Using virtual reality to analyze links between handball thrower kinematics and goalkeeper's reactions

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The ability to intercept objects is one of the most complex characterisitcs of the human perceptivo-motor repertoire. Chardenon et al. [3] state that intercepting objects requires on-line movement regulations based on instantaneously available information to accommodate a future event. For example, the level of expertise of handball goalkeepers depends both on their capacity to anticipate the opponent's actions and on their capacity to decrease their own reaction time [15]. The same authors studied visual search strategies in soccer players [15,16] and demonstrated that several visual elements were used to anticipate the ball's trajectory. To this end, they imposed standardised situations upon a set of subjects through the use of video projection onto a wide screen. The videos were stopped after a given event and the subject had to retrieve the remainder of the sequence. This exercise has also been performed in, tennis [7, 13,11], squash [1] and karate [10].

More recently, such a technique has been linked to portable eye movement recording, in order to identify more precisely those visual elements considered by tennis [17], soccer [12] and handball [8] players. The goalkeeper's reactions were linked to visual elements considered by the subjects through statistics (mainly PCA). However, nothing proved that one element viewed by all the subjects over a significant period of time contributed significantly to the goalkeeper's final reaction. Did an element viewed for a very short period of time have more of an influence on the subject's reactions than that viewed for much longer?

In order to answer such a question, each visual element that might be considered to influence the goalkeeper's decision must be isolated. Then, by asking throwers to modify only one element in their throw we can verify if and how this isolated element influences the goalkeeper's reactions. To be conclusive, the player would have to be able to repeat exactly the same movement several times whilst modifying only one visual element. This presents a problem since in real situations these visual elements tend to work in pairs, and indeed, even elite players cannot adhere to such precise instructions by mechanically reproducing identical movements. .

An alternative could be the use of virtual reality where tests are carried out in a totally controlled environment. In this instance, it may be possible to modify only one element of the simulation and to measure the resulting changes adopted by the goalkeeper. Virtual reality has already been used in human motor control understanding [3]. However, few studies have been carried out in order to identify whether the subjects reacted the same way in virtual reality as they do in the real world. In a given sport duel simulation, [9] real tennis players were asked to interact with virtual tennis players. However, the subjects played through metaphors that were far from realistic tennis movements. Moreover, the subjects were constrained to evolve in an extremely limited space and could only visualise a virtual racket. Indeed, although they looked promising, these techniques have not been proven to accurately investigate and analyse anticipation and behaviour in duels. One may wish to consider then if it is at all possible to scientifically analyse our understanding motor-control process with virtual reality.

As demonstrated by previous litterature [17], the goalkeepers anticipation of his opponents' gestures is linked to visual elements occurring before ball release. Consequently, we propose to use virtual reality to analyse the relationship between the movements of handball throwers and the goalkeeper's corresponding reactions.

Bideau et al [2] have developed a virtual training simulator for handball goalkeepers. This training tool allows to identify similarities between the movements performed by goalkeepers in real and virtual environments.Our aim in this paper is to determine whether such a tool is complementary with portable eye movement recording, and if so, to identify how it can be used to evaluate the influence of visual elements on the goalkeepers' parry. In this experiment, we have examined the influence of three modifications of a reference handball throw (modifying kinematics) on the goalkeeper's reactions. The modifications were selected after carefully studying previous handball results [4,5].

Eight National French League goalkeepers playing at First (three subjects), Second (three subjects) and Third division (two subjects) participated in this study. They were placed in a reality centre system made up of a large cylindrical screen (3,80m radius, 2.38m height and 135° field of vision). Three synchronised videoprojectors (Barco 1208S) driven by a SGI Onyx2 InfiniteReality (Silicon Graphics product) were used to display a 3D environment. A set of glasses synchronised with the system enabled stereovision. A goal was physically placed in the reality centre (Fig. 1),corresponding at once to the goalkeepers position and the position of the virtual camera in the virtual environment.

