A Virtual Reality System for the Simulation of Neurodiversity

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Abstract Autism is a neurodevelopmental disorder characterized by deficits in social communication and repetitive patterns of behavior. Individuals affected by Autism Spectrum Disorder (ASD) may face overwhelming sensory hypersensitivities that hamper their everyday life. In order to promote awareness about neurodiversity among the neurotypical population, we have developed an interactive virtual reality simulation to experience the oversensory stimulation that an individual with autism spectrum disorder may experience in a natural environment. In this experience, we project the user in a first-person perspective in a classroom where a teacher is presenting a lecture. As the user explores the classroom and attends the lecture, he/she is confronted with sensory distortions which are commonly experienced by persons with ASD. We provide the users with a virtual reality headset with motion tracking, two wireless controllers for interaction, and a wristband for physiological data acquisition to create a closed feedback loop. This wearable device measures blood volume pulse (BVP) and electrodermal activity (EDA), which we use to perform online estimations of the arousal levels of users as they respond to the virtual stimuli. We use this information to modulate the intensity of auditory and visual stimuli simulating a vicious cycle in which increased arousal translates into increased oversensory stimulation. Here, we present the architecture and technical implementation of this system.

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X.-S. Yang et al. (eds.), *Proceedings of Sixth International Congress on Information and Communication Technology*, Lecture Notes in Networks and Systems 236,
https://doi.org/10.1007/978-981-16-2380-6_46

Keywords Virtual reality · Neurodiversity · Autism spectrum disorder · Physiology

1 Introduction

1.1 Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that affects social communication and is characterized by repetitive patterns of behavior. Individuals diagnosed with ASD may experience hypersensitivity, enhanced perception, and sensory overload [10, 12]. Some view this hypersensitivity as the result of hyperacute sensation, others, as a lack of prediction, leading to impairments in habituation. Regardless of the cause, these differences in sensory prediction, together with impairments in contextualizing sensory evidence, can handicap the understanding of others' actions and, consequentially, social interactions [7].

1.2 Virtual Reality for Neurodiversity Simulation

With the goal of raising awareness among the neurotypical population about the neurodiverse phenomenology, we developed an interactive virtual reality simulation to experience "neurodiversity". In particular, we wanted to simulate the oversensory stimulation that people with ASD may experience during an ordinary situation. For the simulation environment, we have chosen a classroom given that it is a social context in which many possible stimuli may be present. In order to offer a realistic first-person experience, we chose to use virtual reality (VR) to place users in the perspective of a student affected by ASD (see Fig. 1). Furthermore, we used a wearable device for acquiring physiological signals that we use to estimate arousal levels, which we use in real time to create a closed feedback loop.

ASD encompasses a wide range of traits. As the use case of our project, we have simulated the experience of a teenager, focusing on Level 1 of the 5th Version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) [4] ("Requiring Support"); that is, although diagnosed with ASD, this person would not suffer severe deficits. The reasons to choose this level are because more advanced levels would deal with more complex motor symptoms [9], making it more difficult to simulate the experience, and because individuals under more severe symptoms (such as low intelligence or impaired communication) could even seek sensory stimuli.

Fig. 1 Screenshot of the classroom environment. The user is placed sitting on a desk, surrounded by other peers and in front of a teacher, who gives a lecture on astronomy

1.2.1 Previous Examples

The experience we are proposing is informed both by scientific literature and existing multimedia projects for ASD awareness. The available examples can be classified considering their format and level of interactivity.

- **Videos (regular):** In this type of experience, users can watch in a first-person view what a person with ASD would be experiencing. Examples (all but the first one are homemade): Carly's Café,[1] Walking Down the Street,[2] Sensory Overload Stimulation,[3] and Autism: Sensory Overload Stimulation.[4]
- **360° videos:** In these ones, the viewer can also experience a 360° representation of their surroundings. Examples: Project Cape,[5] The Party,[6] and Autism TMI Virtual Reality Experience.[7]
- **Interactive:** This kind of experience also allows users to interact with the environment. Examples: Auti-Sim (game)[8] and Autism Reality Experience.[9]

As mentioned, a variety of works have been created through different technological means to raise awareness about the sensory overstimulation that someone with ASD could suffer. However, to the best of the authors' knowledge, none of the

[1] https://youtu.be/KmDGvquzn2k.

[2] https://youtu.be/plPNhooUUuc.

[3] https://youtu.be/BPDTEuotHe0.

[4] https://youtu.be/IcS2VUoe12M.

[5] https://youtu.be/ZLyGuVTH8sA.

