



Evaluation of virtual reality-based guided imagery stabilization intervention for post-traumatic stress symptoms: a randomized controlled trial

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Abstract

Post-traumatic stress symptoms (PTSS) have been widely reported among individuals affected by the COVID-19 pandemic. Stabilization interventions aim to reduce distress and enhance emotional regulation as a preparatory step for trauma-focused therapy. This study evaluated a virtual reality (VR)-based stabilization program adapted from three validated guided imagery techniques: light stream, mindful breathing, and containment. In a randomized controlled trial comparing the VR intervention with an imagery- and audio-based mobile App delivering the same therapeutic scripts, participants in the VR group showed significantly greater reductions in PTSS on both self-reported and clinician-rated measures. Moreover, only the VR group demonstrated significant improvements in post-traumatic growth, quality of life, and autonomic regulation indexed by heart rate variability (HRV). These findings suggest that immersive VR can enhance the delivery of stabilization techniques and provide additional psychological and physiological benefits beyond conventional app-based methods.

Keywords Virtual reality · Trauma · Stabilization · Guided imagery · Post-traumatic stress · Psychotherapy

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1 Introduction

Since the beginning of the twentyfirst century, several pandemics have posed significant threats to global public health. Among them, COVID-19 has been widely recognized as a traumatic event, causing psychological distress in individuals who have experienced or witnessed pandemic-related challenges (Hong et al. 2021). Post-traumatic stress symptoms (PTSS) have emerged as a critical mental health concern (Zhou et al. 2021). High prevalence rates of depression, anxiety disorders, and post-traumatic stress disorder (PTSD) have been reported among COVID-19 survivors (Mohammad et al. 2024). For instance, (Mazza et al. 2020) found that approximately 28% of COVID-19 survivors met the clinical threshold for PTSD symptoms one month after hospital discharge. Similarly, (Tarsitani et al. 2021) found that 10.4% of COVID-19 survivors met criteria for PTSD at a three-month follow-up, while an additional 8.6% met criteria for subthreshold PTSD, both associated with significant distress and impairment. These findings underscore the psychological burden faced by COVID-19 survivors and

the need for effective interventions targeting trauma-related symptoms.

Stabilization is a foundational phase in trauma-focused therapy (van der Hart 2012), designed to foster emotion regulation, internal safety, and resource development before trauma memory processing (Özü 2010; Steinert et al. 2017). Among the various approaches used to support stabilization, guided imagery (GI) is a widely applied method aimed at enhancing internal regulation through structured mental visualization (Reddemann 2017). Therapists guide patients to imagine themselves in specific environments or situations, encouraging vivid sensory engagement and enhancing imagination through these techniques (De Paolis et al. 2019). However, GI requires intact imagery capacity and attentional control, which can be compromised in trauma survivors due to dissociation, hyperarousal, or cognitive overload (Holmes and Mathews 2010). Several stabilization techniques which are typically delivered through GI have shown preliminary effectiveness in supporting emotional regulation, including light stream, mindful breathing, and containment. Specifically, the healing light or light stream is a guided visualization technique, where individuals imagine a soothing light passing through the body. This method has been shown to reduce emotional intensity and enhance affect regulation (Shapiro and Brown 2019). Mindful breathing helps participants return to the present moment and reduce emotional arousal by guiding slow, rhythmic breathing. This process enhances bodily awareness and sensory engagement, thereby promoting calm and supporting emotional regulation (Polusny et al. 2015). Containment teaches individuals to mentally “contain” overwhelming emotions or traumatic memories within an imagined safe container, helping to prevent emotional flooding (De Paolis et al. 2019). Other imagination-based techniques include well-established methods such as the safe place exercises (Eichfeld et al. 2019). Digital self-practice, where patients use guided audio exercises on smartphones, has been proposed as a feasible alternative to therapist-led sessions (Zehetmair et al. 2020). However, many individuals face challenges in visualizing or immersing themselves in the suggested imagery, which diminishes the therapeutic impact of the interventions (Zehetmair et al. 2020). Additionally, the limited stimuli that patients can conjure through imagination and the lack of sensory stimulation may hinder the vividness and effectiveness of their experiences (Holmes et al. 2016).

Virtual reality (VR) offers a promising solution to these limitations by providing a safe, controlled virtual environment through head-mounted displays (HMDs) (Lee et al. 2023). Unlike traditional guided imagery, VR eliminates the reliance on visualization and imagination skills, delivering an immersive experience enhanced by interactive function and multisensory feedback (Brelet and Gaffary 2022).

Current VR-based interventions feature calming and pleasant virtual environments, such as natural landscapes, to promote stress regulation and emotional recovery (Lee et al. 2023). However, passive observation of calming environments may not adequately distract patients from negative thoughts and emotions (Gorini and Riva 2008). In everyday life, sensory experiences are crucial in creating enjoyable and meaningful moments. By coordinating sensory inputs, the VR environment can enhance users’ sense of presence, which has been identified as a key mediator of therapeutic engagement and emotional learning (Freeman et al. 2017; Georgieva 2017). Recent theoretical models suggest that higher presence in VR may mediate improved outcomes by fostering attentional absorption and facilitating emotional engagement, which can contribute to positive affect and mental health recovery (Frewen et al. 2020).

VR-based interventions have shown in the treatment of trauma-related conditions due to their capacity to elicit strong immersive experiences, enhance patient agency, and allow for personalized exposure scenarios (Riva et al. 2021; Rothbaum et al. 2010). VR’s capability to immerse users deeply in therapeutic content provides an opportunity to alleviate stress and anxiety (Brelet and Gaffary 2022). Furthermore, the sense of control that users experience in immersive VR environments may reduce negative affective states such as anxiety and helplessness, while enhancing perceived self-efficacy and posttraumatic growth (Quero et al. 2019; Malighetti et al. 2023). The broader utility of VR in rehabilitation contexts has also been demonstrated in motor and coordination interventions (Norouzi et al. 2021), underscoring its versatility across domains.

