2ViTA-B Cognitive: A Virtual Assistant for Cognitive Rehabilitation

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Keywords: Cognitive Rehabilitation, Medical Support, Home Rehabilitation, Virtual Reality, Meta Quest 2, EEG.

Abstract: We present 2ViTA-B Cognitive, an advanced virtual assistant designed to effectively address emotional functioning disorders and enhance emotional well-being. The system is carefully crafted to engage with users and positively influence their emotions, supporting cognitive rehabilitation in both real and virtual environments. A controlled experiment has been conducted to evaluate the benefits of the proposed system. The results provide valuable insights into the potential benefits of immersive virtual reality interventions for improving emotional well-being and cognitive functions. These findings suggest promising avenues for advancements in therapeutic practices within this field.

1 INTRODUCTION

Affectivity, covering emotions, mood, attitudes, and interpersonal relations, significantly influences behavior, well-being, and cognition (Sander & Scherer, 2014). Affective cognition specifically pertains to cognitive functions responsible for processing stimuli with emotional significance (Roiser & Sahakian, 2013). In scientific research, there is an increasing research interest in treating emotional disorders to improve affective functions and reduce symptoms, focusing on the impact of stimuli on emotions and mood.

These stimuli can be administered through both analog and digital means, and more recently, virtual reality (VR) presentations have gained attention (Tageldeen et al., 2017), (Vargas-Orjuela et al., 2017), (Wiederhold et al., 2017). Numerous studies and research initiatives have explored how virtual reality and related technologies can enhance mental well-being (Gaggioli et al., 2014; Oing & Prescott, 2018; Pallavicini et al., 2016). These efforts often align with the principles of positive psychology, a specialized field of clinical psychology focused on mental well-being and human happiness (Huppert & So, 2013). Also, VR is able to improve mood, reducing conditions such as fear, stress, depression, and anxiety (Pizzoli et al., 2019) (Malloy & Milling, 2010) (Garrett et al., 2017) (Wiederhold et al., 2014) (Liu et al., 2015) (Felnhofer et al., 2019) and induce positive emotions (Baños et al., 2014; Felnhofer et al., 2015; Herrero et al., 2014). Furthermore, VR has been applied to the treatment of anxiety disorders, including phobias, generalized anxiety, social anxiety, post-traumatic stress disorder, and obsessive-compulsive disorder (Gerardi et al., 2008; Oing & Prescott, 2018; Pallavicini et al., 2009; Rizzo et al., 2010; Takac et al., 2019).

The unique ability of VR to modulate emotions stems from its highly immersive 360° artificial environment, offering greater engagement and emotional impact than other methods (Browning et al., 2020). However, the use of VR is not without its drawbacks, as it can lead to side effects such as nausea, dizziness, and discomfort, which may impact the quality of the VR experience, depending on individuals' sensitivity.

In line with this research direction, we introduce 2ViTA-B Cognitive, a new software/hardware system, designed for psychological and emotional

Balletti, N., Cascitelli, A., Gabrieli, P., Lazich, A., Marcilli, G., Notarantonio, M., Oliveto, R. and Scognamiglio, D.
2ViTA-B Cognitive: A Virtual Assistant for Cognitive Rehabilitation.
DOI: 10.5220/0012396900003657

In *Proceedings of the 17th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2024) - Volume 2*, pages 545-553
ISBN: 978-989-758-688-0; ISSN: 2184-4305

engagement, using innovative stimuli to influence emotions. With 2ViTA-B Cognitive therapists can customize stimuli sequences, including images, sounds, and videos, in either standard mode or VR for cognitive rehabilitation. The results of a controlled experimented, conducted with 16 participants, revealed the effectiveness of 2ViTA-B Cognitive, and in particular the effectiveness of VR, in enhancing emotional well-being and cognitive functions.

2 RELATED WORKS

Studies have shown that emotions triggered by images correlate with physical and physiological parameters, such as facial expressions (Ekman, 1993), heart rate, and body temperature (Davidson et al., 2009). The valence and activation of images can be measured by methods such as facial electromyography, electrocardiogram and skin conductance (M. M. Bradley et al., 2001) (Lang et al., 1993). Several scientifically validated sets of images are available to evoke emotions (Lang et al., 1997) (Marchewka et al., 2014).

