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Using virtual reality to assess gesture performance deficits in schizophrenia patients

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Introduction: Gesture performance deficits are prevalent in schizophrenia patients and are strongly associated with poor social communication skills and community functioning, affecting their overall quality of life. Currently, video-recording technology is widely used in clinical settings to assess gesture production deficits in schizophrenia patients. Nevertheless, the subjective evaluation of video-recordings can encumber task assessment. The present study will aim to use virtual reality to examine its potential use as an alternative tool to objectively measure gesture performance accuracy in schizophrenia patients and healthy controls.

Methods: Gesture performance in the virtual reality setting will be based on the well-established Test of Upper Limb Apraxia. Participants will be immersed in a virtual environment where they will experience themselves being embodied in a collocated virtual body seen from a first-person perspective. Motion trackers will be placed on participants' hands and elbows to track upper body movements in real-time, and to record gesture movement for later analysis. Participants will see a virtual agent sitting across from them, with a virtual table in between. The agent will perform various types of gestures and the participants' task will be to imitate those gestures as accurately as possible. Measurements from the tracking devices will be stored and analyzed to address gesture performance accuracy across groups.

Discussion: This study aims to provide objective measurements of gesture performance accuracy in schizophrenia patients. If successful, the results will provide new knowledge to the gesture literature and offer the potential for novel therapeutic interventions using virtual reality technologies. Such interventions can improve gesturing and thus advance social communication skills in schizophrenia patients.

KEYWORDS

virtual reality, schizophrenia, gesture performance, social communication, social cognition

1. Introduction

Schizophrenia is a complex mental health disorder that affects ∼1% of the general population. Schizophrenia is characterized by a wide range of clinical symptoms including disorganized thinking, paranoia, hallucinations, motor abnormalities, executive dysfunction, social withdrawal and affective flattening, all of which greatly disturb social communication processes leading to poor community functioning and quality of life (1–3). Successful social communication is highly dependent on one's ability to correctly perceive, interpret and execute socially relevant cues (4). In recent years, gestures serve as an important research tool in understanding social communication deficits in schizophrenia patients (5, 6).

Gestures are biological movements used alone or in combination with speech, to aid in social communication (7). Video-recordings of gesture performance in clinical settings show that schizophrenia patients and individuals at high-risk for psychosis tend to use hand gestures less frequently, or in the wrong context (8–10) and spend significantly less time fixating on the performed gestures (11). In addition, schizophrenia patients have deficits in correctly imitating meaningless and meaningful gestures following visual demonstration from an experimenter. Errors include slow movements with reduced amplitudes, extra movements, omissions, and body-part-as-object (12, 13). These errors are associated with impairments in postural knowledge, tool use, and social perception, suggesting a generalized impairment in non-verbal social communication in schizophrenia (14). Furthermore, deficits in gesture performance predict poor community functioning (15), and are strongly associated with symptom severity, motor abnormalities, and executive dysfunction, such as processing speed, attention, and working memory abilities (5, 11, 13, 14, 16–23).

Video recordings are easy to implement and have provided rich and notable insights on the mechanisms involved during gesture performance in schizophrenia (13, 14, 20, 24, 25). However, there are a few limitations to consider. In clinical settings, video-recordings can modify naturally occurring behaviors (26). In addition, when video-recordings are used to score participants' performance during a task, the data are categorical in nature and the process requires vigorous training for the scorer(s), which can be time consuming and cause inter-rater reliability issues. Further, the positioning of the camera can differ between sessions and participants' affecting viewpoint and body representations that can alter the evaluation of the task. The use of virtual reality (VR) technology can readily tackle most of these limitations (27).

In recent years, VR is increasingly used in the assessment and rehabilitation of movement execution (28). VR allows the creation of a virtual environment where users can interact with virtual characters via spoken language and hand gestures just as they would in the real world (29), supporting a highly immersive experience with increased ecological validity, reliability and reproducibility (30). Images of the virtual environment are displayed via the use of a head mounted display (HMD) where the users' head position and orientation are continuously tracked and updated as they move around (31, 32). Motion tracking devices can be used to substitute the users' body with a gender-matched virtual one seen from a first-person perspective and onto which their real movements are mapped in real-time, resulting in an illusionary ownership over the virtual body (33–35). Data from these tracking devices are multidimensional and provide an objective, reliable and unobtrusive measurement of real-time human behavior that surpasses that provided by video-recording data (36).

