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Detecting Stress in VR 360° Immersive Experiences for Older Adults through eye tracking and psychophysiological signals*

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Abstract. This paper presents the architecture and a preliminary prototype of a system for detecting stress during immersive virtual reality (VR) simulations. The VR4AGE system is designed for professionals that wish to use virtual reality headsets to allow older adults with dementia to experience 360 videos with an increased safety. The system aims at using eye tracking and unobtrusive psychophysiological signal monitoring to detect cognitive activation and distress. Informing as soon as possible the healthcare professionals about the patient's status would allow them to continue or stop the therapy, depending on the patient's reactions. This could help assessing whether nursing home residents with dementia that are unable to speak and express their emotions react positively or negatively to the VR simulation.

Keywords: Virtual Reality · Eye Tracking · psychophysiological signals · stress · dementia.

1 Introduction

In the last years, with the mass production of virtual reality (VR) headsets, we assisted to the flourishing of companies proposing immersive virtual experiences for older adults in retirement homes. Typically, these VR experiences are 360° videos of natural landscapes or other touristic places. Virtual reality experiences are considered as a potential non-pharmaceutical intervention for dealing with Behavioural and Psychological Symptoms of Dementia (BPSD) [2], such as agitation, aggression, depression, and apathy. As the number of people affected by dementia in the world is expected to double every 20 years, reaching 139 millions in 2030, it is expected an increased cost for the care of patients with dementia. Reducing the usage of anti-psychotics in favor of non-pharmacological interventions for the treatment of BPSD is a first-line strategy advocated by the

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international health organizations [14]. According to a recent review of Restout et al. [16] fully-immersive VR interventions using 360° videos are promising for decreasing BPSD and improving the residents' quality of life.

In order to ensure the effectiveness of such VR interventions, healthcare professionals must accompany and stimulate residents all along the experience. Moreover, special VR equipment may be required. Indeed, commercial VR headsets are typically tailored for younger generations [24] and may be perceived as difficult to use by older adults [4]. However, several companies propose nowadays special VR kits that are tailored for nursing homes. Such VR kits are composed by one tablet and one or more headsets and require minimal setup by healthcare professionals before starting the virtual reality immersive experiences. With these kits, healthcare professionals can carry out simultaneous immersive experiences with up to 6 seniors, coordinating the VR content from the tablet. While Restout et al. [16] showed that few adverse cases were registered in previous VR fully immersive interventions, many healthcare professionals are still doubtful about the acceptance of a VR headset by older adults [17]. Rose et al. argued also that since the headset is covering the senior's eyes, it is difficult to assess the affect response of the users, since many affect scales rely on the observation of the patient's gaze [17].

Moreover, as suggested by Baker et al. [3] people with dementia may be unable to show physical or verbal signs of distress. Indeed, in the most severe cases of dementia primary progressive aphasia may lead to the inability to speak [12]. This, however, is considered to be independent from older adults' visual processing ability [12]. Therefore, even nursing home residents with severe dementia conditions and unable to speak might still be able to understand and process the VR video stimuli and thus benefit from a fully immersive VR intervention. As some healthcare professionals are afraid that fully immersive experiences may cause hallucinations in people with dementia [3], when conducting VR interventions with these people, it is paramount to be able to detect distress that may be caused either by the VR equipment (physical comfort) or by the VR content, even when the patient do not manifest any visible or audible sign of such distress.

Therefore, the overarching goal of the VR4AGE project presented in this paper is to detect older adults' distress during VR experiences by means of psychophysiological sensors (i.e., eye tracking, and heart rate) that are directly integrated in the VR headset and to inform the carer as soon as possible about the seniors' reactions to the simulation. The paper is structured as follows. In the next Section, we present the related work; then, in Section 3, we present the result of a workshop aimed at collecting the healthcare professionals' needs for a patient monitoring application during VR simulation. Based on the insights collected during the workshop, Section 4 presents a concept of the system, with a particular focus on the eye tracking monitoring tool and on the stress detection module. Section 5 describes the protocol of an ongoing test that is being carried out to train and validate the stress detection module. Finally, we discuss the insights collected so far and the future research pathway in Section 6.

2 Related Work

With the recent diffusion of commercial VR solutions tailored for older adults, few studies analyzed the impact of immersive 360° experiences on older adults' well-being. 9 of the 10 studies analyzed by Restout et al. [16] showed a significant effect on at least one aspect of the seniors' well-being. In particular, a reduction of anxiety, depression and apathy and an improvement of older adults' emotions, social exchanges and quality of life was recorded by previous studies. These studies also reported limited adverse events caused by the VR simulation. Few isolated adverse events reported dizziness, eye strain and headache. Some subject reported also a discomfort in wearing the VR headset.