However, static images tend to have less emotional impact than dynamic stimuli like video or music (Westermann et al., 1996). For this reason, numerous studies have delved into the impact of music and other sounds, including speech, noises, and sound environments, on the human brain and psychology, particularly in relation to emotions and mood (Rauscher, 1994), (Wang & Cheong, 2006). These acoustic stimuli can induce changes in skin conductance and heart rate as a physiological response (Dillman Carpentier & Potter, 2007), (Khalfa et al., 2002), (Riganello et al., 2010).

While there are few validated sound collections in the literature, some studies creating specific sounds or extracting internet-based sounds validated for user preferences (Greer et al., 2019; Koelsch et al., 2019). Two libraries, validated using physiological measures, are commonly used (Koelstra et al., 2011) (Grewe et al., 2011).

Videos – known to evoke stronger emotions than images or sounds due to their multimodal, dynamic, and immersive nature – are effective in inducing emotional states (Gross & Levenson, 1995; Tempesta et al., 2017). Video stimuli composed of film fragments are often used, but sometimes amateur online videos are also utilized (Samson et al., 2016), (Knautz & Stock, 2011). Video stimulus libraries include various movie categories to evoke a wide range of emotions, from simple ones like anger and disgust to complex ones like joy and amusement (Schaefer et al., 2010).

In Ulrich et al. (1991) the authors have opted to use natural environments as stimuli in virtual reality. This choice is rooted in the Stress Reduction Theory, which posits that exposure to natural settings can activate the parasympathetic system, leading to reduced feelings of fear, anger, and stress.

3 2ViTA-B COGNITIVE SYSTEM

2ViTA-B Cognitive is a comprehensive hardware and software system aimed at enhancing mental well-being and reducing stress. It uses multimedia sequences in standard and VR modes to evoke specific emotions and offers daily cognitive training activities. The system reads physiological data from wearables, applying AI for therapist decision support and includes gamification for user engagement. It has three user roles: *administrators* manage content, *specialists* handle rehabilitation plans, and *patients* participate in training.

Patients are enrolled into the system by the Administrator. During the enrolment phase, patients must complete an anamnesis questionnaire, which therapists use to gather information on the subject's current and past health status.

Multimedia elements are added to the system libraries by Administrators, and they are used by psychologists to create multisensory stimulus sequences for individuals. These multimedia elements include images, sounds, videos, and immersive VR scenes. Patients can also upload multimedia elements from their personal library to the system, but these can only be used within sequences after therapist validation.

When creating a sequence, as shown in Figure 1, psychologists are aided by the 2ViTA-B virtual assistant, which suggests additional elements matching the chosen ones in terms of valence and arousal. However, the psychologist has the final word

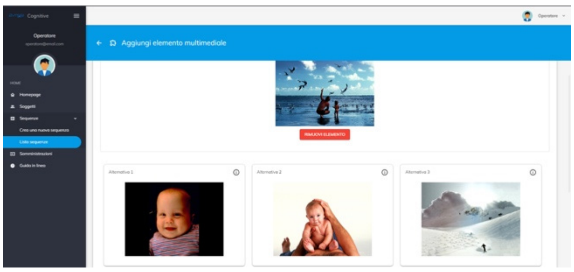

Figure 1: Definition of a sequence for an administration.

in accepting or rejecting these system-suggested elements.

A typical administration of the 2ViTA-B Cognitive system comprises three essential steps:

1. The preliminary screening questionnaire: Perceived Stress Scale (PSS-10).
2. Three self-assessment questionnaires: Positive And Negative Affect Scale (PANAS), Self-Assessment Manikins (SAM), and Global Vigor-Affect Scale (GVAS).
3. A sequence of media items created by the psychologist.

