Two Tell-tale Perspectives of PTSD: Neurobiological Abnormalities and Bayesian Regulatory Network of the Underlying Disorder in a Refugee Context

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Global refugee crisis around the world has displaced millions of people from their homes. Although some of them adjust well, many suffer from significant psychological distress, such as post-traumatic stress disorder (PTSD), owing to exposure to traumatic events and hardships. Here, diagnosis and access to psychological health care present particular challenges for various human-centered design issues. Therefore, analyzing the case of Rohingya refugees in Bangladesh, we propose a two-way diagnosis of PTSD using (i) short inexpensive questionnaire to determine its prevalence, and (ii) low-cost portable EEG headset to identify potential neurobiological markers of PTSD. To the best of our knowledge, this study is the first to use consumer-grade EEG devices in the scarce-resource settings of refugees. Moreover, we explored the underlying structure of PTSD and its symptoms via developing various hybrid models based on Bayesian inference by combining aspects from both reflective and formative models of PTSD, which is also the first of its kind. Our findings revealed several key components of PTSD and its neurobiological abnormality. Moreover, challenges faced during our study would inform design processes of screening tools and treatments of PTSD to incorporate refugee experience in a more meaningful way during contemporary and future humanitarian crisis.

CCS Concepts: • **Refugee crisis → Rohingya refugees**; • **Mental health → PTSD**; • **Neurobiology → EEG signal**.

Additional Key Words and Phrases: Refugee mental heath, Bayesian networks, EEG power, Correlation

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1 INTRODUCTION

With growing refugee crisis caused by forced displacement due to war, violence, and persecution, addressing the basic needs of the refugees has become crucial for their long-term sustainable well-being. However, beyond the atrocities and violation of human rights, the trauma events during forced displacement affect the long-term psychological well-being of the refugees, particularly subverting the victim's sense of safety, attachment, justice, identity-role, and existential meaning [167]. Earlier studies on refugees showed that cumulative exposure to trauma eventually leads to the development of PTSD [79, 104, 121, 156] and increases psychiatric morbidity [112, 113]. However, the issue of mass trauma in non-western population exposed to violence is often questioned [177] due to low prevalence rate of PTSD among the general population [83] even after experiencing a traumatic event. Yet with the controversies involved, many studies have found connection between exposure to trauma and various mental health disorders, such as PTSD, schizophrenia, depression, anxiety disorder, and so on [13, 26, 66, 170]. Previous work on refugees revealed that exposure to trauma deteriorates mental health status and reduces social functioning skills [24]. Besides, PTSD and depression play a key role in the formation of various diseases [111]. However, despite the risk of various diseases, access to mental health care for refugees suffers from different legal and practical restrictions in almost all host countries [47, 126].

1.1 Challenges in Refugee Mental Health Care

Although health-care is an essential factor for the long-term sustainable well-being of the refugees, measures intended to reduce their vulnerability to mental health disorders may entail various difficulties due to a wide range of factors. Limited resources, inequitable distribution of services, difficulties in coordinating national and international efforts, barriers to accessing available health care services, social stigma, etc., greatly impede the process of refugee mental health care [168, 169]. Such challenges are particularly salient in refugee crisis response plan where the dynamics of humanitarian needs are becoming more complex and severe day by day [146, 147]. Besides, the refugees themselves might not realize the necessity of required mental health care, and therefore, ignore this aspect for various ongoing daily stressors, day-to-day sufferings in makeshift camps, and persistent stigma associated with both mental illness and the feeling of being a refugee [85, 116]. Moreover, the existing general and specialized arrangements for diagnosis and treatments of PTSD often suffer from under-utilization [33] due to various challenges and issues involving human interaction and expectation. These include lack of cultural competence and sensitivity, absence of respect and understanding of different traditions, difference in cultural and religious views about mental health and treatment, low level of mental health literacy, lack of linguistically accessible services, lack of trusting relationship between the clinician and the patients, negative experience of services, inability to use self-report questionnaires for low literacy level, and so on [33, 55, 85, 152, 168]. Given these challenges, it is of utmost significance to focus on effective interaction between refugees and health service providers in parallel to looking for other means of effective diagnosis of PTSD.

1.2 A Timely Shift from Psychological Perspective of PTSD to Its Neurobiological Abnormalities

Although PTSD was initially defined from psychological perspectives, it is time to look into this problem through a different dimension. PTSD is traditionally characterized by the presence of several post-traumatic stress symptoms over a time period of a month or more. These post-traumatic stress symptoms might reflect the emergence of an abnormal underlying neurobiological mechanism in response to the stress of witnessed trauma. Recent findings in neuroscience have demonstrated neurobiological abnormalities among PTSD patients and identified several hallmark neurobiological features of PTSD [154, 165]. Various factors, such as neurochemical factors, endocrine factors, changes in brain circuitry, etc., affect the interplay between adverse environmental stimulation and stress responses or reactions. Besides such neurobiological factors, electroencephalogram or EEG has been frequently used to identify potential neurobiological markers for different mental health disorders [134, 153, 188], including PTSD [5, 27, 97].

