Measuring Surroundings Awareness using Different Visual Parameters in Virtual Reality

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***Abstract*—Due to the popularity of digital games, there is a growing interest in using games as therapeutic interventions. The ability of games to capture attention can be beneficial to distract patients from pain. In this paper, we investigate the impact of visual parameters (color, shapes, and animation) on users' awareness of their surroundings in virtual reality. We conducted a user study in which experiments included a visual search task using a virtual reality game. Through the game, the participants were asked to find a target among distraction objects. The results showed that the different visual representations of the target among distraction objects could affect the users' awareness of their surroundings. The least awareness of the surroundings occurred when the target and distractors shared similar features. Further, the conjunction of low similarity between distractors-distractors and high similarity between target-distractors provided less awareness of the surroundings. Additionally, results revealed that there is a strong positive correlation between search time and awareness of the surroundings. Less awareness of the surroundings while playing a game implies that users are positively engaged in that game. These results offered a set of criteria that can be applied to future virtual reality interventions for medical pain distraction.**

Keywords*—*Virtual reality; visual distraction; attention; awareness

I. Introduction

Game playing was recognized as the most attractive activity for individuals all over the world. The success of games is highly dependent on their ability to keep their players engaged [1]. Despite some of the negative aspects of playing games, there is growing research demonstrating the positive effects that game playing can provide. If games succeed to activate users' attentional engagement and motivation, they can be of valuable therapeutic benefits [2]. Playing games offers a promising non-pharmacological distraction technique for pain control by diverting attention away from painful stimuli [3]. The logic behind distraction is that pain requires attention and humans have limited information-processing resources [4]. Therefore, the more attentional resources a distraction intervention consumes, the fewer resources are available for pain perception [3]. The research work conducted by [5] [5] highlights that high attentional engagement during games demonstrates a significant analgesic effect on pain distraction.

Distraction interventions can engage one or more sensory modalities. Each modality could have an impact on the distraction level to attract focused attention. In the range of sensory modalities, vision is the most important in its capacity and utility in terms of perception [6]. Besides, distraction using visual tasks was confirmed to significantly reduces pain compared to other modalities [7], [8]. Numerous studies demonstrated that the majority of processing information comes from the visual modality *(visual dominance)* [9]. A wide range of research supported that our vision captures the most percentage of our attentional resources [10]. Recently, virtual reality (VR) becomes one of the major tools that affect visual perception by offering a highly immersive and tangible interaction experience [11]. Experimental research showed that immersive environments build strong user engagement compared to screen-based environments [11]. VR technologies provide a higher degree of presence through increased interactivity and hence increase the user's attention to the virtual environment [11]. The unique characteristics of VR encouraged researchers to conduct numerous studies, [12], [13], to investigate the effect of VR as a non-pharmacological tool for pain management.

We believe that understanding the visual parameters affecting humans' awareness of their surroundings in VR is valuable. Less awareness of the surroundings increases engagement and immersion in the visual activity. High engagement demands a greater amount of user's focused attention. This is critical for many applications such as game-based learning [14], engagement in games [15], and pain distraction [16]. Tasks that require subjects to detect a particular target among distractors gained a great interest in the research of vision and attention [17]. The results of these tasks depend on the features of the target and distractors. Different features might have different capabilities to guide users' attention in a given task [17]. The efficiency of a visual search can be assessed based on changes in performance such as search time or accuracy [17]. Many studies [18], [19], have presented theories to discuss the factors that affect visual search efficiency in 2D, such as the *feature integration theory* and the *similarity theory*.

In this paper, we provide a user study to measure the impact of different visual parameters on users' awareness of their surroundings and task search time in VR. Experiments in this study focus on the principle of visual search using a simple VR game. Numerous studies proved that using the illusion of VR significantly reduces the perception of pain. Although, to our knowledge, no studies were conducted to determine the impact of visual parameters that affect the users' awareness of their surroundings. The less awareness of the surroundings implies that the VR intervention engages much of a user's attentional capacity. This is valuable, especially when developing VR interventions for pain distraction. Results from this study will be considered in designing future VR interventions for medical pain distraction.

Through the following sections, this paper discusses the background of VR distraction for managing pain in Section II. Then, Section III presents the conducted user study. Furthermore, in Section IV we summarize the main findings of the study. Finally, the discussion and conclusion are included in Sections V and VI, respectively.

II. Background

This section discusses in detail the related work of using VR distraction for pain management. Section II(A) provides some background on VR technology. Section II(B) discusses some applied VR research for pain distraction and reduction.

A. Virtual Reality

With advances in wearable technology, VR became popular across various industries due to its ability to engage users in a multisensory environment. There are several definitions of VR, but the most appropriate one "it is defined as a real or simulated environment in which a user experiences telepresence". This definition is chosen as it describes VR without any implications of technology [20]. VR offers a combination of three effects: *1) Fully immersion*, users wear a headset that visually isolates them from the real world, *2) Stereoscopic vision*, the simulation of the real world in three dimensions, and *3) Motion capture*, allows the tracking of head position and controllers with three or six degrees of freedom [21]. These effects enable VR to provide users with a unique visualization tool to explore, manipulate, and interact with their data.