The PSS-10 assesses an individual's perceived stress (Cohen et al., 1983), while the PANAS questionnaire defines the subject's affective state (Watson et al., 1988). The SAM self-assessment scale measures emotional reactions to stimuli (M. M. Bradley & Lang, 1994).

Multimedia sequences can be divided into two groups: standard and virtual reality. The standard sequence consists of positively valenced images, sounds, and videos from validated sources. In the current implementation of the system there is a library composed of thirty-two images from the International Affective Picture System (IAPS) catalogue (Lang et al., 1997), twenty sounds from the International Affective Digital Sounds (IADS) (M. Bradley & Lang, 1999), and five videos validated by (Maffei & Angrilli, 2019). The multimedia sequence consisted of a random presentation of thirty-two images, twenty sounds, and two videos, all of which had a valence rating greater than 6.5. The display of images and sounds each lasted six seconds, while the videos had a duration of approximately two minutes. A two-second black screen interval separated each stimulus. The total duration of the entire sequence was approximately twelve minutes.

Alternatively, the administration can be performed by using virtual reality. In this case, a VR visor is required. The current implementation of the 2ViTA-B Cognitive is based on the Oculus Quest 2. The virtual sequence offers two immersive reality scenes – one featuring a natural landscape (see Figure 2) and the other taking the viewer into a spacecraft in space (see Figure 3). The choice of these settings is not random: several studies have demonstrated a positive effect of natural environments on affectivity (Browning et al., 2020), (Ulrich et al., 1991), (Huang et al., 2020).

In the first virtual scene, which we will hereafter refer to as the "static scene," our focus was on achieving realism, with a dedicated effort to optimize the scene's quality and performance. In contrast, the second scene, which we will also term as the "dynamic scene," offers patients the ability to navigate within the spacecraft, interact with specific objects, and embark on a virtual space exploration journey.

Figure 2: The first virtual scene: static scene.

Figure 3: The second virtual scene: dynamic scene.

The system alerts therapists when a new session starts, offering the option to monitor patient progress in real-time or later. This includes a dashboard showing patient's profile, medical history, responses, vital parameters, and multimedia sequences (see Figure 4 and Figure 5).

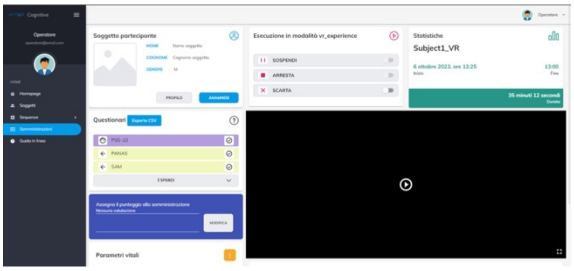

Figure 4: Patient's profile visualization during the execution of administration.

Post-session, therapists can give numerical evaluations and feedback for each session. They can assess a patient's progress by comparing multiple sessions, assisted by an AI algorithm showing score trends. Additionally, the system provides optional blockchain verification to ensure data integrity. On the other hand, after a session patients can access their administration history, including the date, time, and therapist evaluations, and track progress through an avatar-based path in their profile.

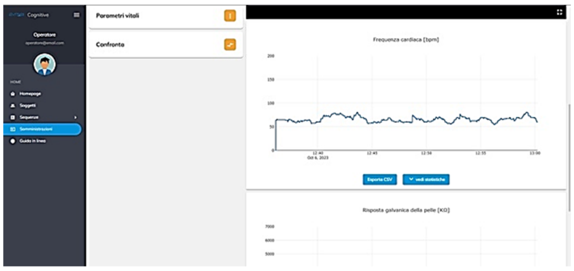

Figure 5: Patient's vital parameters monitoring during an administration.

4 EMPIRICAL STUDY

The experiment we conducted was designed to evaluate the impact of hematogenic stimulation on cognitive attention functions. This section presents the experiment design and the outcomes, which serve to validate the 2ViTA-B Cognitive system, and particularly the effectiveness of using virtual reality during an administration.