So far few studies used psychoghysiological signals or eye tracking to monitor older adults' reaction and detect distress during VR simulations. Eye tracking has been largely used in different VR applications, for example in immersive learning contexts [18], but few studies focused on older adults. Eye tracking has been recently used for the assessment of older adults' cognitive abilities. Davis and Sikorskii [5] used eye tracking to analyse the fixation behaviours of older adults with Alzheimer Disease (AD) during wayfinding, showing that AD patients spend less time on relevant visual cues compared to healthy subjects. As this gaze behaviour is typical of AD patients, the tool can be used for an early diagnosis of AD. Indeed Molitor et al. [13] suggest that eye movement analysis in some task can be useful to identify AD patients and mild cognitive impairments (see also Readman et al. [15] for a recent review).

Recently, Stoeve et al. [25] were able to detect a stress situation in VR with an accuracy of 87.3%, only relying on gaze behaviour and pupil dilation information. However, the study was conducted with young athletes in a sport application scenario. To the best of our knowledge no article used eye tracking for detecting stress in VR simulations with older adults. Pupil size was also used by Zheng et al. [27] to detect emotions elicited by 360° VR videos. Finally, Jyotsna et al. [10], analyzing eye tracking data, investigated the possibility to detect stress generated by 2D videos, and in particular, they tried to find the frames that were causing the stress. Both studies were conducted on young adults.

Many other studies investigated emotion recognition in VR applications (see Marín-Morales et al. [11]for a review). The most used psychophysiological signals in previous studies are heart rate variability (HRV) and electrodermal activity (EDA). Among the papers reviewed, only one study focused on older adults [20]. Another review investigated the ability to measure cognitive load and visual fatigue using eye tracking [22]. Also in this case, only one paper conducted a study on older adults [26].

Further details about relevant stress indicators are discussed in Section 4.2, where we present our proposed architecture for stress detection in VR.

3 Healthcare professionals' needs

In order to understand the needs of the secondary users of a VR monitoring tool, we presented the VR4AGE project to 17 healthcare professionals during a workshop on non-pharmacological interventions. The workshop included the presentation of three different non-pharmacological interventions: the train therapy [8], the Snoezelen multisensory room [22] and VR 360° videos, with a particular focus on the enhancements proposed in this paper, i.e., the possibility to use eye tracking and psychophysiological signals to monitor older adults' reactions during the VR simulation. At the end of the presentations, healthcare professionals answered a live questionnaire (Wooclap) that included the following questions: 1) ranking the three presented therapies, 2) rating the different pieces of information that healthcare professionals would like to have in a monitoring interface for VR immersive experiences, 3) suggestions for the improvement of the VR4AGE project.

The first questions revealed that participants ranked the train therapy highest (M=1.47, SD=0.60), followed by Snoezelen (M=2.0, SD=0.77) and the virtual reality therapy (M=2.5, SD=0.70), with 1 corresponding to their preferred choice and 3 to the last choice. A Wilcoxon Signed-Rank paired t-test showed that participants ranked significantly higher the train therapy compared to the virtual reality therapy (p¡0.01). In the third part of the questionnaire, some participants showed concerns about the bulky VR headset used in the VR4AGE project, also in comparison with other headsets that they are currently already using for VR therapy. Some workshop participants were in general skeptical about the older adults' acceptance of the VR headsets.

In the second question, we asked workshop participants to rate the features that should be included in the monitoring interface. The most appreciated feature was a stress indicator (M=4.3, SD=0.9), followed by the user's history of preferred videos (M=4.1, SD=0.8), the user's cognitive load (M=3.9, SD=0.8), the real-time eye-gaze visualisation in the video (M=3.7, SD=1.2) and finally the heart rate (M=3.2, SD=1.1). Participants were particularly interested in real-time intuitive indicators, while information that requires a more accurate analysis for the interpretation, such us the heart rate, would probably require too much attention for the healthcare professionals.

In the third question, participants also suggested to include in the tool the possibility to store the users' consent for the use of the tool and the data collection (which would be signed either by the patients or by their legal representatives, especially in case of dementia). Finally, workshop participants were interested in a free trial option to evaluate the tool before purchasing it.

