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Research Article

Examining Emotional Engagement during Prolonged Exposure Therapy with Mobile Psychophysiological Technology: A Prospective Study

Alexandra H. Cowden Hindash[1,2,3*], Anna H. Staudenmeyer[1,4*], Allison Diamond Altman[5], Callan Lujan[6], Anna Kim[1], Martha Schmitz[1,2], Sabra S. Inslicht[1,2]

[1]San Francisco Veterans Affairs Health Care System, San Francisco, USA; [2]Department of Psychiatry and Behavioral Sciences, University of California, San Francisco, USA; [3]Veterans Health Administration Advanced Fellowship in Women's Health, San Francisco Veteran Affairs Health Care System, San Francisco, USA; [4]Veterans Affairs Eastern Colorado Health Care System, Colorado Springs, USA; [5]Department of Psychology, University of California, Berkeley, USA; [6]Department of Psychology, Washington State University, USA

**Denotes joint first authorship*

ABSTRACT

This case study provides an example of the potential benefit of augmenting Prolonged Exposure therapy with sensory cues while integrating psychophysiological measurement into clinic-based PTSD psychotherapy. With reference to the emotion processing theory of PTSD, we highlight the potential of integrating psychophysiological measures during treatment to shed light on a person's emotional engagement with their trauma memory. Further, we explore potential differences when processing is focused on a discrete traumatic event during adulthood compared with processing a prototypical event from repeated childhood abuse within the same individual. Objective data from both skin conductance and heart rate, measured by photoplethysmography, were analyzed and compared with subjective measures of distress throughout 23-sessions of psychotherapy. Bivariate correlations between physiological and self-reported distress suggest changes in concordance between objective and subjective distress measurements observed throughout treatment, particularly within sessions identified via clinical judgment as pivotal change sessions. Exemplar sessions are presented to illustrate the utility of integrating psychophysiological reactivity measures into a standard clinic-based PTSD treatment. We conclude with a clinical perspective on the potential benefit of protocol augmentation, the limitations of symptom measures that may not adequately portray therapeutic processes in complex trauma cases, and provide future directions related to the fruitful integration of sensory cues and psychophysiological measurement into therapeutic procedures.

Keywords: PTSD; Heart rate; Electrodermal activity; Prolonged exposure therapy; Physiological reactivity; Treatment augmentation

INTRODUCTION

Posttraumatic stress disorder (PTSD) affects ~4% of the United States population annually and ~8% of people over the course of their lifetime [1,2]. Rates of PTSD are higher for military veterans than civilians [3]. PTSD is defined by five symptom clusters including re-experiencing the trauma, avoidance, hypervigilance, negative changes in mood and cognition, and changes in arousal [4]. Some individuals with PTSD experience hypoarousal and dissociative symptoms compared to the more prototypical hyperarousal profile [4]. Evidence-based treatments for PTSD, such as prolonged exposure therapy, are effective but suffer from high attrition rates [5] and veterans in particular demonstrate less improvement in PTSD symptoms compared to civilian populations [6]. One reason may be decreased emotional engagement with the trauma memory and present day life, deemed critical to treatment efficacy [7,8]. Physiological measures of distress could provide insight into emotional engagement during PTSD treatment. Mobile health technology has the potential to produce objective physiological indicators of emotional distress that could be compared to patient self-reported and clinician-observed distress. These measures can be used to inform and optimize clinical judgment to target treatment outcomes through enhanced emotional engagement.

Symptom under-reporting and under-engagement in PTSD clinical contexts

One challenge faced by clinicians treating PTSD is that individuals

Correspondence to: Sabra S. Inslicht, San Francisco VA Health Care System, 4150 Clement St (116P), San Francisco, CA 94121, USA, Tel: +1 415-221-4810; E-mail: sabra.inslicht@ucsf.edu

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may under-engage or under-report symptoms due to avoidance or lack of clarity about emotional experiences. Under-engagement has been associated with early and chronic interpersonal trauma [9], dissociation, and lack of awareness about PTSD symptoms or treatments [10]. Outside of PTSD specialty mental health settings, PTSD may not be recognized because patients lack symptom understanding and the ability to describe symptoms [11]. This difficulty recognizing and describing emotional experiences is particularly true of adults with early relational trauma [9] and those who have consequently adapted their lives and environments to minimize emotional distress from trauma-related stimuli. Symptom under-reporting may interfere with whether or not evidence-based treatments are initially offered.

Even when engaged in treatment, patients may be more focused on distress symptoms and ignore or deny avoidance or interpersonal conflict symptoms [12]. This pattern can establish a dynamic where clinician intuition and judgments related to the patient's emotional experiences are at odds with the patient's subjective reports. While clinicians may intuitively know to augment therapy protocols in these challenging cases, there is little evaluative research to guide the efficacy of such alterations. Mobile physiological measurement may provide clinicians insight into the patient's emotional experience in PTSD treatment and enhance the treatment process.

Physiological changes in PTSD

PTSD is prototypically characterized by hyperarousal, and extant research has demonstrated autonomic nervous system (ANS) dysregulation amongst those diagnosed with PTSD [13]. Heart rate (HR) is frequently used as a noninvasive measure of ANS activity, and individuals diagnosed with PTSD have shown dysregulation like increased resting HR [14]. PTSD symptoms of increased arousal, re-experiencing, and avoidance have been associated with elevated HR [15]. Yet, in response to laboratory stressors, researchers have consistently shown individuals with PTSD exhibit reduced or muted heart rate variability [16], a key indicator of autonomic functioning and risk factor for cardiovascular disease [15,17].

Electrodermal activity (EDA) is a measure of the ANS that is influenced by the sympathetic nervous system (SNS). EDA is a common measurement of SNS arousal because it reflects the activity of the sympathetic nerve on the sweat glands in the skin [18]. Individuals with PTSD generally have similar resting state EDA reactivity compared with individuals without PTSD [18]. However, low or undetectable EDA measurements have been observed in individuals with the dissociative PTSD subtype [19].

EDA and HR are proxies of the ANS. Whereas EDA measures sympathetic activity, HR is controlled by both the sympathetic and the parasympathetic nervous systems. The ANS typically drives physiologic regulation and facilitates responses to environmental stressors [20]. ANS upregulations occur within the sympathetic nervous system and downregulations in parasympathetic activity occur in response to a stressor. Research has consistently shown that individuals with anxiety disorders and major depressive disorder exhibit reduced autonomic activity via HR, or inflexible responding to environmental stress [21-25]. However, few studies have examined physiological measures during the course of treatment.