EEG refers to a physiological method for measuring the electrical activities generated by a brain. Our motivation behind exploring EEG is that it offers excellent temporal and spatial resolutions for the assessment of brain activities. Besides, study of these brain activities allows us to characterize and detect presences of abnormalities associated with various post-traumatic stress symptoms. Additionally, being a spontaneous phenomena [155], EEG is less susceptible to conflicts and confusions associated with responses of the participants while using traditional questionnaire-based diagnostic tools. Moreover, EEG signals have the capability to identify and differentiate potential neurobiological markers of disorder from that of healthy individuals, even at rest state [60, 77, 196]. Thus, the use of EEG may avoid issues and challenges associated with human interaction and communication, such as that of language barrier, too low literacy level to use self-help questionnaires, etc. In recent times, advances in EEG technology have introduced several inexpensive brain computer interfaces (BCIs) making this technology more affordable and accessible than ever before. Its potential for real-time assessment of a person's cognitive state has facilitated various pervasive brain computer interface applications. For instance, consumer-grade EEG devices have found their use in so many diverse applications ranging from bio-metric system in pervasive environments [67] to real-time EEG based pain control system [135], tracking mental engagement of people with ADD and ADHD [8], exploring momentary gaming experience of players [7], ubiquitous blood pressure monitoring system [98], ischemic stroke detection [141], and so on. Therefore, we believe that the potential of BCIs might be of particular interest in the field of ubiquitous computing, which is concerned with the integration of mobile devices as well as inexpensive and embeddable sensors in various aspects of everyday lives. Besides, in the field of ubiquitous computing, researchers actively strive for opportunities to design and develop flexible, adaptive technologies that integrate with and capitalize on human capabilities and limitations to improve human-computer interactions [92]. BCI based neurotechnologies have been major upholders of this ideology, whose applications have been targeted to overcome obstacles to multi-modal interaction, real-time diagnosis, sophisticated analyses, limitations of computational infrastructure, and so on. Therefore, extending this technology to clinical diagnosis of psychiatric diseases would greatly improve mental health care as well as pave the pathway for interactive patient diagnostic system. Accordingly, in this work, we explored how consumer-grade BCIs perform in detection and diagnosis of PTSD. To the best of our knowledge, no research study has been performed yet to measure the scope, effectiveness, and usability of low-cost, consumer-grade EEG devices for the diagnosis of PTSD, specially in the context of refugee crisis. We believe that our work would shed light on the usefulness of BCIs in the field of ubiquitous health care, monitoring, and diagnostic system.

1.3 PTSD as a Causal System

Though diagnosis plays an important role for the early detection of any disease that might be curable, only it is not enough until the patients in need are provided with proper treatment. To accelerate recovery after exposure to severe trauma events, it is critical to understand the dynamic interplay between different post-traumatic stress symptoms and their manifestation in the form of PTSD. Over the years, many models have been proposed to capture the complex and dynamic interaction between the symptoms and disorder, such as latent variable model (reflective model) [36, 82], network model (formative model) [20, 107], etc.

The reflective model or latent variable model assumes that symptoms are reflective of a latent disorder, and therefore, they correlate with each other. According to this view, the manifestation of PTSD denotes a latent variable that functions as the common cause for each PTSD symptom, i.e., PTSD bears the causal relevance for the observed values of each post-traumatic stress symptom [14, 17, 43]. Therefore, the symptoms correlate with each other because they share a common determinant. For example, in the traditional latent variable approach, trauma events lead to the development of PTSD and this underlying disease entity, in turn, causes the post-traumatic stress symptoms that reflect its presence. On the other hand, the network or formative model interprets the causal relations among the symptoms and disorder in a different way. This model assumes that symptoms are constitutive of mental disorder, not reflective of it. According to this view, symptoms correlate not because they share a common dependence on an underlying latent entity, but because they are coupled through direct and homeostatic links [36, 82]. Therefore, in this model, PTSD is not an underlying disease entity that produces symptoms, rather it is a network of interacting as well as self-reinforcing symptoms [105]. Thus, this model conceptualizes PTSD as a causal system comprising various post-traumatic stress symptoms. For instance, in network models of PTSD, some stressors produce certain symptoms that activate other symptoms, possibly in circular and self-reinforcing ways. Thus, in this view, the post-traumatic stress symptoms are not passive psychometric reflectors of an underlying disorder, rather they are active constituent ingredients of the disorder [52, 53].