VR is unique in that it allows a multisensory experience that involves visual, auditory, and tangible senses [22]. The VR characteristics of immersion, presence, and interactivity provide users with a greater sense of engagement. These three factors may subsequently prompt better distraction outcomes from a VR intervention via increased engagement. Presence describes the subjective experience of being in one place or environment, even when one is physically situated in another [23]. There are two points of view for immersion definition; the first is based on the state of mind (feeling caught up in and absorbed by the virtual world) and the second is based on the technological capability of a VR system (1)Fully immersive, using a head-mounted display (HMD), (2)Semi-immersive, using large projection screens, (3)Minimal-immersive, using window-based display) [24]. Interactivity describes the degree to which users can influence the content of the virtual environment [24]. According to [25], growing improvements in hardware and software make VR technology more affordable for the scientific and commercial community.

B. Virtual Reality Distraction

Various studies have shown that VR distraction is more effective in reducing pain and anxiety than typical distraction techniques such as deep breathing, listening to music, watching a favorite video, and hypnosis [13]. The last decade has witnessed exponential growth in using VR interventions for pain management with encouraging results that recommend VR distraction to enhance treatment outcomes [26]. Numerous studies were conducted to investigate the effectiveness of VR distraction in reducing different types of pain. Research in this area [16], [27], indicates that VR is a promising adjunct for controlling acute and chronic pain.

Patients with severe burn injuries frequently experience extreme pain related to the injury itself or its wound care procedures. VR distraction provided a strong non-opioid pain control technique for both pediatric and adult burn patients even in the Intensive Care Unit [28]. Also, adding VR to the rehabilitation program of pediatric burn patients had a significant effect on decreasing pain [29]. The main finding from these studies is that VR significantly reduces pain and other uncomfortable symptoms experienced by burn patients [30]. Also, the findings of the chronic pain studies supported the efficacy of VR distraction. Patients reported a significant decrease in pain ratings when using VR interventions compared to the control condition [31]. However, the studies focused on the area of using VR with chronic pain were few [13], and further investigations are needed to ensure its feasibility.

Moreover, VR succeeded to offer a powerful distraction tool for patients who suffer from cancer pain. Cancer patients experience pain associated with the disease itself and/or pain caused by examinations and treatments such as chemotherapy. Several studies showed that VR interventions are effective in reducing pain and other chemotherapy-related symptoms in both adult and pediatric patients suffering from different types of cancer [26], [32]. Patients receiving VR during their chemotherapy session reported less time thinking about pain and also an underestimation of the treatment session duration [33]. VR distraction can help cancer patients accept and tolerate the treatment procedures and hence accelerate the recovery process.

Further to the above category of studies that investigated the efficacy of VR distraction, other studies investigated whether VR distraction will provide a larger analgesic effect when used repeatedly during treatment sessions [28], [34]–[36]. Results indicated that VR efficacy did not diminish with repeated use and pain intensity levels dropped significantly. Previous research, as indicated by both [34] and [36], suggested that receiving VR for a longer treatment duration is more effective than the shorter duration.

Moreover, few studies have investigated the impact of low-cost VR technology on pain tolerance [37], [38]. For both studies, participants were suffering from severe burn injuries and results showed that low-cost VR technology succeeded to achieve a promising pain reduction level. This key finding will open the door to conducting further research to generalize using cost-effective technology with many more patients and different types of pain. Finally, VR interventions can also be used effectively to distract young children aged less than four years during their wound care procedure [39]. This study used a projector-based VR system and the results indicated that VR significantly reduced children's acute pain.

Results from the scientific literature support the adjunctive use of VR distraction for pain management. However, it remains unclear what is the impact of different visual parameters such as color, shapes, and animation on users' awareness of their surroundings. Understanding the impact of such parameters on the awareness of the surrounding is valuable in developing powerful VR therapeutic interventions. To this aim, we conducted a study that included a VR game where players searched for a target among distractors. One study has investigated the impact of color congruency on task search time in VR. This study measured the search task performance when target and distractors were varied concerning congruency [40]. Moreover, the study examined the impact of using a flanker item as a visual distraction from completing task flow. Participants were asked to search for daily items on a virtual kitchen countertop and ignore flanker items. Results indicated that the search time became longer when the target and distractors shared color.

