The EXPERIENCE Project: Unveiling Extended-Personal Reality through Automated VR Environments and Explainable Artificial Intelligence

Gaetano Valenza
Univ. of Pisa (Italy)

Mariano Alcaniz
Univ. Politecnica de Valencia (Spain)

Antonio Luca Alfeo
Univ. of Pisa (Italy)

Matteo Bianchi
Univ. of Pisa (Italy)

Vladimir Carli
Karolinska Institutet (Sweden)

Vincenzo Catrambone
Univ. of Pisa (Italy)

Mario CGA Cimino
Univ. of Pisa (Italy)

Gabriela Dudnik
Centre Suisse d'Electronique et de microtechnique (Switzerland)

Andrea Duggento
Univ. of Rome Tor Vergata (Italy)

Matteo Ferrante
Univ. of Rome Tor Vergata (Italy)

Claudio Gentili
Univ. of Padua (Italy)

Jaime Guixeres
Univ. Politecnica de Valencia (Spain)

Simone Rossi
Univ. of Siena (Italy)

Nicola Toschi
Univ. of Rome Tor Vergata (Italy)

Virginie van Wassenhove
Comissariat a l' Energie Atomique et Aux Energies Alternatives (France)

***Abstract*—Virtual reality (VR) technology offers immersive experiences, but its widespread adoption is hindered by technical barriers and a lack of consideration for users' physiological changes. This paper provides an overview of the EXPERIENCE system, which addresses these challenges by enabling individuals to create VR environments using portable devices without technical expertise. The project introduces Extended-Personal Reality (EPR), capturing users' subjective experiences through physiological responses, psychological descriptors, and behavioral outcomes. The comprehensive EPR environment allows for personalized exchanges of psychological and emotional responses. The integration of explainable AI, multisensory biofeedback, and individualized perceptions of time and space enables dynamic calibration and manipulation of the VR environment. The project focuses on minimizing psychological distance, particularly in temporal and spatial perception, to enhance user experiences. The EXPERIENCE technology holds significant potential in the healthcare of mood disorders, as well as gaming, e-learning, and neuroeconomics, offering a user-friendly platform for personalized virtual experiences and potentially creating a new market for unique virtual worlds tailored to individuals' psychological and emotional states.**

***Index Terms*—Experience Project, Virtual reality, Explainable Artificial Intelligence, Extended-Personal Reality, Time perception, Multisensory biofeedback**

I. Introduction

Virtual reality (VR) is an ever-evolving immersive technology that enables users to engage with computer-generated environments as if they were physically present. However, the creation of these digital worlds from scratch often requires technical expertise, impeding widespread adoption. Furthermore, many existing VR environments primarily focus on visual and auditory immersion, disregarding haptic sensations and physiological changes that users may encounter during their interactions.

To address these challenges, the innovative EXPERIENCE project empowers individuals to effortlessly construct their own VR environments using easily accessible portable devices such as smartphones or tablets, without the need for technical skills. The project aims to enable the general public to: i) Create personalized VR environments akin to creating photos and videos, without requiring specialized expertise. ii) Develop virtual simulations that elicit unique psychological, cognitive, neurophysiological, and behavioral responses. iii) Automatically generate VR environments based on neurophysiological data. iv) Easily manipulate VR environments to effectively communicate and evoke specific emotions. v) Harness the manipulation of perceived reality to facilitate the treatment of psychiatric disorders.

By integrating an individual's physiological responses, psychological and cognitive descriptors, and behavioral outcomes, the VR environment captures and encompasses their subjective experience, which we refer to as Extended-Personal Reality (EPR). EPR can be defined as the collective psychological, cognitive, neurophysiological, and behavioral responses that shape an individual's unique experience. In this context, individuals become EPR *providers* by generating their personalized VR environments using their own physiological, behavioral, and cognitive information. Moreover, the EPR can be *transmitted* to and shared with other users, enabling a novel form of personalized experience. This process allows for the exchange and dissemination of subjective realities, fostering new opportunities for immersive and customized experiences among individuals.