Prolonged exposure therapy

Theoretical framework: Prolonged exposure (PE), widely considered a gold standard treatment for PTSD, facilitates healing from a trauma by reactivating and restructuring fear networks associated with the traumatic experience via *in vivo* (real world) and imaginal (memory-based) exposures. Standard PE [7] consists of 9-12 ninety-minute sessions, varying in length depending on individual response. PE is based on the Emotional Processing Theory [1], which proposes that emotional structures [26] consist of stimulus, response, and meaning elements. These structures prepare organisms to survive dangerous situations. Activation of fear structures elicit an adaptive fear response (e.g., increased heart rate) to a threat (e.g., tiger) and meaning (e.g., dangerous), which organizes actions that lead to safety (e.g., fight or flee) [1]. Outside the specific trauma context, elements within the fear structure often do not represent danger or threat. PE works by activating fear structures through imaginal exposure: repeatedly telling the story of the traumatic experience with as much sensory and emotional detail as possible from the first-person perspective. Imaginal exposures begin at session three and are completed throughout the treatment, with early sessions focusing on the entire memory before transitioning to parts of the memory in "hot spot" sessions. During "hot spot" sessions, the individual repeats the most distressing portions of the trauma with as much sensory detail as possible. The process of imaginal exposure demonstrates that the memory itself is not harmful or to be feared, and is followed by therapeutic processing where changes in emotional, physiological, and cognitive responses to the memory are explored.

Emotional engagement during therapy and outcomes: A central tenet of the PE process is activation of the fear structure and habituation [7], which refers to a reduction in response after repeated stimulus presentations. We use the term habituation to maintain consistency with the language used in the emotional processing theory [1], although recent theorists and neuroscience research suggest PE aligns with fear extinction processes [27]. Through repeated exposure to the feared stimulus, emotional intensity and physiological signs of reactivity (e.g., flushing, heavy breathing, speeded heart rate, and increased sweating) decrease and elicit either a reduced or no fear response. Habituation can be observed with physiological measures like HR and EDA. For habituation to take place, the emotional processing theory posits that the fear structure needs to be activated and engaged with, thereby enabling new safety learning [27,28]. Thus, emotional engagement is central to the emotional processing taking place in PE.

Emotional engagement during PE

Emotional activation PE is typically measured by a patient self-report rating called Subjective Units of Distress Scale (SUDS). Clinicians make treatment decisions based on SUDS ratings during imaginal exposure. Scale SUDS are used as a proxy of emotional engagement [29], and increases, decreases, or plateaus are monitored to determine if, when, and what is needed for habituation to occur [7]. However, SUDS rating accuracy depends on a patient's ability to experience and identify their emotional state [30]. A trauma survivor who has difficulty identifying, experiencing, or trusting their emotions may struggle to voluntarily access and experience emotions. Individuals who do not appear to be emotionally activated during session, measured via clinician

observation and/or patient SUDS ratings, represent the challenge of under-engagement [31]. The PE protocol suggests prompting under-engaged patients to increase sensory details to encourage connection to the trauma memory [7]. PE allows the individual to practice and develop mastery over experiencing emotions in manageable amounts. Through this process, an under-engaged person gains the ability to access, name, and experience emotions. If a person remains under-engaged with the trauma memory, the proposed recovery mechanism in PE cannot occur [31].

One way to overcome under-engagement is by utilizing the information obtained from physiological assessments during PE. This may allow clinicians to monitor both objective measures and subjective reports of emotional distress, thereby informing decisions to facilitate emotional processing and clarifying a path forward despite engagement challenges. The proliferation of wearable, mobile physiological devices in the research and consumer arenas provides an opportunity to quantify physiological habituation that can provide insight into emotional engagement. Measurement of physiological responses during PE has the potential to provide greater insight into client engagement during sessions and may provide an objective measure of treatment response. Physiological reactivity can assist therapists as a tool to quantify emotional engagement throughout treatment, an essential component of the fear-habituation paradigm underpinning PE treatment. It can also be used to identify the effects of protocol augmentations on therapeutic response. We present a case study in which a mobile wristband was used to measure autonomic functioning and engagement during treatment. We demonstrate how EDA and HR data from psychotherapy sessions can elucidate the effect of protocol augmentations as well as provide insight into emotional engagement.

METHODOLOGY

Procedures

The participant ("X") undergoing prolonged exposure treatment was recruited to participate in a pilot study that aimed to examine ambulatory physiological monitoring during PTSD treatment. X was included in the mHealth study as a pilot participant based on the clinical judgment of referring and treating clinicians that identified more significant distress than he endorsed on symptom measures, despite not meeting PTSD criteria as determined by a diagnostic interview, likely due to denial of avoidance symptoms. X wore the Empatica E4 [32], a research grade activity tracker wristband to capture physiological reactivity starting in session 4. Table 1 presents a breakdown of individual session procedures as well as peak HR, EDA, and SUDS ratings.

Participants

X is a 71-year-old, White, married, cisgender male Veteran who

Table 1: Therapeutic procedures with peak imaginal exposure reactivity values by session.

Session #	Peak SUDS	Peak EDA	Peak HR	Therapeutic procedures within each session
1				Trauma interview and breathing retraining; index trauma: plane crash on flight deck
2				Common reactions to trauma; creating *in-vivo* hierarchy
3				First imaginal exposure (military trauma) with emotional processing
4	30	0.79	104.61	Imaginal with emotional processing; **first session wearing wristband**
5	45	5.84	105.54	Imaginal with emotional processing
6	50	10.06	102.67	Imaginal with emotional processing
7	40	6.08	98.26	Imaginal **augmented with audio of flight deck crash alarms;** emotional processing
8	80	8.05	107.48	Imaginal **+ audio** with processing; X restarted imaginal after he noticed a lack of engagement
9	80	N/A	131.80	First hot spot session **+ audio**; emotional processing
10	80	7.12	101.33	Hot spots **+ audio** with processing; connection of military trauma to childhood trauma
11	60	1.98	98.99	Hot spots **+ audio** with processing
12	70	5.55	100.22	Hot spots **+ audio** with processing
13	65	N/A	99.54	Hot spots **+ audio** with processing; emergence of guilt
14	70	7.38	103.69	Full imaginal **+ audio** with processing
15		N/A		Processing military trauma treatment gains; **identifying childhood index**, creating *in-vivo* hierarchy
16	65	7.10	124.71	First imaginal of childhood trauma with processing
17		N/A		Current life stressor focus of session
18	70	9.42	103.84	Imaginal with emotional processing
19	75	6.12	119.29	Hot spots with processing
20	75	6.38	87.16	Hot spots with processing **+ HW assignment to write letter to himself as a child**
21	45	6.38	103.46	Hot spots with processing **augmented with pt reading a letter he wrote to himself as a child**
22	65	N/A	92.48	Hot spots with processing
23	45	N/A	93.34	Final PE session: childhood imaginal and processing treatment gains

