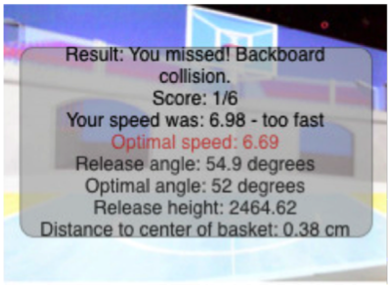

Figure 4: *Offline feedback. It provides the user with information about her performance: success/failure, total score (number of success throws among the total number of trials) and the values of the main parameters at ball release compared to theoretical optimal ones.*

perception, this type of information could reduce these potential effects. We modelled the guidance feedback as a collection of ellipses representing sampled position of the ball along the ideal trajectory, that passes through the centre of the rim. The first ellipse is displayed at the optimal launching point, therefore the task can also be seen in another manner: throwing the ball inside the first ellipse with a velocity vector so that it follows the trajectory modelled by the remaining ellipses. As the distance to the first ellipse is small, we expect that the performance is less sensitive to underestimations of distances in VEs.

This ideal trajectory was computed using the physical model introduced above. The initial ellipse was located at a position described horizontally by the free throw line and vertically by 1.25 * player's height, as this has been identified as the optimal position for a swish [Gablonsky and Lang 2005]. The following ellipses were displayed every 20cm up to the basket. This visual guidance only gives information about the path that the ball should follow but velocity is also a key point. To visualise the optimal speed we consequently added a transparent ball passing through this structure with the ideal speed.

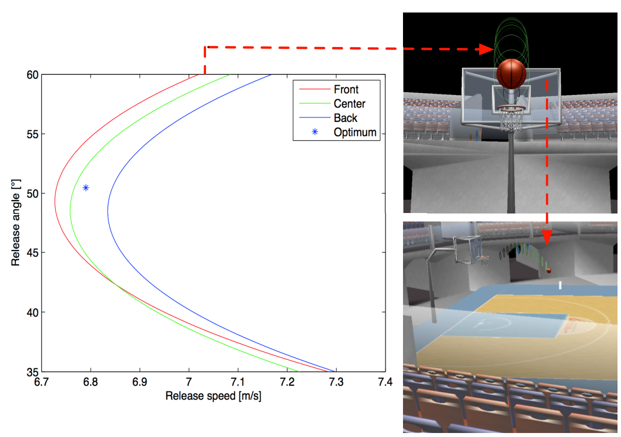

Figure 5: *Guidance feedback. All successful trajectories were computed offline for a range of input heights. Based on similar computation (example for a 2 m height player is depicted on the left), it is possible to display series of ellipses sampled all along the ideal trajectory to provide the user with visual guidance (right-up corner for a front view, and right-bottom corner for a lateral view)*

The type of concurrent feedback displayed in each condition (1PP, 3PP and 3PP+guidance) has been adapted depending on the situation. For example, displaying the virtual ball in 1PP is not necessary and may disrupt the user, as she is also carrying a real ball. Moreover, the screen size limitations (3.2m high) did not allow the visualisation of the whole trajectory under this training condition. For the same reasons, we did not test the training condition 1PP+guidance as most of the ellipses would be displayed outside the screen. In contrast, in the 3PP conditions, where the user does not stand at the foul line, it is absolutely necessary to visualise the position of the virtual ball depending on the user's motion. In these situations, the user holds the real ball, that is tracked by a motion capture system which is recording its position. The participant is situated 3m behind the free throw line, but sees the virtual ball at the foul line following the movements of the ball she is holding. Obviously, this introduces a latency which is difficult to evaluate objectively. However, we evaluated its effects in a subjective way, by the means of a Presence questionnaire, described in section 5.1.4. Another question related to 3PP training conditions was concerning the display of an avatar of the user. This type of feedback could have positive effects on embodiment and presence, but at the same time could affect the user's attention from the actual task by providing too much information that could become confusing. Moreover, we wish to evaluate the effect of using 1PP and 3PP feedbacks and using an avatar would add a new variable. Consequently, in the present paper, we decided to avoid using avatars. Table 1 presents the training conditions used in this protocol.