The research leading to these results has received partial funding from the European Commission H2020 Framework Programme under Grant No. 101017727 of the project EXPERIENCE (https://experience-project.eu/).

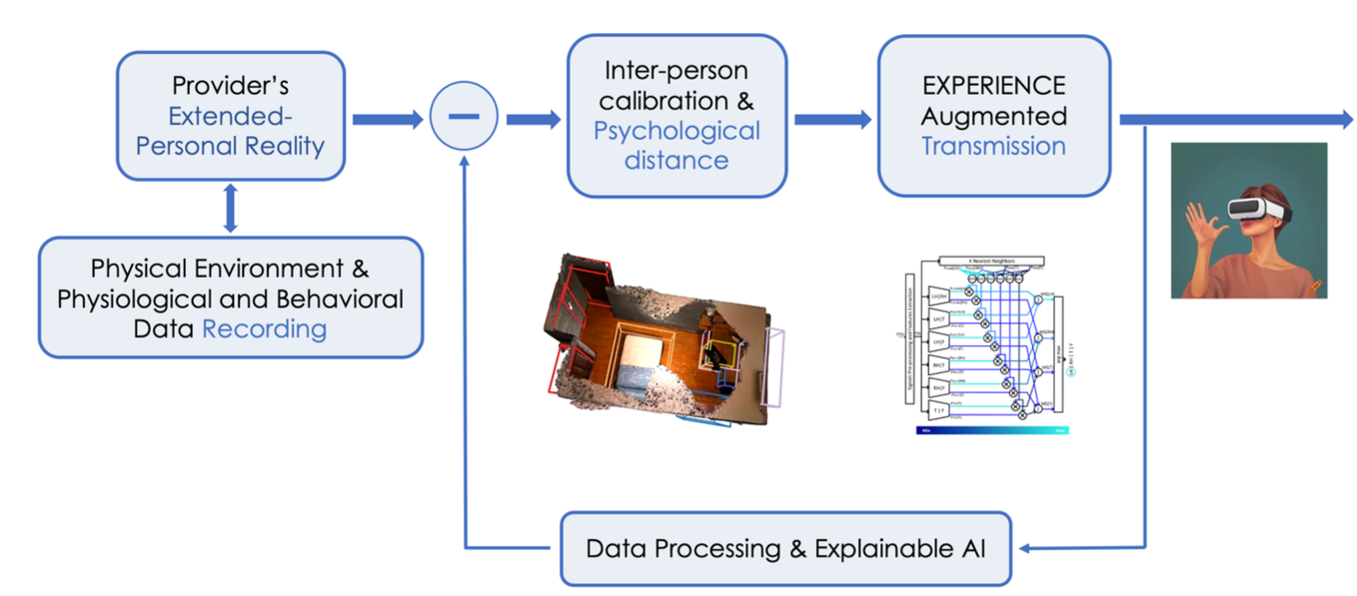

Fig. 1. Block scheme of the EXPERIENCE technological and scientific framework to generate and share the Extended-Personal Reality.

The EXPERIENCE project incorporates advanced explainable artificial intelligence (XAI) routines that integrate information from an individual's EPR to inform manipulation tools, including neuromodulation, multisensory biofeedback (audio, video, haptics), and the subjective perception of time and space. Recognizing the potential differences in perceptual thresholds between EPR providers and users, the project aims to assess and minimize psychological distance through a tailored calibration process. This calibration process focuses on two crucial aspects: temporal distance, which pertains to the perceived separation between the present moment and past or future events, and spatial distance, which denotes the perceived physical separation between an individual and an object or event. Given the VR context, special attention is given to the interplay between spatial and temporal perception, as it significantly impacts users' experiences. This paper provides a comprehensive overview of the EXPERIENCE system, as depicted in Figure 1. Additionally, it introduces novel findings on the development of explainable AI algorithms for depression recognition using physiological and behavioral features collected during the interaction with a VR environment. Furthermore, the paper discusses the potential connections with recent behavioral findings related to the Kappa effect - a time dilation illusion triggered by spatial distances between consecutive stimuli - observed within a VR environment. These findings were obtained through the study of stimuli delivered in a carefully designed VR setting.