Regarding 2D applications, many studies examined the impact of visual representations of the target and distractors on task search time. Treisman et al. [18] provided a framework that explained the hypotheses of the feature integration theory. This theory hypothesized that the search task will proceed slowly when the target and distractors share features. The theory suggested that the human visual system maintains a set of feature maps for different visual attributes (such as color or shape). When the target has a unique feature, one feature map will be accessed and hence leading to a fast response time. Another research work suggested that the amount of difference between the target-distractors and distractors-distractors will affect the search time [19]. This theory hypothesizes that if the "target-distractors" similarity is high, then search efficiency decreases and search time increases. Besides, if the "distractors-distractors" similarity is low, then search efficiency decreases and search time increases.

These researches showed that the presented visual features could significantly affect users' focus of attention and engagement in search tasks. However, one important gap in the literature on virtual reality analgesia is that no studies explored the impact of different visual parameters such as color, shapes, and animation on users' awareness of their surroundings. To address this gap, we performed a user study to determine the impact of these visual parameters on users' awareness of their surroundings and task search time. Moreover, we are also interested in exploring whether there is a correlation between task search time and awareness of the surrounding. The results from this study will help to develop effective VR interventions that engage most of the patient's attention and hence feel less pain.

III. Methods

This study was designed to help in developing a future VR game for medical pain distraction. To provide more distraction effects, it is valuable to determine the impact of different visual parameters on users' awareness of their surroundings while in VR. We found that visual components such as color, shape, and animation are commonly included in any digital game. Accordingly, we focused on determining the impact of these visual components on users' awareness of their surroundings. Experiments in this study focus on the principle of visual search using a simple VR game. We examined the impact of different visual representations of the target and distractors on the search performance and awareness of the surroundings.

A. User Study

The study used a within-subject design where each participant experienced different conditions. These conditions varied with respect to some visual parameters such as color, shape, and animation. The participants were asked to perform a primary visual task, finding a target cube among distraction objects as fast as possible. Moreover, external disruptions (audio or vibration) were generated randomly while performing the search task. These disruptions were used to measure their awareness of the surroundings without affecting the completion of the primary task. The number of these disruptions was fixed among participants, but the order of them was randomized. Each condition consisted of twenty-five trials and had a duration of about three minutes. At the end of each condition, a compulsory break time was offered. During the break, each participant had to fill in a simple questionnaire that asked about the time duration and the observed disruptions - e.g., "How long did you feel the condition take?", and "Did you observe any disruption?".

If they answered "yes" to the latter question, they have to provide which types occur and the number of their occurrence frequency. The experiment took around forty-five minutes per participant including breaks. For all conditions, we recorded the completion time and the generated disruptions. Through the study, we examined task completion time and disturbance awareness for each of the study's conditions. We measured the awareness and illusion errors that were reported by the participants. Awareness error is the number of missed disruptions, while illusion error is the number of disruptions that never happened. These data were collected to measure the participants' awareness of the surrounding environment.

B. Participants

A total of 31 undergraduate students (19 females) (12 males) aged (18-24) years participated in the study. Participants were recruited via a university announcement for voluntary inclusion in the study. All participants were eligible with respect to the criteria determined for the study (had normal visual and normal color vision). Five participants were excluded as they suffered from VR-induced motion sickness. So, a total of 26 healthy participants were included in the study analysis. Informed consent for the publication of identifying information/images in an online open-access platform and for participation in the study was provided by all participants before the experiment. The study was approved by the ethical committee in the Faculty of Computers and Artificial Intelligence, Benha University. All methods were carried out in accordance with relevant guidelines and regulations. The flow of participants is shown in the flow diagram (see Fig. 1).

C. Equipment

We carried out the experiments of the study using a controlled room. Participants delivered the VR experience using a *Xiaomi MI VR* headset with a Samsung Galaxy Note3 phone and a handheld controller as an interaction device. We used this head-mounted display to be able to use a variety of mobile phones. The Samsung Galaxy Note3 phone was attached to the HMD and was used for recording the completion time of the condition. Another mobile phone was used and attached to the participant's left arm. This phone was also used to generate random disruptions and save them. The participants were able to look around and navigate the virtual environment using their heads. The VR application was developed using the Unity engine and the Android application using Android Studio. The condition started once the participant wore the HMD and ended when the twenty-five trials ended. Fig. 2 shows the hardware components used in the experiment besides one of the participant's trials.