	Perspective (1PP/3PP)	Offline feedback (OFB)	Guidance feedback (guidance/no guidance)
1PP	1PP	OFB	no guidance
3PP	3PP	OFB	no guidance
3PP+guidance	3PP	OFB	guidance

Table 1: *Proposed training conditions for the three visual information types*

4.2 Setup

Eleven beginners participated in the experiment. These users are a subset of the twenty subjects who performed the experiment in real world, as explained before. We have chosen to involve only beginners since experts repeat a well-acquired motor program. As a consequence, it might be more difficult to see an adaptation according to the visual feedback. Their task was the same as in the real world, i.e. trying to perform successful free throws (swishes). They performed this task under the three visual conditions (15 throws in each condition). The configurations order was randomised across participants to remove any bias. Experiments were carried-out in Immersia (www.irisa.fr/immersia/), a very large immersive room made of one 10x3m front screen, a floor screen and two 3x3m side projection screens, as shown in Figure 6.

Users were equipped with reflective markers on the standard anatomical joints, similar to the real world setup. Stereoscopic glasses were used at 60Hz (30Hz for the each eye) and synchronised with the immersive room. Providing haptic and tactile information is very important in this type of task, but designing devices to simulate this feedback is still a challenge. Moreover, our goal was to analyse the visual perception of the user to the proposed three conditions. Thus, we decided to use a real basketball ball in the immersive room. The ball was connected to a rope fixed with weights that permitted its natural movement for approximately one meter after its release while protecting the screens. The ball was equipped with seven reflective markers tracked by the Vicon-MX motion capture system, similar to the real world setup. Using the same algorithm, we computed the initial velocity vector by the method described above: detecting the peak of ball velocity before a slight decrease. Afterwards, the trajectory of the ball was computed thanks to the output of the physical model. This allowed us to compare the user's performance in both the real and the virtual environment. This method enabled us to evaluate the effects of the proposed visual conditions on the user's performance and to determine the one that is more appropriate for generating natural movements and performance.

Figure 6: *The basketball free throw simulator presented in an immersive configuration with stereoscopic screens and motion capture (Immersia). The 1PP condition is depicted here.*

We built the VR application in Unity, using the MiddleVR plugin, responsible for visual 3D synchronisation. The 3D objects, drawn in 3dsMax, were imported as Unity objects and several C# scripts were written to obtain the desired functionality. A dedicated thread was in charge of data acquisition from the Vicon system to assure low latency. Custom libraries for computing the release frame and the ball velocity vector were imported through a script. They were used for computing the ball release parameters based on real time data. The position of the ball at each frame was estimated with a frequency of 120 Hz. Another thread was responsible for 3D visualisation and synchronisation.

5 Results and data analysis

This section describes the result obtained with the above protocol, for the three visual conditions, by comparing the user's performance with the one on a real basketball court. Let us recall that we intend to find answers for the following question: 1) How realistic is the task executed in virtual environments, under different visual conditions? 2) Are there any differences in the underestimation of distance between the 3 visual conditions? 3) What was the subjective feeling of the users when experimenting in our training VE?

5.1 Evaluation of the users' performance

For each trial, the following data was collected and computed: (1) the position of the participant, (2) motion of the real ball, (3) release parameters that were used as inputs of the physical model (speed, horizontal angle, height and distance to the target), (4) outcome of the user's performance (success rate, angle of entry in the rim, lateral deviation, distance to the centre of the basket).

