Influence of visual perspective and feedback guidance for free throw training in virtual reality

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Abstract

Accurate distance perception and natural interactions are mandatory conditions when training precision aiming tasks in Virtual Reality (VR). However, there are many factors specific to Virtual Environments (VEs), which lead to differences in the way a motor task is executed in VR compared to real world. In order to investigate these differences, we performed a study on basketball beginners' free throw performance in VEs under different visual conditions. We observed that although the success rate is not statistically different, some adaptations occurred in the way the task was performed, depending on the visual conditions. In the third person perspective visual condition, distance to target seems to be more accurately estimated, as the release parameters indicate. Adding visual guidance information (gradual depth information showing the ideal ball trajectory) also leads to a more natural motor behavior. As the final aim of this study was to offer a reliable basketball free throw training system in VEs, we compared beginners' performance in VR to the experts' model of performance. This comparison is necessary to investigate the training potential of our system, since beginners are supposed to reach experts' performance after training. We concluded that most of the performance variables tend to evolve closer to experts' performance during the training in the VE.

Keywords: virtual reality, user studies, perception, virtual worlds training simulation, sports training, perception of distance in virtual reality, natural behavior in virtual environments

Introduction

Training motor skills is a complex task as it involves cognitive, emotional, psychological, physiological and mechanical phenomena. With the enhancement of immersive technology, VR has been identified as a promising approach for training in various application domains, including sports [1]. Indeed VR provides unique opportunities to control multisensory feedback and physical properties of the user's environment. It also enables to train users on digital mockups for safer, cheaper and longer training sessions than in the real environment. VR is also well known to enhance enjoyment and motivation, increasing the time spent for training. It is obvious that VR offers clear advantages in the training process: 1) the design of standardized 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 promising complementary methods to traditional training practices. 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. However, skill transfer from virtual training to real practice remains an open problem with many elusive aspects related to: how to achieve a natural motor behavior and how to design training protocols?

A first approach in addressing this problem consists of building VEs characterized by both perceptual and functional fidelity. While the perceptual fidelity is related to a realistic rendering and is evaluated in terms of questionnaires, functional fidelity requires an accurate physical model, real time response and a natural user interface [2]. Consequently, the user's experience in the VE has to be realistic, with parameters matching her/his behavior in the real world.

In many sports, players have to throw or kick objects in a more or less accurate manner, such as passing a ball in soccer or shooting a free throw in basketball. Under these constraints, even small variations in the throwing motion or in perception lead to failure. When developing immersive training systems for such an aiming and precision task, it is necessary to evaluate the influence of technical choices on the way users perform the task. The goal of this paper is to investigate if possible underestimation of distance in VE leads to adaptations in the way users perform aiming (free throw) task, considering the potential effect of different types of visual feedback used in the VE.

In the review of literature on VEs for ball sports training, Miles et al. [2012] highlighted several challenges that need to be addressed. However, the topic of spatial perception in large VEs and the use of visual guidance were not discussed. Thus, perception of distances in sport in VEs remains an open question. Spatial perception has been identified as one of the main differences between real and VE, with an underestimation of the distance in the virtual world of up to 50% [4]. The results are not so clear when considering how people perceive distances in LSID environments such as CAVEs [5]. In [6] users estimated the time to walk to a target in both 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 significantly higher in LSID.

The visual perspective from which the user interacts with the VE plays also a crucial role in her/his behavior [7]. 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 third person view (3PP) instead of first person view (1PP) so that the VE could be displayed on smaller screens. This technique is widely used in video games. On one hand, we could expect that 1PP has the advantage of immersing participants with better Presence. On the other hand, screens that are limited in size may be unable to display all the relevant information in 1:1 scale, and may disturb the users (for example, if the ball disappears during part of its trajectory). It has been shown that 1PP is often preferred in navigation tasks, while 3PP is more suitable for tasks that need global knowledge [8]. In ball catching tasks, the same authors have shown that 3PP leads to a better evaluation of distance than other displays when using a HMD. Questions that remain open are: 1) how does changing the visual perspective influence the distance perception in LSIDs, and 2) how does this affect the motor behavior involved in the execution of a high precision task, such as the basketball free throw?

Visual guidance could assist users in successfully performing precision aiming task, which could lead to achieve optimal release parameters, as experts do. Although there exist studies indicating that visual guidance has a positive impact on the early stages of learning, to our knowledge, this type of feedback has never been studied in ball sports in VEs, as explained in [2]. Visual guidance should be designed to avoid cognitive overload that could affect its effectiveness. 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. Could displaying the optimal ball trajectory (named 3PP+guidance condition) improve the experience in the VE and partly compensate underestimation of distances? Does it lead to a more natural motor behavior and a better performance? The optimal ball trajectory does not only provide visual guidance but acts also like a depth cue displaying information closer to the user. Therefore, using close visual guidance instead of only aiming the distant basket, which is 4.2m far away, may diminish the underestimation effect of egocentric distance in VE.

In a previous work [9] we have analyzed the performance of beginners when performing basketball free throws in various immersive conditions. These results support the assumption that natural complex motor behavior is possible in the VE, despite little motor adaptation. As the ultimate goal of this work was to design a VE training system for basketball free throws, in this paper we also compare the performance of beginners in various visual conditions (real and three visual conditions in LSID) to those of expert players in free throw execution in real condition (supposed to be the model to reach). The three visual conditions in LSID were: first person view (1PP), third person view (3PP), and third person view with guidance feedback (3PP+guidance). The key idea is to analyze how different visual conditions affect the performance of novices and to which extent it enables them to get closer or further from the experts' performance.