A virtual player was designed graphically in VRML (Virtual Reality Mark-up, Language http://www.vrml.com). In order to realistically animate the virtual thrower, we carried out a large number of experiments involving throwers' motion capture. We obtained a large database of knowledge involving invariants of the movement and the throwing strategies [6]. The resulting model is based on statistically averaged motions (called reference motions) that can be manupilated through operators in order to take our modifications into account. One reference motion was designed for each type of throw: with and without jumps, and with ball release at various positions in space. An operator **(modification1)** was designed to drive the wrist at a given position at ball release (translation of 15 cm causing a 0.3 rad increase of the elbow angle). Another operator **(modification2)** added a 0.4 rad rotation of the trunk in the frontal plane at ball release. The last operator **(modification3)** delayed the ball release time making the thrower lean more. Past works suggested that the arms' movements and the torso orientation were the visual elements most taken into account by the handball goalkeeper [4,5].

To record the goalkeeper's reactions, we used a motion capture system (Vicon370, Oxford Metrics product) equipped with 7 infrared cameras set up at a frequency of 60Hz. The cameras were placed all around the subject in order to cover the whole field of measurement and accommodate the subjects' natural gestures. 26 circular reflective markers were placed on anatomical landmarks to precisely reconstruct the 3D position and orientation of each segment.

The subjects were placed in the reality centre, inside the goal, as in a real game. They were familiarised with the virtual environment and all the equipment used for the experiment. We then asked the goalkeeper to intercept twenty randomly presented throws, as in a real game. 4 throws exactly simulated from previously recorded trajectories. The computer model calculated 4 throws (called reference motions) in order to reproduce exactly the same previous captured motions. The computer model also calculated 4 throws for each modification (modification 1, 2 and 3) according to the corresponding reference motions. All the above throws were played twice randomly (which raises the number of throws to forty). The ball trajectory was defined by the wrist position at ball release, the final position in goal (linked to the reference motion) and the speed (also provided by the reference motion). Consequently, except for the initial position at ball release, the trajectory remained unchanged.

As the selected reference motions generated high ball trajectories, we chose to focus our analysis on the goalkeeper's arm that was placed so as to intercept the ball's trajectory. Then, we compared the subjects' arm's displacements between a reference motion with and without modification. We particularly studied the arm centre of mass displacements in the total body centre of mass COM reference frame. All the trajectories were standardized in time by an event that was common to each goalkeepers' reactions. This event was the peak of acceleration of the arm's center of mass when the goalkeeper started his parry. Hence, each trajectory could be compared according to a common time scale.

Letting m_i and m_j be the arm trajectories obtained for two trials based on exactly the same situation, we calculated the correlation C_{ij} between m_i and m_j for all the standardised situations, including throws without modification: $C_{ij} = corr(m_i, m_j)$. Then we calculated the mean value of the resulting correlations C_{ij}, for all the possible situations: $\overline{\mathbf{C}}$. $\overline{\mathbf{C}}$ was calculated subject by subject. This value stands for the similarity of two reactions to the exact same throw.

Secondly, we compared the goalkeeper's arm trajectory m_i obtained for a reference throw, to those obtained with modifications (respectively $m1_i$, $m2_i$ and $m3_i$). For all the subjects, we calculated the correlation C1 between the arm center of mass trajectory for the reference throw and the arm center of mass for the same throw with modification 1. In the same way, C2 and C3 were calculated for mofitication 2 and 3 respectivly. .

We also calculated the mean correlation values and standard deviations for each modification within the whole population.

As a result, $\overline{\mathbf{C}}$ varies from 0.96±0.2 to 0.99±0.1 depending on the subject. The high correlations and low standard deviations indicate that the subjects repeated almost unanimously the same movements in front of the same throw. Correlation provides us with a comparison of the arm's trajectories shape. Hence, it does not emphasize constant translations between two movements that could only be due to a change in the initial posture at the beginning of parry.

In Table 1, the first column recalls $\overline{C}$ for each subject. The next three columns represent the three correlations between the arm movement with the reference trajectory and the arm movement obtained with modification 1, 2 and 3 respectively (denoted C1, C2 and C3). One can see that subject 8 exhibits a high C1 correlation that is quite close to C3. This could mean that the subject is approximately equally as sensitive to modification 1 and 3. On the contrary, subject 5 exhibits a lower C1, less close to C3. This subject seems to be more sensitive to modification 1 than to modification 3. Hence, we may conclude that different individuals respond differently to the various modifications.