4 VR4AGE system

The VR4AGE project aims at providing to healthcare professionals an overview of the older adults' eye gaze behaviour and psychophysiological reactions during VR immersive 360 videos interventions. The system takes advantage of the integrated eye tracking and heart rate sensor of the HP Reverb G2 Omnicept headset. To the best of our knowledge, this is the only commercial VR headset that integrates psychophysiological sensors. Indeed, this headset is able to measure the user's heart rate (HR) and heart rate variability (HRV) through a PhotoPlethysmoGraphy (PPG) sensor in the forehead and integrates a Tobii eye tracker with pupillometry. Moreover, thanks to these sensors, the HP Omnicept SDK calculates a cognitive load indicator that is provided through the interface [19]. HP declares in a technical report a classification accuracy of 79% on three classes (low, medium and high cognitive load) and a Mean Absolute Error of 0.11 for the continuous cognitive load indicator (on a scale from 0 to 1) [19]. The HP Omnicept provides already a software development kit and a tool that allows to display during the VR simulation the user's HR, HRV and the estimated cognitive load.

Unlike most of the headsets that are generally used for VR 360° video simulations with older adults, the HP Reverb G2 Omnicept requires a wired connection to a PC, which is running the VR simulation software. Although this setup would add some burden for the patient, because of the cable, and for the healthcare professional, because of the more complex setup of the tool, it provides precious information compared to the standard VR headsets. Thanks to this information, healthcare professionals that should be able to understand whether a patient with dementia is reacting to the VR simulation, by looking at different cues in the video and generates a cognitive activation. The VR4AGE system aims at helping heahtcare professionals also to estimete wether the simulation has a positive effect on the user or it is rather distressing her. Indeed, the tool displays on the PC what the user is currently seeing (the current video frame and the user's eye gaze position in the video) as well as the different psychological indicators, such as the cognitive load and stress indicators. While a higher cognitive load can be considered as a positive response of people with apathetic behaviour, a higher stress indicator may suggest that the patient is uncomfortable because of the headset or the 360° video content. In case of distress, the healthcare professional may decide to stop immediately the simulation, especially if the patient is unable to manifest verbally his or her feelings. Figure 1 presents the general architecture of the tool.

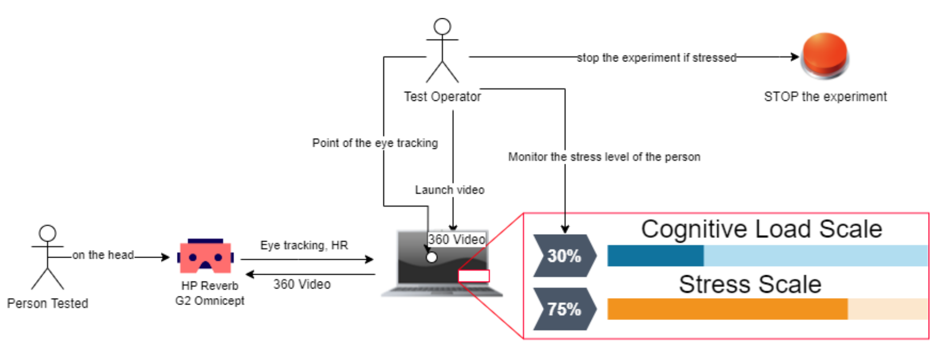

Fig. 1. Architecture of the VR4AGE system

In the next subsections, we present the current prototype of the tool, which is displaying the psychophysiological already available in the Omnicept SDK and thee eye gaze position in the video, and the architecture of the stress detection module that we are currently developing.

4.1 VR4AGE tool for live monitoring

We have developed a tool allowing to display in real-time the video that the patient is currently watching, and the point she is looking at, in the VR headset. The tool has been developed in Unity and it is complemented by the tool for monitoring the psychophysiological signals and cognitive load indicators, which is provided by HP with the Reverb G2 Omicept headset. As a 360° video for the demo, we have chosen a naturalistic environment constituted by a wooden path next to a river and waterfall. Figure 2 depicts the eye gaze view and the Omnicept monitoring view. This tool has been demoed at a geropsychiatry symposium and at the workshop mentioned in section 3. Despite being a preliminary prototype, it aroused the interest of healthcare professionals. For the next version of the tool we are planning to develop an integrated web view that would display the immersive video with eye tracking as well as the different indicators mentioned in section 3, in particular cognitive load and stress. Moreover, the web application will allow to store the profile of the users, their signed consent form, and the history of previous sessions. Further 360° videos will also be added in the tool. The next section describes more in detail the architecture of the stress module that will be integrated in the next version of the monitoring tool.