5.1.1 Comparison of the users' performance in real and virtual environments

Differences in release parameters and performance were analysed using Friedman tests. The significance value was set at $p < 0.05$. Comparison of the different configurations revealed that there was no significant difference in the number of successful throws depending on the visual condition ($\chi^2(2) = 4.9$; p = 0.17). Moreover, no significant difference between real world and all the three visual conditions was reported for all the other evaluated parameters except release speed ($\chi^2(2) = 14.12$; p = 0.003) and release height ($\chi^2(2) = 9.76$; p = 0.02). As we present in Figure 7, the mean values of the release speed vary from 7.11 m/s in the real environment to 6.74 m/s in 1PP, 6.83 m/s in 3PP and 6.89 m/s in 3PP+guidance. Figure 8 illustrates the values for release heights under all the training conditions.

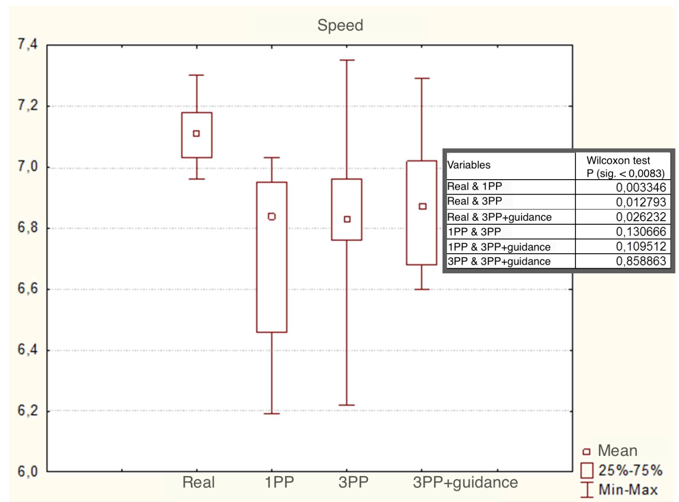

Figure 7: *Release speed values under training conditions*

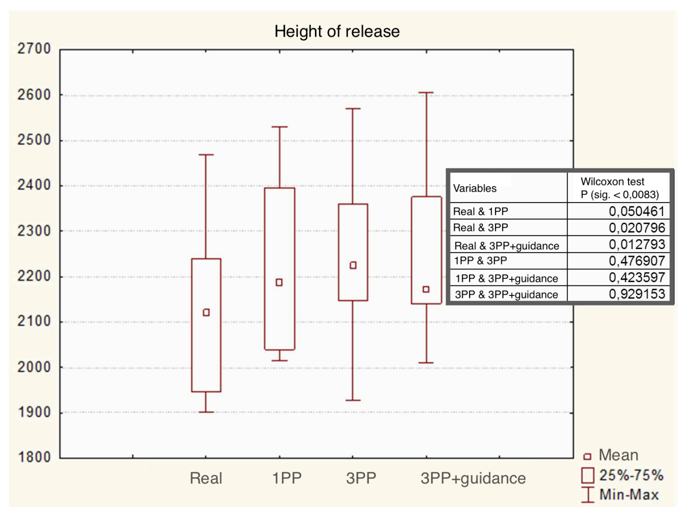

Figure 8: *Height values under training conditions*

These results show that even if the task was performed differently in the VE compared to real world, the global performance is not affected, showing an adaptation to the task in our VE. However, we explain the differences in some of the performance parameters as a result of the changes in the information received in the VE by the user.

5.1.2 Throwing performance in the three visual conditions

The Friedman test indicated the existence of speed differences between the training experience in VEs. In order to better understand the reason of the observed differences, we analysed the results in two different manners: 1) for all the recorded trials, as described previously, and 2) only for the successful throws. The analysis of the successful throws only offers information about user's adaptation to the task in the proposed VE. The data was evaluated through a post-hoc analysis by conducting Wilcoxon singed-rank tests with a Bonferroni correction applied, resulting in a significance level set at $p < 0.0083$.

When considering the total number of throws, results demonstrated that the release speed was significantly different when comparing real world performance with 1PP (p = 0.003). This difference was less significant for 3PP (p = 0.01) and especially for 3PP+guidance (p = 0.03). Thus, we can assume that visual perception was more altered for the 1PP condition. Smaller speed in 1PP tends to indicate that the basket was globally perceived as closer compared to the real world situation.