An earlier study targeting high-risk populations, including healthcare workers and COVID-19 survivors, provided preliminary evidence of reduced subjective distress through stabilization intervention (Dai et al. 2024). However, the evaluation measures in that study lacked clinical guidance. To address this limitation, the present study focuses exclusively on COVID-19 survivors and incorporates both self-reported and clinician-rated scales to comprehensively assess PTSS. In addition to symptom-focused measures, we included the Posttraumatic Growth Inventory (PTGI) and the WHO Quality of Life scale (WHOQOL) as secondary outcomes to evaluate broader aspects of psychological recovery. PTGI measures positive psychological change following adversity, while WHOQOL captures subjective well-being across physical, psychological, and social domains. Prior research has shown that the posttraumatic growth is associated with reduced PTSD symptoms and emotional distress (Ochoa et al. 2017). Furthermore, studies in populations recovering from other traumatic experiences, such as cancer survivors, have indicated that improved quality of life may follow psychological interventions and that

enhanced PTG can mitigate the negative impact of PTSD on quality of life (QoL) (Morrill et al. 2008). Given the elevated rates of psychological distress reported in populations recovering from COVID-19 hospitalization, (Bonazza et al. 2022) provided evidence that targeted psychological interventions in this population can facilitate PTG and improve QoL.

The present study systematically evaluated a VR-based stabilization protocol grounded in established GI principles, combining structured audio scripts with corresponding visualization and interactive elements implemented in VR to facilitate users' engagement with the imagined scenes and resources. A total of 50 participants were randomly assigned to either a VR group ($n=21$) or a mobile app control group ($n=22$), receiving weekly sessions over five weeks. To address limitations of previous work, both self-reported and clinician-rated scales were employed to assess PTSS, alongside physiological measures to capture autonomic responses. Secondary outcomes included the PTGI and WHOQOL, allowing a broader evaluation of psychological and functional recovery.

2 Methods

2.1 Participants

A power analysis conducted using G*Power 3.1 (Faul et al. 2009) determined that a minimum of 25 participants per group was required to achieve 73% power for detecting medium-sized effects ($f=0.25$, $\alpha=0.05$) using ANCOVA. For LMM, we additionally conducted a simulation-based power analysis using the *lme4* package in RStudio (Bates et al. 2015). The results also indicated approximately 73% power for detecting medium effects with the planned sample

size. Although the initial plan included 50 participants, the final sample comprised 43 due to post-hoc exclusion of individuals not meeting minimum PTSS symptom criteria. Despite this, the statistical power remained within an acceptable range for exploratory trials. Additionally, the use of repeated-measures modeling (LMM) accounts for within-subject variability and generally enhances statistical power compared to between-subject designs with equal sample sizes (Gueorguieva and Krystal 2004). Prior meta-analyses of VR-based trauma interventions () and comparable studies (e.g., Vlake et al. 2021) further support the feasibility of detecting medium-to-large effects with similar or smaller sample sizes.

Participants were recruited by recommending participation in the study to individuals who complained of stress symptoms during a visit to a medical institution to which one of the authors belongs. Participants aged 18 to 64 were recruited based on their experience of COVID-19 infection, with the majority having been hospitalized and a small number having recovered without hospitalization. Eligibility was determined using the four-factor DSM-5 model of PTSD symptom clusters (McLaughlin et al. 2015); individuals meeting subthreshold PTSD criteria—defined as endorsing ≥ 2 items rated ≥ 2 in each of the four symptom clusters—were included. No total PCL-5 cut-off score was applied to accommodate individuals with heterogeneous but clinically meaningful symptom profiles. Individuals who were currently pregnant or had mental or physical disabilities that would interfere with participation were excluded.

Participants were randomly assigned to either the intervention or control group using a computer-generated simple randomization sequence with a 1:1 allocation ratio. The randomization sequence was generated in advance by an independent researcher who was not involved in the intervention or outcome assessments. Fifty participants were initially recruited and completed all sessions. In accordance with the inclusion criteria, seven participants (4 in VR group and 3 in App group) who did not meet the criteria were excluded from the analysis. The final analysis was conducted on the 43 participants (VR: $n=21$; App: $n=22$), with the PCL-5 total scores (baseline PTSS severity) ranging from 10 to 71 ($M=29.40$, $SD=12.78$).

There were no significant differences between the VR and App groups in terms of age, education level, or living situation as shown in Table 1. However, there was a significant gender difference between the two groups. Therefore, we conducted a preliminary analysis of gender differences. The results showed no statistically significant differences in symptom levels across all measures by gender ($p>0.05$). To account for any potential confounding, gender was included as a covariate in subsequent ANCOVA models.

Table 1 Demographic characteristics of the participants

Variables	VR ($n=21$)	App ($n=22$)	<i>p</i>
Female, <i>n</i> (%)	16 (76.2)	22 (100.0)	0.006
Age (mean, SD)	36.19 (10.15)	39.14 (9.55)	0.332
Education, <i>n</i> (%)			
Under high school graduate	6 (28.6)	6 (27.3)	0.587
Associate degree	2 (9.5)	5 (22.7)	
Bachelor's degree	9 (42.9)	9 (40.9)	
Master's degree	4 (19.0)	2 (9.1)	
Marital status, <i>n</i> (%)			
Single	10 (47.6)	6 (27.3)	0.140
Married	9 (42.9)	15 (68.2)	
Estranged/divorced	2 (9.5)	0 (0.0)	
Bereaved	0 (0.0)	1 (4.5)	
Dwelling, <i>n</i> (%)			
Living alone	7 (33.3)	3 (13.6)	0.157
Living with family	13 (61.9)	19 (86.4)	
Living with non-relatives	1 (4.8)	0 (0.0)	

Furthermore, there were no significant differences in the primary and secondary psychological scale scores between VR and App groups, including PCL-5 ($p=0.207$), CAPS-5 ($p=0.968$), PTGI ($p=0.724$), and WHOQOL ($p=0.969$). There were no significant differences in HRV data either, including SDNN ($p=0.197$), RMSSD ($p=0.912$), TP ($p=0.135$), VLF ($p=0.167$), LF ($p=0.237$), and HF ($p=0.327$). Whole HRV data is provided in Appendix, Table 7.

2.2 Interventions

Three stabilization techniques—light stream, mindful breathing, and containment—were selected to in both the VR and App interventions. All techniques followed the same therapeutic scripts and lasted approximately 8–10 min. In this study, we utilized the VR-based stabilization program, validated in the previous work (Dai et al. 2024).

2.2.1 VR intervention

For the VR condition, the same scripts were translated into immersive, multisensory experiences using Unity and an HTC Vive Eye headset, enabling visualization, externalization, and enhanced embodiment.