Despite these individual behavioural patterns, statistical analysis was performed on the entire group. In order to verify if the resulting correlations were significantly different from the mean $\overline{\mathbf{C}}$ value**,** we performed a Kolmogorov-Smirnov test of normality. We then analysed the data through an RM ANOVA (Friedman test). Significance was obtained for $p<0.05$. Significance indicates that the goalkeeper performed a different movement when he tried to stop a modified throw. A post hoc test (Student Newman-Keuls test) was also performed.

The results of this test are p=0,000171 for $\overline{C}$ vs C1, p=0,002604 for $\overline{C}$ vs C2 and p=0,000140 for $\overline{C}$ vs C3. Those results show that there are significant differences ($p<0.003$ for the highest values) between the subjects' reactions to each modified throw. Thanks to these results, it is possible to sort the modifications by increasing order of significance according to their correlations. Hence, modification 1 seems to be more influential than modification 3 and modification 2.

Salience of the goalkeepers' reactions in the virtual environment has been validated in previous work [2]. With this in mind, we studied so-called presence that was defined as "the subjective feeling of being there" [14]. Instead of using questionnaires to evaluate presence, we compare goalkeepers' kinematics in a real and in a virtual game [2].The results provided us with correlations between movements in the two environments ranging from 0.96 to 0.98.

As the gestures in virtual reality seem compatible with those in a real game, we can conclude that we were able both to identify (qualitatively) and measure (quantitatively) the degree to which modifying certain visual elements affected the goalkeeper's reactions. Our results are coherent with those of past studies. As other authors [4,5] did, we also concluded that the movements of the goalkeeper's arm catching the ball seem to be very important in handball.

With portable eye movement recording [15], it might be possible to make an inventory of all the visual elements taken into consideration by the subject, and to suggest which of them appear to be the most significant. With our approach, it is possible to validate these findings by isolating certain visual elements and verifying their influence on the subject's reactions. Our animation model also makes it possible to test several combinations (with various different visual elements) in order to investigate the possible influence of their relationship on the goalkeeper's decisions.

However, this preliminary work could be improved by using, for example, more precise motion comparison tools. Nevertheless, our method was accurate enough to determine the varying significance of different visual elements

In our experiment, we did not use a physical link to synchronize the virtual reality center and the motion capture system. Despite this limitation, our results show that indentical throws caused the goalkeeper to produce indentical gestures. On the contrary, modified throws produced significant differences in the goalkeepers' movements. The lack of a temporal dimension in our method meant that no analysis of reaction time could be carried out thus limiting the scope of our experiment. For future investigations, we propose to physically link together the two systems in order to study both reaction time and, as a consequence, anticipation.

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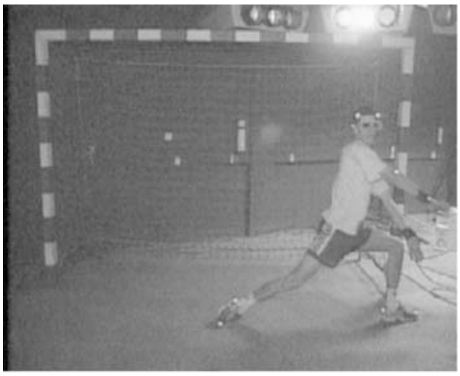

Figure 1: goalkeeper equipped with reflective markers and stereoscopic glasses in the virtual simulator (see videoprojectors above).

Subject	$\overline{C}$	C1	C2	C3
1	0.98±0.01	0.8±0.02	0.94±0.01	0.91±0.01
2	0.98±0.01	0.78±0.01	0.92±0.01	0.87±0.01
3	0.98±0.01	0.78±0.02	0.92±0.01	0.85±0.01
4	0.97±0.01	0.79±0.01	0.93±0.01	0.89±0.01
5	0.98±0.02	0.77±0.01	0.92±0.02	0.89±0.01
6	0.97±0.02	0.76±0.01	0.96±0.01	0.85±0.01
7	0.97±0.02	0.82±0.01	0.94±0.02	0.9±0.01
8	0.96±0.02	0.86±0.02	0.93±0.01	0.9±0.01
Mean	0.97±0.01	0.80±0.03* p<0.0002	0.93±0.01* p<0.003	0.88±0.02* p<0.0002

Tab. 1: $\overline{C}$ and correlations C1, C2, C3 between reactions to a reference throw and those to modification 1, 2 and 3 respectively. * stands for a significant difference with $\overline{C}$ (p<0.05)