We observed the same behaviour also when we analysed just successful throws. In case of swishes, results showed a less significant statistical difference for the launching speed in immersive conditions 1PP (p = 0.06) and 3PP (p = 0.04), when compared to the real world performance, as shown in Figure 9

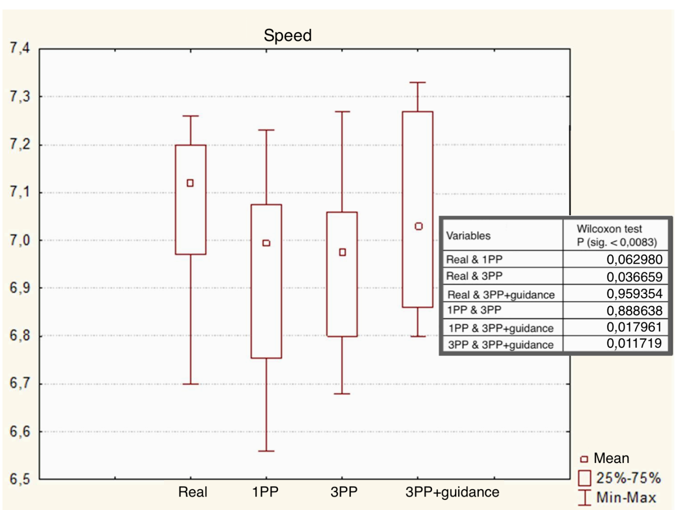

Figure 9: *Release speed when only successful throws were considered*

This was in accordance with previous work [Plumert et al. 2004; Piryankova et al. 2013] stating that users underestimate egocentric distance in a LSID VE. However, unlike previous work [Piryankova et al. 2013], our proposed VE is not a cabin, but a large immersive room. Such an immersive environment has the potential to offer a more realistic experience (enabling more natural displacements and large display of the environment). Similar results were presented also in smaller LSID presented in [Miles et al. 2014], where participants did not estimate correctly target distances in a rugby simulator. However, the evaluation was based on a small number of users (three) and the authors considered just the exposure to 1PP.

Statistical analysis showed that the majority of the throwing parameters were not affected when performing a free throw in a real or in a virtual environments. However, values for speed and height were statistically different and coherent with an underestimation of the distance (throwing at a shorter distance), especially for 1PP. Under 3PP the user's performance was closer to real world experience even if some tendency to underestimate distances could still be observed.

5.1.3 Role of the visual guidance

Two of the training conditions we tested used 3PP in the presence or absence of guidance feedback. Release speeds under 3PP paradigms were closer to real world values, especially when depth cues were present in 3PP+guidance. When we displayed the guidance feedback, the performance parameters improved slightly, indicating that guidance ellipses tended to partly compensate the distance underestimation effect. Further experiments would be needed to carefully examine performance in both situations, especially because performance is not regular for beginners.

When the analysis was focused only on swishes, we noticed that the value of the release speed increased when guidance feedback was present (p = 0.96 compared to real performance). This indicated that release speeds under guidance feedback and real world circumstances have close values. This observation is also consistent with results obtained for the total number of throws. Thus, we emphasize once more that displaying a guidance feedback can produce a more realistic user performance, a necessary condition in the development of a training protocol. When performing a distance aiming task, the guidance feedback seems to provide players with a visually correct representation of a perfect trajectory. Consequently, they had both speed and ball placement information. This feedback combined with the 3PP has afforded the player the opportunity of picking up proper information to increase launch speed.