The EXPERIENCE project also strives to generate VR environments using neurobehavioral data. Through the utilization of advanced deep generative computational architectures, neuroimaging data is effectively processed to automatically create VR scenarios that faithfully capture brain-body responses. As a result, the EXPERIENCE VR seamlessly extends an individual's subjectivity, providing a highly personalized and immersive experience. Encouraging preliminary findings from this brain decoding activity are presented in further detail below.

II. The EXPERIENCE Technological Platform

The EXPERIENCE technological platform incorporates an efficient wearable monitoring system, automated VR creation capabilities, and an interpretable AI engine.

A. *Wearable monitoring system*

The EXPERIENCE monitoring system introduces a lightweight and comfortable wearable solution for physiological and biometric monitoring. This system pioneers the integration of cutting-edge vision and healthcare wearables, employing cooperative sensors to monitor brain and autonomic regulation, inertial motion, stereoscopic vision using multiple cameras, hand kinematics, and environmental noise. To ensure compliance with medical regulations, all sensors are thoughtfully positioned on the user's head and chest. The collected data can be securely stored in a wearable data logger or transmitted in real-time to a gateway device, such as a mobile device, enabling effective real-time biofeedback.

This technological pillar encompasses novel wearable devices designed specifically for recording the user's EEG, ECG, respiration, environmental vision and sound, movement, hand kinematics, as well as marking or annotating significant events. These wearable devices integrate dry passive electrodes, eliminating the need for batteries and facilitating user-friendliness. They produce high-fidelity signals without requiring skin preparation or gels. Notably, flat-ended finger electrodes optimize scalp contact, even in the presence of hair, ensuring exceptional signal quality. The EEG cap, following the 10/20 International System, enables precise placement of

EEG sensors. This cap connects to a dedicated data acquisition module responsible for reading and transmitting EEG data to a recorder located on a belt or harness. Alongside the cap, a headband is incorporated, integrating a depth camera and microphone for environmental recording. Prior to recording, the image data is encrypted, ensuring privacy throughout the recording sessions. Furthermore, a standalone chest belt or harness, equipped with dry electrodes and a data logger, facilitates the recording of raw EEG, ECG, and respiration signals, as well as processed parameters. The biosignals are synchronized, and a sensor within the chest belt data logger can mark "special" events (e.g., moments of heightened arousal) by double-tapping on the enclosure.

B. Automatic VR creation

A user-friendly software engine processes the multivariate data captured by the EXPERIENCE wearable described above, enabling fully automated 3D reconstruction - see also companion paper [15]. To this end, EXPERIENCE aims to empower non-expert users to engage in 3D customization by leveraging detection-and-pose estimation of 3D objects, 3D object retrieval, semantic analysis of the scene, and style transfer techniques. The automatic reconstruction process begins by collecting the image and depth data, which are then utilized to reconstruct a dense 3D scene using pose estimation algorithms like BundleFusion. BundleFusion is a real-time 3D reconstruction algorithm that incorporates on-the-fly surface reintegration of the RGB image. Once the 3D reconstruction is completed, the point cloud undergoes preprocessing steps, including denoising, mesh simplification, and mesh alignment.

Next, an automatic 3D scene understanding phase takes place, where the different objects within the scene are identified, and the boundaries of the captured scene are extracted. Object detection, a challenging task in computer vision, plays a vital role in this process as it involves detecting visual object instances of various classes such as cars, people, animals, and floors. With the object labels obtained, a realistic scene is rendered, allowing for the replacement of previously modeled objects. Additional significant steps include layout estimation, which provides information about the boundaries of the scanned environment, and the style transfer algorithm, which blends the objects seamlessly with the real scene and alters the overall appearance of the 3D scene. The result is an automatically virtualized scenario that exhibits precision, photorealism, and efficient adaptation to multiple VR systems.