Overview

To evaluate the relevance of 1PP, 3PP, 3PP+guidance compared to real practice, we proposed a two-step analysis. Firstly, we carried-out experiments with beginners (never practiced basketball in clubs) and experts in basketball playing (national level). We recorded their natural motor behavior and success rate when performing a free throw task on a real basketball court. This first step enabled us to calibrate the physical model of ball in a specific free throw simulator that computes the ball trajectory and the result of the throw according to initial conditions (ball speed, orientation of velocity vector, spin angular velocity and position of the hand at ball release).

Secondly, we asked the beginners to perform the same experiment in VR, with three main immersion conditions: 1PP, 3PP and 3PP+guidance. Their performance can be compared to the one they previously had in the real condition. Compared to experts who developed specific motor skills and motor programs in such a well-known task, we assumed that beginners were more sensitive to perceptual disturbances. Expert's performance was considered as a reference for the motor behavior that beginners need to reach after the training sessions.

Experiment with experts and beginners on a real basketball court

Twenty subjects (age = 27.25±8.32 years, height = 1.76±0.12m, weight = 74.6±9.87kg) who have never practiced basketball before participated in a motion capture session in a real stadium, as shown in Figure 1. They were placed in a real free throw situation with an official ball. They were equipped with 45 reflective spherical markers (9mm diameter) placed on standardized anatomical landmarks. 14 flat markers were placed all over the ball surface, to give a good estimation of its volume. A Vicon-MX motion capture system was used to accurately measure the 3D position of these markers. Markers were also placed around the basket rim.

Seven experts (age = 25.42±11.08 years, height = 1.89±0.07 m, weight = 85.71±15.82 kg) with a competitive basketball experience of more than 7 years (national level) also participated in this study.

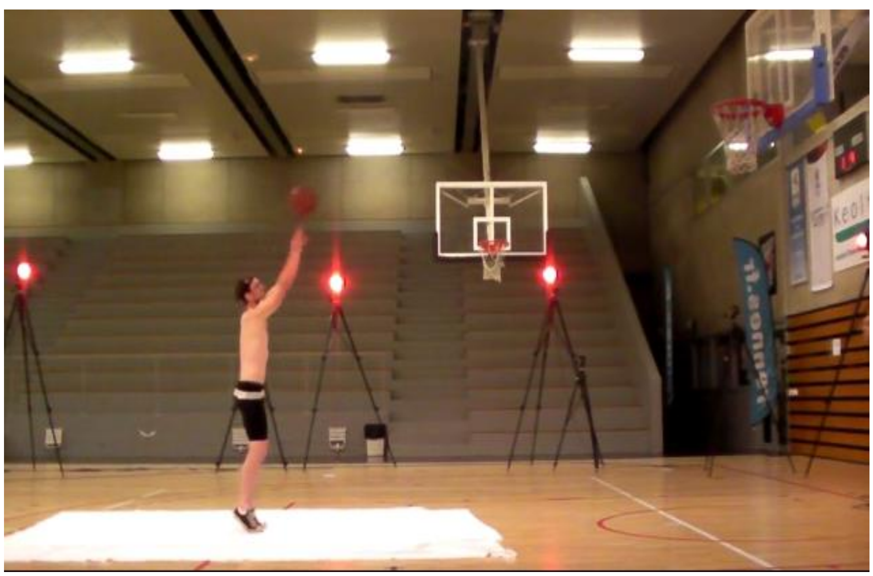

Figure 1: Motion capture session in a real basketball stadium with beginners and experts

Participants trained for 10 minutes to become familiar with the environment. Then, each participant performed 30 throws from the free throw line. They were asked to try to score as many swishes (a successful throw without a previous contact with backboard or rim) as possible.

The success rate for experts when performing swishes was measured as 53.8% ± 10.79%. The percentage of free-throw misses was 10% for all the expert players. This value corresponds to their career performances. For beginners, who did not have any club experience in basketball free throwing, the success rate was of 15.45% ± 11.76%.

Using the motion capture system described above, we recorded the 3D kinematic data of the subjects and the ball before, during and after ball release. We mainly focused on the initial parameters of the ball at ball release: ball speed, angle of velocity vector compared to horizontal line, height of ball, and spin angular velocity. We also analyzed the angle under which the ball is entering the basket: the higher the angle, the higher the margin of error for the ball to enter the basket.

In the remaining of the paper, these parameters were used to compare the performance of the subjects in real condition as well as in three VR conditions (1PP, 3PP, 3PP+guidance). The trajectory of the ball was used to tune the mechanical model used in the free throw simulator.

Free-throw simulator

To achieve the goal of this paper, we have designed a specific free throw simulator. As we address complex aiming tasks in which accuracy is very important, we developed and calibrated a physical model of ball with software modules to improve the quality of the motion capture measurement. One of the requirements of this simulator was to ensure that throws performed by the users look as natural and realistic preventing from non-correspondence between the users' motion and the trajectory of the ball.

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).

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. We developed a ballistic model of the ball for basketball free throws, as suggested in [10]. This model is parameterized by the mass of the ball, the initial position of the ball at release, its velocity vector and angular velocity, and the drag coefficient. Although most of the parameters are known, the drag coefficient depends on the characteristics of the ball. Consequently, to provide 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 characterizing the ball release: 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 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.