Release height is another important parameter in succeeding a free throw, as showed in [Hamilton and Reinschmidt 1997; Tran and Silverberg 2008]. In [Tran and Silverberg 2008] the authors concluded that a player aiming for a swish should release the ball as high as possible. The first ellipse composing the guidance feedback is placed at the height professional player throw their ball [Gablonsky and Lang 2005]. We demonstrated the efficiency of this type of information through increase of release height under 3PP+guidance. When considering the total number of throws, we observed that height slightly increased even if it was not significant (p = 0.01). But, When focusing on successful throws only, the difference between real world and 3PP+guidance release height was significant (p = 0.005). Surprisingly, we observed that users throw the ball at a 5-7% higher height in the 3PP+guidance condition compared to real condition. Thus, the release height in 3PP+guidance is supposed to be better than the one observed for the same user in real situation, suggesting that it tends to guide the user toward a better throwing technique.

The experiment showed that users were unable to correctly perceive the distance under 1PP in the chosen environment. The 3PP produced slightly better results. When guidance feedback was used, we observed an improvement of ball release (velocity and height) that was significant when analysing the swishes. These two aspects are important elements in training a high precision distance aiming skill. Thus, we conclude that using a training condition that exposes the user to 3PP and provides guidance depth information is the first step towards generating a realist behaviour in the VE and improving the user's technique. Therefore, for the chosen skill (basketball free throw), 3PP+guidance seems to be the most suitable paradigm for training because it produced slightly better results.

