Non Intrusive Measures for Determining the Minimum Field of View for User Search Task in 3D Virtual Environments

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***Abstract*—In this paper, we report on an experiment to determine the minimum field of view that permits the user to perform an effective search task in a 3D virtual environment, by analyzing how the user controls the virtual camera. Our study exploits a model based on the use of several novel non-intrusive temporal and quantitative measures of visual attention, such as: fixation, gaze, and movement. Seven out of ten measures gave significant results with the same findings.**

Keywords-Field of view; virtual environment; video games; visual attention.

I. INTRODUCTION

Visual attention is the ability of a vision system, whether human or artificial, to quickly select the most pertinent information from the environment in which it operates [1].

Eye tracking has been used to measure visual attention for many years. It is the process of using sensors to localize the position and the behavior of the eyes. It helps us to determine what a person is looking at, what he/she is not looking at, but also what he/she does and does not pay attention to. Through eye tracking systems we can provide many visual attention measures, such as: fixation, gaze, and movement, in order to analyze users' ocular behavior.

A principal means of interacting with 3D VEs (Virtual Environments), in the case of video games, for example, is the use of the virtual camera, which is relatively easy to access and manipulate via game engines. The use of this virtual camera can show interesting results for non-invasive study and characterization of user behavior - especially in the absence of eye tracking systems, which can sometimes be unavailable.

Our work is focused on the FOV (Field of View) effect of the virtual camera for determining the minimum FOV that allows users to perform an effective search task in a 3D VE.

The remainder of this paper is organized as follows: Section II presents related work. Section III describes our experiment that analyzes user behavior in a 3D VE via the virtual camera. Section IV summarizes our paper and provides an outlook for future work.

II. RELATED WORK

Gaming is an increasingly prevalent cultural pastime [2], and today the video game is one of the most popular types of software applications in the world. More than half of all Americans play video games, for example [3][4]. Video games can provide a framework for testing many types of attention measures [5], e.g., playing video games, such as Pac Man, can improve the reaction times of older adults [6].

During everyday interactions, our eyes provide a lot of information that reflects our emotional and mental states. Eye movement data reflect moment-to-moment cognitive processes during task execution [7]. When we look at an object in space (e.g., a wall with windows and doors), our eyes concentrate much more on some parts of this object (e.g., one of the windows), while the other parts of the object may receive less attention [8].

Studying ocular behavior in the context of human computer interaction (e.g., web browsing or video games [9][10][11][12]), allows us to identify and provide many indicators that can be used to evaluate user attention in order to improve the design of an user interface such as, for example, a digital library [13].

Much research has been conducted towards the study of ocular behavior during playing video games. In a FPS (First Person Shooter) video game, for example, the player pays more attention to the center of the screen around the reticule because he shoots enemies through the reticule; by contrast, the attention area is larger in an adventure game because the player's attention is not constrained by any specific area of the screen [14][15].

There are many types of eye behaviors: fixation, being the moment when the eyes are relatively stationary, taking in or encoding information with a minimum duration of 100 milliseconds [16]; saccade, being the eye movement that occurs between fixations with durations of approximately 150–200 milliseconds [17]; and gaze, being the moment when the eyes look at a display element [18]. When we look at an object in a visual display, we may make many fixations on this object. The number of these fixations shows the importance of the display area. A large number of fixations, however, can also reflect a poorly designed interface [18].

To study user behavior in a 3D VE, a common approach is to ask users to complete search task in order to know how he/she interacts with the 3D VE, e.g., users may have to find objects that have specified numbers displayed on them [11], or to find a maximum number of hidden keys distributed in a 3D VE [19].

Our idea was to use the virtual camera of a 3D VE to examine several visual attention measures, such as: fixation, gaze and movement. The use of the 3D VE's virtual camera provides an indirect method for analyzing the effect of FOV on user behavior, given that the useful FOV is the total area of the visual field within which individuals can obtain useful information without moving their heads or eyes [20][21].

In order to study and characterize user behavior in a 3D VE through the virtual camera, we selected several visual attention measures employed by Gibbs et al. [9]. The measures selected are expressed by the number of fixations, fixation duration, and gaze duration. We also introduced new measures to give more information about how the user performs an effective search task in our 3D VE. The measures that we added are expressed by: the number of gazes, the number of movements, the movement duration, the sum total duration of all fixations per task, the sum total duration of all gazes per task, the sum total of all movements per task, and the total duration of each task.