However, both of these models (reflective and formative model of PTSD) often miss the complexity, multiplicity, and non-linearity of relationships that lie between the symptoms and the disorder. Since there are so many social, psychological, and neurobiological factors that are important in the etiology of PTSD, it is often difficult to capture all these into a single model. For instance, with latent variable model, it is implausible for a single factor to explain the diversity of all post-traumatic stress symptoms because such a latent construct can not be necessarily isomorphic and generalized across people [19]. Besides, since all the symptoms are caused by a single latent entity in this model, correlations among the symptoms cannot be direct. Additionally, the presence of a single common factor makes their correlation entirely attributable to the underlying disorder, and therefore, the symptoms are likely to be locally independent of each other. However, such local independence of the symptoms is implausible in psychopathology [18]. On the other hand, the network model conceptualizes PTSD as a cluster of directly related symptoms. The network model of PTSD is based on a theoretical conjecture resting on the implausibility of local independence among symptoms. However, in reality, not all symptoms equally contribute to the development of PTSD, which we confirm by our sudy in this paper. Our investigation reveals that some symptoms may interact with each other and give rise to PTSD, while some others may emerge as a consequence of the disorder. Therefore, a hybrid model of PTSD comprising aspects from both reflective (latent variable model) and formative (network model) models of PTSD would be inevitable in road to revealing relationships among PTSD and its symptoms.

1.4 Our Motivation and Research Context

In this work, we have examined the psychological and neurobiological characteristics of Rohingya refugees living in Bangladesh. The Rohingyas are an ethnic minority, consisting of mainly Muslims, who have lived in Buddhist-majority Myanmar for centuries [72]. However, officially they are not recognized either as an ethnic nationality or as legal citizens of the country by the Myanmar Nationality Law of 1982 [192]. In fact, their struggle for legal citizenship status against the military junta of the country dates back to 1950s [34, 96]. Since then, the Rohingyas have been victimized to systematic discrimination, targeted violence, ethnic cleansing, persecution, and other state-imposed strict regulations [72, 192]. Even the United Nations reported them as the most persecuted ethnic minority in the world [117]. To escape torture and death, the Rohingyas have been fleeing to neighboring countries, particularly into Bangladesh, over the course of many decades with significant spikes following violent attacks in 1978, 1991-92, and again in 2016-17 [72, 129]. After the start of 2016-17's Rohingya persecution, more than 640 thousand Rohingyas have been forced to seek refuge in Bangladesh [185]. In fact, this humanitarian crisis has been termed as one of the fastest-growing refugee crises in the world [35]. At present, more than 800 thousand Rohingyas are passing their days in sheer distress in various refugee camps in Cox's Bazar, Bangladesh

[72]. With the continuation of growing influx of refugees, the situation remains critical for pressing demands on land and limited local resources. As a result, the refugees are being forced to live in precarious conditions within congested camp areas, where living conditions are difficult and often dangerous [186]. Besides logistical and resource limitations, overcrowded living areas, lack of adequate drinking water and sanitation facilities, acute malnutrition, and other factors continue to exacerbate existing public health risks. The overburdened health care facilities in Sadar Hospital in Cox's Bazar along with the ill-equipped local (Teknaf and Ukhia) health complexes are not sufficient to provide for the growing influx of refugees [127]. Though different humanitarian organizations are bringing in health care aids, challenges such as severe acute malnutrition, communicable disease risks, sexual and reproductive health risks, etc., are way too many to be handled effectively in addition to mental and psychological health risks [63]. Besides, the understandings on disease and health by Rohingyas are intertwined with spirituality and religion. Accordingly, mental health issues are sometimes spoken about as a result of jinn possession [150]. On the other hand, the issues of mental and psychological health risks are largely stigmatized and misunderstood in Bangladesh [74]. The overall mental health care scenario in the country is very grim lacking adequate trained doctors and nurses with no facility for follow-up care or even in some cases no facility for day treatment program for mental health [194]. Under such circumstances, where the issue of mental health of the host community is heavily ignored, mental health issues of the refugees hardly stand a chance. Therefore, acknowledging these factors would help us in terms of diagnosis and to figure out how the solutions should be explored in the social and cultural contexts of refugees as well as that of the host community.