Note: EDA = Electrodermal Activity; HR = Heart Rate; HW = Homework; SUDS = Subjective Units of Distress Scale. Modifications to the Prolonged Exposure Protocol are bolded under the description of therapeutic procedures. Peak EDA, HR, and SUDS values are drawn from the imaginal exposure component of each Prolonged Exposure Session

served in the Navy during the Vietnam Era. He was stationed on the flight deck of combat-support aircraft carriers. He described the tireless, high-risk and high-reward nature of the flight deck as "absolute organized chaos." The Veteran explained that any break in the orchestration of flight deck operations would have disastrous consequences, and during his Naval career he witnessed countless plane crashes, equipment malfunctions, and accidents resulting in sudden deaths. X had a successful career following the Navy as a retail executive. Although he struggled with anger, alcohol, and distant relationships with his wife and children throughout his young and middle adulthood, he did not discuss his traumatic history until after retirement, when he presented for a mental health intake at a Veterans Affairs hospital. In addition to mental health diagnoses of PTSD and major depressive disorder, X was diagnosed with a chronic lung condition which impacted his ability to exercise, which is how he previously coped with anger.

During his clinic evaluation for PTSD, which consisted of a semi-structured interview utilizing the PTSD Checklist for DSM-IV (PCL-4) [33], the clinician observed a disconnect between his subjective report and clinical assessments of distress. He endorsed the minimal symptoms on the PCL-4 needed for a diagnosis of PTSD. However, his verbal report suggested under-reported suffering, indicated by perseverating on Navy-related traumas and nonverbal behaviors of crying, flushing, avoiding eye contact, and stammering. The participant completed a clinical interview but failed to meet full PTSD criteria due to denial of avoidance symptoms. X was offered PE treatment through the clinic based on clinical judgment that his complex trauma history (discussed below) likely precluded his ability to organize and describe his internal experience [9]. Clinical judgment gave greater weight to his observed emotional and physiological arousal, organization of his lifestyle to avoid trauma cues, and the discrepancy between his observed distress and subjective reports.

Measures

X completed a battery of self-report measures pre- and post-treatment to assess PTSD and depression symptoms, anger, disability, and quality of life. The PTSD Diagnostic Scale (PDS-5) [34] is a brief, 24-item self-report measure used to evaluate PTSD symptom severity. PDS-5 items factor into subscale scores for each symptom cluster required for diagnosis. The internal consistency of the PDS-5 has been found to be high (α=.95) [34]. The Beck Depression Inventory – Second Edition (BDI-2) [35], is a well-established 21-item self-report measure of depression symptoms where higher scores indicate greater depressive symptomatology. The BDI-2 exhibits high internal consistency in community (α=0.81) and clinical (α=0.86) samples [36]. The Spielberger's State-Trait Anger Expression Inventory (STAXI), is a 44-item self-report measure of the experience, expression, and control of anger with higher scores indicating greater levels of anger and expression. Each subscale has demonstrated high internal consistency [37]. The World Health Organization's (WHO) Disability Assessment Scale II (WHO-DAS-II) [38], is a 12-item measure of health and disability which addresses six domains of functioning, including cognition, mobility, self-care, getting along, life activities, and participation, where higher scores indicate a greater level of disability. All six domains have been found to have "acceptable" to "very good" values of internal consistency, with Cronbach's alphas ranging from 0.47 to 0.94 [38]. The WHO Quality of Life (WHO-QOL-BREF) [39] is a measure of quality of life in four domains including physical health, psychological health, social relationships, and environment as well as overall and general health. The measure has demonstrated excellent internal consistency across all four domains with Cronbach's alpha ranging from 0.66- 0.81 [39].

Additionally, PTSD and depression symptom measures were collected at the start of each treatment session. PTSD symptoms were assessed through the PTSD Checklist for DSM-5 (PCL-5) [40]. The PCL-5 has strong internal consistency in a military population (Cronbach's alpha=.96) [41]. Depression symptoms were measured using the Patient Health Questionnaire - 9 (PHQ-9) [42]. The PHQ-9 has demonstrated excellent validity and reliability (Cronbach's alpha=0.89) to measure depression severity [42].

Physiological recordings

The E4 wristband has four embedded sensors to record physiological responses; an electrodermal activity (EDA) measure for skin conductance, a photoplethysmogram (PPG) for heart rate (HR) measurement, a sensor for skin temperature measurement, and a 3-axis accelerometer for movement measurement. For the present analyses, only the EDA and HR measurements were utilized. EDA and HR data acquisition followed standard guidelines using the E4 suggested placement, recording, and data processing procedures [32]. Example reactivity from baseline and turning point sessions are presented in Figures 2 and 3 to illustrate the complex pattern of emotional engagement, as assessed by measurements of arousal, during the course of PE for PTSD.

PE procedures and protocol modifications

X met with his therapist (AS) for a total of 23 PE treatment sessions. In the first session, X completed the PE trauma interview to identify which trauma would be the focus of treatment and to assess lifetime trauma exposure. X identified a stateside Naval training accident as the index trauma, the experience he felt was the most haunting. During a nighttime training exercise, X witnessed a plane's crash-landing in front of him on the flight deck in which the pilot had to eject. X watched a young sailor working on the flight deck killed in this accident and also feared that he himself would be killed. During this series of traumatic events, the ship's loud klaxon crash alarm sounded, and a General Quarters announcement was initiated to preclude fire spread. X disclosed childhood abuse and neglect. Early life traumas included being abandoned by his birth parents at age 5 and then separated from his siblings through adoption. X reported his adoptive mother perpetrated ongoing physical and psychological abuse while his adoptive father failed to protect him. His adoptive parents also neglected X by leaving him alone for days at a time without providing reassurance they would return. Prior to joining the Navy, X experienced and witnessed death repeatedly. As a child, he was told to look at a dead body by his adoptive father. As a teenager, X witnessed the death of a friend in an accident and lost another friend to drowning during the same year. X joined the Navy at age 17, feeling liberated to leave his adoptive parents and the pain of his upbringing. He reflected joining was "the best thing I ever did. And the food was so much better than home."