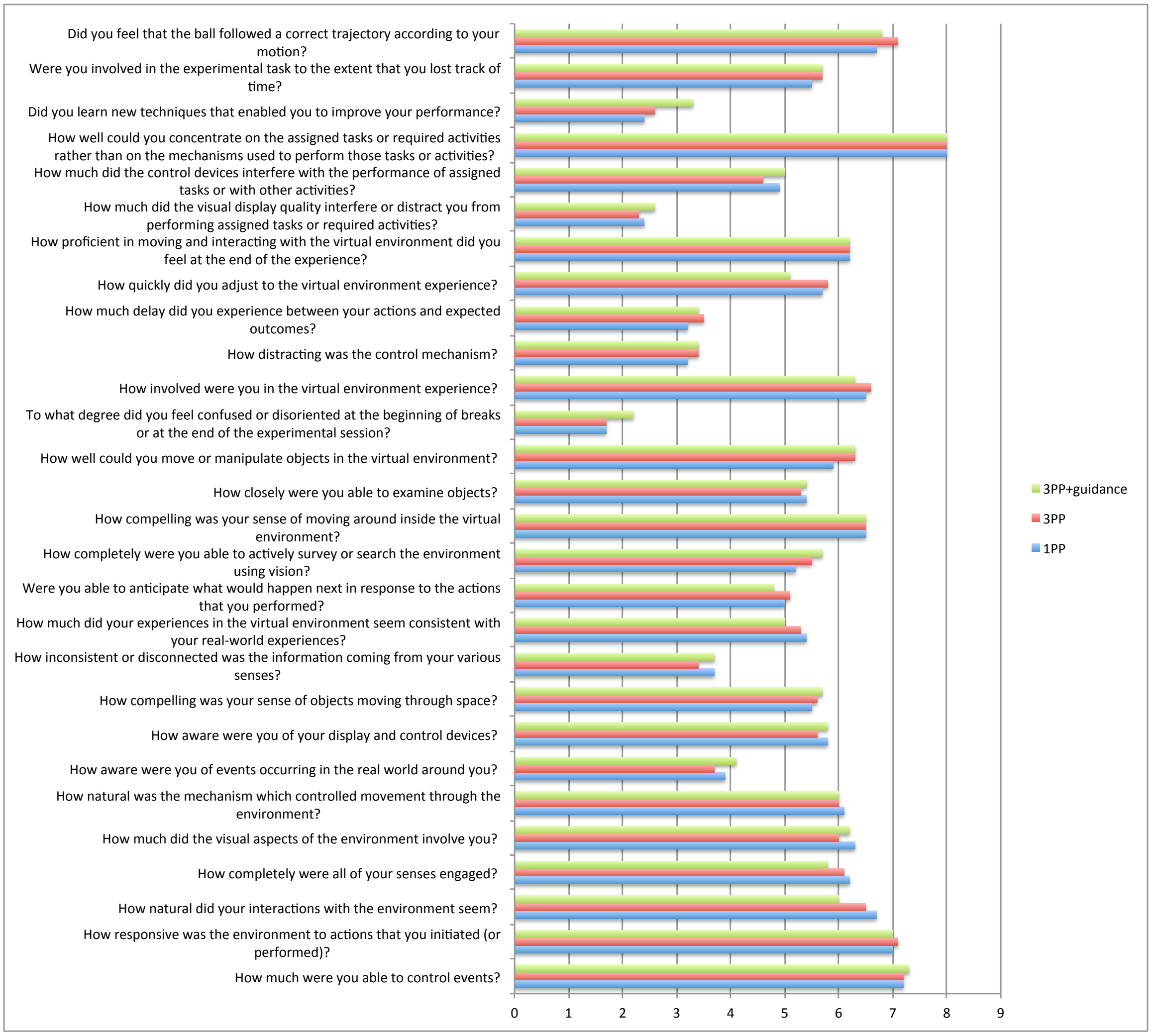

Figure 10: *Qualitative evaluation by the means of a questionnaire*

5.1.4 Subjective feedbacks of the users

In the previous subsections, we gave the quantitative results linked to the performance of the user in the three visual conditions. However, it is still difficult to relate these results to actual perceptual disturbances. Hence, as perceptual fidelity has also an important role in the user's experience in an immersive environment, we asked the users to assess the simulator in the three visual conditions.

In order to provide a subjective evaluation of the simulator, participants had to fill-in a questionnaire including 28 questions (presented in Figure 10 that were grouped around 6 categories of interest. Questions were adapted from the famous Witmer Presence questionnaire [Witmer and Singer 1998]. Each category is shortly described by one of the contained questions as follows:

- Involvement/Control: How much were you able to control events? How responsive was the environment to actions that you initiated (or performed)?
- Naturalness: How natural did your interactions with the environment seem?
- Interface quality: How distracting was the control mechanism?
- Accuracy of simulator: Did you feel that the ball followed a correct trajectory according to your motion?
- Personal profit: Did you learn new techniques that enabled you to improve your performance?
- Interaction with the virtual simulator: How well could you move or manipulate objects in the virtual environment?

For each item, the rating score ranged from 1 (worst rating) to 10 (best rating). The realism of the simulator was confirmed by the questionnaire filled-in by the participants. There were no significant rating differences between the visual conditions. The average rating of "Involvement/Control", "Naturalness", "Interface quality", "Accuracy of the simulator", "Personal profit", "Interaction with the virtual simulator" were rated 6.8. In general, participants felt that they could control the environment and that their interaction with the VE was natural (7.1 points out of 10), they appreciated the accuracy with 7.1 points out of 10, and thought that they could not entirely benefit personally from the session of training (3.3 points out of 10). These results show that although the experience in the VR was considered as almost realistic, beginners prefer the real environment because it is difficult for them to adapt and to make use of all the feedback. This can be explained through the fact that when interacting with a VE for the first time, adaptation is necessary in order to obtain the aimed outcomes.

This questionnaire provided also a mean to evaluate latency in a subjective way. The question addressing this was: "How much delay did you experience between your actions and expected outcomes? (0 ? no delay, 10 ? significant delay)". The average rating was 3.5, showing that the users were not significantly disturbed by the system latency.

6 Conclusion

In this paper we presented and analysed the performance of eleven amateur subjects who performed free throws in both real and virtual environments. Our goal was to analyse their behaviour when training under different visual conditions. The population we have chosen for this experiment consisted of beginners. One of the reasons for this was that the simulator aims at training beginners by offering them information about a limited set of parameters (ball parameters at ball release). The procedure is meant to help them to find the correct position and velocity vector to shoot. Pro players already have this type of knowledge and a possible improvement would be subtle and impossible to evaluate. Moreover, pro players have spent a long time tuning their gesture and could repeat the motion accurately from one trial to another, independent of the visual feedback. Again as they are used to perform this gesture, we assumed that changing visual feedback would lead to very small differences, difficult to evaluate.