Our goal was to examine the FOV effect of the virtual camera on user behavior, and to determine the minimum FOV that allows the user to perform an effective search task in a 3D VE. FOV size is very important for rapid extraction and identification of information in a 3D VE. The effective search task, in the context of our experiment, consists of a simple navigation within the 3D VE for the purpose of finding all objects (e.g., hidden buttons distributed around the VE) using: the least possible number of fixations and the shortest fixation duration; the least possible number of gazes and the shortest gaze duration; the least possible number of movements and the shortest movement duration; the shortest sum total duration of all fixations per task; the shortest sum total duration of all gazes per task; the shortest sum total duration of all movements per task; and the shortest total duration of each task. Our results provide information that can be of benefit to game designers, allowing them to improve gameplay, manage the difficulty of game environments, and optimize the distribution of visual resources.

III. OUR EXPERIMENT

Gibbs et al. used an eye tracking system to determine whether ocular behavior differs between newspaper websites and TV-oriented websites. They used several visual attention measures to test ocular behavior, such as: number of fixations, fixation duration, and gaze duration. Within the contest of FPS video games, our research uses these measures employed by Gibbs et al., as well as our own measures to analyze user behavior, using the VE's virtual camera instead an eye tracker. The aim of our experiment is to determine the minimum FOV that permits the user to perform an effective search task in a 3D VE, and to generate information for game designers to help them manage and adapt the difficulty of a 3D VE according to user behavior.

The users in our experiment use a mouse and a keyboard to manipulate the virtual camera of our 3D VE as they would in a FPS video game (e.g., Half Life, Counter Strike). The measures employed in our experiment, consist of various types, such as: fixation, being a short pause in movement, represented quantitatively by the Number of Fixations (NF) and temporally by the Fixation Duration (FD), which vary between 100 and 300 milliseconds; gaze, which is the time spent looking at a display object, represented by the Number of Gazes (NG) and the Gaze Duration (GD), which starts from 300 milliseconds; the movement between two fixations or gazes, represented by the Number of Movements (NM) and the Movement Duration (MD), which starts from 100 milliseconds.

We also added four measures to those specified above: the Sum Total Duration of all Fixations per task (STDF), the Sum Total Duration of all Gazes per task (STDG), the Sum Total Duration of all Movements per task (STDM), and the Total Duration of each task spent by the user to complete the required task (TD).

A total of 14 volunteers (10 male and 4 female) participated in this experiment. Their ages varied between 25 and 42 years, with a mean of 30. All participants are right-handed and healthy. The experiment was performed on a desktop personal computer with an LCD display with a resolution of 1920×1040 pixels.

A. Procedure

The purpose of the following experiment is to compute visual attention measures and to study the FOV effects on user behavior during a visual search task in a 3D VE. Fig. 1 shows our 3D VE, which is a virtual art gallery similar to the static environment of Lee et al. [11]. We used Unity3D version 3.5 to create our 3D VE, including all the objects and the buttons. The virtual camera is positioned at the level of the eyes of the user's avatar.

The participants were first invited to complete a short form to provide information including their name, age, gender, and whether or not they often play FPS video games. Secondly, the participants were asked to perform a free navigation in the 3D VE with a FOV of 80°, simply navigating in the 3D VE and observing the virtual objects using the mouse and the keyboard to control navigation motion. This step was created as a training phase to learn manipulation of the virtual camera. The participants used the mouse to change the orientation of the virtual camera (yaw and pitch angles) and the keyboard to move the virtual camera. We used an 'AZERTY' format keyboard with the following key mapping: Z: forward, S: back, D: right, Q: left.

Figure 1. Our 3D virtual environment (the art gallery).

Finally, the participants were asked to perform a visual search task to find and validate hidden buttons in the 3D VE. They had to find ten buttons randomly distributed on the surfaces of objects in the 3D VE (each object in our VE contains one hidden button).

Each participant had to find all the hidden buttons using the reticule area (a rectangle 250×150 pixels situated in the center of the screen), and validate them by pressing the Space key. A number is displayed at the top left of the screen to indicate how many hidden buttons are left.