EXPERIENCE aims to create deep generative architectures to automatically generate VR environments faithfully representing a persons recall from their neuromonitoring data only. To this end, models able to capture and disentangle most of the complexity of the 3D multisensory input that generates brain responses, hence flattening and evening out the perceptual manifold like human brains might do, are devised. In this regard, we present a pioneering approach that translates functional Magnetic Resonance Imaging (fMRI) activity into a 3D scene using a deep learning architecture based on Long Short-Term Memory (LSTM) combined with a latent diffusion model. The resulting 3D scene is then projected onto the surface of a sphere, enabling an immersive experience within a VR environment. This methodology holds immense potential for sharing subjective experiences among individuals, ushering in a new era at the intersection of cognitive neuroscience and VR. A schematic representation of the proposed method for generating a realistic 3D scene from fMRI data is shown in Fig. 2. We utilized the Natural Scenes Dataset [6], a 7T

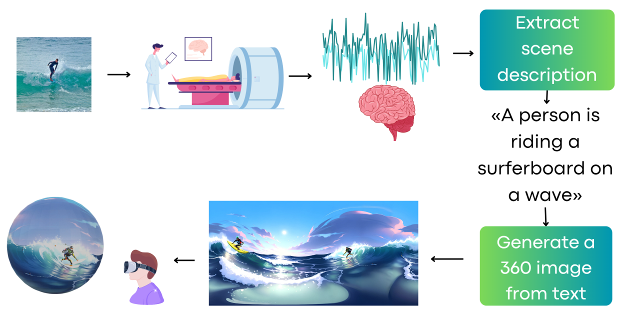

Fig. 2. Schematic representation of the proposed method for generating a realistic 3D scene in a VR. The process begins with the fMRI activity of a subject viewing an image. This fMRI activity is utilized to compute a scene description, which is then passed to a latent diffusion model. The latent diffusion model is capable of generating a 360-degree image, capturing the immersive essence of the scene. Finally, the generated 360-degree image is mapped onto a spherical surface, resulting in a realistic and immersive 3D scene suitable for virtual environments.

fMRI dataset consisting of 8 subjects who viewed approximately 9000 natural images (stimuli) from the COCO image dataset. For our analysis, we processed the fMRI data by computing a General Linear Model across all the different stimuli. From this, we selected a Region of Interest comprising approximately 15,000 voxels. To accomplish our objective, we employed a pretrained image captioning model, which combines a convolutional neural network and a recurrent neural network, capable of generating text descriptions from images. However, we modified the initial part of the model by replacing the image input with a mapping from the fMRI data to the latent space of the CNN. By keeping the weights of the LSTM model frozen, we adapted it to process the fMRI data instead. Consequently, our LSTM-based architecture takes as input the fMRI data of a subject who observed a specific scene. The network is trained to transform this data into a textual description of the scene. This conversion is guided by previous research in the field of neuroimaging, which has successfully established links between specific patterns of brain activity and visual or semantic concepts [7], [8].

The LSTM network generates a textual description, which is subsequently processed by a latent diffusion model to produce a 3D scene. The latent diffusion model belongs to the family of generative models that learn to generate new data with similar statistics to the training set. It excels in generating complex, high-dimensional objects like 3D scenes. The model initiates the scene generation by constructing an initial 'rough' version based on the textual description. It then iteratively refines this version, enhancing its accuracy and realism by traversing a learned latent space that captures the statistical properties of the training data. This process of diffusion through the latent space allows the model to generate intricate 360 scenes that faithfully represent the original fMRI data. To achieve these results, we utilized a pretrained model from Blockade Labs (https://www.blockadelabs.com/), which is a finetuned version of the StableDiffusion model [9] trained on the LAION dataset. To create an immersive VR experience, the generated 3D scene is mapped onto the surface of a hemisphere. This mapping is challenging due to the inherent differences between flat and spherical surfaces. To address this, we employ spherical projection, a technique that maps each point of the 3D scene to a corresponding point on the hemisphere's surface.