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 filtered data, we computed the center of the ball position using a geometrical method: finding the center 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 such as: 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]. We found that the difference between computed and recorded height was minimal for a drag coefficient close to 0.4 (see Figure 2).

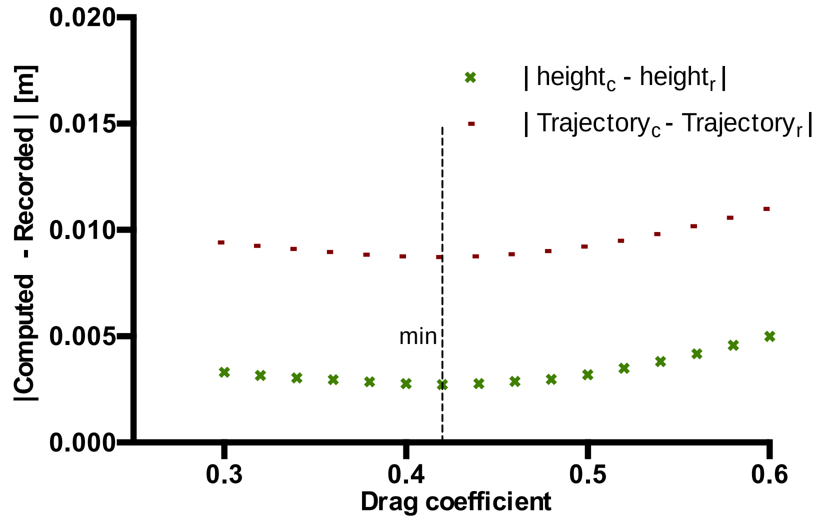

Figure 2: Difference between computed and recorded data (height and trajectory) depending on drag coefficient

Next, we checked the influence of the drag coefficient value on the whole trajectory, from ball release to the rim. Figure 3 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.

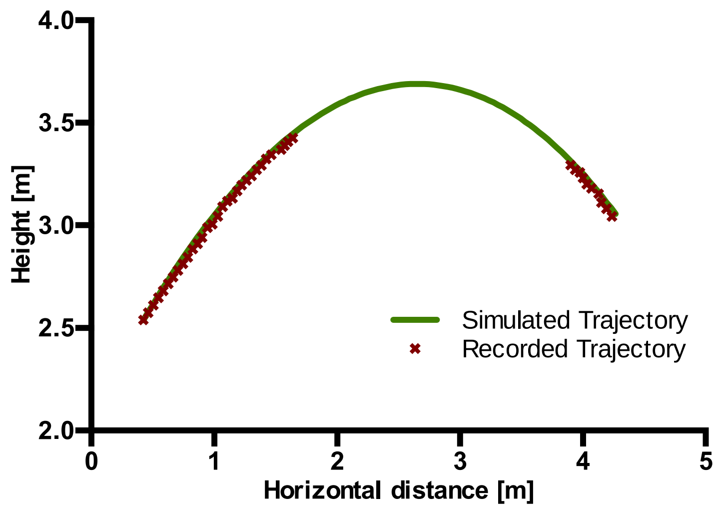

Figure 3: Simulated and recorded trajectory for a random selected throw

The accuracy of the model was assessed using two parameters. Firstly, we checked the correspondence between real and simulated results: does a swish with the simulated ball correspond to an actual swish in the real experiment? The input data consisted of 575 trials (experts and beginners). The results showed that 510 of them were correctly estimated (success throw or failure) by the simulator (i.e. 88.7%). 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.

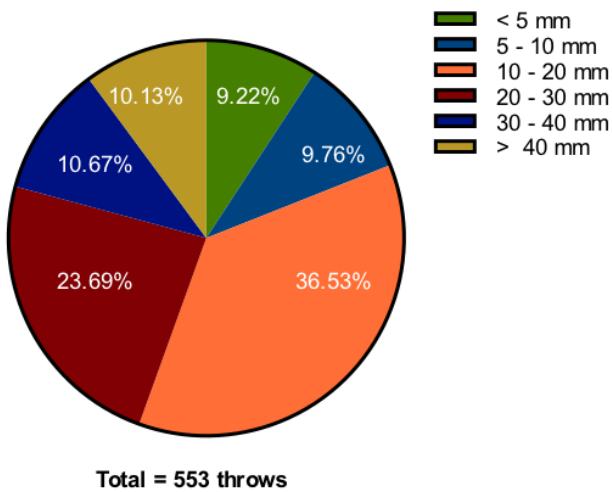

Figure 4: Evaluation of mean differences between simulated and recorded trajectory for all throws using RMSE, for the 575 trials

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 summarized in Figure 4. Most of the trials (almost 80% of the trials) leaded to a RMSE, smaller than 30mm along the 4m-long trajectory.

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 and how these setups influence the way users perform the free throw task in an immersive environment. We have chosen to perform this analysis on beginners because we wanted to evaluate first the effects of the VE on players who do not have an automatic technique. However, in order to evaluate the way the motor behavior changes and if VE can be used as an additional way of training we compared the results of the VE session with real world experts' performance.

VE training conditions

Regardless of the visual condition, our VE system aims at computing coherent feedback, such as an accurate trajectory of the ball, and at providing the user with relevant information about his performance. Informative feedback, that describes the user's current performance, is very important to adjust her/his motion for the next trial. It is also important that users are informed about the result of their 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 users with offline feedback at the end of each throw. 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 center of the rim.