4.1 Study Definition and Context

The objective of this study was to analyze the use of virtual reality in the context of cognitive rehabilitation activities and evaluate its potential impact on the emotional well-being and affectivity of the assisted users. To assess the advantages of employing virtual reality, a controlled experiment was conducted.

In the context of the experiment, participants interacted with two versions of the virtual assistant. In the first version of 2ViTA-B Cognitive participants engaged in cognitive rehabilitation sessions using multimedia content. This version was designed to modulate the subjects' affect, with a particular focus on reducing negative affect levels (Burattini et al., 2021). The second is the VR version. In which participants were involved in virtual reality sessions aimed at modulating affectivity and enhancing cognitive functions.

The experiment involved 16 healthy participants (13 males and 3 females) aged between 22 and 63, recruited with the assistance of the Italian Ministry of Defense using convenience sampling.

The participants were divided into two groups and instructed to complete two separate rehabilitation sessions using 2ViTA-B Cognitive once and 2ViTA-B Cognitive VR the other time. As said before, the Oculus Meta Quest 2 headset is used to experience immersive sessions. Also, independently by the version of the 2ViTA-B Cognitive system, the participants wore the Muse S (Gen 2) EEG band to assess their brain activity (*i.e.*, selective attention).

4.2 Experimental Design

As previously mentioned, the controlled experiment is designed to ascertain whether the incorporation of virtual reality into cognitive rehabilitation activities yields enhancements in participants' affectivity and cognitive functions. Additionally, we are keen on pinpointing methodologies for gauging the positive impact of this technology on therapeutic approaches and the well-being of users.

As a result, we formulate the following two null hypotheses:

- H_{01}: *The use of 2ViTA-B Cognitive VR does not result in enhancements in self-assessment affectiveness.*
- H_{02}: *The use of 2ViTA-B Cognitive VR does not lead to improvements in participants' attention.*

Thus, this study is guided by the following research questions:

- RQ_1: *Does the use of 2ViTA-B Cognitive VR improve self-assessment affectiveness?*
- RQ_2: *Does the use of 2ViTA-B Cognitive VR improve participants' attention?*

To answer these questions, we defined and controlled several independent variables and defined and observed several dependent variables. The independent variables we defined and controlled are described below. Treatment variable identifies the type of treatment utilized. It distinguishes between the conventional version of our 2ViTA-B Cognitive software (referred to as "Standard"), which allows users to access multimedia content through a standard web browser, and the new 2ViTA-B Cognitive VR (referred to as "VR") version, offering immersive experiences through virtual reality. Administration represents the two administrations selected, denoted with "S1" and "S2".

Instead, the dependent variables we defined and observed are outlined hereafter. Attention is defined as the cognitive process of selecting specific environmental stimuli from many available options at a given time while disregarding others. We assessed this cognitive function using the cognitive Stroop test (Stroop, 1935) and by examining electroencephalography (EEG) biosignals recorded during the administration sessions. Self-assessment affectiveness pertains to the outcomes derived from self-assessment questionnaires employed to evaluate the affectivity of the participating subjects. Specifically, our goal was to gauge the impact of stimulation on affectivity by administering questionnaires before and after the presentation of multimedia sequences or immersive experiences. This allowed us to calculate the difference in responses and ascertain the extent to which the stimulus influenced the emotions of participants.

Given these defined variables, the experiment's design is detailed in Table 1.

Table 1: Experiment design.

	Group A	Group B
S1	VR	Standard
S2	Standard	VR

In this trial, the combinations explored involved Group A, who initiated with a VR session followed by a Standard administration, while Group B followed the reverse order. A substantial temporal gap (*i.e.*, one/two days) was introduced between the two administrations to mitigate potential overlapping effects of the sessions.

This strategic design facilitated the examination of distinctions between Standard and VR administrations, considering diverse ordering scenarios within the two groups. By systematically analyzing these combinations, our aim was to detect the effect of VR without any bias caused by the order of the administrations.

4.3 Preparation

Individuals of both genders were approached through direct acquaintances and personal connections of the researchers involved. Those who expressed a voluntary interest in participating in the trial without any form of compensation were requested to complete a medical history questionnaire and the PSS-10 stress assessment.