The light stream technique aimed to promote a sense of comfort and safety through visual and thermal stimuli. Participants observed a virtual light flowing through an avatar of their own body, synchronized with thermal feedback delivered via a wearable heating device on their arms,

within a tranquil forest setting illuminated by soft, ambient light (Fig. 1a).

The mindful breathing technique guides participants to engage in slow, rhythmic breathing. A naturalistic seaside environment was presented, featuring ocean sounds and a floating circular visual that expanded and contracted in synchrony with breath pacing instructions delivered via voiceover (Fig. 1b).

Guided mindful breathing was used to support stabilization by helping participants return to the present moment and reduce emotional arousal. The technique involved voice guidance, ambient natural sounds, and visual breath pacing (Fig. 2b). Participants were instructed to observe the breath gently, promoting attentional anchoring and physiological calm without requiring effortful control or retraining.

The containment technique supported symbolic emotional control by externalizing intrusive content. Participants were instructed to visualize distressing memories or feelings as a framed image, which was then placed into a large virtual container. The container was visually sealed and audibly locked, providing a clear representation of psychological containment (Fig. 1c).

2.2.2 App intervention

For the App condition, the three techniques were delivered through the MAEUM Program developed by the National Center for Mental Health in Korea (Oh et al., 2025). The program provided voice-guided exercises accompanied by natural environment images and text instructions. Unlike the VR version, the app lacked interactivity or real-time



Fig. 1 Representative imagery for each VR stabilization technique. **a.** Light stream. Top: a tranquil forest environment with ambient lighting; Bottom: a virtual arm avatar with real-time thermal feedback aligned with a radiant light stream. **b.** Mindful breathing. Top: a calm beach setting offering visual and auditory cues; Bottom: a breathing circle

expands and contracts to guide paced respiration. **c.** Containment. Top: a picture frame symbolizing distressing memories and an open container; Bottom: the frame is sealed inside the container, which is then closed and locked, representing emotional containment.

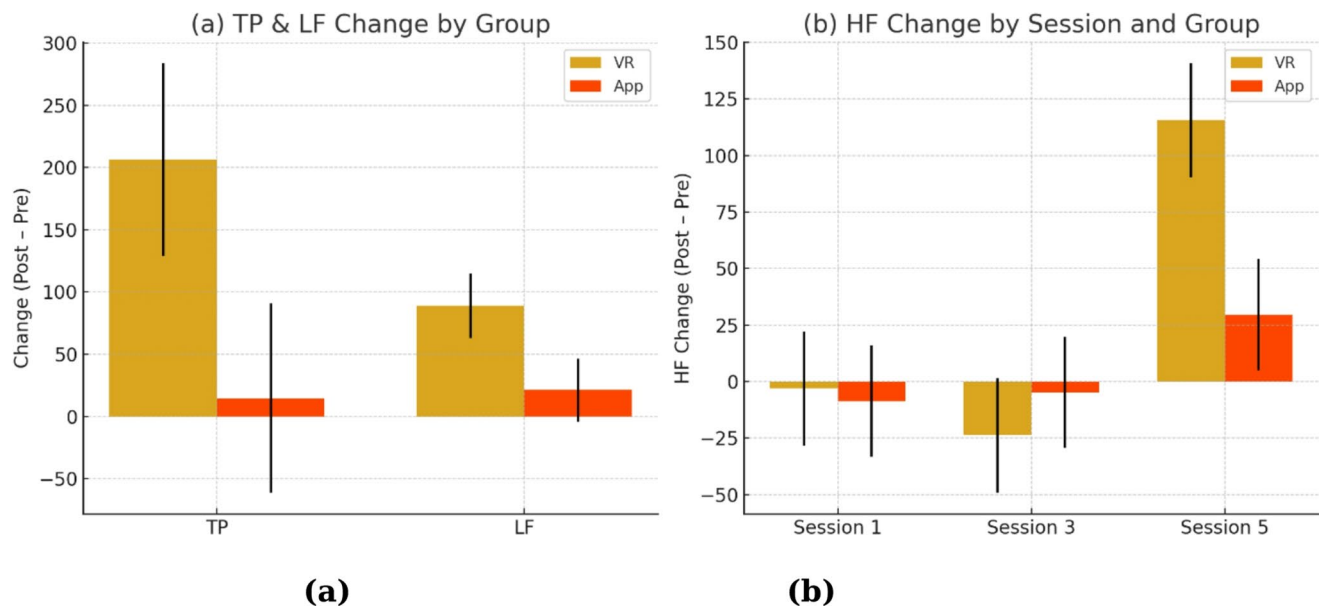


Fig. 2 Group-wise comparisons of HRV change scores (post-pre) for each HRV component. **a** TP and LF changes by treatment group. **b** HF changes across sessions (Session 1, 3, and 5) by group

feedback, with participants listening to the exercises through headphones and following the script guide.

2.3 Measurements

The clinician-rated evaluations were conducted by certified mental health and welfare workers who were trained to perform standardized clinical assessments following a predetermined manual. The assessors were blinded to participants' group assignment throughout the study.

2.3.1 Psychological scales

Primary outcomes including both self-reported and clinician-rated psychological assessments focused on evaluating PTSS levels, while secondary outcomes assessed post-traumatic growth and quality of life as indicators of positive change.

PTSD checklist for DSM-5 (PCL-5) The PCL-5 is a self-reported, 20-item measure designed to evaluate PTSD symptoms based on DSM-5 diagnostic criteria (Blevins et al. 2015). Responses are rated on a five-point Likert scale (0=not at all, 4=extremely), with higher scores indicating more severe symptoms. A total score exceeding 23 is considered indicative of possible PTSD, as recommended by prior validation studies (Mohammad et al. 2024).

Clinician-administered PTSD scale for DSM-5 (CAPS-5) The CAPS-5 is a clinician-administered tool used to determine DSM-5 PTSD diagnostic status and symptom severity

(Weathers et al. 2018). The analysis included 20 items rated on a five-point Likert scale (0=absent, 4=extreme).

Both scales are structured, non-specific trauma assessments that do not focus exclusively on COVID-19 hospitalization but instead assess general trauma experiences. However, participants were guided to anchor their responses specifically to their COVID-19 hospitalization, including experiences such as fear for life, illness-related distress, and isolation during the hospital stay. This approach ensured that PTSD symptoms were contextualized in relation to the hospitalization event.