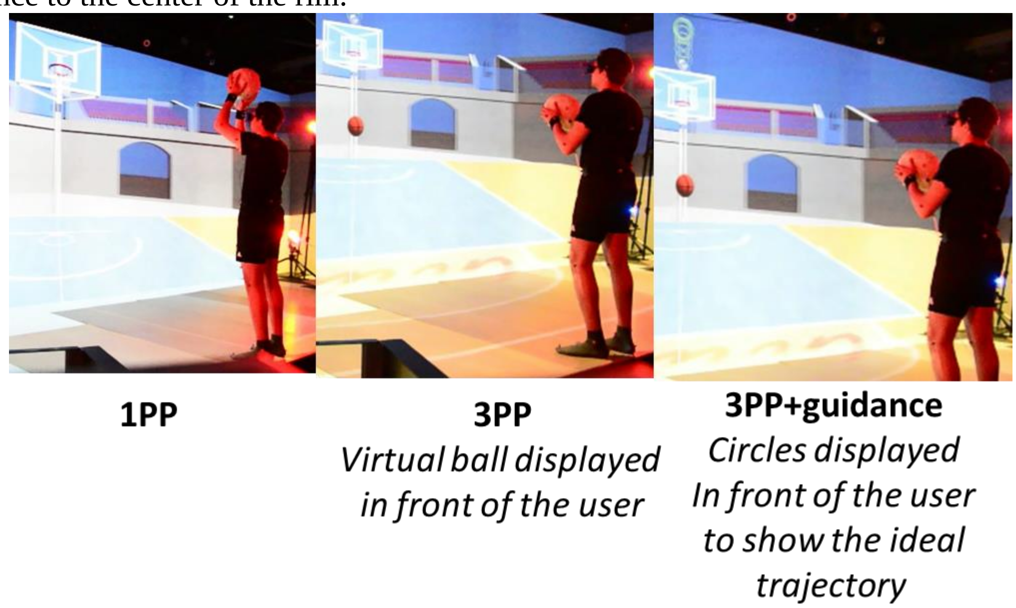

Figure 5: The three visual conditions used in the VR experiment: 1PP, 3PP, 3PP+guidance from left to right

Concurrent to user's performance, we also provide online guidance feedback. One of our aims is to evaluate the effects of various types of feedback conditions (1PP, 3PP, 3PP + guidance) on user's behavior (see Figure 5). In the latter condition, visual guidance is a concurrent visual cue meant to guide the users towards performing a successful free throw. 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, users need to control the motion of their limbs and make the ball fly directly through the rim, which is a complex task. Considering this, we designed the guidance feedback to simplify the given task. Moreover, given the fact that aiming at long distances could be altered by spatial perception, this type of information could reduce these potential effects. We modeled the guidance feedback as a collection of ellipses representing sampled position of the ball along the ideal trajectory that passes through the center 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 modeled 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 specifically designed for the experiment. 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 [10]. 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 visualize the optimal speed we consequently added a transparent ball passing through this structure with the ideal speed.

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 users, as they are also holding a real ball. Moreover, the screen size limitations (3.2m high) did not allow the visualization 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 fundamental to visualize the position of the virtual ball depending on the user's motion. In these situations, the users hold the real ball that is tracked by a motion capture system. Participants are situated 3m behind the free throw line, but see the virtual ball at the foul line following the movements of the ball they are 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 below. Another question related to 3PP training conditions concerned the display of an avatar of the user. Such a 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 aim at evaluating the effect of using 1PP and 3PP visual conditions. Using an avatar would add a new variable with effects difficult to be quantified. Consequently, in the present paper, we decided to avoid using avatars and to focus on the influence of the other types of feedback.

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 randomized 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 synchronized 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 analyze the visual perception of the user under 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 ViconMX motion capture system. We computed the release moment in a similar way to the method described above for the real world experiments. Afterwards, the trajectory of the ball was estimated using our physical model. 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 (1PP condition) presented in an immersive configuration with stereoscopic screens and motion capture (Immersia)

We built the VR application in Unity, using the MiddleVR plugin, responsible for visual 3D synchronization. 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 120Hz. Another thread was responsible for 3D visualization and synchronization.

Results and data analysis

This section describes the results obtained with the above protocol, for the three visual conditions, by comparing the user's performance in VR with the one on a real basketball court. The objective of these results is to answer 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 three visual conditions? 3) Are there differences between VR and real world beginners' performance if we compare it with the expert's motor behavior? 4) Can we identify a set of necessary elements in a VE that can lead to a natural behavior while improving some aspects of the technique? 5) What was the subjective feeling of the users when experimenting in our training VE?

Evaluation of the users' performance

For each trial, the following data was collected and computed: (1) the position of the participant, (2) the motion of the real ball, (3) the release parameters that were used as inputs of the physical model (speed, horizontal angle, height and distance to the target), (4) the outcome of the user's performance (successful rate, angle of entry in the rim, lateral deviation, distance to the center of the basket). Each result was also compared to the performance of the experts in real situation in order to evaluate whether the visual conditions change the users' performance toward a more expert one or reversely. To this end, for each studied parameter we computed the following ratio:

$$\frac{\overline{Param_{Exp}} - Param_{Novice}}{\overline{Param_{Exp}}} \times 100$$

Where $\overline{Param_{Exp}}$ stands for the average value for the experts for this parameter, and $Param_{Novice}$ stands for the studied parameter for the beginners in the studies visual condition.