Fig. 3 shows two exemplary results obtained from the application of the proposed brain decoding methodology.

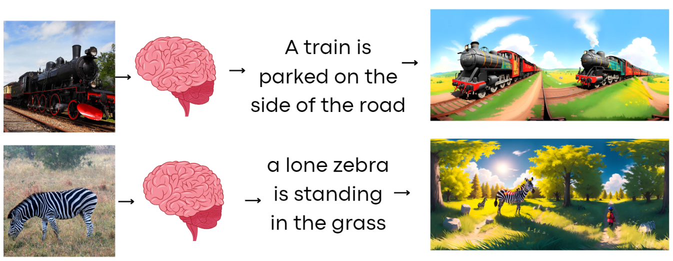

Fig. 3. Exemplary images of train and zebras used to synthetize descriptors that capture the main content of an image. This is used as input for the generation of a 360 image.

C. Explainable Artificial Intelligence (XAI) engine

The field of AI has made significant advancements in the analysis and classification of physiological and behavioral data, demonstrating promising potential within the context of the EXPERIENCE project. However, one major concern with AI models is their often perceived black box nature, where the inner workings of these models are opaque and challenging to interpret. As AI models become increasingly complex, there is a growing demand for explainable artificial intelligence (XAI) algorithms that can shed light on the reasoning behind their outputs [12].

XAI approaches aim to provide explanations for the decision-making process of AI algorithms, thereby allowing domain experts such as biomedical scientists to validate and trust these algorithms more effectively. By attaching explanations to the predictions made by AI models, XAI facilitates a smoother integration of AI into real-world clinical decision-making processes. This perspective aligns with recent regulations on personal data processing, such as the General Data Protection Regulation, which highlight the importance of explainability as a prerequisite for utilizing AI in practical healthcare settings.

D. Exploiting time perception in VR

Building upon recent findings reported in [1], the EXPERIENCE project harnesses the manipulation of time perception in VR through the multimodal visual-tactile Kappa Effect. The choice of employing multimodality is driven by the objective of creating a captivating extended reality experience that ensures user immersion. In the Kappa Effect, the perception of inter-stimulus time (IST) across multiple stimuli is influenced by the spatial distance between them. Specifically, greater spatial distances result in longer perceived IST, while shorter distances lead to shorter perceived IST.

To induce the Kappa effect, an HMD (Head-Mounted Display) presents a virtual representation of the user's arm with synchronized distributed visual stimuli displayed on this virtual representation (see Figure 4). Additionally, a wearable device delivers synchronized distributed tactile stimuli to the user's forearm. By comparing visual-only, tactile-only, and multimodal conditions, our investigations revealed that the Kappa effect primarily stems from the visual channel, while the introduction of multimodal stimuli did not significantly affect the illusory time perception. These findings align with the results obtained from previous studies involving concurrent visual and tactile stimuli delivered through a wearable device equipped with LEDs and tactile actuators [2]. Moreover, a relationship between participants' ability to discriminate the duration of time intervals and the magnitude of the Kappa effect exists. This observation is noteworthy, as it can be integrated into the explainable AI layer to facilitate subject-specific adjustments of temporal perception alteration, in conjunction with emotional assessment.