Keeping the above mentioned factors in mind, in our work, we investigate potential use of various inexpensive diagnostic tools of PTSD. Here, we consider limited resources and inequitable prioritization of sectors in refugee context. Our first step towards the investigation was to measure the prevalence of PTSD among the Rohingya refugees with traditional interview-based diagnostic tools followed by the analysis of background EEG activity of refugees diagnosed with PTSD. Next, we focused on developing various models to analyze and define the relationships between different post-traumatic stress symptoms and PTSD. To build these models, we utilized concepts from both reflective and formative models of PTSD. Our hypothesis in favor of developing these hybrid models is that, some symptoms constitute PTSD while some are reflective of it. Therefore, keeping in line with our hypothesis, we first built a PTSD correlation network (PTSDCN) where nodes are used to represent PTSD and other post-traumatic stress symptoms, and the edges reflect significant association between the symptoms themselves and with PTSD. Although correlations between entities provide an initial approximation of the underlying structure, they potentially obscure the directions of functional associations. For example, correlation between two entities A and B may arise when A influences B, or B influences A, or a third entity C influences both A and B [18]. Therefore, simple correlation networks fail to differentiate between such interactions. However, our motivation behind computing PTSDCN was to identify clusters or groups of entities where an entity correlates with all other entities in the same group. We used the notion of maximal clique [15] to derive such groups of correlated symptoms from PTSDCN (see supplementary). These groups of correlated entities might be of particular interest in determining potential targets for the treatment of PTSD [128]. It would potentially help us to devise different treatment strategies that would be effective for targeting large numbers of post-traumatic stress symptoms together.

However, PTSDCN does not give us any idea about the type of functional association between the symptoms and the disorder. Therefore, our next step was to build a partial correlation network of PTSD (PTSDPCN). In a partial correlation network, an edge depicts the correlation between two entities where the influences of all other entities have been controlled statistically. Thus, PTSDPCN gets rid of any indirect association that is likely to be induced by a third entity and contains only the ones that are results of direct associations between two entities. However, both PTSD correlation network and partial correlation network are undirected graphs. To determine which symptoms actually constitute PTSD and which symptoms are reflective of it, we further built a directed acyclic graph (DAG) for PTSD regulatory network using Bayesian network of interactions [39].

Bayesian networks (see supplementary) have been widely used in many different fields and recently found its way in reflective (latent variable) model analysis of bullying [109] and formative (network) model analysis of PTSD among adults reporting childhood sexual abuse [106]. Bayesian network is basically a DAG, which tries to capture the hierarchical dependency among a set of variables by using conditional dependencies among them. The nodes in this DAG represent observable or latent variables and edges represent the direction of functional associations. The motivation behind developing a directed PTSD regulatory network is that, the use of DAGs can provide us insights about admissible causal relationships among PTSD and its various symptoms. They are not only able to detect associations between pairs of symptoms or between a symptom and disorder but also find out the direction of these associations. As a result, they provide suggestions about hypotheses on potential causal relations [136], such as, which symptoms constitute PTSD and which might be reflective of it. Besides, DAG analysis is capable of determining most likely functional associations among multiple variables resulting in a cascade of causal relations. Moreover, similar to the case of partial correlation, Bayesian inference also controls the indirect influence of other entities given the entity directly influencing a particular component in the network is known.

Now, to quantify the importance of each post-traumatic stress symptom to the overall development of PTSD, we calculated two indices of centrality in PTSDPCN and PTSDRN. The measures of centrality identify the most important nodes in a graph or network. For our purpose, we calculated two measures of centrality, namely strength [58] and betweenness [29] (see supplementary). Strength quantifies the level of connectivity associated with a particular entity, whereas, betweenness measures the level of control asserted by a particular entity on the interactions among other entities. For all measures of centrality, higher values reflect a node's greater importance to the network. Therefore, identifying such components of higher importance within PTSD networks would provide us potential targets for the diagnosis of PTSD and treatment thereof [61].

1.5 Our Contributions

Considering the demographic and cultural issues as well as risk factors associated with refugee crisis, our work in this paper contributes the following:

(1) We took a holistic approach for diagnosing PTSD among Rohingya refugees using a simple, yet powerful set of questionnaire. Here, we performed on-site data collection by overcoming common barriers in different aspects, such as language, confidence, belief, etc., through a judicious approach of inclusive interviewing.
(2) Besides, we used a low-cost, consumer-grade, portable EEG headset to examine the neurobiological characteristics of healthy Bangladeshi citizens as well as that of trauma-inflicted Rohingya refugees. To the best of our knowledge, this study is the first to explore the potential of EEG signals to diagnose PTSD in the scarce-resource context of refugees. We identified several neurobiological abnormalities associated with PTSD using this brain computer interface device, which corresponds to findings from previous literature in several cases along with having new findings. Moreover, we found association between EEG signal and a group of completely interconnected post-traumatic stress symptoms along with PTSD.
(3) Additionally, the attention and relaxation values available through our EEG headset enabled us to analyze PTSD related attention deficit and hyperarousal.
(4) Moreover, we took into account concepts from both reflective and formative models of PTSD to build a PTSD regulatory network. In this regard, our hypothesis was that some symptoms constitute PTSD (formative property) while some others reflect the underlying disorder (reflective property). To our knowledge, ours is the first to combine aspects from both reflective and formative models into a single hybrid model. Our model revealed several post-traumatic stress symptoms as key components to the etiology of underlying disorder, such as sleeping disorder, avoidance, feeling of nervousness, nightmare, etc.