Comparison of the users' performance in real and virtual environments

Differences in ball release parameters and performance were analyzed using Friedman test. Post Hoc analysis was performed using Wilcoxon signed rank tests. Bonferroni correction was applied to consider multiple comparisons: the significance value was set to $p < 0.0083$.

No significant difference exists between the conditions for the successful rate of the basketball free throw (χ^2 (11,3) = 4.98, p = 0.17). The arising question is: did participants achieve this success rate with similar behavior or did they use different motor strategies according to each visual condition? To answer this question, we performed the analysis in two steps: 1) a comparison of the users' performance in the various conditions for all the 30 performed throws, and 2) a comparison in the specific case of successful throws (swishes).

Let us consider now the results obtained with all the 30 performed throws (successful and failed throws).

Figure 7 depicts ball speed at release for the various visual conditions. Ball speed in beginners' throws is generally lower than the one in experts' throws (negative values of the ratio). In 1PP condition, beginners threw the ball with a significantly lower speed (p=0.003) compared to real condition. This difference is not significant in 3PP condition (p=0.013) and especially in 3PP+guidance condition (p=0.0264), which is close to real world condition. The absolute values of the release speed vary from 7.11±0.09 m/s in the real environment to 6.74±0.27 m/s in 1PP, 6.83±0.27 m/s in 3PP and 6.89±0.21 m/s in 3PP+guidance.

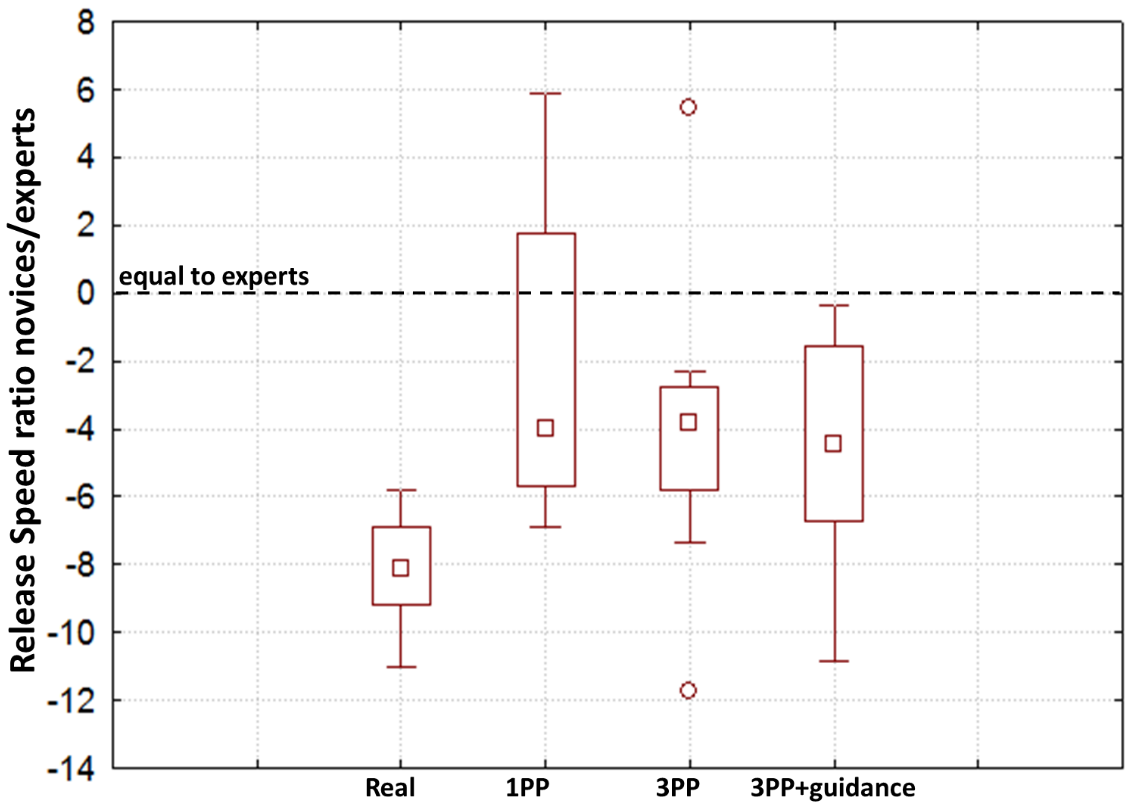

Figure 7: Box plot of the release speed values under various visual conditions, compared to the experts' reference release speed (all throws)

Figure 8 depicts the same type of results but for the release height. Beginners threw the ball at a lower height compared to experts in all the visual conditions (positive values of the ratio in the figure). No significant difference exists between the different visual conditions but there is a tendency to release the ball at a higher height in VR compared to real situation (p=0.04, 0.02 and 0.01 for 1PP, 3PP and 3PP+guidance respectively when compared to real situation). We want to emphasize that the visual guidance (3PP+guidance condition) was obtained based on expert data. Visualization of the optimal values of the release parameters encouraged users to release the ball from a comparable height, corresponding to the first ellipse of the ideal trajectory. This is supported by these results.