To our knowledge, no study to date has utilized VR to examine accuracy of hand gestures in schizophrenia patients. To this end, the aim of the present study is to apply VR technology to collect measurements of naturally occurring hand gestures during an imitation task in schizophrenia patients and compare their performance to healthy controls. Additionally, we will administer motor, socio-cognitive and community functioning assessments used in previous research from our lab to determine their relationship with hand gesture accuracy in VR. In accordance with previous studies (5, 13, 14, 20), we hypothesize that schizophrenia patients will perform the required gestures less accurately than healthy controls and that these deficits will be linked to their psychopathology, motor abnormalities, as well as compromised socio-cognitive and community functioning.

2. Materials and methods

2.1. Study design

This is an exploratory cross-sectional observational study using VR technology to assess the performance accuracy of different hand gestures. An HMD will be used to immerse participants in the virtual environment. Motion trackers, attached to the hands and elbows, will provide participants with real-time upper body tracking (see section VR apparatus for more details). Data from the HMD and motion trackers will be continuously stored on a computer for analyses. We plan to recruit 60 schizophrenia patients and 60 age and gender matched controls over a 2-year period. The duration of the study is ∼6 h. The assessments are separated into 2-h sessions/per day and all assessments are completed within a 72-h period.

2.2. Participants

Schizophrenia patients will be recruited from the inpatient and outpatient departments of the University hospital of Psychiatry and Psychotherapy in Bern, Switzerland. All potential schizophrenia patients will be screened using the Mini International Neuropsychiatric Interview (37) for the DSM-5 criteria. Healthy controls will be recruited through advertisement and by word-of-mouth. Inclusion criteria for all participants include: right-handedness, 18–65 years of age, no substance abuse (except nicotine), and no history of neurological disorders or any other severe mental health disorders. Additionally, for controls only, no personal, or first-degree relatives with a history of any mental health disorders.

2.3. Primary outcome

2.3.1. Gesture assessment in VR

The VR gesture task is based on the Test of Upper Limb Apraxia (TULIA), which was developed in accordance with the central domains and semantic characteristics of gesture performance (38, 39). TULIA measures accuracy of finger and hand movements in 48 items across two domains: the imitation domain (gesture performance following visual demonstration from the experimenter) and the pantomime domain (gesture performance following verbal command from the experimenter). Within these domains three different semantic categories of gestures exist:

(a) meaningless (new gestures without semantic elements), (b) intransitive (highly learned communicative gestures, such as waving good-bye), and (c) transitive (tool-based gestures, such as using a toothbrush). Scores for each item are rated using a 0–5 scale. The maximum score earned in the TULIA test is 240 (120 per domain), which is indicative of superior gesture performance (38). Administration of the TULIA test requires both the participant and the experimenter to be seated across from each other with a table between them; both with their hands placed flat on the table. For the imitation domain, which is the focus of this study, participants are asked to execute the required gestures with their dominant hand only after the experimenter has demonstrated the gestures in a mirrored manner and has returned their hand to the original position (flat on the table). Participants are informed on the nature of the gestures following each block. The TULIA test is video-recorded and later quantified by an independent experimenter.

2.4. VR procedures

The development of the virtual environment for gesture assessment in VR was inspired from clinical applications of the TULIA task and created using the real-time 3D engine Unity 2020 LTS.[1] Animations for the TULIA movements were recorded using the Glycon 3D[2] motion capture software and edited with Autodesk MotionBuilder 2019.[3] The virtual environment consists of an office room equipped with a table in its center (Figure 1A). Windows and a door are also present on the left and right side of the room, respectively. Across from participants, on the other side of the table, a virtual agent is seated on a chair with her hands flat on the table (Figure 1B). Outside the virtual environment, in the physical laboratory, participants are placed in a similar scenario with their hands flat on a table in front of them. Motion trackers are placed on the hands and elbows of each arm, and the HMD is adjusted for each participant (Figure 1C). The HMD provides a stereoscopic display of the virtual environment and of the autonomous agent seen from an embodied first-person perspective, while the motion trackers provide participants with virtual arms that they can control using their own movements. Participants' virtual body will be gender matched. Once immersed in the virtual environment participants will be instructed via pre-recorded verbal instructions to look around and describe what they see. In addition, they will be instructed to move their hands up and down to induce the illusion of body ownership over the virtual body, following earlier examples (33–35). After this introductory phase, participants will be trained on the task. They will be informed to closely look at the movements of the agent seated across from them performing the gestures in a mirrored manner. Their task will be to imitate those same gestures as accurately as possible using their dominant hand (right hand). To ensure that participants perform the gestures only after the agent places her hands back on the table, a red light is added as a visual cue, and participants will be informed to only perform the gestures once this light turns off. Similar to