(5) The key findings from both neurobiological abnormalities and underlying structure of PTSD provide potential directions for the diagnosis and treatment of PTSD. Since sleeping disorder emerged as the highly central symptom in PTSDRN, we hypothesise that targeting this symptom would result in potential remission of different post-traumatic stress symptoms and disorder to a greater extent.

2 METHODOLOGY OF OUR STUDY

Previous research indicates that resource limitation, differences in patterns of seeking help, ways of coping, inability to take time away from daily hurdles, etc., complicate the task of screening and treating mental health disorders of immigrants and refugees [16, 85, 86]. These already revealed findings influenced our choice of methodology in two ways. First, for qualitative measure of PTSD, we chose a simple yet comprehensive diagnostic tool. Second, for quantitative measure of PTSD, we chose a low-cost consumer-grade EEG device. Using this two-way methodology, we tried to figure out potential neurobiological markers of PTSD as well as to explore different models that could reflect possible interactions among different post-traumatic stress symptoms and PTSD.

2.1 Participants in Our Study and Coordination of the Interviews

To examine whether the mental and neurobiological status of Rohingya refugees differ from that of healthy individuals or not, we interviewed and collected EEG signals from 45 healthy Bangladeshi citizens (aged between $14-60$) who volunteered to participate in our research. They comprise the comparison group of our study. The data collection and interview took place in the premises of Bangladesh University of Engineering and Technology, Dhaka in December, 2017. These interview sessions were conducted in Bengali which is the mother tongue of both the interviewers and the participants of comparison group.

On the other hand, to collect data from our population of interest, i.e., Rohingya refugees, five of our authors visited Kutupalong refugee camp in Ukhia, Cox's Bazar. It is the world's largest reported refugee camp with an estimated population of about 886,778 refugees, majority of whom have migrated to Bangladesh after the violence escalated in 2016-17 in the Rakhaine state of Myanmar [145]. The permission of data collection was officially granted by District Commissioner (DC) of Cox's Bazar. Our interviewers, occasionally accompanied by camp officials, invited refugees within the camp-area to participate while they were engaged in their daily activities. Now, to build PTSD correlation networks of large effect size ($r = 0.50$), we needed to determine the required sample size for our analyses. For this purpose, we used pwr package available in R [28]. We found that at least 37 participants were required to create correlation networks of desired effect size at a minimum of 0.05 level of significance and 90% level of power. Again, to compare the neurobiological characteristics of refugee group with that of comparison group, we needed at least 34 participants in each group for 90% power at a minimum of 0.05 level of significance.

To meet the minimum requirement for sample sizes, initially, we invited 86 refugees at random within the camp-area. 71 of them (aged between $10-70$) turned up during the interview while others declined to participate, mostly due to their engagement in different activities or discomfort with the idea of being interviewed. The interviews were conducted at the camp registration office where most of the refugees register themselves as residents of different camps and therefore, the office was a familiar place for them. While conducting our interviews, we took permissions from the participants before collecting any data from them. The data was collected in January, 2018. The conversation mainly took place in Chittagonian dialect and Bengali. Since Rohingya dialect and Chittagonian dialect are closely related, it is commonly understood by refugees living in the camps [50]. Having home town in Chittagong, one of the female interviewers among us could fluently converse in Chittagonian dialect. It greatly helped us in overcoming the language barrier during the interview and engaging the participants in an interactive conversation. Besides, during the interviews, many participants were accompanied either by their relatives or 'majhi', the Rohingyas who are members of camp organizing committee and thus, treated as local leaders. Such presence of fellow familiar refugees during the interviews also boosted the confidence of many participants.

2.2 Diagnostic Tools

Many screening tools are currently available for evaluating trauma history and post-traumatic symptoms. Examples include MINI, IES, PTSD checklist, DTS, SPAN, CAPS, SCID, etc., [130–132, 164]. Some of them are in interview format and some are in the form of self-reports. Among the available screening tools, we decided to use Chittagonian translated version of ICD-10 PTSD module of MINI [71]. The main reasons behind adopting MINI are as follows:

(1) MINI offers a short inexpensive questionnaire compared to others that demand the participants to answer a lot of questions.
(2) It is easy to administer for its simplicity since the diagnosis of each symptom is coded with a simple 'yes' or 'no' response.
(3) MINI is less time-consuming with reported administration time of about 15 minutes compared to other diagnostic tools, which demand administration time ranging from $45 - 120$ minutes [171]. As reported in earlier work, refugees often tend to neglect sessions with long administrative time since they have to spend a substantial period of their day-to-day lives in facing various challenges [85].
(4) MINI is compatible with both ICD-10 and DSM-V criteria [164].
(5) The PTSD module of MINI is highly sensitive (0.85) and particularly capable of detecting high proportion of patients with PTSD [164]. It is useful in many psychiatric emergency settings where PTSD is under diagnosed.
(6) The PTSD module has high inter-rate reliability (Kappa statistic, $\kappa = 0.78$) [164].