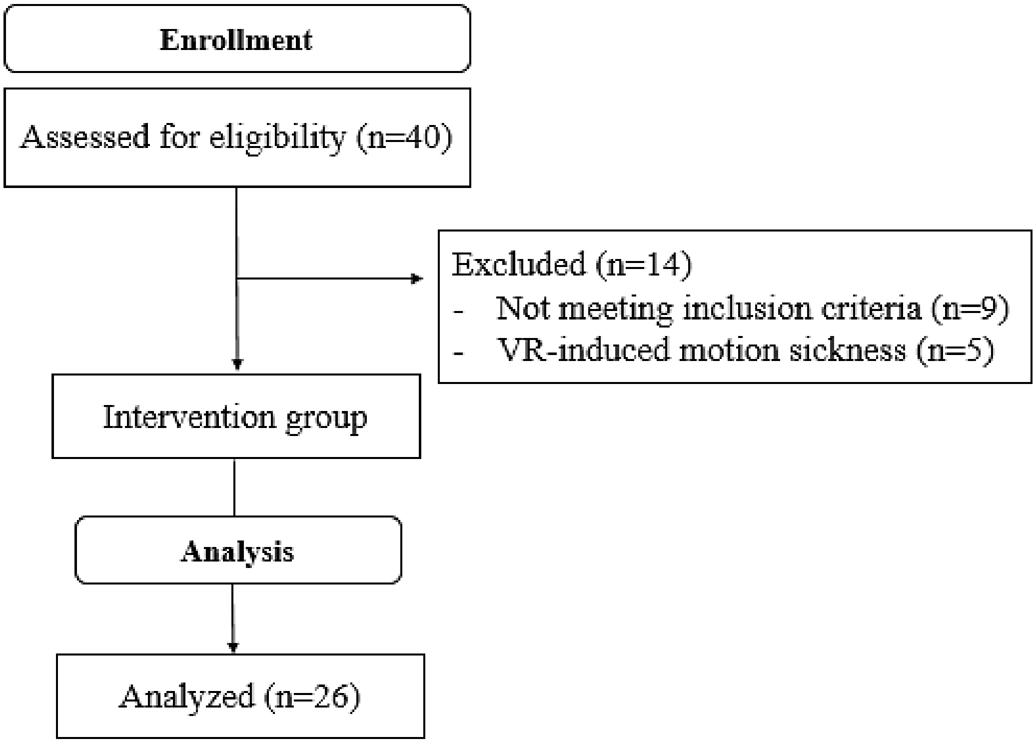

Fig. 1. Flow of participants.

Fig. 2. Experiment hardware components (left), and a participant trial (right).

D. Stimuli

Participants were situated in a full virtual closed room surrounded by a number of distractive objects. There was only one real target cube which was always spawned randomly at the eye level of the user. The size of the objects was scaled according to their distance away from the camera's location (size was around 10 % of the display width and 22 % of its height). The distractive objects were spawned at fixed random locations within the room. Colors were defined by the following RGB values: target (R=0, G=255, B=118), in conditions 2 and 5 distractor's red color (R=255, G=0, B=0), in conditions 3, 4, and 6 the colors of the cubes were generated randomly while spheres in condition 6 used the same target color. The environment was populated with 20 distractive objects. The experiment took around forty-five minutes per participant. Each participant performed 150 trials: 6 conditions × 25 trials per condition.

E. Study Design

The study was carried out in immersive VR and included six different conditions with the same task. The participants were asked to find a target object in the presented VR condition. Each condition included a different visual representation of the target and distraction objects, which is our study's independent variable. This differentiation among conditions is used to investigate the different visual parameters and their impact on users' awareness of their surroundings. The following are our study's conditions:

1) Condition1: Single-cube.
2) Condition2: One-color cubes.
3) Condition3: Multi-color cubes.
4) Condition4: Animated cubes.
5) Condition5: Spheres.
6) Condition6: Cubes-spheres.

All conditions included one target green cube along with other distraction objects spheres or cubes. The order of exploring the conditions was randomized among the participants. We previously conducted a pilot study to determine the best visual design for the conditions. Also, the pilot study helped us to determine the break time duration which was set to five minutes.

Fig. 3 shows our study's six conditions, where the visual representation of the target and distraction objects varied between them. Fig. 3(a) shows "Condition1" that included the target green cube only with no distraction objects. Fig. 3(b) shows "Condition2" with one-color distraction objects. Participants were asked to find the target green cube which was allocated randomly with the fixed distraction red cubes. Fig. 3(c) shows "Condition3" with a fixed multi-color distraction objects. The participants had to find the target green cube out of the multi-color presented cubes. Fig. 3(d) shows "Condition4" with animated multi-color cubes as distraction objects. Condition4 included an extra effect which was animation. Fig. 3(e) shows "Condition5" in which participants had to find the target green cube hidden between fixed red spheres. Condition5 included different shapes as distraction objects. Fig. 3(f) shows "Condition6" in which participants had to find the target green cube which was surrounded by fixed one-color spheres (the same target color) and fixed multi-color cubes.

The participants were asked to complete the six conditions. The completion time and the generated disruptions were recorded for each condition by the application. The *completion time* was automatically recorded from the start of the condition till the participant finished the twenty-five trials. The completion time represented the total time taken to finish the condition. Moreover, we recorded the response time taken to find the target in each trial. We calculated the *search time* for the condition as the average of the twenty-five trials' response time. The completion time was saved on the mobile attached to the HMD, while the generated disruptions were saved on the other mobile phone. On the other hand, the estimated time and errors were reported by the participants via the questionnaire that was filled out after each condition. All of the data was recorded and transcribed to a computer spreadsheet for later analysis.

