Human Performance Evaluation in a Virtual Reality Archery Simulation

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ABSTRACT

This paper describes two experiments which were conducted to investigate human performance in a virtual archery simulation. In the first experiment, we evaluate the effect of backward movement mapping (mapping between the virtual arrow movement and the user hand) on user performance. In the second one, we evaluate the effect of predictive scoring displays and dynamic camera viewing. In our simulation, the user simultaneously controls the virtual arrow orientation and backward movement while pulling the bowstring. The orientation and initial speed of the arrow is obtained from the relative position of two 3D magnetic sensors positioned on the bow and a data-glove. This glove is used to detect user's hand opening and therefore to trigger the release of the arrow. In both experiments, subjects were instructed to aim at the bull's eye of a target positioned in a virtual environment. In the first experiment, four backward movement mappings were tested: (C1) no backward movement, (C2) half backward, (C3) normal backward, (C4) double backward. Results showed that C1, C2 and C3 conditions lead to statistically equivalent performance. In C4 condition, subjects had more difficulties to achieve the task, resulting in a lower score and a longer aiming time. Results from the second experiment reveal that predictive scoring display is a very efficient visual cue when available. These results could be very useful for VE entertainment application designers.

CR Categories: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/Methodology, User-Centered Design; H.1.2 [Information Systems]: User/Machine Systems—Human Factors

Keywords: virtual reality, virtual environment, archery simulation, human performance, training

1 INTRODUCTION

Virtual Reality (VR) is a computer-generated immersive environment with which users have real-time, multimodal interactions that may involve visual feedback [1, 2, 3], 3D sound [4], haptic feedback, [5] and even smell and taste [6] [7]. By providing both intuitive interaction techniques and multi-sensorial immersion, VR presents an exciting medium for the study of human behaviour and performance. Virtual environments (VEs) can be utilized for motor learning, training and rehabilitation of disabled people [8]. For example, training in VEs offers both theoretical and practical advantages over real-world training that include safety, time, space and equipment, and cost efficiency. However, VR-based training applications are mostly geared toward very complex motor skills which have a large cognitive component (such as military training) [9, 10], or a very high level of eye-motor coordination (such as surgical training) [11]. Although, many sport / gaming oriented VR applications have been developed [12], relatively few studies have investigated the use of VEs to train skills that are more predominantly perceptual-motor in nature such as sportive skilled movements. In this context, human performance studies have to be carried out in order to increase simulator efficiency (allowing a better training transfer from the virtual to the real-world) and reduce after effects. Of particular importance is the effect of sensory-motor conflicts that may arise from time delay or spatial errors (offset, non-linear mapping etc.) between user's movements in the real world and their graphics representation in the virtual environment. In the context of archery simulation, the mapping between the virtual arrow backward movement and the user hand could have a significant effect on movement coordination and control of pulling forces. Another interesting aspect of this research is the use of software assistance to improve visuomotor coordination, learning processes, or training transfer.

Figure 1: A user aiming at the target

In our case, visual display of the arrow impact point on the target or numerical presentation of the score is definitely one of the more interesting feedback cues. In the next section, we review existing archery simulations and describe the one we have developed. Then we describe the protocol and the results of two experiments.

2 ARCHERY SIMULATION

One of the first archery simulator developed by Virtalis was commissioned by Motorola for use on the company' exhibition stand on CEBIT 1995. The archery simulator system combined VR headset technologies with a composite bow, instrumented with a Polhemus spatial tracking system and transducers measuring bowstring forces when drawn back. The virtual environment, utilizing the Sense8 WorldToolKit, presented users with a standard archery target within an olympic class stadium. High-scoring visitors were later invited to prove their virtual archery skills by using the bow to "light" the olympic flame. Another VR archery simulator was constructed at the Institute of Electronic Systems, at Alborg University. This simulator enabled the user to practice target archery

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in a virtual environment using a bow as the primary tool of interaction. The system uses computer vision to track reflective markers on the bow, and uses stereo vision to reconstruct the bow's position in 3D space. The spatial relations of the markers were used to detect when arrows are shot, and to calculate a light path for the arrow. The simulation is presented to the user as a graphical projection of a virtual world. In our archery simulation the bow is equipped with a $Flock - of - Birds^{TM}$ tracking system.