Post-traumatic growth inventory (PTGI) The PTGI measures positive psychological changes that arise in response to trauma, representing growth beyond mere resilience (Kim et al. 2018). It comprises 25 items and total scores range from 0 to 150, with higher scores indicating greater post-traumatic growth.

World health organization quality-of-life scale (WHOQOL) The WHOQOL was utilized to evaluate participants' QoL. It consists of 26 items and each item is scored on a five-point Likert scale (0=not at all, 4=completely true), with higher scores reflecting better QoL (Bonomi et al. 2000).

2.3.2 Physiological responses

Heart-rate variability (HRV) HRV measures the variation in time between successive heartbeats, which reflects

autonomic nervous system (ANS) function. Low HRV is closely linked to a reduced ability to manage internal and external stressors, often observed in individuals with PTSD (Kim et al. 2018). HRV analysis incorporates time-domain and frequency-domain data. The time-domain data includes the standard deviation of the inter-beat interval of normal heartbeats (SDNN) and root mean of successive differences between normal heartbeats (RMSSD). A low SDNN value is observed in individuals with PTSD, suggesting that the sympathetic nervous system (SNS) is activated. The RMSSD, which is closely related to the parasympathetic nervous system (PNS), is also low in patients with PTSD (Kurt Gleitsch 2013). Frequency-domain measurements establish the distribution of the absolute or relative power into four frequency bands. Heartbeat vibration can be classified into ultra-low frequency (ULF, ≤ 0.003 Hz), very-low frequency (VLF, 0.0033–0.04 Hz), low frequency (LF, 0.04–0.15 Hz), and high frequency (HF, 0.15–0.4 Hz) bands by frequency (Malik 1996). In general, the HF band is strongly associated with the activity of the PNS (Malik 1996) and the LF band reflects baroreflex, PNS, and SNS (Roach and Sheldon 2018; Shaffer and Ginsberg 2017). In the previous meta-analysis of studies using HRV as an indicator of PTSD, the most of the observed indicators as a result of the study were LF, HF, LF/HF, SDNN, and RMSSD (Nagpal et al. 2013). In addition, we included VLF, an area close to LF, the main indicator of frequency domain, and TP, which means total power, in the analysis.

In this study, HRV was assessed using the SA-3000P device (Medicore Co., Ltd, 2015). All abnormal beats not generated by sinus node depolarizations were automatically detected and excluded by the built-in algorithms, in accordance with the Task Force guidelines (Electrophysiology 1996). Cleaned NN intervals were then used to compute time-domain and frequency-domain HRV indices for each recording session. HRV measurements were performed in both the VR and App groups, at baseline and prior to each weekly intervention session. All recordings were conducted in a seated resting position over a 5-minute duration, following Task Force guidelines for short-term HRV assessment. Participants were instructed to refrain from smoking, consuming caffeine or alcohol, and to ensure at least 8 h of sleep prior to each session. During measurement, participants remained silent and still to minimize movement artifacts. Seven HRV metrics were extracted, including time-domain (SDNN, RMSSD), frequency-domain (LF, HF, LF/HF ratio, VLF and TP). Given the intercorrelation among HRV indices, we report results with effect sizes (Cohen's *d*), 95% confidence intervals, and apply the Bonferroni procedure to control false discovery rate in post hoc comparisons.

2.3.3 Usability and presence

NASA-Task Load Index (NASA-TLX) The NASA-TLX evaluates the perceived physical and psychological workload of tasks through six questions rated on a six-point scale, with higher scores indicating greater difficulty (Hart and Staveland 1988).

Simulator sickness questionnaire (SSQ) The SSQ assesses cybersickness symptoms, with higher scores reflecting greater discomfort (Kennedy et al. 1993).

Slater-Usch-Steed presence questionnaire (SUS) The SUS measures the sense of presence within the VR environment on a scale of 1 to 7, with higher scores indicating a stronger sense of presence (Slater et al. 1994).

2.4 Procedure

The researchers detailed the experimental procedures, which were approved by the Institutional Review Board (IRB), and the information to be collected during the study (IRB document No. SCHCA202208032-HE001). After ensuring participants fully understood the procedures, they signed an informed consent form to confirm their voluntary participation.

Both the VR and App groups received five weekly sessions in a standardized lab environment. All sessions were supervised by trained mental health professionals following a structured manual received verbal guidance if needed. The experimental treatment consisted of five weekly sessions over five weeks. During each session, participants performed a specific stabilization technique: the light stream technique in the first session, mindful breathing in the second session, and containment technique in the third session, using either the VR or mobile App intervention. In the fourth and fifth sessions, participants were allowed to freely choose and practice their preferred stabilization technique.

Primary and secondary outcomes were assessed before and after completing the five experimental interventions to evaluate their overall effects. HRV data were collected at three time points: before and after the first session, the mid-point session (third), and the final session (fifth). Usability and presence were assessed using three questionnaires (NASA-TLX, SUS, and SSQ), which were administered once after the experiment.

2.5 Data analysis

All statistical analyses were conducted using IBM SPSS 26. Demographic variables (e.g., gender, age, education level) were compared between groups using independent samples

t-tests and chi-square tests to confirm baseline equivalence. The data were winsorized based on the interquartile range (IQR) to reduce the influence of outliers.

For subjective measures (PCL-5, CAPS-5, PTGI, WHOQOL), within-group changes from pre- to post-intervention were analyzed using paired t-tests. To evaluate between-group differences while controlling for baseline symptom severity and potential confounding due to unequal gender distribution, ANCOVA was conducted with pre-intervention scores and gender included as covariates, and post-intervention scores as dependent variables. Effect sizes were reported as Cohen's *d* (small=0.2, medium=0.5, large≥0.8) in paired t-test and partial eta squared (η^2 ; small=0.01, medium=0.06, large=0.14) in ANCOVA and linear mixed model.

For physiological outcome measures, as HRV was measured repeatedly across multiple time points, a linear mixed model (LMM) was employed to evaluate intervention effects over time. The LMM included treatment group (VR vs. App), measurement time point (pre vs. post), measurement session (1st, 3rd, 5th), and their interactions as fixed effects. Participant-level variability was modeled as a random intercept. Biological gender was included as a covariate to account for imbalances across groups, and age was included as a covariate given its established association with HRV. A first-order autoregressive (AR(1)) covariance structure was specified to account for temporal correlations among repeated measurements. Bonferroni correction was applied to control for multiple comparisons across HRV indices.