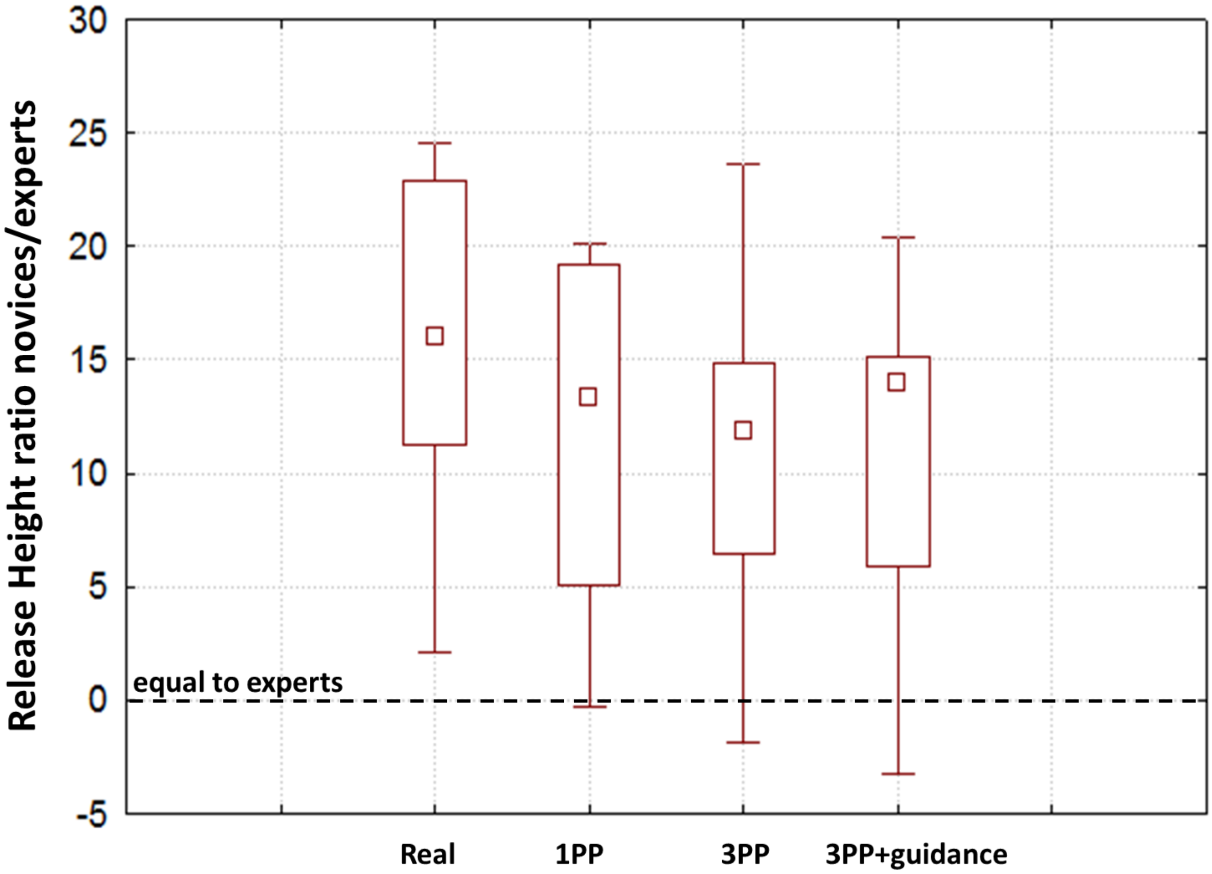

Figure 8: Box plot of the height values under various visual conditions, compared to the experts' reference height values (all throws)

Figure 9 depicts the angle under which the ball was entering the basket. This parameter is important because a high value leads to a maximum margin of error. In this case, the ball enters the rim perpendicularly. Low values indicate a tangent trajectory of the ball, which leads to less margin of error. For beginners, this angle is higher than for experts, especially in 1PP, 3PP, 3PP+guidance conditions (negative values of the ratio in the figure). Significant differences exist in 3PP and 3PP+guidance conditions compared to real condition, and a similar tendency exists in 1PP condition (p=0.003 and 0.003 for 3PP and 3PP+guidance respectively when compared to real situation). We assume that distance underestimation in VR leads to higher ball trajectories that maximizes the margin of error, requiring also higher ball speed (as reported above). In real condition, this angle is similar to the one of experts. The difference is more important for immersive conditions, because it supports the idea that the subjects adapt their performances to the training conditions.