During the early stages of treatment, the disconnect between subjective report and clinically observed emotional activation led the therapist to consider treatment modifications to enhance emotional engagement with the trauma memory. In session 3,

the first treatment session involving imaginal exposure (i.e., recounting the index trauma), X expressed doubt that reciting the flight deck crash memory would lead to much emotion. At one moment during this session, he endorsed a SUDS of 5 out of 100 while stating "I'm still able to breathe somewhat normally, but not unless I focus on my breathing." For sessions 4-6, X's subjective report continued to diverge from clinician observed physiological indicators of distress, including shallow breathing, flushing, and anxious movement. To enhance his emotional engagement with the trauma memory, auditory trauma cues were added to the imaginal and hot spot sessions, including the high-pitched wailing klaxon alarm and the ominous General Quarters announcement, which X found for homework. Starting at session 7, and during each subsequent imaginal session focused on military trauma, the therapist played the queued-up audio recordings during the traumatic event for each imaginal exposure repetition. After this modification, the therapist's assessment of X's engagement matched his SUDS ratings.

Starting in session 10, X began to make parallels between his military and childhood traumas. When processing imaginal exposures, he connected feeling small in the moment of the plane crash to memories of awaiting abuse from his adoptive mother. In session 12, when describing the young man killed by the airplane, his words closely matched descriptions of his childhood physical abuse and neglect: "His body is stretched out, nothing is being done; he's so little and crumpled; nobody's home." The literal and metaphorical similarities between his military index trauma and childhood trauma and neglect clarified the complexity of X's symptoms and his well-developed survival strategies, including avoiding painful emotions. As processing began to involve more discussions of his childhood, his PCL-5 and PHQ-9 scores increased. X explained, "I know I've been trying to keep the filing cabinet closed on my childhood, I don't know what's inside and I'm scared to find out." X and the therapist made a collaborative decision to devote imaginal exposures to a prototypical childhood index trauma following the completion of PE sessions for military trauma.

Session 14 marked the last military trauma imaginal exposure, and session 15 served as a transition session between exposures focused on military trauma and the start of exposures focused on childhood abuse. Interestingly, during these imaginal sessions, an opposite pattern was observed from the pattern for the early military imaginal exposures: X reported slightly higher SUDS ratings than in previous sessions, but there were fewer indications of distress observed by the therapist. Again, the protocol was modified to enhance emotional engagement with the trauma memory. The therapist suggested that X write and read aloud a letter addressed to his childhood self, which was processed in session 21. The full PE protocol ended in Session 23, which was the final imaginal repetition of the full childhood trauma memory as well as therapy termination with the trauma therapist.

Data processing

As the E4 was placed and began recording while X was in the clinic waiting room, data was subset to the time of the session using reported timestamps. Mean EDA and HR values were extracted from the minute prior to a SUDS rating because the patient is asked to rate their distress for the moment prior to being asked. Further, this range in time provides some correction for external clock time measurement errors (e.g., normal variations in clocks within a single room). The E4 records EDA at a rate of 4 Hz. The signal was measured in microSiemens (μS) and processed using continuous decomposition analysis in LedaLab [43]. The E4 records HR at a rate of 1 Hz via a PPG sensor, which measures blood volume pulse (BVP), from which HR is derived. Prior to conducting all planned analyses, HR was parsed into 10-second epochs by computing continuous averages of every 10 seconds, in order to reduce the noise across measurements.

RESULTS

X scored a total of 15 on the PDS at pre-treatment, indicative of significant distress although he denied avoidance symptoms. At post-treatment, he scored a 7 - a substantial decrease by 8 points. Subscale scores decreased in the intrusions, arousal, and cognitive and negative affect domains. Notably, X endorsed avoidance symptoms for the first time at posttreatment. X also endorsed a decrease in BDI-2 measured depressive symptoms, moving from mild (BDI-2=16) to minimal (BDI-2=10) depression during treatment. X's Scores on the STAXI reduced from a 34 pre-treatment to a 25 post-treatment, suggesting significant general reductions in anger experiences. Additionally, X saw a reduction in the STAXI Anger expression subscale from a pre-treatment score of 52 to a post-treatment score of 48. X exhibited little change in quality of life measures. On the WHO-QOL-BREF, X had a one-point improvement in overall quality of life, moving from a pretreatment score of 3 to a post-treatment score of 4. X reported a decrease in the psychological well-being domain, with a pre-treatment score of 24 and a post-treatment score of 22. His scores in the physical health domain dropped from 21 to 17 by treatment end, consistent with increased mobility loss. Additionally, scores on the WHO-DAS-II increased from a pre-treatment score of 14 to a post-treatment score of 16. Consistent with a decline in pulmonary health, X indicated the number of days spent physically disabled went from 5 days at pre-treatment to 20 at post-treatment.

Concordance between objective and subjective measures of distress

For both the EDA and HR data, mean reactivity values from the 60 seconds prior to a SUD rating were compared to the SUD ratings within a session. Bivariate correlations compared SUD ratings with mean EDA and HR as a measure of concordance between subjective ratings (SUD) and objective measures (EDA and HR) of distress during the imaginal exposure procedures of PE therapy sessions. Using the Fisher's r to z transformation, we next examined the difference between bivariate correlation values between baseline and clinically significant sessions for EDA and HR correlations separately. Bivariate analyses were performed in R 2.1 (R Core Team, 2015), while session r coefficient comparisons were calculated using the Psychometrica online calculator [44]. Figure 1 displays the Pearson's r coefficient for each session. We excluded the final therapy session due to concern termination effects would obscure the emotional engagement concordance pattern. Sessions with high concordance included sessions 7 and 9 from the military trauma processing and 21 from the childhood trauma processing. Notably, the sessions of highest concordance between self-reported and psychophysiological reactivity were therapeutically important turning points of treatment augmentations. As such, we examine

these pivotal sessions in greater detail after first presenting X's baseline reactivity.