Figure 2: Experimental virtual environment

A second magnetic sensor is attached to a data-glove that is used to detect the user's hand opening and to trigger the release of the arrow (Figure 1). The user simultaneously controls the virtual arrow orientation and backward movement while pulling the bowstring. The opening and closing of the hand are detected when the average of flexion of two fingers (index, and middle finger) exceed a threshold value. The relative position of the 3D magnetic sensors is used to calculate the orientation of the arrow, while their relative distance is used to calculate the initial velocity of the arrow. The user's view point is situated just behind the arrow and directed toward the target (Figure 2). Two viewing modes are available : the camera either keeps its initial position (static camera viewing mode) or follows the arrow (dynamic camera viewing mode). The second viewing mode allows a better visualization of both the arrow trajectory and scoring. After each shot, a new arrow is created and appears on the screen at the starting position as soon as the user closes his/her hand. When the user closes his/her hand, he/she then pulls the string and aims at the virtual target. A keyboard is used to adjust a few parameters such as glove and sensors sensitivity, stiffness of the virtual string, camera viewing mode (static or dynamic), initial position of the target and 3D sounds. Our archery simulation was developed in C/C++. OpenGL Graphics Library was used as well as some video game tools and tutorials.

2.1 Arrow dynamics

The initial orientation of the arrow is obtained from the relative position of the magnetic trackers. Angles and distance calculations are based on sine, cosine, and tangents. Orientation with respect to both the horizontal and vertical plane (elevation angle) and the power of the shot (initial velocity of the arrow) are deduced from these parameters. The arrow trajectory is calculated by a simple time-based equation. The power of the shot is calculated according to Eq. (2.1), where V_0 is the initial velocity of the arrow and the mass of the arrow is fixed.

$$V_0 = \Delta\sqrt{k/m} \qquad \text{Eq (2.1)}$$

with :

Δ : amplitude of the backward movement
k : stiffness of the virtual string
m : mass of the arrow (30 gr.)

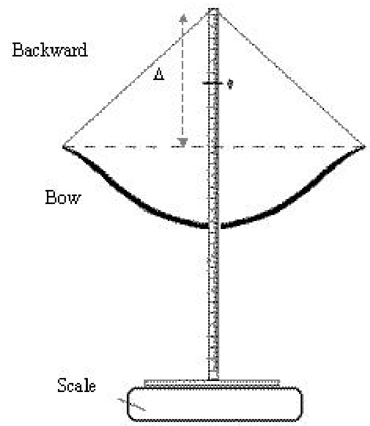

Figure 3: Calibration method

2.2 Collision detection

Since the arrow velocity is high, we needed to calculate its 25 intermediate positions were calculated between the current frame and the previous one, in order to ensure collision detection. Then, for each calculated position, we determine the intersection between a line segment (the arrow) and a polygon (the target). When a collision is detected, a function returns the distance between the bull's eye and the intersection point.

2.3 Scoring

The score is calculated as the distance between the arrow intersection and the center of the target. In the reported experiments, we used a linear scoring calculation rather than the color of the intersection point (as it is the case in real archery), in order to obtain more accurate data on user performance.

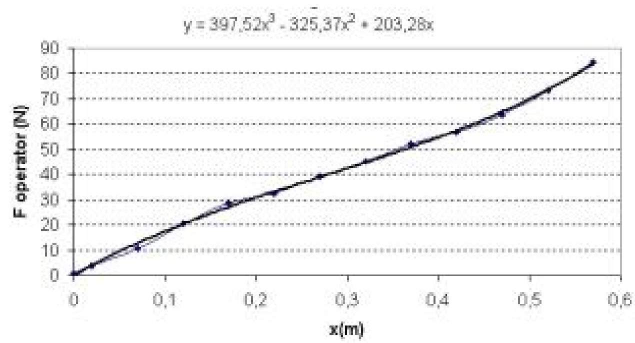

Figure 4: Calibration results

2.4 Calibration

In order to assess the pulling forces applied by the user on the string, we performed the following calibration. For different amplitudes of the backward movement (measured in the simulation by the relative distances between the two magnetic sensors), we measured the corresponding forces using the method illustrated in (Figure 3). Results of the calibration are illustrated in Figure 4. We observe that the calibration data could be represented by a third order equation. According to archery experts, the inflexion point (30 cm in our case) corresponds to the most comfortable backward movement. This backward movement corresponds in our case to a pulling force of about 45 N.