With all these considerations, MINI appears as a particularly suitable tool for screening tests aimed at providing primary care in psychiatric emergency settings. Our Bengali translated version of MINI questionnaire consists of three screening questions, which if positively answered, are followed by two more diagnostic questions. A diagnosis of PTSD is recorded if the participant (after positively answering all screening questions) either responds positively about avoiding trauma-related stimuli or faces at least more than one symptom associated with trauma-related arousal and reactivity [71] (see supplementary for more details). We used the data collected from this interview to develop various models of the underlying psychiatric disorder. For all the models we built for our analysis, we used the following abbreviations to designate various PTSD symptoms:

Table 1. Abbreviated terms for different post-traumatic stress symptoms used in PTSDCN (Section 3.4), PTSDPCN (Section 3.5), PTSDRN (Section 3.6), centrality measurement (Figure 7), and relative EEG power analysis (Section 3.7).

Abbreviation	Symptom	Abbreviation	Symptom
Dst	Feeling distressed	Ngh	Nightmare
Avd	Avoiding trauma-related stimuli including trauma-related thoughts or feelings and reminders	Rcl	Inability to recall key features of trauma
Slp	Difficulty in sleeping	Irr	Irritability or outbursts of anger
Cnc	Difficulty in concentrating	Nrv	Feeling nervous or being on guard

2.3 EEG Recordings, Pre-processing and Data Analysis

Before collecting electroencephalogram (EEG) signals from Rohingya refugees, we asked for permission from Army authority of the camp. At first they denied since they thought that, in case some participant refugee suffered from headache or any other problem, he/she might attribute it to the use of EEG headset during our interviews. Thus, according to their understanding, such events, in case they happen, might spread rumors. However, later, we received official permission to use the EEG headset from the Refugee Relief and Repatriation Commission (RRRC) under Ministry of Disaster Management and Relief, Government of Bangladesh. All EEG signals were recorded using MindWave mobile headset developed by NeuroSky (Figure 1) [124]. Among various available brain-computer interfaces, MindWave is the most affordable for its comparatively cheaper price ($112.00) [124]. Therefore, we preferred this low-cost, easy-to-control, and wearable package considering the scarce-resource context of the refugees. This headset has only one main electrode that needs to be placed at FP1 site and a reference electrode that needs to be placed near the ear following the international $10-20$ system of EEG electrodes placement [101]. As a result, it requires less preparation time and remains easy to control [44].

Fig. 1. A glimpse of the interview session organized for Rohingya refugees. One of the interviewers is setting NeuroSky MindWave mobile EEG headset on the head of a participant.

The NeuroSky device comes with ThinkGear technology that collects brain-wave signals through attached sensors, amplifies them, removes ambient noise and muscle movements, and processes all of them on its chip. We used the processed ASIC_EEG_POWER_INT values generated by the device at 1 Hz sampling rate. It is the ASIC equivalent of EEG power and it produces outputs for eight commonly recognized brainwaves, namely delta ($0.5-2.75$ Hz), theta ($3.5-6.75$ Hz), low alpha ($7.5-9.25$ Hz), high alpha ($10-11.75$ Hz), low beta ($13-16.75$ Hz), high beta ($18-29.75$ Hz), low gamma ($31-39.75$ Hz), and mid gamma ($41-49.75$ Hz). These values have no units and are only meaningful when compared to each other and to themselves. Besides, NeuroSky includes eSense^{TM} proprietary algorithm [122] for characterizing mental states such as attention and relaxation. The meter reports the status of these mental states on a relative eSense scale of 1 to 100. On this scale, a value of $1-20$ indicates 'strongly lowered' levels of eSense, $20-40$ denotes 'reduced' levels, $40-60$ represents 'neutral' levels, $60-80$ refers to 'slightly elevated' levels, and values from $80-100$ are considered as 'strongly elevated' levels. The 'neutral' levels on this scale (values from 40 – 60) are similar in notion to 'baselines' that are established in conventional EEG measurement techniques [122]. With respect to these 'baseline' values, a score greater than 'neutral' levels may be interpreted as that the levels of attention or meditation are higher than normal for a given person. On the other hand, any score below 'neutral' levels may indicate states of distraction, agitation, or abnormality, according to the opposite of each eSense [122]. These relative eSense values have been successfully used previously to measure users' attention and meditation levels through various standardized tests [37]. Therefore, these values are particularly useful for assessing cognitive deficits such as concentration problem, feeling of nervousness, etc., among PTSD patients.