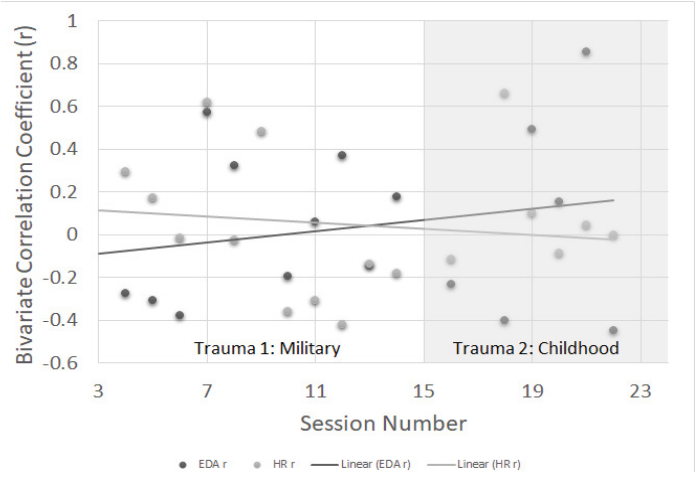

Figure 1: Correlations between Subjective Unit of Distress Scale (SUDS) ratings and mean Heart Rate (HR) and mean Electrodermal Activity (EDA) from the minute prior to the SUDS rating. Correlation coefficient r represents the correlation between objective and subjective distress measures during the imaginal exposure procedure of each session over the course of treatment.

Discrete military trauma

Session 4. This was the first imaginal exposure session where physiological measures were recorded during the PE treatment protocol. Typically, we expect increased distress during the trauma memory recounting in early therapy sessions. X demonstrated the opposite pattern, becoming disengaged during the memory recounting, exemplifying under-engagement.

The excerpt below represents X's reporting through the early imaginal sessions (3-6). He recounted the memory with great detail yet in a removed way, seeming to put effort into a measured accounting of what happened.

X: The klaxon sound cuts through, I feel the adrenaline, I'm frightened. Where do I go, what do I do? Is this going to be it? The airplane hits the deck, I feel the impact of the shock wave, I smell fuel, I hear the bang of the pilot's ejection seat, I see the flame of the rocket.

Therapist: What are your SUDS?

X: 20.

X included sensory (feel, smell, hear, and see) detail in his memory recollection. "Frightened" was likely an under-estimation of the extreme emotion he was feeling. Though he shared some thoughts, posing them as questions may have created distance between himself and the terror he felt during the trauma. His low SUDS ratings further suggested under-engagement with the trauma memory, despite the fact X was offering robust sensory details. A mismatch between his SUDS ratings and his experience of emotion and observable physiology continued.

X exhibited a flattened, or inflexible HR trajectory over the course of the imaginal exposure during this session (Figure 2A), even in the presence of SUDS rating change. Although his SUDS ratings indicated some subjective distress, he failed to exhibit objective distress except for a higher than average HR, potentially due to his lung condition, leading to low concordance between his HR and SUDS ratings (r=0.295). Within the EDA measure, X displayed a low response throughout the session (Figure 2B). This pattern is discordant with his SUDS ratings, leading to low, negative concordance between his EDA and SUDS ratings (r=-.272). Given this general low EDA and unvaried HR, a significant flattening in his physiological response during the imaginal exposure procedure is evident.

Session 7. The clinician modified the PE protocol by adding two auditory cues (klaxon alarm and General Quarters announcement) to augment emotional engagement during the imaginal exposures. Surprisingly, X's SUDS did not significantly differ from the previous sessions. However, for the first time, X stopped himself during the imaginal stating *"I'm in my head,"* and ranked his SUDS as a 10. This behavior seemed to signal new insight into his avoidance strategies, and was a moment reflecting concordance between his subjective report of low SUDS and the therapist's observation of under-engagement. This behavior change suggests the treatment augmentation impacted X's emotional experience during imaginal exposures.

In this session, as evidenced by the trajectories in Figure 2C and 2D, high concordance between X's HR, EDA, and SUDS was demonstrated. There was a higher correlation between SUDS ratings and HR (r=0.621) than with the EDA (r=0.574). There was also a moderate correlation between the two physiological measures during this session (r=0.457). In comparison with where X started in session 4, there was a significant increase in EDA concordance (z=-1.729, p=.042) but not in HR concordance (z=-.784, p=.217). This suggests the alarm increased his emotional engagement with his trauma memory, leading to greater concordance between his subjective and objective measures of distress, particularly as measured by EDA. New emotional content emerged from the trauma memory after the addition of auditory cues. He articulated physiological, frozen terror in sessions 7-10 (*"I'm terrified, rigid, stuck, waiting with my heart in my throat. My stomach is tied, I hurt in my chest"*) anger in session 11 (*"the world is upside down and unfair"*), and empathy in sessions 12-14 for the "little fella" who was killed during the crash.

Session 9. This was the first session during which X identified "hot spots" to focus on in imaginal exposures. X's hot spot focused on the moment the klaxon alarm sounded, signaling an impending crash on the unlit flight deck. The following excerpt from this session contrasts X's shared details from the imaginal exposure during session 4.

X: Something is getting ready to happen, I don't know what's going to happen, I'm terrified, I'm scared, I want to run and hide but there's no place to go...I can't do anything...It's going to hit, there's going to be a fireball, we are going to be gone.

Therapist: What are your SUDS?

X: 80.

Enhanced emotional engagement with the trauma memory, reflected in higher SUDS, was likely a function of the hot spot procedure and the addition of auditory cues. As X spoke, he was observably out of breath, flushed, with fear audibly chopping his narrative, consistent with his SUDS ratings and suggesting emotional engagement to the clinician. Concordance between HR and SUDS ratings was also high in this session (r=0.482;

Figure 2E), although they did not differ significantly from his baseline in session 4 (z=-.604, p=.273). Thus although his concordance improved, indicating harmony between the objective and subjective distress markers, it was not a significant increase in concordance. Unfortunately, there was an apparent malfunction with the EDA sensor, leading to invalid EDA data during this session.

Repeated childhood trauma

Session 16. During this session, X started imaginal exposures with a childhood index trauma, a specific memory of prototypical physical and emotional abuse perpetrated by his adoptive mother as a punishment for getting in trouble at school in the third grade. X disclosed there would be further abuse if he displayed an emotional response (e.g., getting in more trouble if he would cry during the abuse). As illustrated in Figures 3A and 3B, HR and EDA are highly correlated with one another (r=0.988) yet both are negatively correlated with SUDS ratings (HR r=-0.133; EDA r=-0.232). However, it appears there was some variation in reactivity during his first retelling which was not captured in the SUDS ratings. The therapist's decision not to disrupt the first retelling of a memory to get SUDS ratings is part of the PE protocol, as the goal is to allow the person to express the memory in full once without disruption.