The participant was asked to repeat the search task six times, knowing that we had changed the positions of all the objects and buttons, as well as the FOV size of the virtual camera before each of the six attempts at the task (10° for the first attempt, 20° for the second, 30° for the third, 50° for the fourth, 80° for the fifth, and 110° for the sixth attempt). The order of the attempts was randomized for each of the participants in order to eliminate the adaptation effect. The purpose of changing the FOV size (i.e., from 10° to 110°) was to discover how FOV affects user behavior and to determine the minimum FOV that enables the user to perform an effective search task in a FPS type 3D VE, given that the default FOV in a FPS game ranges from 75° to 110°.

B. *Results*

A one-way ANOVA was conducted to see whether the FOV of the virtual camera affected user behavior during the search task in our 3D VE. A total of 14 subjects took part in the experiment. We sought to discover whether there is a significant difference between the measures that we obtained by changing the FOV size between 10°, 20°, 30°, 50°, 80° and 110°. We expressed our measures by way of a natural logarithm and tested the measures' normality using the Shapiro Wilk test [22]. Then, we used the ANOVA test to analyze the variance between all our measures. We note that, for our statistical analysis, we do not take into account the random spatial distribution of objects, nor the random order of the tasks.

Table I shows the means, standard deviations and analyses of variance of all our measures. Our ANOVA results show a significant difference between certain measures used in our experiments when we changed the FOV; such as: the Number of Fixations (NF), the Number of Gazes (NG), the Number of Movements (NM), the Sum Total Duration of all Fixations (STDF), the Sum Total Duration of all Gazes (STDG), the Sum Total Duration of all Movements (STDM), and the Total Duration of each task (TD). However Fixation Duration (FD), Gaze Duration (GD), and Movement Duration (MD) don't show any significant difference.

To determine the minimum FOV that allows the user to conduct a search task within our 3D VE, we performed another ANOVA that examined all our measures between each FOV pair that we used in our experiment. The results of this ANOVA do not show a significant difference between a FOV of 10° and a FOV of 20° (p=0.0585), but they do show a significant difference between a FOV of 10° and a FOV of 30° (p=0.015*), 50° (p=0.012*), 80° (p=0.011*), and 110° (p=0.0002***). The ANOVA results also show a significant difference between a FOV of 20° and a FOV of 110° (p=0.005**), but they do not show a significant difference between a FOV of 20° and other FOVs. Finally, this ANOVA shows that there is no significant difference between FOVs of 30°, 50°, 80°, and 110°.

Impact of FOV on the TD: We observed that the TD decreases when the FOV increases (see Fig. 2).

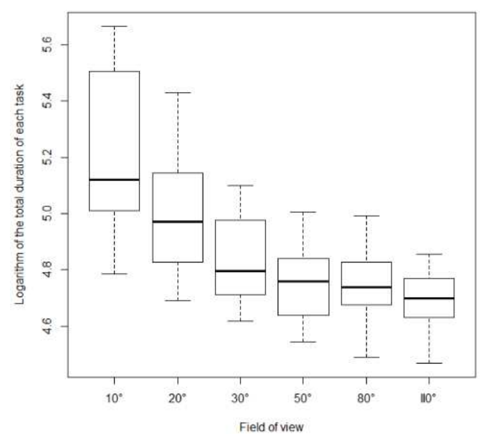

Figure 2. The Total Duration of each task (TD) by Field of View (FOV)