F. Procedure

Prior to running the study, we had explained many rules and cautions to the participants. We told them to take off the HMD and stop running the condition if they felt any VR-induced motion sickness during their running. We showed an example display of the conditions to explain how to play. The participants heard the audio disruptions and felt the vibrations to get familiar with them. We had two types of audio disruptions (*ringtone and beep*) and two types of vibrations that varied in duration *(short: one second and long: three seconds)*. After getting ready the participant wore the HMD, hold the handheld controller, and attached the other mobile phone to his/her left arm to start the condition. The participants used the handheld controller to press on the target green cube when found.

The primary purpose of the study was to determine the impact of different visual parameters on users' awareness of their surroundings in VR. The conditions varied according to many parameters such as color, shape, and animation. The main task was to search for the green target cube and find it as fast as possible. When the target fell into the participant's view, he/she focused the cursor of the handheld controller on the target and place a single click. Finding the target indicated the end of a trial and the start of a new one. After the click, the target disappeared and a new target object was randomly located in another location within the same room. Through each condition, the mobile attached to the participant's left arm randomly generated *four* disruptions. The type and occurrence frequency of these four disruptions were used to measure both the awareness and illusion errors. We supported different types of disruption to measure the participants' awareness of the surrounding environment. The number of disruptions (four) was fixed among conditions and participants. After twenty-five trials, the current condition was ended and the compulsory break time must be taken.

During break time, the participants were offered to take off the HMD and were asked to fill out the user-experience questionnaire. The participants were asked to report the estimated time duration of the condition in minutes. Also, they were asked to report the observed disruptions that occurred during running the condition. After the break time, the participants return back to continue running the study and repeat the same procedure with a new condition. Each participant completed a block of six conditions. The order of experiencing the conditions was randomized among the participants.

IV. Experimental Results

Analyses of the sample data (N = 26) were conducted using IBM SPSS Statistics v25. For all analyses, an alpha level of 0.05 was used unless otherwise specified.

A. Completion Time

We ran the study to measure if the visual parameters affect the task completion time or/and users' awareness of the surroundings in VR. We recorded the data as we calculated the time difference values by subtracting the completion time (automatically recorded) from the estimated time (reported by the participant). This time difference was used to generate the *less_than* and *greater_than* values. *Less_than* indicated

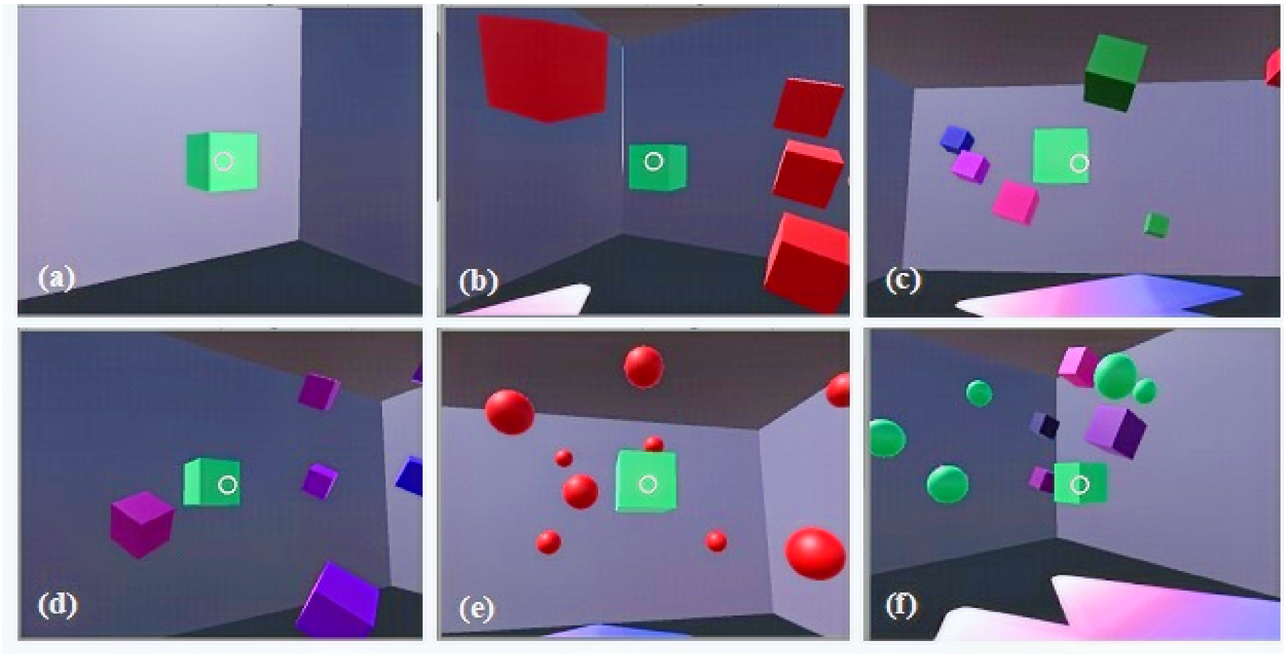

Fig. 3. Example displays for (a) Condition1, (b) Condition2, (c) Condition3, (d) Condition4, (e) Condition5, and (f) Condition6.