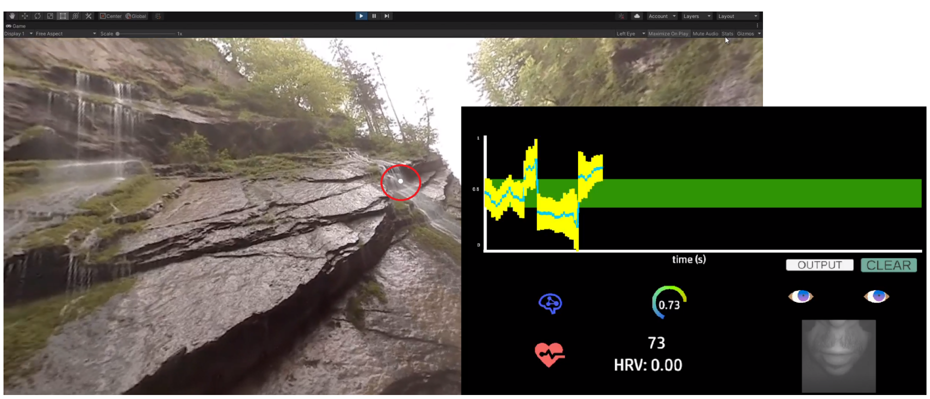

Fig. 2. Current version of the monitoring tool. On the left, the Unity application with the white dot (circled in red) the user's gaze position. On the right, the HP Omnicept monitoring tool

4.2 VR4AGE Stress detection module

The aim of this module is to detect stress through eye tracking data analysis. Indeed, the results shown by Siegel et al. [19] for the prediction of cognitive load suggests that eye tracking data alone may be sufficient to obtain an accuracy similar to that of eye tracking data combined with HR and HRV data. The processes carried out by the stress detection module include filtering data for quality, analysing pupil size, fixation duration, blink frequency, gaze position and speed. These features will be used to train a machine learning model, which will then be evaluated for accuracy. The trained model can be applied to predict stress levels in new data. The goal is to ensure accurate predictions through a thorough evaluation of the machine learning model. The process involves several key tasks, including:

- Data Filtering: It is important to first filter the data for only those rows where the eye tracking sample is valid, as defined by the valid column. This helps to ensure that the analysis is based on high-quality data that accurately reflects the participant's gaze behaviour.
- Pupil Size Analysis: Pupil dilation is a well-established physiological indicator of stress [6,7,9] and more recently to detect stress for mental health [10]. By computing the average pupil size for both eyes using the "PupilLeft_mm" and "PupilRight_mm" columns, we can quantify the extent of pupil dilation and use this information as a feature in our analysis.
- Fixation Duration Analysis: Fixation duration is a measure of the amount of time that the gaze remains on a single target. By counting the number of consecutive rows with the same "TargetName" and computing the difference in time between the first and last of these rows using the "Timestamp" column, we can compute the duration of each fixation and use this information as a feature in our analysis. Recent studies suggests using the number of fixations and the duration to detect mental stress [10, 21] for monitoring the mental health.
- Blink Frequency Analysis: Blinking is a common behaviour that can be influenced by stress. By counting the number of instances where the pupil size drops to zero, or near zero, within a brief time window, we can compute the frequency of blinks and use this information as a feature in our analysis. [10, 21] use also this stress indicator.
- Gaze Position and Speed Analysis: The distribution of gaze points, as well as the gaze speed and acceleration can provide valuable information about the participant's gaze behaviour. Jyotsna et al. [10] analysed the gaze location during stressful situations. By analysing these features, we may be able to identify patterns that are indicative of stress, such as increased saccadic eye movements or increased gaze dispersion.
- Machine Learning Model Training: Once the relevant features have been extracted, we can train a machine learning model, such as a decision tree or a support vector machine, to predict stress levels based on the eye tracking data. This can be done by using the computed features as inputs and labelled stress data as outputs.

– Model Evaluation: It is important to evaluate the performance of the trained model on a test set to assess its accuracy. This will help to identify any potential problems with the model and allow for adjustments to be made to improve its performance.
– Predictive Model Application: Once the model has been trained and evaluated, it can be used to predict the stress levels of new eye tracking data. This can be done by inputting the relevant features computed from the new data into the trained model and using the model's output to generate a stress level prediction.

Figure 3 depicts the proposed pipeline for stress detection.