FIGURE 1
The virtual reality setup. **(A)** A third-person perspective of the virtual setup depicting the position of the participant on one side of the table and the virtual agent on the other. **(B)** The virtual environment as seen from the participant's first-person perspective. The participant has a view of their own hands and gender-matched body and they can see the virtual agent sitting across from them with the hands resting on the table. **(C)** The participant in the physical laboratory equipped with the HMD and upper body tracking devices.

the TULIA task, participants will be informed on the nature of the gestures before each block. Each block contains 6 different gestures and will be repeated twice during the experiment. All gesture blocks (meaningless, intransitive, and transitive) will be randomized across participants. A post-experiment questionnaire will be used to record participants' subjective feeling of presence and embodiment with respect to their virtual body, as well as, other questions related to how participants evaluate the virtual female agent and their interaction, and overall experience using a −3 ("not at all") to a 3 ("very much") scale (Table 1). In addition, possible side effects (i.e., dizziness), as well as, personal thoughts and feelings regarding participants' exposure to VR will also be accounted for directly after the experiment and at the follow-up session, 2-weeks after exposure. The VR procedures are demonstrated in Supplementary Movie S1.

2.5. VR apparatus

The HTC VIVE Pro[4] virtual reality headset will be used to display the virtual environment. It has a combined resolution of

1 https://unity.com/
2 https://www.glycon3d.com/
3 https://www.autodesk.com/products/motionbuilder
4 https://www.vive.com/us/product/vive-pro2-full-kit/overview/

TABLE 1 The post-VR questionnaire.

Variable	Question
Body	"How much did you feel that the *virtual body* you saw when looking down at yourself was your own body?" *(−3...3)*
Mirror	"How much did you feel that the *virtual body* you saw when looking at yourself in the *mirror* was your own body?" *(−3...3)*
Agency	"How much did you feel that the movements of the virtual body were caused by your own movements?" *(−3...3)*
Real person	"How much did you feel like the person sitting in front of you was a real person?" *(−3...3)*
Friendly person	"Was the virtual person sitting in front of you friendly toward you?" *(−3...3)*
Trustworthy	"Did you find the virtual person sitting in front of you trustworthy?" *(−3...3)*
Distress	"Did the virtual person sitting in front of you make you feel distressed?" *(−3...3)*
Valence	Please circle the manikin that you think better expresses how you felt while being in the virtual room. Choose one manikin in each of the two figures.
	Valence manikin
Arousal	Please circle the manikin that you think better expresses how you felt while being in the virtual room. Choose one manikin in each of the two figures. *Arousal manikin*

2,880 × 1,600 pixels (1,440 × 1,600 pixels per eye), a refresh rate of 90 Hz, and a field of view of 110°. The motion tracking equipment which will allow participants to control their virtual body arms in real time is performed using the VIVE trackers (four in total—2 placed on the hands and 2 on the elbows as seen in Figure 1C). The application will run on a computer with a Core i9-11900H @ 3.50 processor and an Nvidia GeForce RTX 3080 graphics card.

2.6. Secondary outcomes

We will include additional non-verbal communication tasks outside of VR to assess participants' ability to recognize and perceive non-verbal social cues such facial expressions, biological movements, and voice tone. Motor, cognitive and community functioning domains will be assessed using well-established standardized rating scales and symptom severity and antipsychotic medication usage in all patients will also be accounted for. All clinical, motor, socio-cognitive and community functioning assessments can be found in Table 2.