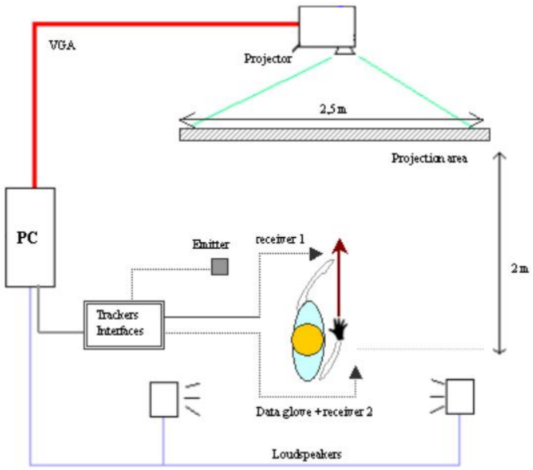

Figure 5: Virtual archery system

3 Experiment 1 : Effect of backward movement mapping on user performance

In this first experiment, we investigated the effect of backward movement mapping on human performance while aiming at a stationary target in a virtual environment.

3.1 Design

Twenty four right-handed volunteer novice subjects participated in this experiment. Each subject performed the task in the following conditions : no backward movement (Condition 1), half backward (Condition 2), normal backward (Condition 3), double backward (Condition 4), in a randomized order. This was done to avoid any training transfer between conditions. The viewing mode selected in this experiment was always the static camera viewing mode. Each of the 4 sessions corresponding to the experimental conditions consisted of 15 shots with 30 seconds rest period between each group of 5 shots, and 1 minute rest period between each session. The total number of shots was, therefore, 60 for each subject.

3.2 Procedure

Subjects were instructed to aim at the bull's eye of a target positioned in the virtual environment. Before starting the experiment, calibration of the glove and the 3D sensors was done. During glove calibration, we asked the subjects to open and close their hand in order to detect the opening threshold value used for the release of the virtual arrow. For the tracker calibration, subjects were asked to aim at the center of the screen (corresponding to the bull's eye of the target). Then, we allowed each subject to shoot 4 arrows in the virtual environment in each experimental condition, with no target displayed, to get acquainted with the system. Subjects stood at 2m from a 2m x 2.5m rear-projected screen and held the bow as in real archery (Figure 5). The target was positioned in the virtual environment at a distance of 18 m. Its virtual size was 80 cm.

3.3 Results

In order to assess user performance, the following data were collected for each experimental condition : aiming time (time between the beginning of each single trial and the release of the arrow), amplitude of the backward movement (distance between the two trackers), score of the shot (from 0 to 1000), and the vertical elevation angle. Once collected, the data were analyzed using an analysis of variance (ANOVA).

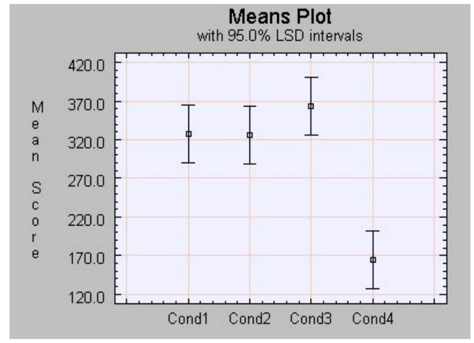

Figure 6: Mean score vs. backward mapping

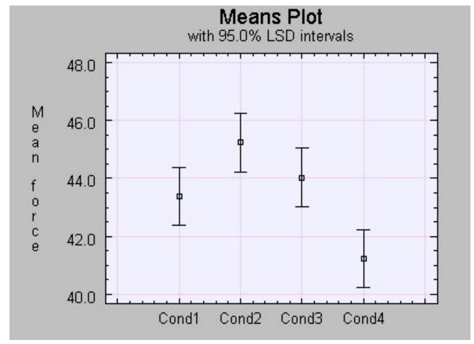

Figure 7: Mean applied force vs. backward mapping

3.3.1 Score

The ANOVA revealed a significant effect of backward mapping on user performance ($F(3,23) = 5.84$, $p < 1.0E\text{-}4$). Results show that conditions 1 (no backward), 2 (half backward) and 3 (normal backward) led to no statistically significant differences in scoring (Figure 6). Scores recorded are about 327 (Std : 206) for condition 1, 326 (Std : 218) for condition 1, and 363 (Std : 217) for condition 3. We observed that for the double backward condition (4), user performance significantly dropped (score of 164 - Std : 119). This shows that subjects had some difficulties accurately aiming at the target.