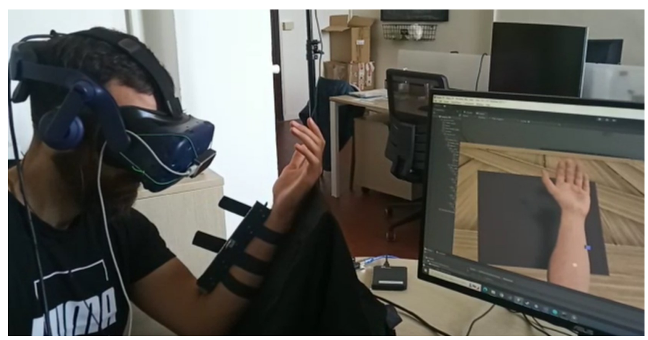

Fig. 4. Experimental setup to induce the Kappa effect using a HMD and a wearable device delivering synchronized distributed tactile stimuli to the user's forearm (from [1]).

Quantitative assessment of perceptual threshold is exploited in EXPERIENCE for the definition of psychological distance felt between individuals, as well as to guide the calibration process to reduce such a distance. To address this challenge, the perceptual thresholds for various dimensions of interest (such as auditory, visual, tactile, duration, etc.) are measured for both the EPR provider and the receiver. This facilitates the sensory calibration of the VR environment, bringing one's EPR closer to that of the other individual. In essence, while the VR experience may differ between the provider and receiver, the EPR is brought closer, thereby reducing the mental distance between self and other. Conflicting multisensory information are intentionally utilized to bias perceptions, including the perceived spatial location of one's body and time perception itself, through techniques such as emotional induction. For example, consecutive and distributed tactile stimuli can be perceived as more temporally separated when the spatial distance between them increases.

III. Application in a clinical scenario

In this study, we present an exemplary evaluation of EPR in a clinical setting focused on diagnosing depression. The entire experimental design has received ethical approval from the local ethics committee (Comitato Etico della Ricerca Psicologica (AREA 17), prot. No. 4688) on 26th April 2022. We collected data from a total of 94 subjects. To screen participants, we employed the Patient Health Questionnaire-9 (PHQ-9) [10], a self-report measure that assesses the presence and severity of depressive symptoms. Individuals with a PHQ-9 score higher than 9, indicating moderate to severe depression, were included in the group with depressive symptoms. They are then asked to complete a survey to evaluate whether they meet the inclusion criteria for the study, considering any applicable exclusion criteria. Similarly, individuals with a PHQ-9 score lower than 5 are included in the healthy control group. They are also asked to complete a survey to determine their eligibility based on the exclusion criteria.

The objective of our study is to identify individuals with depression, utilizing the interaction with the virtual environment as an indicator of curiosity and depressive state.

Fig. 5. A frame of the VR environment used for the EXPERIENCE clinical applications

To fulfill our objectives, we have developed a VR scenario that encompasses a house-like environment with five distinct spaces (see Fig. 5). The central room functions as a combined dining and living room, while the remaining four rooms represent bedrooms and offices accessible through individual doors. From a functional standpoint, these spaces are divided into three rooms, with the central lounge serving as a pivotal area and an initial bedroom acting as the participant's starting point. The scenario guides the participant to unlock the exit door by exploring and examining the different rooms, each creating a sad, neutral, or happy ambiance. Access to each room is granted upon engagement in Serious Games, including TMTA, Wisconsin, RVIP, and 2-BACK. Additionally, interactive elements and objects are strategically placed throughout the scenario to stimulate participant interaction and evoke curiosity. This setup enables the use of diverse behavioral features, such as the duration spent in each room, eye tracking information, game-related data, and interaction data. These data elements facilitate subsequent analysis aimed at identifying the symptoms of depression. During the interaction with the VR scenario, we also gathered physiological measures including ECG and electrodermal activity.