[6] https://youtu.be/OtwOz1GVkDg.

[7] https://youtu.be/DgDR_gYk_a8.

[8] http://gamejolt.com/games/auti-sim/12761.

[9] https://www.training2care.co.uk/autism-reality-experience.htm.

existing systems includes biofeedback to more realistically and dynamically recreate that experience. By using multiple physiological signals in real time, we aim at overcoming this limitation and thus deliver a more complete simulation.

1.2.2 Affective State Estimation from Physiological Signals

The autonomic nervous system modulates physiological responses, such as heart rate, respiration, and pupil dilation. This is directly reflective of certain internal human states, such as emotions and cognitive load. Thus, it is possible to use a variety of sensors to measure different physiological signals, such as the electrical activity of the heart using an electrocardiogram (ECG) or the skin's electrodermal activity (EDA), to learn about the users' states. In particular, these signals are known to correlate with affective states such as arousal [13], including in VR experiences [6].

Electrodermal activity is the fluctuation of the electrical properties of the skin as modulated by sweat gland activity. This is controlled by the sympathetic nervous system in correlation with arousal [8]. Heart rate variability (HRV) is a measure of the variation of time intervals between heartbeats [1], which can be derived from ECG data or photoplethysmography (PPG) data [3] and also correlates with arousal levels [2]. We use EDA and PPG together for increased robustness.

In this paper, we present a novel virtual reality experience to simulate the oversensory stimulation that neurodiverse people might face in their daily lives in order to promote awareness of this among the neurotypical population. This experience is enhanced by biofeedback using physiological signals to dynamically adapt the experience. Here, we describe the outcome, focusing on the stimuli used and the implementation in terms of its architecture and the estimation of the user's internal states, before discussing the resulting work.

2 Neurodiversity Experience

2.1 Stimuli

While immersed in the virtual reality experience, users are exposed to a series of stimuli whose properties (such as intensity and duration) are manipulated to induce a state of oversensory stimulation. The chosen stimuli are informed by a body of research on sensory overload in ASD and self-reports from individuals in the ASD spectrum. Considering the types of oversensory stimulation, the stimuli can be divided between visual and auditory (see Table 1).

Apart from being triggered, these stimuli can be modulated in intensity within a continuous range of values. Thus, they can be regulated depending on a number of factors, including arousal levels of the users as inferred using their physiological responses.

Table 1 Examples of stimuli used in the experience, divided between auditory and visual

Type	Stimulus	Examples
Audio	Background noise	Peers talking
Audio	Sudden noise	Car horn
Visual	Color	Shiny colors
Visual	Distortions	Moving patterns
Visual	Light	Excess of light

2.2 Implementation

We have developed the "Neurodiversity Experience" as an interactive virtual reality experience augmented by biofeedback using a wearable device and implemented via a combination of different hardware and software technologies.

2.2.1 Architecture

As a platform for the VR experience, we chose the Oculus Rift S headset (Oculus from Facebook Technologies, U.S.A.), a head-mounted display that provides the audiovisual experience to the users, as well as handling body movements (particularly head) and integrating two wireless controllers for interaction.

We engineered the virtual environment and the foundation of the experience using the Unity real-time development platform (Unity Technologies, U.S.A.). Using Unity, we developed the 3D environment in which users are situated during the experience to perceive a series of stimuli. This environment is populated by human-like characters, including other students and the teacher. They are animated realistically, in terms of both body movements and facial expressions. In the case of the teacher, the avatar moves around the space while gesturing, simulating the delivery of a lecture on astronomy. Mouth movements of this character are synchronized with a recording of the speech, performed by a human actress.

This 3D application is also the basis for the interaction process, taking care of integrating both explicit interaction, such as body movements and actions with the controllers, and implicit interaction, deriving mental and affective states from physiological signals.

The sensor used to acquire physiological signals is the Empatica E4 wristband (Empatica Inc., U.S.A.), a wearable device equipped with multiple sensors, including a photoplethysmography (PPG) sensor and an electrodermal activity (EDA) sensor. It offers the possibility of real-time data acquisition and streaming using wireless connectivity via Bluetooth to a computer (see Fig. 2).