3. Statistical analysis

Measurements collected from the tracking devices during gesture performance will be analyzed using linear mixed models. These will include upper body rotational data per gesture across all experimental blocks. Data are saved at a frequency of 60 Hz (16 ms). The rotational data between participants and the virtual agent performing the gestures will be compared across time based on distance metrics such as Dynamic Time Warping (DTW) that measures similarity between time series by considering the temporal relationship between rotational vectors. Group (patients and healthy controls) and gesture category (meaningless, intransitive, and transitive), as well as, their interaction will be added as fixed effects, while a single intercept parameter estimated for each participant will be added as random effects. Covariates in the model will also be considered if demographic characteristics such as age, gender or education are different between patients and controls. In addition, differences in symptom severity and motor deficits between inpatient and outpatient participants will also be considered. The Kruskal–Wallis test will be used to assess such differences. In addition, we will apply partial correlation analyses using the spearman method to examine the relationship between gesture performance accuracy in VR with symptom severity, motor, socio-cognitive and community functioning scores, while controlling for medication. This will help in determining if gesture performance accuracy using VR in patients is linked to a specific domain or is generalized across multiple domains.

4. Trial status

Recruitment for the study begun November 1st 2022, and is expected to be completed November 2024. As of May 2023, we recruited 23 patients and 8 controls, and completed assessments for 19 patients and 7 controls.

5. Discussion

The crucial feature of this study is the implementation of a VR setup to assess real-time movements to objectively quantify gesture performance accuracy in schizophrenia patients and healthy controls. To date, assessment of gesture performance in schizophrenia patients is mostly based on categorical data, and doesn't take into account all the attributes and features associated with gesture performance. VR captures multidimensional data that may reveal hidden insights on the mechanisms attributed to gesture deficits in schizophrenia patients. If our VR setup proves to be successful in capturing and measuring gesture deficits in schizophrenia patients this has the potential to generate new knowledge regarding non-verbal communication that can help in designing therapeutic interventions to improve treatments for schizophrenia patients (36). Such treatments are valuable as there are often substantial costs to patients, their family and friends, caregivers and to the society as a whole (64). In the following section, we briefly discuss the types of therapeutic interventions

TABLE 2 Clinical, motor, socio-cognitive and community functioning assessments of participants.

Secondary outcomes	References
Psychopathology	
Brief negative symptom scale	(40)
Positive and negative syndrome scale	(41)
Thought and language disorder scale	(42)
Motor scales	
Abnormal involuntary movement scale	(43)
Bush Francis Catatonia rating scale	(44)
Neurological evaluation scale	(45)
Salpêtrière retardation rating scale	(46)
Unified Parkinson's disease rating scale	(47)
Socio-cognitive assessments	
Biological motion	(48, 49)
Dot counting task	(50, 51)
EMOREC-B	(52)
Hinting task	(53)
MATRICS consensus cognitive battery	(54)
Postural knowledge test	(55)
Profile of nonverbal sensitivity	(56)
Community functioning	
Global assessment of functioning	(57)
Social level of functioning	(58)
Social and occupational functioning assessment score	(59)
University of California, San Diego performance-based skills assessment brief	(60)
Self-reports	
Brief assessment of gestures	(61)
Post-VR questionnaire on presence and embodiment	(62)
Self-report of negative symptoms	(63)

available to schizophrenia patients, and discuss future directions on how VR can support and expand their impact.

Thus far, most treatments for schizophrenia heavily relied on pharmacological interventions, with heterogeneous results (23). Recent evidence suggests that neurostimulation (65–67), cognitive remediation therapy (52, 68–70) and social skills training (70, 71) promote neuroplasticity and can alleviate non-verbal communication deficits in schizophrenia patients, such as the evaluation and interpretation of emotional expressions, eye contact and body language but none are exclusive in tackling gesture deficits. In fact, therapeutic interventions specifically targeting gesture deficits and, in particular, gesture performance deficits in schizophrenia are limited. One recent study used a specific multimodal speech-gesture training that integrates non-verbal communication, working memory abilities and natural communication (72) to improve gesture processing in schizophrenia and showed significant improvements in patients' quality of life, which was significantly correlated with changes in the neural processing of abstract speech-gesture content (73). Another study, which combines neurostimulation and social cognitive remediation therapy to examine their effectiveness in improving gesture performance in schizophrenia is currently underway (68).