All data were checked for normality using the Shapiro-Wilk test. Most outcome measures showed no significant deviation from normality ($p>0.05$), with only a few variables demonstrating mild departures. In addition, model residuals were examined for ANCOVA to assess normality and homoscedasticity. Shapiro-Wilk tests of residuals indicated acceptable adherence to model assumptions, although some residuals showed minor deviations from normality, overall model assumptions were sufficiently met to support parametric analyses. For LMM, formal residual testing

was not conducted, as these models are generally robust to moderate assumption violations under restricted maximum likelihood estimation (Schielzeth et al. 2020). Given the moderate sample size and prior evidence that ANCOVA and t-tests are robust to minor violations of normality, we retained the use of parametric analyses. All tests were two-tailed with a significance level set at $p<0.05$, and data with $p<0.10$ also reported as trend-level effects in line with the exploratory nature of this study. No missing data were observed for key outcome measures in the final sample. All participants completed both pre- and post-assessments.

3 Results

3.1 Psychological scales

As reported in Sect. 2.1, baseline PCL-5 scores ranged from 10 to 71, with most participants falling in the subclinical to moderate symptom range.

Paired samples *t*-tests revealed significant reductions in PTSD symptoms following the intervention (Table 2). In the VR group, both PCL-5 and CAPS-5 scores significantly decreased from pre- to post-intervention (PCL-5: $p<0.001$, $d=1.03$; CAPS-5: $p<0.001$, $d=1.02$), indicating large effect sizes. In the App group, both PTSD measures also showed significant reductions (PCL-5: $p=0.008$, $d=0.62$; CAPS-5: $p<0.001$, $d=1.09$), although the effect size for PCL-5 was moderate.

Regarding secondary outcomes, the VR group demonstrated significant improvement in posttraumatic growth (PTGI: $p=0.001$, $d=0.85$) and quality of life (WHOQOL: $p=0.001$, $d=0.86$), both with medium to large effects. In contrast, the App group did not show significant changes in either PTGI ($p=0.459$, $d=0.16$) or WHOQOL ($p=0.673$, $d=0.09$), suggesting that the VR intervention may offer additional psychological benefits beyond symptom reduction.

To evaluate between-group differences while controlling for baseline levels and gender, ANCOVA was conducted

Table 2 Pre-post paired *t*-test of psychological outcomes within the VR and within the app groups

Outcome	Group	Pre (M±SD)	Post (M±SD)	t (df)	d (95% CI)	p value
PCL-5	VR	26.86±9.51	13.62±9.51	4.74 (20)	1.03 [0.49, 1.56]	<0.001
	App	31.82±11.11	21.91±12.21	2.93 (21)	0.62 [0.16, 1.08]	0.008
CAPS-5	VR	14.43±9.87	5.43±4.21	13.01 (20)	1.02 [0.48, 1.62]	<0.001
	App	14.55±9.03	8.95±6.67	5.13 (21)	1.09 [0.55, 1.58]	<0.001
PTGI	VR	78.71±19.41	94.52±22.19	−7.30 (20)	0.85 [0.34, 1.39]	0.001
	App	81.09±24.04	84.27±20.77	−0.75 (21)	0.16 [−0.58, 0.26]	0.459
WHOQOL	VR	75.67±18.74	87.05±16.56	−5.38 (20)	0.86 [0.35, 1.36]	0.001
	App	75.91±22.11	75.32±21.79	−0.43(21)	0.09 [−0.33, 0.51]	0.673

PCL-5=PTSD Checklist-5, CAPS-5=Clinician-Administered Post-traumatic Stress Disorder Scale for DSM-5, PTGI=Post-Traumatic Growth Inventory, WHOQOL=WHO Quality of Life questionnaire

Table 3 Between-group comparison of VR baseline as covariate) and app groups using ANCOVA (baseline as covariate)

Outcome	F (Group effect)	<i>p</i> value	Partial η^2
PCL-5	5.202	0.028	0.118
CAPS-5	7.175	0.011	0.155
PTGI	4.174	0.048	0.097
WHOQOL	13.128	0.011	0.252

PCL-5=PTSD Checklist-5, CAPS-5=Clinician-Administered Post-traumatic Stress Disorder Scale for DSM-5, PTGI=Post-Traumatic Growth Inventory, WHOQOL=WHO Quality of Life Scale

Table 4 Fixed effects shown in LLM analysis of the changed HRV data (post-pre) of 1st, 3rd, and 5th session

Indicator	Fixed effect	F (df1, df2)	<i>p</i>	η^2
TP change	Treatment	F (1,40.27)=3.12	0.085	0.072
LF change	Treatment	F (1,45.13)=3.50	0.068	0.072
HF change	Treatment * Session	F (2,63.97)=2.94	0.060	0.084

TP=Total power, LF=low-frequency domain power, HF=high-frequency domain power, η^2 = partial eta squared

with pre-intervention scores and gender as covariates, and post-intervention scores as the dependent variable (Table 3). Given that the VR group showed greater pre-post improvements than the App group, ANCOVA confirmed significant group effects across all outcome measures, as reflected by significant group effects on PCL-5 ($F(1, 41)=5.202$, $p=0.028$, $\eta^2 = 0.118$) with medium effect sizes and CAPS-5 ($F(1, 41)=7.175$, $p=0.011$, $\eta^2 = 0.155$) with large effect sizes.

Significant group differences also emerged for secondary outcomes, including PTGI ($F(1, 41)=4.174$, $p=0.048$, $\eta^2 = 0.097$) with medium effect sizes and WHOQOL ($F(1, 41)=13.128$, $p=0.001$, $\eta^2 = 0.252$) with a large effect. These results suggest that, relative to the App condition, the VR intervention was more effective in improving both PTSD-related symptoms and broader psychological well-being.

3.2 Physiological responses

There were no significant differences ($p < 0.05$) in the baseline HRV data. Among the RCT HRV data, differences were mainly observed in the frequency-domain data. Based on the LMM analysis, the VR group exhibited a medium sized trend-level effects ($p < 0.1$) in the changed value of TP, LF, HF area among the frequency-domain data (Table 4). Overall data is provided in Appendix, Table 8.