We employ CatBoost as a XAI method. CatBoost is an open-source library that utilizes gradient boosting on decision trees for model training and optimization [13]. The algorithm constructs an ensemble of decision trees and employs a gradient descent approach to minimize the loss function with respect to the ground truth labels of the recognized instances. CatBoost begins with an initial model, such as a simple decision tree, and subsequently iteratively builds and adds decision trees to the ensemble, with each tree aimed at correcting the recognition errors made by the previous ones. The final prediction is obtained by aggregating the predictions of all trees in the ensemble [13]. We chose CatBoost for this study due to its advantageous properties [14], including: (i) excellent recognition performance, (ii) capability to handle numerical, categorical, and missing values in the data, (iii) prevention of overfitting through ensemble-based modeling, and (iv) availability of a built-in feature importance measure, enabling global model explanation. The feature importance measure, a key XAI approach, explains the behavior of the AI model by evaluating the contribution of each input feature to the recognition outcome [12]. CatBoost provides a built-in feature importance measure that assesses the average change in predictions when a specific feature's value is modified. A higher importance value signifies a greater average impact on predictions when the feature is altered. To ensure comparability, the feature importance values are normalized, resulting in a sum of 100 across all features.

Due to significant data corruption issues (such as missing entire logs or time series caused by hardware recording problems), the final dataset was reduced to 84 subjects. The performance of CatBoost in recognizing individuals with depression from the provided data is evaluated in terms of accuracy, represented as the average and standard deviation obtained from 5 repeated trials. The results indicate an accuracy of 90% $\pm$ 6%. These findings demonstrate a good recognition performance for subjects with depression. This conclusion is further supported by comparing it to similar studies in the field. For instance, a recent survey [11] reported lower accuracy (best case, 0.86) for machine learning approaches utilizing data collected during VR experiences to recognize depressed individuals.

IV. Discussion and Conclusion

The EXPERIENCE project aims to push the boundaries of VR, enabling greater inclusivity, creativity, and therapeutic potential within the realm of immersive technology. The EXPERIENCE technology holds tremendous promise across various cutting-edge fields, including healthcare, gaming, e-learning, and neuroeconomics. By providing a user-friendly platform for personalized virtual experiences, it has the potential to create a new market centered around the creation and sharing of unique virtual worlds tailored to each individual's psychological and emotional state.

By decoding the brain activity of individuals as they experience specific scenes, transforming this activity into 3D representations, and rendering them in a VR environment, we unlock the ability for others to fully immerse themselves in the subjective experiences of the original observer. This approach has profound applications across various domains. In psychological therapy, it offers therapists a deeper understanding of their patients' perspectives, facilitating more effective treatment and empathy. For artists, it provides new avenues for expressing their visions, allowing them to create immersive 3D scenes that can be shared and experienced by others. Furthermore, this approach opens up exciting possibilities for a new form of communication. While there are still significant challenges to overcome, such as improving the accuracy and resolution of fMRI-based decoding, the integration of neuroscience, machine learning, and VR holds immense promise for the future. As our understanding of the brain continues to advance, so too does our ability to translate its intricate activity into shared and immersive forms.

The EXPERIENCE project is dedicated to driving forward the diagnosis and treatment of affective disorders, with a particular focus on conditions linked to altered multisensory perception, such as depression. Current diagnostic protocols for depression heavily rely on self-reports and verbal communication between patients and psychiatrists. However, these methods are subject to potential biases, as they depend on accurate symptom expression by the patient and the psychiatrist's ability to interpret and identify symptoms correctly. Acknowledging the limitations of relying solely on self-reports and questionnaires, it is imperative to enhance existing diagnostic protocols to improve the efficiency and reliability of diagnosing affective disorders. Our objective is to transition towards more reliable and objective procedures by incorporating assessments of actual behaviors and implicit reactions to specific emotional stimuli. To achieve this, we propose the use of a purpose-built immersive VR environment, where psychometric scales and behavioral tasks can be explored and completed within a narrative-driven serious game. By integrating quantitative measurements gathered from the patient's EPR, we aim to improve the current diagnosis and treatment of psychiatric illnesses. Through the immersive VR environment, we can continuously measure behavioral indicators related to patients' executive functioning, implicit decision-making patterns, memory, and other relevant factors by exposing them to various EXPERIENCEs. This approach allows us to redefine psychiatric illnesses based on the extended-personal reality of each individual, enhancing the reliability and objectivity of future clinical diagnoses. By integrating objective measurements and behavioral assessments, we strive to advance the accuracy and effectiveness of diagnosing and treating psychiatric disorders.