While conventional therapeutic interventions are essential in recovery, they are organized in accordance to one's environment, reaching only a portion of the patients who can benefit, and are strongly dependent on the availability and expertise of therapists. The application of VR in clinical settings can provide flexible, ecologically valid, reproducible and highly-controlled environments of real-life situations offering cost-effective exposure therapy in terms of time and expenses while reaching a much larger population. This coupled with the convenience and privacy it provides, clinicians have utilized VR in pain management, cognitive and motor rehabilitation in stroke and Parkinson's patients, and therapy and training exposure for patients suffering from anxiety, depression and psychosis (74–76).

VR use in schizophrenia has been successfully applied to alleviate auditory hallucinations and paranoid ideation (77, 78) to improve interpersonal communication by having patients interact with various characters with different behaviors, and help them acquire new social and interview training skills (79, 80). Patients in such treatments have previously expressed enjoyment and increased motivation when using VR (79, 81). However, no previous studies have explored the potential of VR in movement rehabilitation in schizophrenia patients in order to improve gesture performance. Evidence from neurological patients suggests that VR as a multifaceted system promotes motor learning, a process where the acquisition of newly learned movement skills via experience and practice induces a permanent change in one's ability to execute these newly learned movements (82). If our VR setup proves effective in measuring movement discrepancies during gesture performance in schizophrenia patients, it can be applied to generate new therapeutic interventions, specifically targeting gesture deficits using motor learning, and assess potential changes over time resulting from these interventions. Moreover, VR's adaptable and diverse technological features enable its integration with existing therapies like cognitive remediation therapy and social skills training. This integration can provide more accurate and objective measurements of naturalistic behaviors arising from ongoing interactions that cannot otherwise be quantified using traditional methods. This constitutes VR the ideal candidate in providing patients with an enjoyable and add-on alternative to help in retaining and transferring motor learning in their daily life (83, 84). These newly acquired movement skills can improve how schizophrenia patients express themselves to their family, friends', doctor, or therapist, and how they handle day-to-day tasks, thus enhancing their overall social communication and functioning, whilst promoting independence.

6. Limitations

The study does have certain limitations. First, this is a cross-sectional study measuring gesture performance accuracy in VR at a single time-point. Conducting longitudinal studies could offer a more comprehensive understanding of how gesture performance can progress over time in schizophrenia patients. Second, it is crucial to take into account the potential effects of antipsychotic medication on gesture performance. While we intend to account for antipsychotic medication use as a covariate in our analyses, it is important to acknowledge that patients might be on other types of medication that may still influence our findings. Third, although the optical body tracking was designed to avoid occlusion and reduce tracking discrepancies, tracking losses might still occur leading to potential inconsistencies in the data. Fourth, our application currently supports only gender-matched virtual bodies to substitute the participants' real body. However, in future updates, we aim to use personalized avatars that can consider ethnic characteristics as well. This enhancement could allow for accommodating potential variations in body ownership. This may be particularly important to address in patients with schizophrenia, whereas for healthy individuals it has been demonstrated that body ownership illusions can be induced over distinct virtual bodies, including different race (85–87).

7. Conclusion

The study aims to provide an objective measurement in assessing gesture performance accuracy in schizophrenia patients and healthy controls using VR. If this study proves to be successful it opens the possibility of utilizing VR paradigms to carry-out therapeutic interventions using motor learning elements to improve gesture deficits in schizophrenia patients and measure possible changes over time in response to these interventions. These types of interventions can be beneficial to other mental health disorders patients who exhibit gesture deficits such as depression (88, 89) or suffer from social cognitive deficits that interfere with non-verbal communication skills such as bipolar and autism spectrum disorders (90, 91).

Ethics statement

The studies involving human participants were reviewed and approved by Kantonale Ethikkommision Bern (KEK 2021-02047). The patients/participants provided their written informed consent to participate in this study.

Author contributions

AP: conceptualization, organization, obtained ethics approval, supervision, and drafted the manuscript. GG: designed and set up the VR environment and apparatus. DB: designed and set up the VR environment and apparatus and funding. SW: funding and supervision. All authors reviewed and edited the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

SW received honoraria from Neurolite, Janssen, Mepha, Lundbeck, Sunovion and Otsuka.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyt.2023.1191601/full#supplementary-material

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