TABLE I. MEAN, STANDARD DEVIATIONS AND ANALYSES OF VARIANCE OF THE VISUAL ATTENTION MEASURES IN THE SIX SIZES OF FOV

	10°	**20°**	**30°**	**50°**	**80°**	**110°**	***F***	***p***
NF	2.15 (0.32)	1.84 (0.23)	1.78 (0.16)	1.66 (0.18)	1.60 (0.17)	1.57 (0.14)	14.92	<0.0001 ***
NG	1.93 (0.34)	1.66 (0.27)	1.50 (0.24)	1.45 (0.23)	1.43 (0.23)	1.40 (0.17)	8.99	<0.0001 ***
NM	2.35 (0.32)	2.06 (0.24)	1.96 (0.18)	1.87 (0.19)	1.82 (0.19)	1.79 (0.13)	12.68	<0.0001 ***
FD	2.23 (0.02)	2.23 (0.02)	2.21 (0.02)	2.22 (0.04)	2.22 (0.03)	2.21 (0.03)	1.12	0.358
GD	2.90 (0.09)	2.95 (0.12)	2.93 (0.11)	2.89 (0.10)	2.88 (0.11)	2.90 (0.12)	0.94	0.489
MD	2.44 (0.19)	2.53 (0.25)	2.49 (0.24)	2.51 (0.26)	2.57 (0.26)	2.47 (0.30)	0.41	0.838
STDF	4.37 (0.33)	*4.07 (0.21)*	3.99 (0.17)	3.89 (0.18)	3.82 (0.15)	3.78 (0.13)	15.81	<0.0001 ***
STDG	4.83 (0.40)	4.61 (0.33)	4.43 (0.32)	4.33 (0.31)	4.31 (0.32)	4.30 (0.27)	5.80	<0.0001 ***
STDM	4.79 (0.22)	4.59 (0.25)	4.45 (0.15)	4.37 (0.13)	4.39 (0.14)	4.26 (0.22)	13.91	<0.0001 ***
TD	5.20 (0.30)	4.99 (0.21)	4.85 (0.16)	4.76 (0.13)	4.75 (0.14)	4.69 (0.11)	14.84	<0.0001 ***

*** p <0.0001, ** p <0.001, * p <0.01, NF: the Number of Fixations, NG: the Number of Gazes, NM: the Number of Movements, FD: the Fixation Duration, GD: the Gaze Duration, MD: the Movement Duration, STDF: the Sum Total Duration of all Fixations, STDG: the Sum Total Duration of all Gazes, STDM: the Sum Total Duration of all Movements, and TD: the Total Duration of each task.

In Fig. 2, the boxplot presents the TD means of all participants in the six sizes of FOV. We found that the TD becomes convergent from a FOV of 30°. We also found that there was not much change in user behavior when he/she used a FOV of 30°, 50°, 80° or 110°; however, a FOV of 10° or 20° shows a lot of change in user behavior. For example, users took a long time to complete the task when they used a FOV of 10° or 20°, while they took less time when they used other FOVs.

Impact of FOV on the NF: We also note that the NF measure decreases when the FOV increases (see Fig. 3).

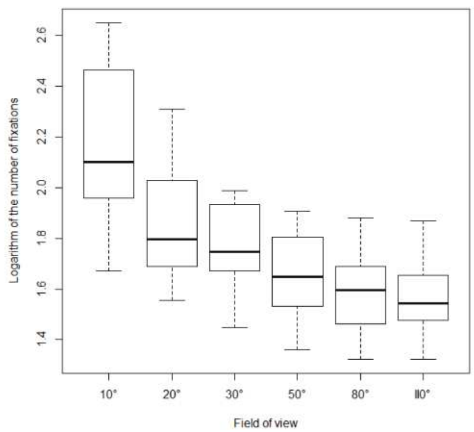

Figure 3. The Number of Fixations (NF) by Field of View (FOV).

Impact of FOV on the STDF: We also found that the STDF becomes convergent from a FOV of 30° (see Fig. 4).

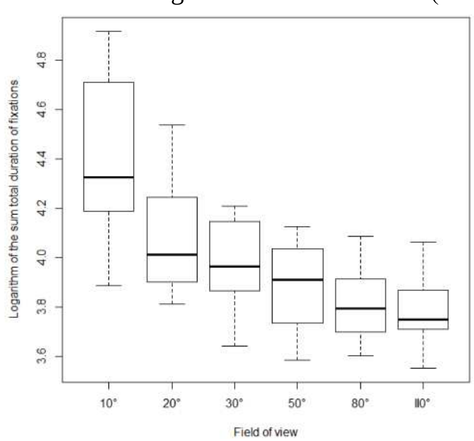

Figure 4. The Sum Total Duration of Fixations (STDF) by Field of View (FOV).

Impact of FOV on the NG: The NG in the fourth task (FOV = 50°) was high compared with the third, fifth, and sixth tasks (respectively: FOV = 30°, 80°, 110°). This is because users had difficulty in finding the hidden buttons in this task (see Fig. 5).

Impact of FOV on the STDG: We observed that the STDG in the sixth task (FOV = 110°) was high compared to the fifth task (FOV = 80°), due to the use of a large FOV (see Fig. 6).

Impact of FOV on the NM: We also found that the NM in the fourth task (FOV = 80°) was high compared with the third, fifth, and the sixth tasks (respectively: FOV = 30°, 80°, 110°) (see Fig. 7).