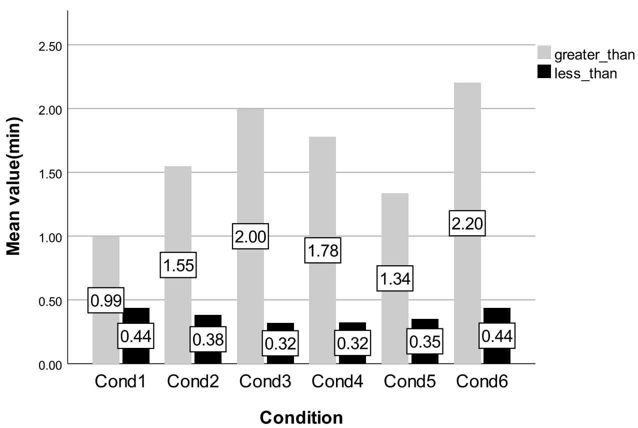

Fig. 4. Condition's mean values less_than and greater_than.

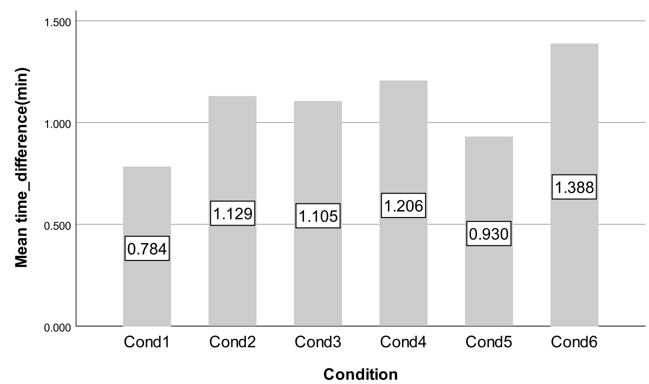

Fig. 5. Time difference per condition.

that the participant reported time less than the actual time, while *greater_than* indicated the opposite. Then we calculated *less_than* as the negative value in the time difference and *greater_than* as the positive value. We used the absolute value for all of the time differences, *less_than*, and *greater_than values*. For each condition, we ran paired samples t-Test between the *less_than* and *greater_than* values to determine the significant condition. The results showed there was a significant difference between *less_than* and *greater_than*, but with a high mean for *greater_than* values (see Fig. 4).

We ran the time difference values through one-way repeated measures ANOVA. Mauchly's test indicated that the assumption of sphericity had not been violated, but when it was violated, the Greenhouse-Geisser corrected tests were reported, $\chi^2(14) = 19.06, p = 0.165$. The results showed that there was a significant main effect of the different visual parameters (color, shape, and animation) on the time difference, $F(5, 125) = 2.51, p = 0.034$. Fisher's Least Significant Difference (LSD) post hoc analysis of the results showed that participants significantly overestimated the time duration of cubes-spheres condition $(mean = 1.39; SD = 1.53)$ compared to the single-cube condition $(mean = 0.78; SD = 0.80; p = 0.018)$ and the spheres condition $(mean = 0.93; SD = 0.99; p = 0.020)$. There was no significant difference between the other pairs of conditions. Fig. 5 shows the mean values by condition for the time difference.

We ran the study's search time results values through one-way repeated measures ANOVA. Mauchly's test indicated that the assumption of sphericity was met, $\chi^2(14) = 21.72, p = 0.086$. The results showed that there was no significant main effect of the different visual parameters on search time, $F(5, 125) = 0.393, p = 0.853$. Fig. 6 shows the mean values by condition for the search time.

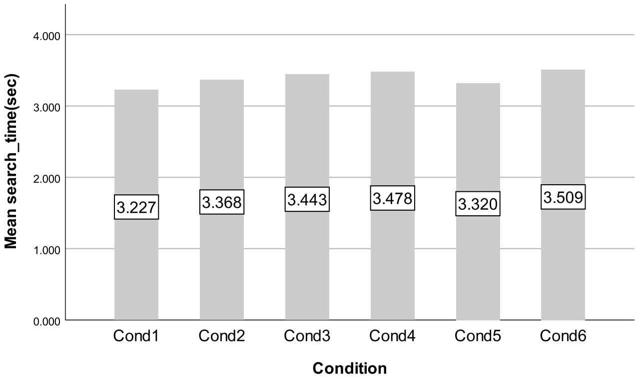

Fig. 6. Search time per condition.