The evaluation of the system consisted of comparing a set of parameters between-groups to assess whether the training in the VE has better performances compared to real world training. Although success ratio analysis was not the goal of this paper, we can notice that its values did not show any significant difference between virtual and real setup. However, we cannot conclude about an improvement of the performance especially because the experiments were just instantaneous performance, not training. However, we observed different behaviours in the three proposed training conditions. In all the VE scenarios, the users needed some time to adapt and to calibrate their shots considering the provided feedback. Our main observations reinforce the conclusions in [2010], stating that 3PP is more efficient for certain tasks, but further work would be required to study this type of statement in training condition.

Performing high precision tasks in a VE is a challenge. There are several factors that one needs to consider when building a VE for such a complex task, including the accuracy of the simulation, the latency of the interfaces, the quality of the multi-sensory feedbacks, the relevance of additional information. The discussion of skill transfer from virtual to real world is still open with questions related to the best design of training protocols.

In the present paper, we have presented a basketball simulator and have shown that it provides a realistic ball trajectories (87.25% of over 500 throws were estimated correctly). For such a high-demanding precision task, accuracy of the model is a key point. In this paper we used accurate motion capture systems and have identified the physical values to ensure high fidelity of the model. It looks difficult to increase the accuracy of the model because of technological limitations. This would be a limitation for this type of application especially when using low-cost systems. Further research would be required to overcome this technological limitation.

Based on this simulator, we proposed three training conditions that combine different types of visual feedback. Our main results are: 1) 1PP tends to lead to an underestimation of distances in our chosen aiming task causing changes in the manner the user were performing the task, 2) 3PP is a little bit more adapted in such a case, 3) users found another way of performing the task in the VE and finally reached a similar success ratio compared to real world, and 4) adding visual guidance helped users to perform the task closer to their performance in the real world.

Distance underestimation or any other perceptual disturbance in VEs make people adapt to the task. They finally reached the same success ratio by finding a new way for throwing the ball despite this incoherence between perception and action. If distance is misestimated, it has consequences on velocities and accelerations. It resembles being immersed in a world with different physical laws: the motion that would be required to perform an aiming task for such a perceived distance in no more appropriate in the VE. In our proposed system, people managed to adapt after a sequence of trials-and-errors, and succeeded in executing a number of free throws. Our subjects were beginners in basketball, thus they had the same trial-and-error approach also in performing this aiming task in the real world. In the light of these observations, we think that it would be interesting to analyse the same protocol with experts to address this new question.

As part of this work, we have also recorded the motions performed by all the subjects in all the evaluated conditions. The data has not been used in this paper but future work will analyse if joint coordination changed depending on the visual condition. As the height of release and ball speed changed, we could expect to see some differences in joint kinematics. However, despite these adaptations, due to the high number of degrees of freedom, there exists a large space of joint strategies to achieve the same ball speed and position. Analysing if people change their motion control strategies in various visual conditions would help to better understand the adaptations performed in VE. The final goal is to train motor skills that the subjects could transfer in real world. In that sense, two opposite strategies arise: either developing highly accurate VE to train this special skill, or the possibility offered by VE to control and change the situation in order to make users learn how to adapt to many different situations. Further research in learning would be required to develop the most appropriate strategy.

Another interesting aspect that can add value to real world practice is the evaluation of the performance in the VE under different stress situations. The result of the free throw can be influenced differently by a friendly or hostile crowd or by a decisive moment. In this paper, we only focused on motor performance, but it would be interesting to address new questions including stress as a variable, especially because it is straightforward to add stressors in the environment we built.

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