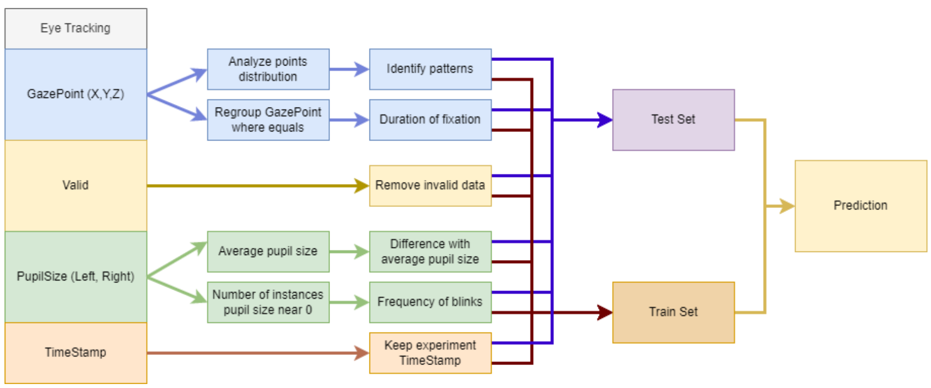

Fig. 3. Architecture of the VR4AGE stress detection pipeline

5 Protocol for dataset collection

In order to develop a model that can accurately detect stress in real-time we have set up a controlled study aimed at providing a stressful situation in VR. Although the goal of the module is detecting stress of older adults (possibly with dementia) while watching 360° immersive videos in VR, we decided to first train the model on young healthy subjects by collecting data with a validated stress test. To this purpose, we used the Trier Social Stress Test [1], adapted for virtual reality by Standard et al. [23]. If the model is able to detect stress with healthy subjects in the controlled conditions, further test will be then conducted with healthy older adults while watching 360° videos, to verify the generalization capability of the model. If the model performances are confirmed, further trials will be conducted with patients with dementia. For this study, we added an Empatica Embrace Plus watch to the original setup shown in Figure 1. The Empatica Embrace plus allows to record additional psychophysiological data and in particular EDA, which is often used to detect stress. These data will be used to train and compare the eye tracking-based stress detection module with a model based on more psychophysiological indicators, in order to compare the performances and assess if the eye tracking features alone are sufficient to ensure a satisfactory stress prediction accuracy.

The participants will be randomly assigned either to the experimental group or to a control group. The participants will complete two tasks in virtual reality. The first task will involve the control group describing a book or film they like (Task 1), while the experimental group will participate in a simulated job interview in front of a panel of judges, ant they should try to persuade the jury that they are the best fit for the job (Task 1). For the second task, the experimental group will be tasked with repeatedly subtracting 17 from 2023 (e.g., 2023-2006-1989-1972) (Task 2), while the control group will be tasked with adding 15 from 0 (Task 2).

The participant's psychophysiological data will be recorded both with the HP Reverb G2 headset Omnicept and with the Empatica Embrace Plus watch. A NASA-TLX questionnaire will be administered at the end of the experience to assess the perceived stress of the participant. All anonymized data will be cleaned by removing any unnecessary or false information (retaining only the temporality of the testing periods, checking for any erroneous or extreme values, and normalizing the data so that no feature is more important than others). Two machine learning models, (one based only on eye tracking features and another including also the other psychophysological sensor features) will be trained to classify the data according to the stress condition (no stress, i.e, at the baseline; i.e., the control group, and high stress, i.e., the experimental group). Results of the classification will be compared with the perceived stress reported by the users.

6 Discussion and Conclusion

In this paper, we presented the VR4AGe project, which aims at developing a tool for investigating the benefits of VR experiences for older adults, including people with dementia who are unable to manifest verbally their feelings. Indeed, while the benefits of VR experiences for older adults have been already shown in previous studies [16], many questions are still open on the benefits of VR experiences for people with dementia. Thanks to a VR headset with an integrated eye tracking and heart rate sensor, we aim at providing healthcare professionals with a tool able to detect in real-time weather the VR simulation is beneficial for the patient or, conversely, stressful. Our investigations show that healthcare professionals are interested in such tool, although virtual reality is still perceived as in intrusive non-pharmacological intervention. The possibility to see in real-time the users reactions and in particular to detect in real-time the stress and cognitive load of the user is perceived as a valuable help by healthcare professionals. They considered important to have in the tool also the history of the patient preferences and reactions, as well as a record of the consent form.

At present the first prototype allow to follow the user's eye gaze in the video and the cognitive load. We are currently building a machine learning pipeline to compute a stress indicator that could help healthcare professionals to immediately stop the VR experience in case of distress of the user. The tool will be also improved with a richer web interface, which will allow the healthcare professionals to monitor the users' progress across multiple sessions.

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