3.3.2 Pulling force

Results illustrated in Figure 7 revealed that the backward mapping has a significant effect on applied force ($F(3,23) = 5.55$, $p < 1.0E\text{-}4$). For the first three conditions, average recorded backward movement corresponded to pulling forces of 43.38 N (Std : 10.11), 45.24 N (Std : 10.74) and 44.03 N (Std : 9.37) respectively. We observed that for condition 4, average applied force was significantly lower (about 41.23 N- Std : 7.47).

3.3.3 Aiming time

Results revealed that the backward mapping has a significant effect on aiming time ($F(3,23) = 15.48$, $p < 1.0E\text{-}4$). For the first three conditions, aiming times were respectively 5.79 (Std : 2.9), 5.82 (Std : 2.2) and 5.62 sec. (Std : 2.5). For the last condition, adjustment of the aim required more time (6.38 sec - Std : 2.8).

3.3.4 Elevation angle

Results revealed that the type backward mapping has a significant effect on elevation angle (F(3,23) = 3.39, $p < 1.0E\text{-}4$). For the first three conditions elevation angle were-3.3 (Std : 0.9), -3.0 (Std : 1.84) and -2.5 (Std : 1.18) degree respectively. In condition 4, the average elevation angle was -1.5 degree (Std : 1.42). This result shows that subjects tried to compensate the lower initial velocity of the arrow by aiming higher.

4 Experiment 2 : Effect of software assistance on user performance

In this second experiment, we investigated the effect of both a predictive display of information (visual display of the arrow impact point onto the target and the score) and a dynamic camera viewing mode on human performance. Moreover, we evaluated the efficiency of these software aids for learning.

Figure 8: Predictive display : impact point and scoring.

4.1 Design

This experiment was carried out in two successive steps : a training session and then a testing session in order to investigate the training transfer associated with each of the conditions. Twenty four right-handed novice volunteers subjects participated in this experiment. They were separated into 5 groups of 5 subjects as illustrated in Table 1. For the training session, each group experienced one of the following conditions : no predictive scoring information (condition 1), predictive impact point (condition 2), both predictive impact point and predictive numerical presentation of the score (condition 3), predictive numerical presentation of the score (condition 4) and dynamic camera viewing mode (condition 5). The static camera viewing mode was always selected except for condition 5. Both predictive impact point and predictive numerical presentation of the score are illustrated in Figure 8. For the testing session, no software assistance was available (no predictive display and no dynamic camera viewing mode).

4.2 Procedure

Subjects were instructed to aim at the bull's eye of the target. As in the first experiment, trackers calibration was done. During glove calibration, subjects had to open and close their hand back and forth to detect the opening threshold value. We allowed each subject to shoot 4 arrows with no target displayed, to get acquainted with the system. Both sessions (training and testing) were made of 30 shots with 30 seconds rest period between each group of the 5 shots. A one minute rest period occurred between each session.

Table 1: Software assistance vs. Group and Sessions

	Experimental Sessions	
Groupe	Training	Testing
1	None (fixed cam.)	None
2	Predictive impact point (static cam.)	None
3	Predictive impact point and scoring (static cam.)	None
4	Predictive scoring (static cam.)	None
5	Dynamic camera	None

4.3 Results

In order to assess average user performance, the following data were collected in each experimental condition : aiming time (time between the beginning of each trial and the release of the arrow), amplitude of the backward movement (distance between the two trackers), score of the shot (from 0 to 1000), and elevation angle. Once collected, the data were analyzed using an analysis of variance (ANOVA). We observed that aiming time, elevation angle and amplitude of the backward movement were not significantly different. However, scoring performance was strongly affected by software assistance.