All participants confirmed that they had no existing medical conditions, no history of psychological disorders, were not taking any medications, did not engage in excessive alcohol consumption, and did not use recreational drugs.

Prior to the commencement of the study, all participants provided their informed consent. The experimentation received approval from the Ethical Committees of the "Celio" Military Policlinic.

The experimentation was conducted in the laboratories of the "Veterans Defence Centre" in Rome, Italy. Before the start of the experimentation, volunteers were briefed on the administration process, how to utilize the devices (included the VR headset), and the underlying rationale behind the Stroop test.

4.4 Experiment Material and Execution

As previously mentioned, participants were engaged in two experimental sessions: one involving a cognitive administration in the standard version and the other in virtual reality. Efforts were made to evenly distribute the participants into the two experimental groups, A and B (see Table 1).

The experimental protocol employed in the study encompassed three successive phases. These phases are described below. **(i) PRE**: participants donned the vital parameter monitoring devices, GSR, and fitness tracker. They subsequently completed the PANAS, GVAS, and SAM questionnaires. Following this, they wore the EEG device and underwent a brief calibration of the instrument. To verify correct positioning, the device prompted participants to relax for 30 seconds and then concentrate for an additional 30 seconds. Upon completing the calibration, the cognitive Stroop test was administered, which could be conducted in real or virtual reality depending on the treatment. **(ii) STIM**: in this phase participants viewed the sequence of multimedia elements or immersive reality scenes, depending – once again – by the treatment. **(iii) POST**: this phase mirrored the PRE phase, with the same steps performed in the same order, *i.e.*, participants filled out the PANAS, GVAS, and SAM questionnaires once more and repeated the Stroop test. In the case of virtual administration, participants were required to briefly remove the headset before completing the three questionnaires and then put it back on to perform the Stroop test before concluding the administration.

After the execution of the experimentation, we gathered the results from the self-assessment questionnaires, which were used to assess affectivity (PANAS), as well as the data from the Stroop test for the evaluation of selective attention. Specifically, for the Stroop test, we calculate a score by assigning 1 point for each correct answer, -1 point for each incorrect answer, and 0 points for unanswered questions.

Additionally, bio-signal parameters recorded by the EEG wearable device were collected. Specifically, we collected data on Beta waves, which tend to increase during periods of high mental activity, like reading and conversation. These waves are associated with attention, complex problem-solving, and various cognitive processes, typically falling within the range of 0.1 to 30 Hz. To facilitate result comparisons, we utilized the Beta score provided by the mind band vendor. This score is a normalized value that falls within the range of 0 to 1.

After collecting the data, we performed descriptive statistical analysis and examined statistical differences using a one-tailed Wilcoxon signed-rank test. We set a significance level of 5% (p-value = 0.05) to determine whether to reject our null hypotheses.

4.5 Experiment Results

In the following we present the results obtained with the aim of addressing our research questions and testing our null hypotheses.

RQ_1: ***Does the use of 2Vita-B Cognitive VR improve self-assessment affectiveness?*** Table 2 presents the descriptive statistics of the scores computed from the PANAS questionnaires in both the treatment (VR or Standard). The scores represent the difference between the POST and PRE executions for administrations S1 and S2. The table also reports the difference of the scores achieved in the two treatments.

Table 2: Descriptive statistics of PANAS questionnaire. A high score suggests a positive emotional state, while a low score suggests a less positive or more neutral emotional state.

	Treatment		Difference
	VR	Standard	VR - Standard
Mean	39.37	-12.50	51.88
Median	35.00	-10.00	40.00
Std.dev.	57.90	56.74	73.50

Based on the results of the self-assessment affectiveness questionnaire, it is evident that immersive virtual reality experiences outperformed the standard administration in significantly enhancing subjects' perceived affectivity. Specifically, the mean score achieved with the VR treatment is 39.37, while with the standard treatment, the score is notably lower, at -12.50. It is noteworthy that one subject reported the lowest score of -50 among all participants in the VR treatment group. This decrease in score can be attributed to her experience of nausea during the VR administration.