In order to process the physiological signals online and estimate the internal states of the users for interaction purposes, we developed an architecture integrating

Fig. 2 Setup of the experience. The user is wearing an Oculus Rift S headset and an Empatica E4 wristband. The computer screen allows observers to see what the user sees

several software technologies (see Fig. 3). We use the existing E4 streaming server [10] to forward real-time data using TCP socket connections. We developed a Python script that connects to that server, obtaining all data acquired by the wristband and relaying it using the lab streaming layer (LSL) system,[11] a protocol for streaming data which handles the networking and time-synchronization of signals for both online usage and recording. Then, we use the Modular Integrated Distributed Analysis System (MIDAS) [11] to perform the online analysis of the signals streamed using LSL. To do this, we developed a node for each of the signals of interest (PPG and EDA), integrating the necessary analysis functions to estimate arousal levels. The virtual reality application then performs requests using a REST JSON API at regular intervals to obtain the processed arousal levels, which are used to modulate the intensity of the stimuli presented to the users.

2.2.2 Online Physiological Signal Analysis

In order to estimate the arousal level of the users, we use a combination of two physiological signals: photoplethysmography (PPG) and electrodermal activity (EDA). From the blood volume pulse (BVP) measured by the PPG sensor, we derive heart rate variability (HRV). EDA and HRV are used in conjunction to estimate arousal levels.

To compute the changes in the physiological signals, we use a moving average algorithm based on two overlapping time windows. The shorter time window, corresponding to the last 10 s, is compared to a longer time window of 30 s that includes

[10] https://developer.empatica.com/windows-streaming-server.html.

[11] https://github.com/sccn/labstreaminglayer.

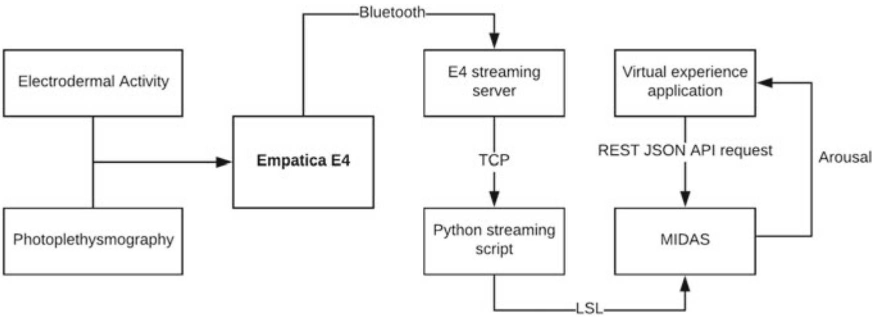

Fig. 3 Architecture to process the physiological signals to estimate arousal levels online for interaction with the virtual reality experience. The physiological signals from the Empatica E4 wristband are transmitted to be streamed using LSL, to be analyzed online by MIDAS to infer arousal levels for a closed-loop interaction

the shorter window. By dividing the mean value during the short window over that of the long window, a measure of change is computed, centered around a value of 1. Values over 1 indicate an increase in arousal, while lower values denote a decrease.

This moving average is computed for each signal type individually, on the analysis node corresponding to each. Then, an additional node combines the result from the physiological processing nodes by computing an average that will act as the estimation of arousal levels [5].

3 Discussion and Conclusions

We developed an innovative setup for a VR experience that places users in a classroom where they can assume the role of a student during a lesson. Throughout the experience, users are exposed to a series of stimuli to simulate their experience in ways that people with ASD may perceive them. To do this, we use a series of visual and auditory stimuli that are triggered depending on the timing and the actions of the users. The intensity of many of these effects is regulated using estimations of the arousal levels of the users, computed in real time from physiological signals acquired by a wristband they are wearing, to further reinforce the experience using biofeedback for achieving increased effectiveness and realism. To accomplish this, we developed a software architecture that transmits the raw signals obtained by the wristband's sensors, processes them online, and makes them available for real-time usage by the VR environment to dynamically adapt it to the user.

The main implication of this experience is to raise awareness about the daily life of a student with ASD. To do so, this system will be deployed in several neurodiversity-related events, where users will be able to experience it. Moreover, it will allow us to understand the relation between physiological signals, sensory overload, as well as attention and memory retrieval in classroom environments. This would be useful not only for gaining scientific knowledge and contribute to understanding the neurodiverse phenomenology but also for possibly helping teachers design more inclusive classrooms.

3.1 Further Steps

This paper presents the technical implementation of our study focused on building an interactive VR experience targeting the neurodiverse phenomenology. A further step in the validation of this experience will be to perform a user evaluation.

As a longer term possibility, this experience could also support ASD individuals themselves. Previous studies have discussed the need for techniques to improve predictive skills, rather than just treating ASD symptomatology. This could be done by adapting the type, intensity, and timing of the sensory overload stimuli to the degree of overload suffered by the individual.

Acknowledgements This research received funding from H2020-EU, ID: 787061 and ERC (PoC) H2020-EU, ID: 840052.

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