The model fit indices showed acceptable values across outcomes (TP: AIC=1920.65, BIC=1929.09; LF: AIC=1677.36, BIC=1685.80; HF: AIC=1538.11, BIC=1546.55), indicating generally adequate model fits. Notably, the HF change model yielded the lowest information criteria, suggesting a relatively better fit compared to other HRV indices. For TP, the VR group showed a greater increase than the control group, with a trend-level effect

Table 5 Group-wise HRV change scores (post-pre) for TP, LF, and session-specific HF

Variable	Session	Group	Mean (ms ²) $\pm$ SE	95% CI
TP	–	VR	206.19 $\pm$ 77.57	(49.45, 362.94)
		App	14.77 $\pm$ 75.79	(– 138.37, 167.92)
LF	–	VR	89.00 $\pm$ 25.96	(– 5.22, 140.94)
		App	21.14 $\pm$ 25.36	(– 140.94, 5.22)
HF	Session 1	VR	– 3.01 $\pm$ 25.25	(– 53.03, 47.01)
		App	– 8.74 $\pm$ 24.67	(– 57.61, 40.12)
	Session 3	VR	– 23.80 $\pm$ 25.25	(– 73.82, 26.22)
		App	– 4.81 $\pm$ 24.67	(– 53.68, 44.05)
	Session 5	VR	115.61 $\pm$ 25.25	(65.59, 165.63)
		App	29.61 $\pm$ 24.67	(– 19.26, 78.48)

TP= Total power, LF=low-frequency domain power, HF=high-frequency domain power

Table 6 Independent *t*-test of usability and presence

Outcome	Group	Mean $\pm$ SD	Cohen's <i>d</i> (95% CI)	<i>p</i> value
NASA-TLX	VR	20.05 $\pm$ 5.47	0.32 [– 0.92, 0.29]	0.303
	App	21.77 $\pm$ 5.36		
SSQ	VR	5.43 $\pm$ 4.21	0.22 [– 0.81, 0.39]	0.485
	App	8.29 $\pm$ 6.71		
SUS	VR	87.05 $\pm$ 16.56	0.87 [0.24, 1.49]	0.007
	App	80.33 $\pm$ 24.83		

NASA-TLX=NASA Task Load Index, SSQ=simulator sickness questionnaire, SUS=slater-usoh-steed questionnaire for presence

observed ($F(1, 42.67)=3.46$, $p=0.070$, $\eta^2 = 0.0751$). Similarly, LF indicated a comparable trend ($F(1, 45.13)=3.50$, $p=0.068$, $\eta^2 = 0.0719$), suggesting potential benefits of VR-based intervention on autonomic recovery. For HF, a trend-level interaction effect of Treatment $\times$ Session was found ($F(2, 68.75)=2.99$, $p=0.057$, $\eta^2 = 0.0801$).

Follow-up analysis showed that this interaction was primarily driven by a substantial HF increase in the VR group during Session 5 (115.61 $\pm$ 40.48 vs. 29.61 $\pm$ 17.39). Detailed values for each group and timepoint are shown in Table 5, and Fig. 2.

3.3 Usability and presence

Independent-samples *t*-tests were conducted to compare usability-related outcomes and perceived presence between the VR and App groups as shown in Table 6. There were no statistically significant differences in perceived task load (NASA-TLX: $p=0.303$, $d=0.32$) or simulator sickness (SSQ: $p=0.485$, $d=0.22$), suggesting that both interventions were similarly manageable and well-tolerated in terms of cognitive demand and cybersickness.

However, the VR group reported significantly higher levels of presence than the App group ($p=0.007$, $d=0.87$), indicating a large effect size. These findings suggest that while usability was comparable across conditions, the

immersive experience was significantly more pronounced in the VR condition.

4 Discussion

4.1 Main findings

The primary outcomes of the study demonstrated clear advantages of the VR intervention over the App-based control. After five sessions, participants in the VR group showed large within-group reductions in both self-reported and clinician-rated PTSS ($d=1.03$ and $d=1.02$, respectively), while improvements in the App group were modest or moderate ($d=0.62$ for PCL-5 and $d=1.09$ for CAPS-5). Crucially, ANCOVA results confirmed that the VR group achieved significantly greater reductions in PTSS relative to the App group when controlling for baseline differences (PCL-5: $F=5.202$, $p=0.037$, $\eta^2=0.118$; CAPS-5: $F=7.175$, $p=0.011$, $\eta^2=0.155$). These effects were in the medium-to-large range, supporting the conclusion that the VR program was not only effective but meaningfully more impactful than the self-help App. As the PCL-5 and CAPS-5 reflect symptom severity from different sources—participant self-report and clinician evaluation—their convergence strengthens the credibility of the findings, indicating consistent improvements across subjective and objective perspectives.

These findings are particularly noteworthy because participants in this study did not meet the diagnostic threshold for PTSD but still exhibited moderate PTSS. While immersive virtual reality exposure therapy (VRET) has demonstrated efficacy for individuals with diagnosed PTSD in previous studies (e.g., Maples-Keller et al. 2017), our results suggest that VR-based interventions may also be effective for individuals in earlier or subclinical stages of trauma response. Compared to the App-based condition, the VR group showed significantly greater symptom reduction across both self-reported and clinician-rated outcomes, indicating a potential advantage of immersive approaches. This supports the idea that immersive VR tools could serve as accessible preventive or stabilizing interventions for at-risk, nonclinical populations. This aligns with emerging stepped-care frameworks—which advocate for scalable, low-burden treatments as a first-line response to trauma exposure—and early intervention models that aim to mitigate symptom progression before full disorder onset (Roberts et al. 2019).

Beyond reducing PTSD symptoms, our findings point to potential benefits of VR intervention in psychological adaptation and life functioning. Higher levels of PTG are associated with lower distress and improved coping in trauma-exposed populations (Ochoa et al. 2017). Moreover, psychological interventions that facilitate emotional

stabilization may promote growth through mechanisms such as trauma memory integration and emotional legitimization, as theorized by (Herman 1998). Our results suggest that VR-based interventions may contribute to broader recovery trajectories, particularly among individuals who have experienced hospitalization, emotional turmoil, or vicarious trauma due to the pandemic, by not only alleviating symptoms but also fostering positive psychological change and improved well-being.