Session 21. In line with the protocol augmentation described earlier, X read a letter he had written to his childhood self at the start of the session. The rest of the session focused on a hot spot from the childhood trauma memory. There was low HR and SUDS concordance during this session (r=0.046) but high EDA and SUDS concordance (r=0.856). In comparison with where X started in session 16, there was a marginally significant increase in EDA concordance (z=-1.514, p=.065) but no significant increase in HR concordance (z=-0.160, p=.437). As evident by Figures 3C and 3D, there was more physiological reactivity prior to the imaginal exposure, when he was reading the letter aloud.

DISCUSSION

This study highlights many of the challenges providers face when implementing PE with individuals who have experienced and learned to cope with chronic trauma. X's treatment gains expose shortcomings of measuring treatment progress and determining success via self-report measures when individuals have spent years or decades constructing their lives to minimize experiencing uncomfortable emotions. This case offers an example of measuring emotional processing objectively, as demonstrated by the successful integration of ambulatory physiological recordings during treatment. This addition provided insight into the impact of protocol augmentations.

Based on his post-treatment PDS score, X did not meet criteria for PTSD. Ironically, due to avoidance symptom under-reporting, he did not meet criteria for PTSD at the beginning of treatment according to the PDS either. X denied avoidance because he had designed his life to eliminate engaging with trauma cues, instead experiencing anger and numbness. While these behaviors are classified as avoidance in PTSD, assessing this symptom necessitates insight into the function of such behaviors. If trauma begins early in life, or if patients have lived longer with PTSD than without it, they may only cope with distress through emotional and physical avoidance. In these cases, clinicians may not realize the extent of the traumas' impact on the individual's quality of life without deeper queries about their relational, occupational, and daily functioning [12]. During his clinic intake, therapists used extended assessment and noticed implied avoidant behaviors and discordance between X's verbal report and observed emotional and physiological arousal - indicative of trauma pathology. Unfortunately, he was denied entry into a PTSD treatment effectiveness study because of lack of insight into and under-reporting of his avoidance symptoms.

X made substantial gains over the course of imaginal exposure sessions. He began to approach painful emotions like terror, shame, guilt, and sadness – a sharp departure from his longstanding avoidant coping style. While in initial sessions the clinician visibly observed disconnect between his physiological indicators and verbal reports, over time he displayed more insight into his distress and emotional states. These observations were confirmed by increased concordance between SUDs and physiological arousal over the course of treatment, particularly in sessions focused on the military trauma. Post-treatment, X reported experiencing fewer trauma intrusions and less fear and anger. X stated he could feel a wider range of emotions and revisit memories without believing himself to be broken. He noted, "I'm a better friend, and I'm a better listener" and reported making more deliberate attempts to connect with friends and family and also increased his time volunteering.

A core mechanism of change in PE can be summarized as "healing through feeling." X learned to identify and express his emotions. Protocol augmentations facilitated emotional engagement with the trauma memory, allowing X to connect his verbal report to clinician observations and device recorded physiological arousal. As can be seen in Figure 2, the addition of auditory cues in session 7 significantly increased X's emotional engagement, suggested by increased physiological reactivity between session 4 (Figures 2A and 2B) and 7 (Figures 2C and 2D). A similar pattern was observed after a second protocol augmentation, where X displayed the opposite pattern of under-engagement – higher SUDS despite lower physiological reactivity (Figure 3). Greater variability in both EDA and HR prior to imaginal exposure processes is visually apparent across sessions. His physiological reactivity consistently flattens during the imaginal exposures, especially during early sessions for each trauma memory. Notably, only the EDA measure demonstrated significantly greater concordance with SUDS over time, suggesting greater change in the sympathetic branch of the ANS. Improved EDA/SUDS concordance may reflect movement towards greater emotional awareness during imaginal exposure processes and/or movement away from suppression or dissociation [19]. The concordance between his HR and SUDS did not follow the same pattern. It is possible his lung condition contributed to high baseline HR, which obscured increased flexibility over time. Increased physical depressive symptoms (e.g., fatigue) may also explain discord between his HR and EDA post-treatment, as HR and heart rate variability are affected by depression whereas EDA is not [45]. Sessions with protocol augmentations had highest concordance between physiological and subjective distress ratings. These sessions also mark when the therapist observed significant changes in X's emotional awareness and engagement. When pivotal change sessions are compared with each trauma's baseline imaginal exposure sessions, we see a pattern of increased engagement physiologically and a greater range in SUD ratings.