For our analysis, we collected background EEG activity from both comparison group and refugee group for different sets of activities. For the comparison group (Bangladeshi citizens), we collected EEG data while they were (i) talking (casual conversation) (n = 26), (ii) at rest (n = 9), and (iii) at calm sitting positions (n = 30). For the Rohingya refugees, we collected EEG data while they were (i) talking (casual conversation) (n = 51), (ii) recalling and sharing the trauma events they experienced (evoking trauma related memories) (n = 54), and (iii) drawing pictures of their past and expected future homes (n = 45). The subset of participants involved at different activities were not mutually exclusive. Some participants took part in all three activities while some participated in one or two. Therefore, for some participants we had EEG data for all three activities and for some we had EEG data for one or two activities. However, no participant from either refugee group or comparison group reported any discomfort or trouble while using the EEG headset.

We transferred the data collected through EEG headset to laptops via Bluetooth connection. Though we did not lose any data from comparison group, EEG signals of 8 Rohingya refugees were lost due to some technical difficulties during data collection. Since our comparison group and refugee group had only one activity in common, talking (casual conversation, such as, introducing themselves and providing various demographic information), we used EEG signals collected during this phase for further analysis and comparison between these two groups. However, the signals collected for each individual and each activity varied in terms of duration. Therefore, for each individual and each activity we considered EEG power values of 40 seconds duration by truncating the signals at the onset and end of each activity. This further resulted in 43 samples of EEG activity while talking, 49 samples of EEG activity while recalling trauma events, and all 45 samples of EEG activity while drawing from the refugee group. From comparison group, we finally retained 25 samples of EEG activity while talking, 8 samples of EEG activity while they were at rest, and all the 30 samples of EEG activity while they were at calm sitting positions.

2.4 Challenges during Data Collection

The participants in our comparison group were recruited from the campus of Bangladesh University of Engineering and Technology and its surrounding neighborhoods. We randomly selected from the people who volunteered to participate in our study and did not go through any traumatic experiences in the past. All the volunteers co-operated thoroughly during the interview and data collection sessions. As a result, we hardly faced any difficulties with them. However, that was not the case with the Rohingya refugees.

The refugees in our study were recruited from camp area via random sampling. Initially many refugees were not interested in talking to us or sharing their experiences. In the camp, there were some Rohingyas who migrated to Bangladesh years ago and they were more willing to talk to us than the newly migrated ones. However, neither all the refugees whom we approached agreed to participate nor did everyone attend, who gave their consent for the interview. Day to day struggle, look out for work, foods, and scarcity of resources made many of them feel reluctant because they might not have found it worthwhile to spend their time in an interview rather than utilizing it to meet their own needs. Therefore, to avoid the problems associated with non-response and refusal for participation, we recruited more participants than that was actually necessary to meet the power requirements of the study.

We took informed consent from all the participants before collecting any data from them. Since most of the refugees in our sample were not much literate, we administered an oral interview using MINI diagnostic tool rather than simply handing out questionnaires to them. During the interview, some of them appeared confused and uncomfortable with the idea of being interviewed. Therefore, to encourage their continuing participation, our interviewers engaged them in a heartfelt conversation regarding their lives and ordeals both in Myanmar and refugee camp. This helped the participants to overcome their initial uneasiness and open up themselves. Moreover, to build rapport, we offered chocolates and other light food items to the children who accompanied their parents/ other participants during the interview.

Now, during the interviews, some participants became intensely emotional while recalling their traumatic experiences in Myanmar and soon strayed from the course of the interview. Some broke into tears, whereas, some elderly participants turned a bit angry while describing how they were forced to leave behind their homes and all their belongings. As a result, some interviews took more time than others. However, our interviewers ensured that the participants do not indulge too much in discussing distressing trauma related memories and remain on track so that the interview turns out to be an overall positive experience for them.

On the other hand, the use of EEG headset introduced some new challenges in our study. As we have already mentioned, the Army authority of the camp initially denied us to give permission to use the device. Though later we received an official permission from RRRC, our difficulties did not end here. While collecting data via EEG headset, some participants co-operated thoroughly, whereas, some participants appeared scared with the idea of wearing the device. Some of them even thought that using the device would let us learn what they were thinking and this made them feel really nervous. Therefore, we had to assure them that this was not the case. We explained them that the device would do them no harm and took their informed consent before collecting any data. In some cases, the interviewers themselves put on the EEG headset to assure the participants that the device will not cause them any harm. In other cases, the interviewers demonstrated the use of the device while collecting EEG signal from a participant. This convinced the fellow refugees and after being properly acknowledged in these ways, no participants quit the interview and they co-operated through the rest of the data collection session.

Finally, at the end of the interview, some randomly selected participants were asked to draw their past and expected future homes. It was really difficult to communicate this task to them. As they are currently living stateless and homeless, the idea of drawing their expected future homes might have sounded quite foreign to them.