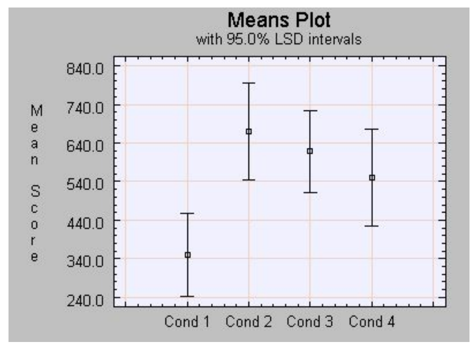

Figure 9: Mean score vs. conditions for the training session

4.3.1 Effect of predictive display

Training session The ANOVA revealed a significant effect of predictive display on user performance (F(3,4) = 5.24, $p < 1.0E\text{-}4$). Results showed that condition 2 (Predictive impact point), condition 3 (Predictive impact point and scoring) and condition 4 (Predictive scoring) were not significantly different with respect to scoring at the $p < 0.5$ level (Figure 9). Scores recorded are about 696 (Std : 136) for condition 2, and 617 (Std : 129) for condition 3 and 585 (Std : 185) for condition 4. Scoring was much lower for condition 1 (351, Std : 64). This demonstrates that the predictive display was very useful in achieving a good performance.

Testing session In this session, no predictive information were displayed. The ANOVA revealed no significant difference between conditions (F(3,4) = 0.54). The average score was 462 (Std : 78) for condition 1, 429 (Std : 212) for condition 2, 439 (Std : 145) for condition 3 and 527 (Std : 205) for condition 4. This shows that predictive displays do not lead to any training transfer.

4.3.2 Effect of dynamic viewing mode

Results show that condition 5 (dynamic camera) during training session lead to a better average score (471 ; Std : 158) than condition 1 (no software assistance) (351 ; Std : 64) (Figure 10), but not as high as in conditions 2, 3 or 4. Thus, the dynamic camera viewing mode is not as efficient as the predictive displays in improving user performance. However, recorded average scores during testing session were a 462 (Std : 78) for condition 1 and 581 for condition 5 (Std : 103). That suggested that the dynamic camera viewing mode may result in better training transfer.

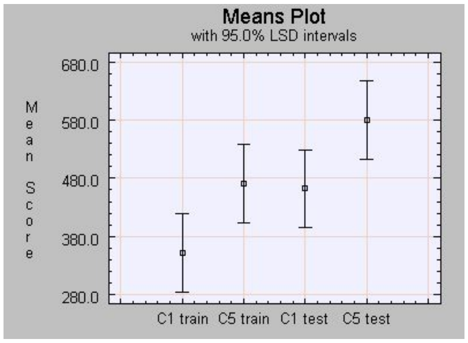

Figure 10: Mean score comparison vs. conditions for the training session and for the testing session

5 CONCLUSION

In this paper, we investigated both the effect of backward movement mappings and software aids, such as predictive impact point and predictive scoring numerical display, on human performance in a virtual reality archery simulation. The user controlled the virtual arrow orientation and backward movement while pulling the string of a real bow. Subjects were instructed to aim at the bull's eye of a target positioned in a virtual environment. Four backward movement mappings were studied : (C1) no backward movement, (C2) half backward, (C3) normal backward, (C4) double backward. An ANOVA analysis showed that C1, C2 and C3 conditions lead to statistically equivalent scoring, average arrow initial velocity, and aiming time. In C4 condition, subjects had more difficulties in accurately aiming at the target. Indeed, we observed a visual-dominance effect resulting in a reduced pulling force. Results from the second experiment reveal that predictive displays are very efficient visual cues for improving human performance. However, such cues are not effective for learning. We observed that a better knowledge of the arrow scoring and flight trajectory associated with the dynamic camera viewing mode leads to a better training process. Both users' feedback and observation highlight the ease of use of the system. However, some subjects asked about the possibility of avoiding the spatial offset between the real bow and the virtual arrow. In order to investigate both subjective and objective effect of this offset, we are going to carry out the same experiment using augmented reality techniques (using see-through head-mounted display). Further experiments will also investigate visuomotor control and motor learning in tasks involving moving targets.

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