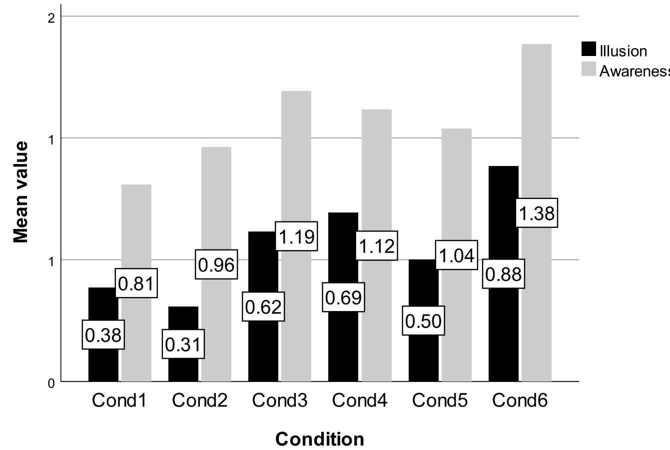

Fig. 7. Mean values for the awareness and illusion errors.

B. Task Errors

Following in the two sections we are presenting the analysis results for the awareness and illusion errors reported by the participants. Awareness error is the number of missed disruptions, while illusion is the number of disruptions that never happened. These errors were collected to measure the participants' awareness of the surrounding environment.

1) Awareness error: For each condition, we ran the awareness error through one-way repeated measures ANOVA. Mauchly's test indicated that the assumption of sphericity was met, $\chi^2(14) = 15.19, p = 0.368$. The results showed that there was a significant main effect of the different visual parameters on the awareness error, $F(5, 125) = 1.29, p = 0.273$. LSD post hoc analysis of the results showed that participants were significantly less aware of their surroundings in the cubes-spheres condition $(mean = 1.38; SD = 1.28)$ compared to the single-cube condition $(mean = 0.81; SD = 0.89, p = 0.037)$.

2) Illusion error: For each condition, we ran the illusion error through one-way repeated measures ANOVA. Mauchly's test indicated that the assumption of sphericity was met, $\chi^2(14) = 16.57, p = 0.282$. The results showed that there was a significant main effect of the different visual parameters on the illusion error, $F(5, 125) = 1.77, p = 0.124$. LSD post hoc analysis of the results showed that participants were significantly less aware of their surroundings in the cubes-spheres condition $(mean = 0.88; SD = 1.14)$ compared to the single-cube condition $(mean = 0.38; SD = 0.63, p = 0.030)$ and the one-color cubes condition $(mean = 0.31; SD = 0.54, p = 0.041)$. Fig. 7 represents the mean values of awareness and illusion errors by condition.

C. Search Time and Awareness of Surroundings

We ran Spearman's correlation test to determine if there is a relationship between participants' search time and the awareness error. The results showed that search time and awareness error have a statistically significant relationship $(r_s = 0.886, p = 0.019)$. The direction of the relationship is positive where search time and error rate are positively correlated, meaning that these variables tend to increase together. The magnitude of the association is strong $(0.5 < |r| < 1.0)$.

A Spearman's correlation test again was computed to assess the relationship between participants' search time and illusion error. There was a positive correlation between the two variables $(r_s = 0.829, p = 0.042)$. Overall, there was a strong, positive correlation between search time and illusion error. Increases in search time were correlated with increases in the rating of illusion error.

V. Discussion

The goal of this experiment was to determine the impact of different visual parameters on the users' awareness of their surroundings. The least awareness of the surroundings means that the user is highly engaged in the VR content. High engagement increases the levels of immersive experience, thus, increasing the impact of future VR interventions for medical pain distraction.

A. Completion Time

Based on the study analysis, the time difference (estimated - actual) data revealed that there is a significant difference between the cubes-spheres condition and both the single-cube and the spheres conditions. These results indicated that more attentional resources were engaged in the cube-spheres condition and hence the passage of time got distorted. This implies that the cubes-spheres condition affected the users' perception of time in VR. Due to the visual representation of the target and distractors in the cubes-spheres condition, participants focused their attention on detecting the target and hence failed to judge the time duration.

We further measured the search time of each condition. The analysis showed that there was no significant difference between the six conditions. However, the cubes-spheres condition required more search time to detect the target compared to the remaining conditions. Results revealed that the search time increases when it is hard to identify the target among distractor objects. This implies that the visual representations of the target and distractors affect the search time in VR. Our results revealed that the spheres condition was the lower-order condition against the cubes-spheres condition with the higher-order. The target in the spheres condition had unique features color and shape, so participants were able to detect it easily. The cubes-spheres condition is the highest due to sharing multiple features color and shape with the distracting objects. Sharing similar features between target and distractors increased the response time for the search task. Our finding comes in line with the conducted research in other 2D and 3D platforms [40], [18]. Fig. 6 shows the mean values of search time for the six conditions.