Impact of FOV on the STDM: We observed that there is a user in the third task (FOV = 30°) that is out the boxplot. This is because the user had difficulty in manipulating the virtual camera (see Fig. 8).

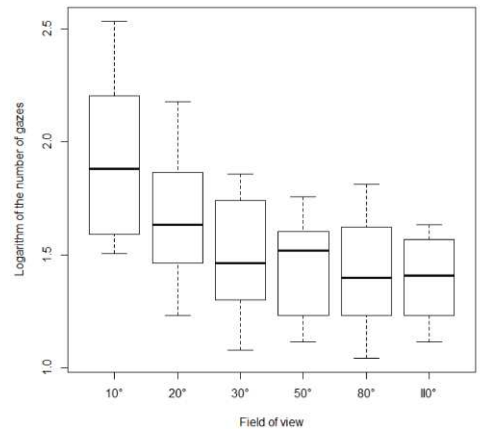

Figure 5. The Number of Gazes (NG) by Field of View (FOV).

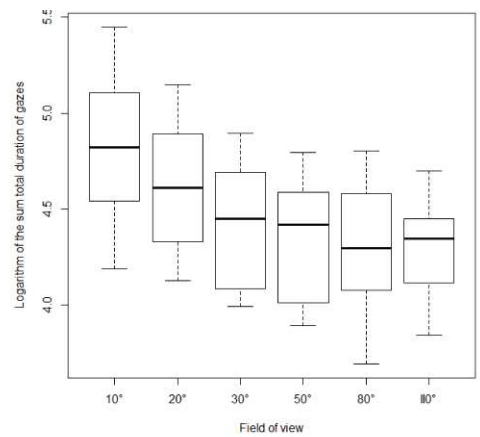

Figure 6. The Sum Total Duration of Gazes (STDG) by Field of View (FOV).

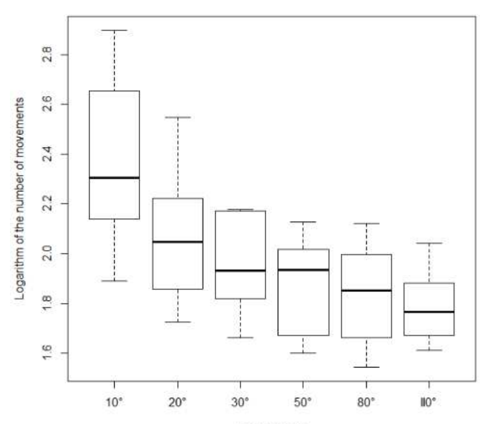

Figure 7. The Number of Movements (NM) by Field of View (FOV).

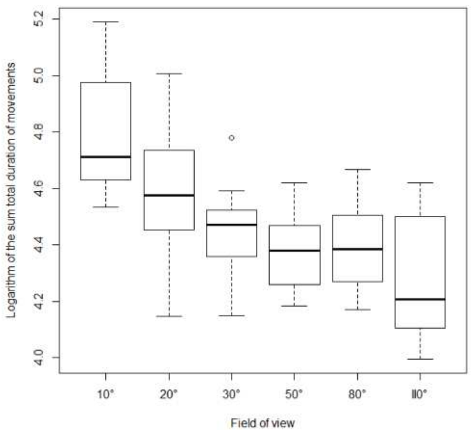

Figure 8. The Sum Total Duration of Movements (STDM) by Field of View (FOV).

After analyzing all our participants without taking into consideration their video games experience, we divided our subjects into two categories: video game players (VGP) and non-video game players (NVGP). Fig. 9 shows a comparison between the VGPs and the NVGPs using the TD measure. We found that the non-video game players took more time than the video game players to achieve the required task.

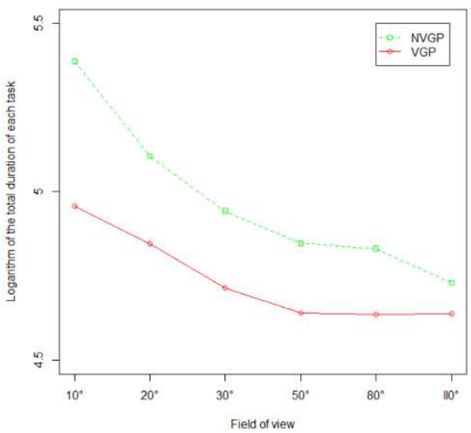

Figure 9. The difference between the gamers (VGP) and the non gamers (NVGP) using the Total Duration of each task (TD).