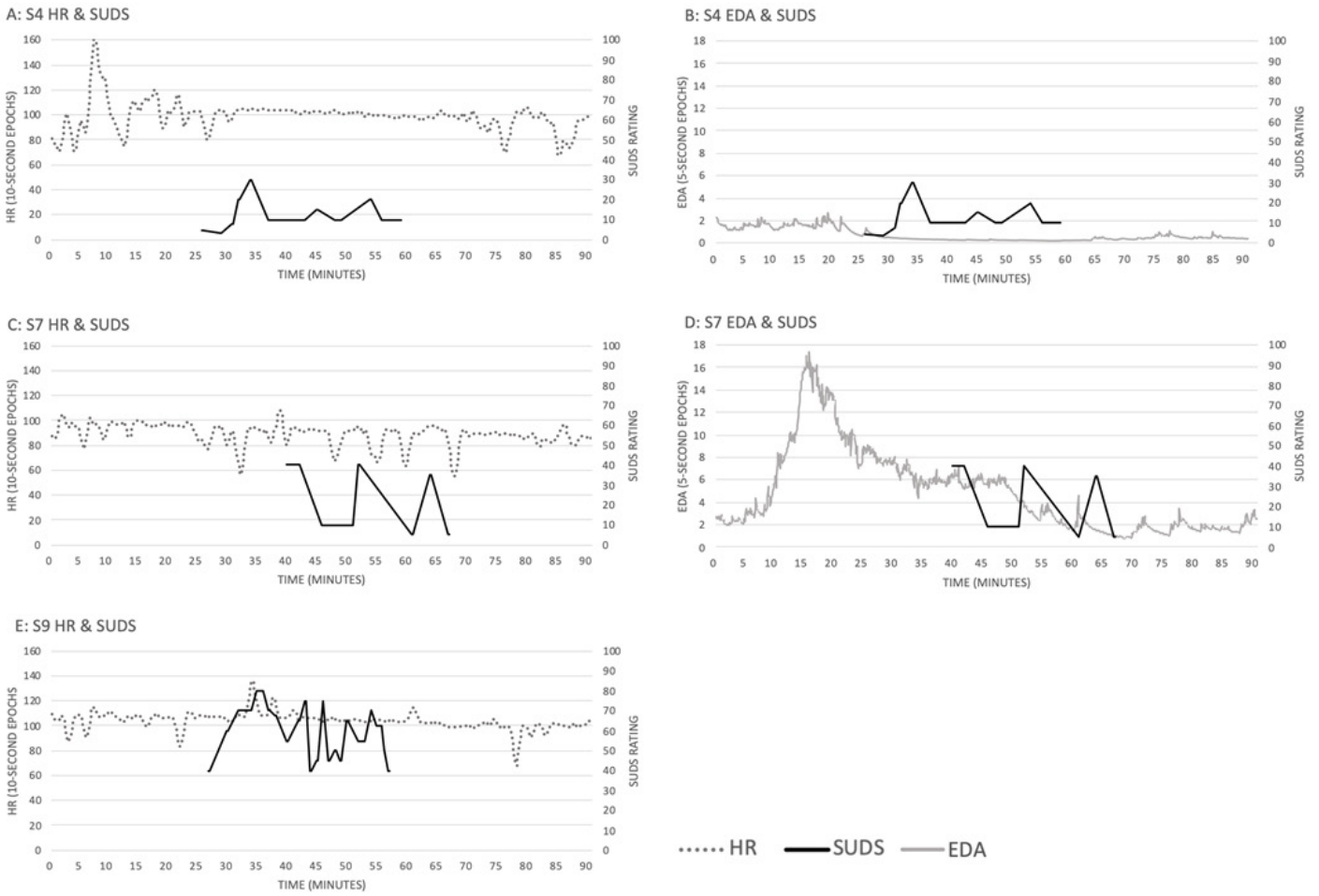

Figure 2: Changes in physiological reactivity during pivotal Military Trauma focused Prolonged Exposure Sessions. Heart rate (HR), electrodermal activity (EDA), and subjective units of distress scale (SUDS) ratings are shown for the entire 90-minute therapy session. Baseline distress is displayed for Sessions 4 in panels A and B. Reactivity after the introduction of alarm sounds during session 7 is displayed in panels C and D. Reactivity during the initialization of the hot spots procedure during session 9 is displayed in panel E. *EDA data for session 9 was invalid and therefore is not presented.

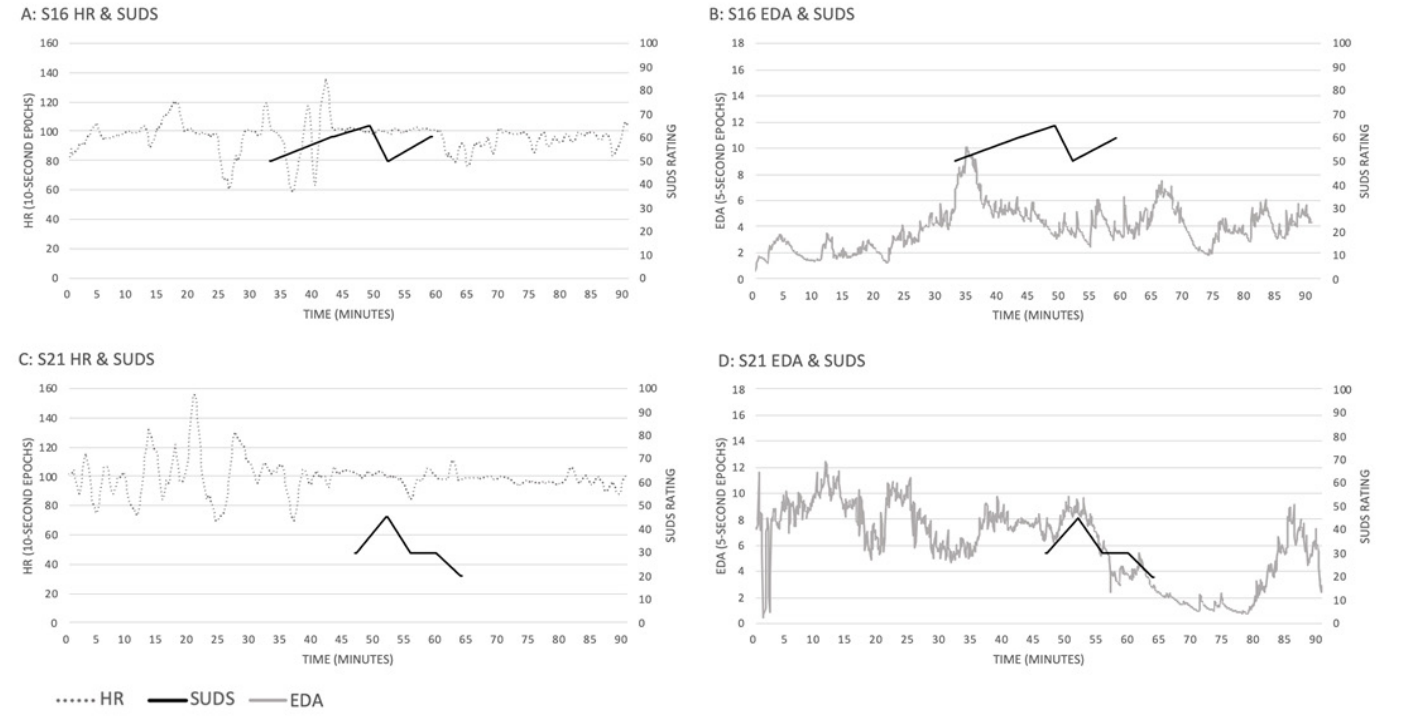

Figure 3: Changes in physiological reactivity during pivotal Childhood Trauma focused Prolonged Exposure Sessions. Heart rate (HR), electrodermal activity (EDA), and subjective units of distress scale (SUDS) ratings are shown for the entire 90-minute therapy session. Baseline distress for imaginal exposures related to the index childhood trauma is displayed for Session 16 in panels A and B. Reactivity during the session where X read a letter written to himself as a child during session 21 is displayed in panels C and D.

Although X's posttreatment self-reported symptoms may suggest little improvement or even worsening of symptoms numerically, this more likely reflects increased emotional awareness. Specifically, post-treatment X self-reported increased disability and PHQ-9 measured depressive symptoms (although decreased depression per the BDI-2). Overall increased concordance between his EDA and SUDS ratings during treatment supports our interpretation that his post-treatment symptom self-reports are more accurate than pre-treatment reports. X completed PE during a transition into older adulthood and retirement. X's quality of life scores may reflect greater awareness of painful emotions and the impact of his traumatic experiences on his relationships, as well as adjustment to life transitions and a worsening medical condition.