Another important issue is that the similarity between the (target-distractors) and (distractors-distractors) also affected the search time. In the spheres condition the similarity between the target and distractors was low accompanied by the high similarity between distractors-distractors and in turn, search time decreased. On contrary the target-distractors similarity in the cubes-spheres condition was high and the distractors-distractors similarity was low. Thus, participants in the cubes-spheres condition required more time and also more focused attention to identifying the target. This finding is aligned with the finding presented in [19]. Overall, our findings indicated that the search time was higher when the target and distractors shared similar features. Further, the conjunction of low similarity between distractors-distractors and high similarity between target-distractors provided a long search time. This finding shows a similarity in results between the task search time in VR and desktop 2D platforms.

Finally, it may be worth considering the qualitative data. It is interesting to state that the comments from the participants further supported the statistical findings. For the overestimation of time, participants claimed that the task completion time influenced their judgment of the estimated time. Therefore, as the task became longer the total time was assumed to become longer. This explains why participants overestimated the time duration of the conditions.

B. Task Errors

The analysis of awareness error showed that there was a significant difference between the cubes-spheres condition and the single-cube condition. As shown in Fig. 7, the cubes-spheres condition has the highest awareness error rate. We found that participants in this condition required more of their focused attention to identifying the target among distractors. Therefore, participants were less aware of their surroundings in this condition compared to the others. Participants missed observation of many auditory and vibration distractions in this condition. As indicated, the cubes-spheres condition included conjunctions of many visual factors that led to increased engagement. Sharing similar features between the target and distractors demanded more attentional resources and hence decreased the participants' awareness of their surroundings. Moreover, participants were less aware of their surroundings when the similarity between target-distractors was high and the similarity between distractors-distractors was low. In line with the previous analysis, the condition that provides more distraction from surroundings is that of the longest search time and the highest awareness error.

Regarding the illusion error, the results showed that participants in the cubes-spheres condition were less aware of their surroundings compared to the single-cube condition and the one-color cube condition. Participants in the cubes-spheres condition reported a significant number of disruptions that never happened, which implies that their focus attention was affected by the visual representations of this condition. Similar to awareness error, participants' attention was significantly engaged in the cubes-spheres condition. The superiority of that condition as an influence on awareness and illusion errors strongly suggests that this condition effectively decreased the participants' awareness of their surroundings. Participants in the cubes-spheres condition consumed a high capacity of attentional resources to detect the target compared to other conditions. This implies that the participants were highly engaged in that condition. In our VR game, the least awareness of the surroundings was provided when the target shared similar features with distractors along with the conjunction of low similarity between distractors-distractors and high similarity between target-distractors. Thus, these visual representations of the target and distraction objects should be considered when developing a VR intervention for pain distraction.

C. Search Time and Awareness of Surroundings

Regarding the results of search time and task errors (awareness and illusion), there was a strong positive correlation between search time and awareness of the surroundings in immersive VR. When the search task requires more time, the awareness of the surroundings decreases. The awareness of the surroundings is represented by the awareness error and illusion error. Notably, participants lost awareness of their surroundings when the search task required more of their focused attention. Therefore, they missed the observation of many disruptions that were generated during playing the game. The logic behind this is that humans' attentional resources are limited. When the search task requires more time, a great amount of these resources will be captured to perform the task. Thus, less attention is available to process incoming signals from the surroundings. This finding offers potential, especially for medical applications that can make benefit from using VR interventions for pain distraction. Future VR interventions should employ these findings to maximize distraction effects and provide more reduction in pain intensity.

We would like to highlight the following limitations, which should be thoughtfully considered within the context of the study's findings. Firstly, our participant pool was comprised of individuals aged 18 to 24 years, who had minimal experience of using VR. To enhance the generalizability of our findings, future research should encompass more diverse participant populations, spanning various age groups and educational backgrounds. Furthermore, future studies should examine gender and age differences, the outcomes may be linked to variables such as gender and age. Another limitation is related to the relatively short duration of each condition which led to participant overestimation of the time duration. To address this limitation, future studies should consider implementing longer VR interventions. Lastly, this study was limited to examining the main components of visualization however, later we need to examine the combination of these components.

VI. Conclusion

There is solid evidence from controlled research that VR distraction is effective for pain distraction. Based on our knowledge, none of the previous controlled studies has examined the impact of the different visual parameters on users' awareness of their surroundings in VR, so our study examined in-depth the visual parameters and their impact on users' awareness of their surroundings. Results showed that when the search task required more time, the awareness and illusion errors were high. High errors indicate less awareness of the surroundings and more engagement in the game. Moreover, results revealed visual features that affect search time and capture a viewer's focus of attention in 2D games are also feasible in VR. This key finding in addition to immersion renders VR an effective tool for pain distraction. This study is an elementary study conducted to determine the visual representation of target and distractors that provides the least awareness of the surroundings in VR. This visual representation will be employed in our next VR game designed for distracting patients from pain. By using VR technology we may make a significant step towards increasing the therapeutic benefits of VR for pain management.

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