The direct impact of VR on psychological states may be more prominent than the direct alleviation of symptoms. The advantage of VR is that it provides an interactive and multisensory experience. These unique features may primarily affect participants' psychological states, attitudes toward life, and cognitive appraisals of trauma, thereby indirectly contributing to the alleviation of long-term PTSS. Thus, although the direct impact on PTSS appears modest, the significant improvements in secondary outcomes may indicate that VR interventions have long-term potential. Although the relationship between PTG and PTSD remains unclear, previous studies have shown that higher levels of PTG are associated with reduced psychological distress and post-traumatic stress symptoms (Ochoa et al. 2017). Factors contributing to PTG, such as providing a safe environment, skill development, and fostering a sense of control (Capaldi et al. 2024), are closely aligned with the core concepts of this VR stabilization intervention. This consistency highlights the potential of VR to lay the foundation for meaningful psychological growth and recovery for trauma-affected populations.

The HRV results also supported the potential effectiveness of the VR intervention, showing a trend-level main effect of treatment (VR vs. App) on TP and LF changes, and a treatment-by-session interaction on HF changes. HRV spectra were interpreted as reflecting autonomic balance: LF indexes baroreflex-mediated cardiac control, whereas HF reflects parasympathetic (vagal) tone (Rahman et al. 2011; Gruionu et al. 2024). And LF augmentation has been associated with improved cardiac coherence and homeostatic balance (Weibel et al. 2023). In healthy regulation, greater HRV (especially in LF and HF bands) indicates stronger parasympathetic (vagal) engagement and more adaptive stress coping (Shaffer and Ginsberg 2017). The HF increase observed in the VR group by session 5 likely indicates enhanced respiratory sinus arrhythmia and delayed parasympathetic activation. This suggests that participants achieved deeper relaxation or more synchronized breathing by the end of training. Even transient increases in TP and HF are consistent with reduced sympathetic arousal and improved regulatory flexibility.

These trends are consistent with previous studies showing that immersive VR-based HRV training can enhance

autonomic regulation. For example, Weibel et al. found that delivering paced-breathing and HRV-biofeedback through an immersive headset produced significantly greater boosts in LF power and cardiac coherence than identical training on a screen (Weibel et al. 2023). Similarly, Pratviel et al. reported that guided breathing in a calming VR scene led to stress and anxiety reductions on par with a real-world HRV-biofeedback device (Pratviel et al. 2024). Clinically, even these small HRV enhancements may be meaningful for post-COVID recovery. Emerging evidence indicates that long-COVID patients often exhibit autonomic imbalance – for instance, reduced HRV – which is tied to persistent symptoms and poorer outcomes (Cano et al. 2025). In this context, any intervention that nudges HRV upward could help restore the neurovisceral equilibrium. Higher HRV is associated with stronger top-down regulation (greater prefrontal control and cognitive flexibility) and more adaptive stress responses. In sum, the HRV trends hint that immersive VR breathing may promote autonomic rebalancing in this post-COVID sample, although we must interpret these findings with caution given their trend-level strength.

Lastly, the significantly higher presence scores in the VR group underscore the added value of immersive delivery in enhancing the effects of guided imagery (GI). Presence—the subjective sense of “being there”—is a key mechanism for emotional engagement and therapeutic learning (Freeman et al. 2017), and may help explain the observed reductions in PTSD symptoms and improvements in QoL and PTG. In this study, embedding GI within a rich sensory VR environment likely externalized therapeutic content, reducing the cognitive demands of self-generated imagery and increasing emotional resonance—particularly valuable for trauma survivors with imagery or attentional difficulties (Holmes and Mathews 2010). According to (Frewen et al. 2020), presence may interact with other experiential features—such as vividness and attentional absorption—to form a mediating process that amplifies emotional engagement and treatment effects. While our study did not include validated measures of these factors, the significantly higher presence scores provide preliminary support for this mechanism. VR intervention not only maintained comparable usability and comfort to the App intervention, but also offered a more engaging and embodied experience that may have contributed to improved stabilization outcomes.

4.2 Comparison with existing research

Most prior trauma-related VR studies have focused on high-intensity events such as combat, sexual assault, or interpersonal violence (Olff et al. 2019). These forms of trauma are typically discrete, acute, and event-specific. In contrast, the present study targeted individuals who experienced COVID-19-related hospitalization, which represents a qualitatively different form of trauma—characterized by prolonged stress, uncertainty, and isolation. Such experiences are more chronic and ambiguous in nature, often lacking a singular traumatic incident (Horesh and Brown 2020). According to (Birkeland et al. 2021), different trauma types may elicit distinct symptom profiles, indicating the importance of trauma-specific intervention design. By addressing trauma in a public health crisis context, this study fills a gap in VR literature and expands its relevance to broader populations.

In terms of intervention design, our study builds on but also meaningfully departs from earlier immersive VR approaches. While VR has been widely used for trauma-focused exposure therapy (Carl et al. 2019), few studies have applied VR to stabilization-based techniques—an important first-phase strategy in trauma care. Our intervention was grounded in established trauma therapy frameworks (Cloitre et al. 2011), incorporating techniques like light stream, mindful breathing, and containment. These methods are designed to enhance emotional regulation and safety before trauma processing. By embedding these techniques in a multisensory VR environment, our approach addresses the common difficulty trauma-exposed individuals face in engaging with traditional imaginal techniques, offering an embodied and more accessible alternative.

Finally, our methodological rigor enhances the contribution of this work. Unlike many earlier studies that relied on waitlist or minimal-control conditions, our design included an active control group matched on content, session duration, and researcher involvement. This allows for a more valid assessment of the added benefits of immersive VR beyond general engagement or placebo effects. Multisensory features in the VR condition (e.g., thermal feedback during light stream visualization) were implemented to enhance emotional presence and resonance—factors believed to increase treatment impact (Levine 2010). Although these

elements were not directly assessed, future research may examine how sensory fidelity and interactivity influence outcomes. In this way, our study not only introduces a novel VR-based stabilization format, but also sets the stage for more systematic investigations into the therapeutic mechanisms of immersive interventions.