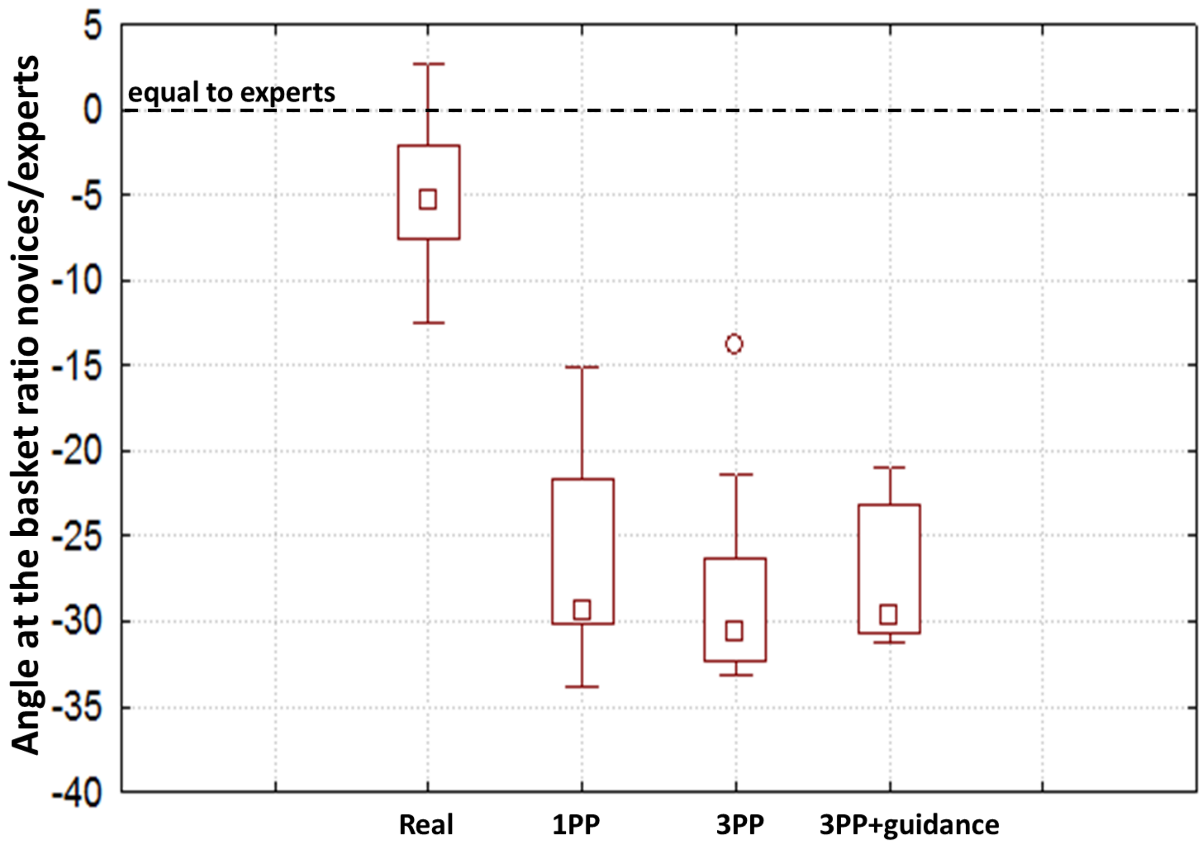

Figure 9: Box plot of the angle of entrance in the basket under various visual conditions, compared to the experts' reference angle of entrance (all throws)

All 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 of some of the performance parameters as a result of the changes in the visual information perceived by the user in the VE.

When focusing the statistical analysis to successful throws only, the same tendencies can be observed. For the angle under which the ball is entering the basket we observed very low standard deviations for 1PP, 3PP and 3PP+guidance compared to those in Figure 9 for all the 30 trials. The ratio between standard deviation and mean value was 0.75, 0.02, 0.30 and 0.01 for the real, 1PP, 3PP and 3PP+guidance respectively.

The results reported in this paper are in accordance with previous work [6] stating that users underestimate egocentric distance in a LSID VE. Similar results were present also in smaller LSIDs presented in [11], where participants did not correctly estimate 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.

Role of the visual guidance

The above results support the idea of underestimation of distance in VE, leading to an adaptation of the subjects to the task in the various conditions: lower ball speed, slightly higher height of ball release, and higher angle when the ball was entering the basket, compared to real condition. In this section, we wish to focus on the role of 3PP+guidance condition. We chose to study the potential modifications in motor behavior that appear under 3PP+guidance because we assume that it will manage to diminish the effect of the distance underestimation. Placing guidance ellipses closer to the user is meant to reduce the extent to which the task is affected by distance underestimation in VR.

The results confirmed our theory. When we displayed the visual guidance feedback, the performance parameters became slightly closer to the real world beginners' values. This indicates that guidance ellipses tended to partly compensate the distance underestimation effect, and determined the user to throw the ball similar to the experts' trajectories.

A similar tendency, but with more statistical power, can be noticed also if we focus on successful throws only (only trials with a swish). Indeed, when considering only the successful throws, the release speed tends to get closer to the one observed in real condition when guidance feedback was present: $p = 0.444$, 0.018 and 0.012 for real, 1PP and 3PP conditions respectively when compared to 3PP+guidance condition, as shown in Figure 10. This indicates that release speeds under 3PP+guidance condition and real world circumstances have close values. We also noticed that 3PP+guidance condition leaded to different users' performance than the one obtained in the other immersive conditions. Thus, we emphasize that displaying a guidance feedback can produce a more "natural" user performance. This condition is necessary for the development of a training protocol. Moreover, since when performing a distance-aiming task, the guidance feedback provides players with a visual representation of a perfect trajectory both speed and ball placement information were available. This feedback combined with the 3PP has afforded the player the opportunity of picking up proper information to increase launch speed.