C. Discussion

We notice that in Table I there is a significant difference between the results based on most of our measures: the NF, NG, NM, STDF, STDG, STDM, and TD. This difference between these measures is due to the change in the FOV (i.e. between 10°, 20°, 30°, 50°, 80°, and 110°), where we observe that the FOV affects user behavior during navigation within a 3D VE. We note that these measures decrease as the FOV increases, e.g., the NF mean value for all the subjects had a natural logarithm of 2.15 when we used a FOV of 10°, and this NF decreased to 1.57 when we used a FOV of 110°. Additionally, the NG mean value for all subjects had a natural logarithm of 1.93 when we used a FOV of 10°, and this NG decreased to 1.40 when we used a FOV of 110°. We observe also that the NM mean value for all our subjects had a natural logarithm of 2.35 when we used a FOV of 10°, and this NM decreased to 1.79 when we used a FOV of 110°. We found also that the STDF decreased as the FOV increased, where the STDF mean value for all the subjects had a natural logarithm of 4.37, and this STDF decreased to 3.78 when we used a FOV of 110°. The STDG mean value for all the subjects had a natural logarithm of 4.83, and this STDG decreased to 4.30 when we used a FOV of 110°.The STDM mean value for all subjects had a natural logarithm of 4.79, and this STDM decreased to 4.26 when we used a FOV of 110°. Finally, the TD mean value for all subjects had a natural logarithm of 5.20, and this TD decreased to 4.69 when we used a FOV of 110°. The decrease is important for determining the FOV within which one can navigate effectively within a 3D VE.

The ANOVA preformed on each pair of FOVs allows us to define two groups of FOVs according to measure values: Group 1, with FOVs of 10° and 20°, and Group 2 with FOVs of 30°, 50°, 80° and 110°, given that there is not a significant difference between a FOV 10° and a FOV 20°; and between a FOV 30°, 50°, 80°, and 110°; but that there is a significant difference between a FOV of 10° and a FOV of 30°, 50°, 80°, and 110°; and between a FOV of 20° and a FOV of 110°. User behavior in Group 1 was less effective than user behavior in Group 2 because users in Group 2 performed the search task quicker than users in Group 1 with: the least possible number of fixations, the least possible number of gazes the least possible number of movements, the shortest sum total duration of all fixations per task, the shortest sum total duration of all gazes per task, the shortest sum total of all movements per task, and the shortest total duration of each task. We found that these measures become convergent from a FOV of 30°. We note that the user can use a FOV of 30° as a minimum FOV for performing the search task in a short time with minimum movement of the virtual camera. We observe also that the user can perform an effective search task using this FOV of 30° in cases where we did not find much change in user behavior based on the virtual camera when he/she uses a large FOV, such as 80° or 110°.

Finally, we see also in Fig. 9 that the NVGPs have spent more time than the VGPs to achieve a visual search task in a 3D VE, and therefore we can deduce that the VGPs perform better on the required task than the NVGPs because the VGPs are accustomed to playing video games.

IV. Conclusion and Future Work

In this paper, we have presented our experiment for determining the minimum field of view that permits the user to perform a search task in a 3D virtual environment using the virtual camera, which is accessible in all game engines.

We used several non-intrusive visual attention measures to monitor user behavior. Our results, which are based on the use of a virtual camera of a 3D virtual environment, show differences in user behavior resulting from differences in the field of view.

The participants in our experiment could perform an effective search task better when the visual attention measures' values were smaller.

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We have shown that the field of view of the virtual camera affects user behavior during navigation within a 3D virtual environment to complete a visual search task. Our quantitative and temporal measures were evaluated by changing the field of view of the virtual camera. We found that the user needed less time to achieve his/her visual search task if he/she used a large field of view. We showed that the minimum field of view for performing an effective search task in a 3D virtual environment is 30°. Finally, we showed that video game players perform better in the 3D virtual environment.

Our model can be used in the context of video games to give additional information to game designers about the improvement of gameplay and management of difficulty by modifying the field of view of the virtual camera relative to difficulty level or player's needs.

For future work, we plan to prototype a First Person Shooter video game to show how our model can be of benefit to game designers. We will also test how our model can be used in the service of cognitive rehabilitation: specifically, for facilitating search tasks and adapting the difficulty of a 3D virtual environment.

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