The difference between the two treatments is not only substantial but also statistically significant. When analyzing the one-tailed Wilcoxon signed-rank test, we obtain a p-value of 0.006 (with z at -2.54 and W at 12). Therefore, we can confidently reject the null hypothesis H_{01} and conclude that ***the use of 2ViTA-B Cognitive VR results in a substantial improvement in self-assessment affectiveness***.

RQ_2: ***Does the use of 2Vita-B Cognitive VR improve participants' attention?*** Table 3 provides descriptive statistics for the Stroop test scores, including data for both treatment groups and the difference between the two treatments.

Table 3: Descriptive statistics of the Stroop test score differences, calculated as the difference between the Stroop test scores before and after the administrations.

	Treatment		Difference
	VR	Standard	VR - Standard
Mean	2.86	0.50	2.38
Median	2.00	0.50	1.00
Std.dev.	3.56	2.45	4.32

Once more, we have observed a greater number of correct responses during the VR administrations, signifying a significant increase in the number of participating subjects experiencing benefits from the immersive experience-based therapy. Such a difference is evident but non statistically significant. When analyzing the one-tailed Wilcoxon signed-rank test, we obtain a p-value of 0.05 (with z at -1.61 and W at 22.5). Therefore, we cannot reject also the null hypothesis H_{02} and ***we cannot conclude that the use of 2ViTA-B Cognitive VR improves participants' attention measured through the Stroop test***.

Similar considerations apply to the EEG analysis. Therefore, based on the results achieved we cannot reject the null hypothesis H02 also considering the EEG Beta score. Thus, ***we cannot conclude that the use of 2ViTA-B Cognitive VR improves participants' attention measured through EEG beta score***.

Table 4 reveals that VR does not contribute to enhancing participants' attention. In fact, after the VR administration, subjects' attention slightly decreases, while with the standard treatment, the difference between the beta scores before and after administration is close to zero. When analyzing the one-tailed Wilcoxon signed-rank test, we obtain a p-value of 0.12 (with z at - 1.18 and W at 24). This result suggests that while VR is effective in eliciting positive emotions, it might also impose a higher cognitive workload, thereby potentially negatively affecting attention.

Table 4: Descriptive statistics of EEG Beta score differences, calculated as the difference between the beta scores before and after the administrations.

	Treatment		Difference
	VR	Standard	VR - Standard
Mean	-0.11	0.02	-0.13
Median	-0.40	0.01	-0.06
Std.dev.	0.27	0.23	0.45

Therefore, based on the results achieved we cannot reject the null hypothesis H_{02} also considering the EEG Beta score. Thus, ***we cannot conclude that the use of 2ViTA-B Cognitive VR improves participants' attention measured through EEG beta score***.

4.6 Threats to Validity

The primary threat to the validity of the study arises from the representativeness of the participants. The sample size of 16 participants may not be sufficient to ensure the robustness of the results. While this is a common challenge in human experiments, recruiting individuals who are willing to participate without any form of compensation was particularly challenging, especially considering each participant underwent a double experimental session.

Additionally, the gender distribution among participants is notably skewed towards males. Research has shown that emotional responses can vary based on gender, potentially influencing the data collected and subsequent results.

Finally, it is crucial to note that the system is still in its early testing stages and has not yet received medical device certification. As a result, our experimentation was limited to enrolling only healthy individuals.

5 CONCLUSION

We introduced 2ViTA-B Cognitive, a virtual assistant aimed at positively influencing human emotions. A controlled experiment with sixteen participants evaluated its effectiveness in cognitive rehabilitation using VR. The results showed a positive effect on affectivity but less efficiency in enhancing attention. These findings suggest avenues for improving 2ViTA-B, including replicating the experiment and integrating EEG data with biofeedback techniques in VR environments to enhance participant awareness of their cognitive state.

ACKNOWLEDGEMENT

The 2ViTA-B project was developed as part of the National Plan of Military Research (PNRM), with funding being provided by the Ministry of Defence.

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