References

[1] Y. D. Pra, V. Catrambone, V. van Wassenhove, A. Moscatelli, G. Valenza, and M. Bianchi, Altering time perception in virtual reality through multimodal visual-tactile kappa effect, IEEE Transactions on Haptics, pp. 16, 2023

[2] Y. De Pra, V. Catrambone, V. Van Wassenhove, G. Valenza, and M. Bianchi, Toward the manipulation of time and space in extended reality: a preliminary study on multimodal tau and kappa illusions in the visual-tactile domain, in 2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN), 2022, pp. 179184

[3] R M Awangga, T L R Mengko, and N P Utama. A literature review of brain decoding research. IOP Conference Series: Materials Science and Engineering, 830(3):032049, 2020.

[4] Sikun Lin, Thomas Sprague, and Ambuj K Singh. Mind reader: Reconstructing complex images from brain activities, 2022.I. S. Jacobs and C. P. Bean, Fine particles, thin films and exchange anisotropy, in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271350.

[5] F Ozcelik and R VanRullen. Brain-Diffuser: Natural scene reconstruction from fMRI signals using generative latent diffusion. 2023 Pre-print on Arxive: https://doi.org/10.48550/arXiv.2303.05334

[6] EJ. Allen, *et al.*. A massive 7t fmri dataset to bridge cognitive neuroscience and artificial intelligence. Nature Neuroscience, 25(1):116126, 2022.

[7] S. Takada, R. Togo, T. Ogawa and M. Haseyama, "Generation of Viewed Image Captions From Human Brain Activity Via Unsupervised Text Latent Space," 2020 IEEE International Conference on Image Processing (ICIP), Abu Dhabi, United Arab Emirates, 2020, pp. 2521-2525.

[8] M Ferrante, T Boccato, N Toschi. Semantic brain decoding: from fmri to conceptually similar image reconstruction of visual stimuli, 2023, preprint on Arxiv https://doi.org/10.48550/arXiv.2212.06726

[9] R Rombach, A Blattmann, D Lorenz, P Esser, B Ommer. High resolution image synthesis with latent diffusion models, 2021. URL https://arxiv.org/abs/ 357 2112.10752.

[10] Spitzer, R. L., Kroenke, K., Williams, J. B. W. Validation and utility of a self-report version of PRIME-MD: the PHQ primary care study. Primary Care Evaluation of Mental Disorders. Patient Health Questionnaire. JAMA, 282(18), 17371744, 1999. https://doi.org/10.1001/JAMA.282.18.1737

[11] Chitale, V., Baghaei, N., Playne, D., Liang, H. N., Zhao, Y., Erensoy, A., Ahmad, Y.. The use of videogames and virtual reality for the assessment of anxiety and depression: A scoping review. Games for Health Journal, 11(6), 341-354, 2022.

[12] A. L. Alfeo, A. G. Zippo, V. Catrambone, M. G.C.A. Cimino, N. Toschi, G. Valenza. "From local counterfactuals to global feature importance: efficient, robust, and model-agnostic explanations for brain connectivity networks", Computer Methods and Programs in Biomedicine 236, 107550, 2023

[13] Yandex, N. Catboost is a high-performance open source library for gradient boosting on decision trees, 2017.

[14] Dhananjay, B. and Sivaraman, J. Analysis and classification of heart rate using CatBoost feature ranking model. Biomedical Signal Processing and Control, 68, 102610, 2021.

[15] C Garcia, P More, M Ortega, E Ivorra, ML Alcaniz, G Valenza, Virtual Experience Toolkit: Enhancing 3D Scene Virtualization from Real Environments through Computer Vision and Deep Learning Techniques, proceedings of IEEE MetroXRAINE 2023.