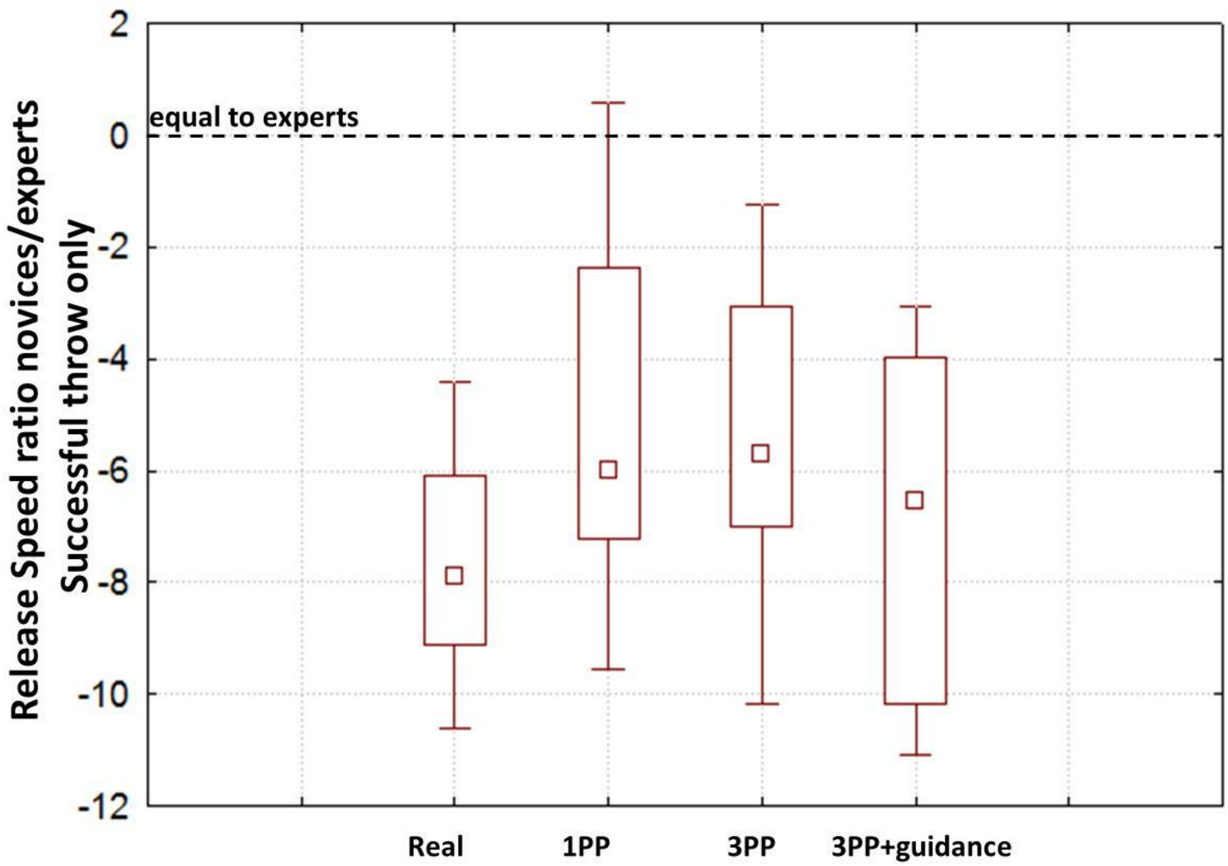

Figure 10: Box plots of the release speed values under various visual conditions, compared to the experts' reference release speed. Only successful throws were analyzed in this figure.

Release height is one of the important parameters in succeeding a free throw, as showed in [12]. These 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 threw their ball relatively to the size of the subject [10]. When considering the total number of throws, we observed that height of ball release slightly increased in this immersive condition compared to real condition, even if it was not significant (p = 0.013). But, when focusing on successful throws only, the difference between real world and 3PP+guidance release height was close to significant (p = 0.009). This tendency was not present in the other immersive conditions

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 other VR conditions tend to also increase the height of release but with slightly less difference (p=0.04 and 0.02 when comparing to real condition for 1PP and 3PP respectively).

The experiment showed that 1PP was the worst condition to perceive distance in this protocol. 3PP condition produced slightly better results when compared to real condition but 3PP+guidance was again better (especially for ball speed and height of ball release). However these small differences in ball release in VR conditions compared to real one led to significantly different angles under which the ball is entering the ring, as shown in Figure 9. Despite this result, it seems that using a training condition with 3PP visual condition combined with guidance is the first step towards generating a realistic behavior in VR. Moreover, these conditions could also be used in other training systems meant to determine users to release the ball at a higher height.

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 in VE. 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 grouped around 6 categories of interest, described below. Questions were adapted from the famous Witmer Presence questionnaire [13].

- Involvement/Control: How much were you able to control events?
- 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 was no significant rating difference 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.

Conclusion

The population studied in VR for this experiment consisted of beginners only. The main motivation 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. Expert players already have this type of knowledge and a possible improvement would be subtle and impossible to evaluate. Moreover, expert players have spent a long time tuning their gesture and could repeat the motion accurately from one trial to another, independently 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 experience in the VE leads to different performance compared to the real world. Contrary to previous paper [9], we decided to analyze each variable as an index value compared to experts’ performance. This approach allowed us to automatically compare each parameter with the reference value. We showed that most of the performance variables were surprisingly closer to experts’ performance, except for the angle under which the ball is entering the basket. It would be interesting to better understand this phenomenon, and especially how it might be used to make beginners learn the experts’ model in an efficient manner. Further analyses are required to address these issues about training and about how motor skills trained in VR can be transferred to real practice.

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. As stated above, 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 that requires a high precision task. Accuracy of the model is a key point in this kind of task. Thus, the calibration of the physical model according to motion capture data is necessary. It appears 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.

Distance underestimation or any other perceptual disturbance in VR make people adapt to the task. Users finally reached the same success rate by finding a new way of throwing the ball, despite this incoherence between perception and action. The main observations reported in this paper reinforce the conclusions in [8], stating that 3PP is more efficient for certain tasks, but further work would be required to study this type of statement in training condition.

A wrong perception of distance leads to consequences on velocities and accelerations. It resembles being immersed in a world with different physical laws. 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 novices, thus they had the same trial-and-error approach also in performing this aiming task in the real world.

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 analyze 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. Analyzing if people change their motion control strategies in various visual conditions would help to better understand the adaptations performed in VR and design more efficient training systems.

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