4.3 Limitations and future works

This study has several limitations that warrant consideration. First, although we did not use a strict PCL-5 total score cutoff, participants met subthreshold PTSD criteria based on symptom cluster models, which allowed the inclusion of clinically relevant cases that may not meet full diagnostic thresholds. Such subthreshold symptoms have been associated with functional impairment and are important targets for early intervention (Cukor et al. 2010; McLaughlin et al. 2015). Additionally, we did not collect data on the timing of trauma exposure, which could influence responsiveness to stabilization interventions; future research should consider incorporating this variable. Second, the power estimation was based on a larger sample ($N=50$) than the final analyzed group ($N=43$), due to post-hoc exclusion of participants with low baseline symptoms, which may have slightly reduced statistical power. The relatively small sample size may have limited our power to detect small effects and restricts generalizability, though the observed medium-to-large effect sizes for PTSS outcomes indicate promise. Lastly, the sample had a higher proportion of female participants, which reflects established gender differences in trauma exposure and PTSD prevalence but limits generalizability; future studies should aim for more balanced representation to enhance the applicability to the broader population.

Physiological outcomes also raise important considerations. Although significant changes were observed in LF HRV, RMSSD and HF changes were less pronounced. The interpretation of LF remains debated, as it may reflect both sympathetic modulation and baroreflex sensitivity. Moreover, multiple intercorrelated HRV indices were analyzed, increasing the potential risk of inflated Type I error. While we applied Bonferroni corrections, future studies should pre-register primary HRV outcomes and adopt statistical

approaches tailored for psychophysiological data. These steps may improve both interpretability and methodological rigor.

Finally, future work could examine the potential mediating roles of presence and attentional absorption in therapeutic outcomes. Exploring how intervention content or delivery can be personalized may further enhance engagement and efficacy. Integrating immersive VR approaches with existing therapeutic frameworks and investigating relevant physiological markers, such as HRV, could help clarify the mechanisms underlying stabilization effects and guide the design of more effective trauma interventions. Despite its limitations, this study adds to growing evidence supporting VR as a promising tool for psychological stabilization and highlights its potential as a meaningful adjunct in trauma-focused care.

5 Conclusion

This study presents a VR stabilization intervention consisting of three stabilization techniques: light stream, mindful breathing, and containment. We utilized both self-reported and clinician-rated psychological scales, as well as objective measures of HRV. Post-traumatic growth and quality of life were measured as indicators of positive changes. The results indicated that VR interventions significantly alleviated PTSS while promoting improvements in the quality of life and post-traumatic growth of patients. Compared with the App intervention, the VR intervention provided a higher sense of presence and had a significant symptom-reduction effect on PTSS. In addition, the VR intervention resulted in positive changes, including quality of life and post-traumatic growth, which were not achieved by the App intervention. Therefore, VR stabilization interventions are usable and effective, and some patients may have a greater chance of benefiting from VR interventions.

Appendix

See the Tables 7 and 8.

Table 7 Means and standard deviation for HRV data at each time point for each group

		Pre-										Post-									
		SDNN	RMSSD	TP	VLF	LF	HF	LF/HF	SDNN	RMSSD	TP	VLF	LF	HF	LF/HF						
VR	Session 1	34.544 (10.973)	23.18 (12.266)	946.334 (531.172)	453.396 (324.805)	265.262 (215.594)	227.676 (206.298)	2.5 (2.334)	35.495 (14.09)	23.851 (12.375)	937.234 (614.441)	402.091 (326.776)	257.743 (228.28)	217.786 (207.287)	2.513 (2.265)						
	Session 3	30.825 (15.76)	21.646 (14.753)	770.339 (678.822)	277.312 (262.596)	203.693 (203.043)	201.61 (205.883)	2.071 (2.337)	31.482 (14.312)	22.295 (13.727)	827.669 (630.897)	351.447 (298.998)	260.402 (224.567)	186.91 (177)	2.481 (2.383)						
	Session 5	31.669 (12.424)	21.969 (13.332)	742.85 (577.985)	343.169 (264.091)	201.885 (191.951)	176.662 (180.852)	2.265 (2.351)	62.919 (45.143)	25.082 (11.934)	1097.578 (714.665)	481.34 (380.617)	370.487 (304.109)	245.751 (181.842)	2.679 (2.577)						
App	Session 1	31.164 (11.961)	22.786 (13.133)	681.468 (533.188)	319.301 (338.341)	163.288 (144.412)	198.879 (176.969)	1.638 (1.677)	29.31 (8.847)	21.432 (10.563)	645.477 (525.903)	275.379 (255.905)	240.911 (221.626)	182.822 (141.389)	2.075 (2.141)						
	Session 3	30.436 (11.71)	21.254 (12.478)	754.975 (575.328)	341.978 (299.604)	184.899 (187.827)	172.369 (158.257)	1.617 (1.35)	28.529 (10.29)	19.854 (10.753)	613.724 (406.276)	366.23 (327.247)	144.177 (113.328)	172.649 (162.887)	1.406 (1.362)						
	Session 5	27.272 (13.104)	18.364 (11.64)	538.283 (478.144)	239.594 (222.876)	130.107 (116.955)	113.16 (120.032)	2.018 (2.103)	30.553 (12.37)	20.115 (13.576)	726.265 (524.477)	363.997 (326.46)	206.14 (211.949)	156.128 (160.52)	2.455 (2.338)						

Table 8 Whole statistic result data for HRV liner mixed model analysis

		df1	df2	F	p
SDNN change	Treatment	1	40.233	0.311	0.58
	Session	2	68.902	4.419	0.016
	Treatment * Session	2	68.902	0.204	0.816
RMSSD change	Treatment	1	35.166	0.007	0.935
	Session	2	58.371	4.756	0.012
	Treatment * Session	2	58.371	0.041	0.96
TP change	Treatment	1	40.271	3.115	0.085
	Session	2	75.036	5.573	0.006
	Treatment * Session	2	75.036	1.513	0.227
VLF change	Treatment	1	41.921	0.498	0.484
	Session	2	81.073	3.765	0.027
	Treatment * Session	2	81.073	0.589	0.557
LF change	Treatment	1	45.134	3.497	0.068
	Session	2	80.022	5.607	0.005
	Treatment * Session	2	80.022	2.183	0.119
HF change	Treatment	1	38.54	1.053	0.311
	Session	2	63.966	8.676	<0.01
	Treatment * Session	2	63.966	2.936	0.06
LF/HF change	Treatment	1	32.894	0.543	0.466
	Session	2	65.026	1.006	0.371
	Treatment * Session	2	65.026	1.319	0.275

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Data availability Data is provided within the manuscript. The whole data sets used and analyzed during the current study contain the data that can identify personal information, and are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate This study was supervised and approved by the local IRB, document No. SCHCA202208032-HE001.

Competing interests The authors declare no competing interests.

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