Differences in processing military versus childhood trauma

X's return to low physiological reactivity and poor concordance between his physiological and self-reported distress when the focus of therapy changed to childhood abuse can be interpreted in several ways. X may have returned to long-standing emotional avoidance or under-engagement when the focus of treatment shifted to memories of his traumatic childhood which he reportedly attempted to suppress prior to treatment. X disclosed he would be further abused if he displayed an emotional response during abuse, indicating early life training to suppress emotional expression. Thus, discord between subjective and objective distress measures during early imaginal exposures would be expected. However, X reached greater concordance between EDA and SUDS than HR and SUDS during sessions focused on childhood trauma as during the military trauma. It is possible that the primary emotional experience differed between the two traumas. In this case, X expected abuse when he returned home, thus it was not surprising or unexpected – whereas his military event was unexpected. Further research needs to elucidate processing differences when primary emotions differ between trauma types. The physiological differences observed during processing for these events highlight the usefulness of integrating physiological measures during treatment to explore complex emotional processes during trauma focused treatment.

Childhood maltreatment and emotional numbing

Studies indicate veterans with histories of childhood maltreatment have greater levels of emotional numbing (i.e., difficulties experiencing and expressing emotions) than those without childhood maltreatment histories. Numbing and dissociation are adaptive ways to cope with inescapable trauma. Emotional numbing perpetuates and maintains psychological distress and increases emotion dysregulation and use of emotion-focused coping strategies [46]. Veterans with high childhood maltreatment histories may be more vulnerable to deployment-related stress due to poor development of flexible coping skills [47,48]. Early childhood maltreatment survivors may more limited emotion regulation abilities due to reliance on emotional avoidance, suppression, numbing, or dissociation to survive chronic abuse. Because numbing and dissociation are involuntary and habitual, a survivor may have difficulty accessing voluntarily and experiencing emotions. This poses a challenge for trauma-processing treatments predicated upon a person accessing and experiencing their emotions.

The DSM-5 PTSD criteria changes included the new symptom cluster of negative thoughts and mood in an attempt to capture the greater array of emotional experiences survivors report. Unfortunately, this did not lead to adequate measurement of emotional numbing. These measures are predicated on the adult survivor having experienced the trauma more recently (versus decades ago as with Vietnam veterans or childhood trauma survivors) and having access to emotionally varied and safe experiences prior to the trauma. Survivors of childhood maltreatment may never have experienced secure and healthy relationships or enjoyed adult related recreational activities. Thus, they may not fully comprehend how emotional numbing negatively impacts their relationships with others. Finally, measures fail to capture the effect of emotional numbness on the full range of emotional experiences – specifically situationally appropriate negative (e.g., sadness or loss related to death of a loved one) or positive (e.g., joy or pride related to the success of a loved one) emotions. Yet, because this experience is not captured in our measurements, it is left to clinical judgment to assess the impact of emotional numbness on the survivor's life. Assessing alexithymia (i.e., difficulty identifying and describing emotions) and dissociation could provide clinicians and researchers alike with valuable information regarding emotional awareness and clarity during treatment.

Emotional flexibility in response to situational demands is one signal of emotional health [49]. Post-treatment measures focused on decreases in psychiatric symptoms do not accurately portray psychological health. Treatment outcomes should include a broader assessment of the survivor's involvement in meaningful activities and relationships. We recommend assessing the full functioning of individuals pre- and post-treatment, including obtaining collateral reports of interpersonal functioning given evidence survivors may be unaware of how their symptoms affect their relationships [12].

Furthermore, imaginal exposure to the trauma memory is an integral component of the PE protocol [7]. There is little research regarding the incorporation of easily attainable sensory cues, writing assignments, or other emotionally evocative stimuli designed to heighten emotional experiences during sessions. Yet, it is likely clinicians informally include such additions into their PE sessions. The systematic study of protocol augmentation would elucidate the benefits of protocol enhancement and identify which enhancements are most helpful.

LIMITATIONS

This study has a number of limitations which need to be addressed in future research. First, as a case study, it is meant for hypothesis generation regarding emotional engagement during PE and these findings should be further interrogated with larger study designs. Second, aspects of working within the clinical setting may have limited physiological measures, including difficulty or failure to ascertain precise time metrics. Specifically, SUD ratings are recorded according to the clinician's clock, which may be off time from the Unix standard timestamps provided by the E4. Without reliable event markers, reactivity estimates are potentially imprecise. We corrected for this by taking the mean value for EDA and HR from the minute prior to the SUDS rating. However, regular PE regular procedures during procedures during PE can have SUDS taken within a single minute (e.g., at the end and beginning of a repetition, during hot spots procedures) further. Third, as demonstrated in this case study, the reliance on self-reported symptoms - in either clinical interview or written

measures - may be unreliable when working with individuals who lack emotional clarity or understanding about PTSD symptoms. X demonstrated increased insight into his own symptoms evidenced by endorsement of avoidance symptoms post-treatment. However, likely due to his under-reporting, we were unable to observe clear numerical indications of his improvement. Finally, important factors like alexithymia and dissociation were not expressly measured in the current study, leaving us to speculate about X's internal states through clinical judgments.

CONCLUSION AND FUTURE DIRECTIONS

Despite these limitations, this case study exemplifies how physiological measures during psychotherapy can provide clinical insight into under-engaged individuals with the potential to provide rapid feedback on the impact of protocol augmentation. Integration of physiological measurement into psychotherapy provides clinicians data that can enhance confidence in their clinical judgments about a patient's experience, particularly during exposure-based therapies. Based on our experience working with X, we suggest that future studies integrating physiological measures during therapy ensure: 1) A protocol by which important therapeutic events are indicated via event markers during the session to increase event specific reactivity precision, 2) Procedures that maintain data validity while also facilitating flexibility with the flow of patient care, given that working within a clinic requires flexibility, 3) That measures of dissociation, numbing, and alexithymia are included to explore underlying factors for flattened HR and EDA responses within PTSD and during exposure therapy processes, 4) That treatment effects of the addition of sensory cues to enhance emotional engagement are documented, and 5) That a wide variety of treatment outcome measures are utilized, including collateral reports when possible.

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