2.5 Statistical Analysis

Despite all the difficulties faced during participant recruitment to data collection, we were able to manage substantial amount of data to conduct the qualitative and quantitative analyses of our study. We performed different statistical analyses over the collected data using R version 3.5.2 [142]. Here, we conducted the following analyses:

(1) Earlier studies identified that different socio-demographic factors, such as, age, sex, level of education, employment status, etc., work as significant mediators of PTSD symptoms [24, 121, 150, 172, 175]. Therefore, to identify whether the demographic characteristics and psychiatric symptoms of Rohingya refugees have any relation or not, we used chi-squared test (chisq.test()) available in R stats package [142] along with Cramer's V test (cramersV()) from lsr package [118] in R to measure the goodness of association in case any statistically significant relation is observed.
(2) Besides the demographic characteristics, trauma events emerged as a significant contributor to PTSD among different groups of trauma survivors [24, 111–113, 158, 175]. Therefore, to measure whether trauma

history has any effect on post-traumatic stress symptoms score and psychiatric status of Rohingya refugees we used t-test (t.test()) and general linear model (glm()) available in R stats package [142].

(3) Now, to analyze the underlying structure of PTSD and its various symptoms we developed various hybrid models. We built all the models using qgraph() package available in R [46]. To build the simplest of models, PTSD correlation network (PTSDCN), we used Pearson's correlation test (corr.test()) from R package psych [148] to identify how different symptoms and PTSD might correlate with one another and whether there exists any statistically significant association ($r >= 0.25$ and $P < 0.05$) between them or not.

(4) Since PTSDCN fails to discern between direct and indirect association among different symptoms and PTSD, we developed PTSD partial correlation network (PTSDPCN) to account for this. To build this network, we used partial correlation which measures the degree of association between two entities while controlling the effects of other entities within the system. For this purpose, we used pcorr.test() method available in R package ppcor [84] to measure partial correlations among different symptoms and disorder.

(5) However, both PTSDCN and PTSDPCN fail to provide any useful cue about the direction of association between different symptoms and PTSD. Therefore, we developed a Bayesian regulatory network, called PTSDRN, to capture the underlying structure of PTSD and its symptoms. In this regard, we used bnlearn() package available in R [159]. To measure the degree of association between different symptoms and PTSD, we used greedy hill-climbing search (hc()) along with Bayesian Dirichlet sparse score, as it is less sensitive to model's hyperparameter values and appears to provide better accuracy in case of structure learning [160].

(6) We also tried to identify whether there exists any group or cluster of PTSD symptoms that affect one another or not. Therefore, we checked if there exists any maximal clique, the group of completely interconnected symptoms, in our developed models of PTSDCN and PTSDPCN. In this regard, we used two implementations of Bron-Kerbosch's maximal clique finding algorithm [90, 125] on the models of PTSDCN and PTSDPCN.

(7) Apart from this, we wanted to see which symptoms play important role in the underlying structure and dynamics of PTSD. For this, we used measure of centrality to identify the influential symptoms in our developed models of PTSDPCN and PTSDRN. We used centrality() method available in R package qgraph [46] to calculate different measures of centrality, such as, strength and betweenness, for each symptom in PTSDPCN and PTSDRN.

(8) Besides all these qualitative data on mental health status of Rohingya refugees, we also had temporal data of background EEG activity of Rohingya refugees and comparison group of healthy Bangladeshi individuals. Prior to conducting any test on this data, we performed Shapiro-Wilk normality test (shapiro.test()) available in R stats package [142] to check whether the distribution of background EEG activity differed significantly from that of normal distribution. Since we found no significant difference, we decided to perform parametric test, such as, t-test or F-test on this data for further analysis.

(9) Since we had EEG data of two different groups of people (comparison group and refugee group), we wanted to check whether the background EEG activity of PTSD-diagnosed Rohingya refugees varied significantly from that of healthy individuals or not. For this purpose, we used F-test (var.test()) and t-test (t.test()) from R stats package [142] to compare EEG activity between these two groups of people.

(10) Besides EEG data, NeuroSky MindWave mobile produces attention and relaxation values of an individual during different activities. Therefore, we wanted to check whether the attention and relaxation values of the refugees, who faced difficulty in concentrating and constantly felt nervous or on guard, differed significantly from that of other participants who faced none of these problems. For this comparison, we used t-test (t.test()) available in R stats package [142].

(11) Now, every time we compared data, whether qualitative or quantitative, among different groups of people we actually tested multiple hypotheses in each case. Therefore, to control false discovery rate for multiple tests we used Benjamini-Hochberg correction [103].

3 RESULTS

We interviewed a total of 116 people including both Rohingya refugees as well as Bangladeshi citizens. We were able to collect EEG signals from 108 people among them. We present the psycho-social and neurobiological characteristics obtained from these groups of people in detail.

3.1 Participant Profile

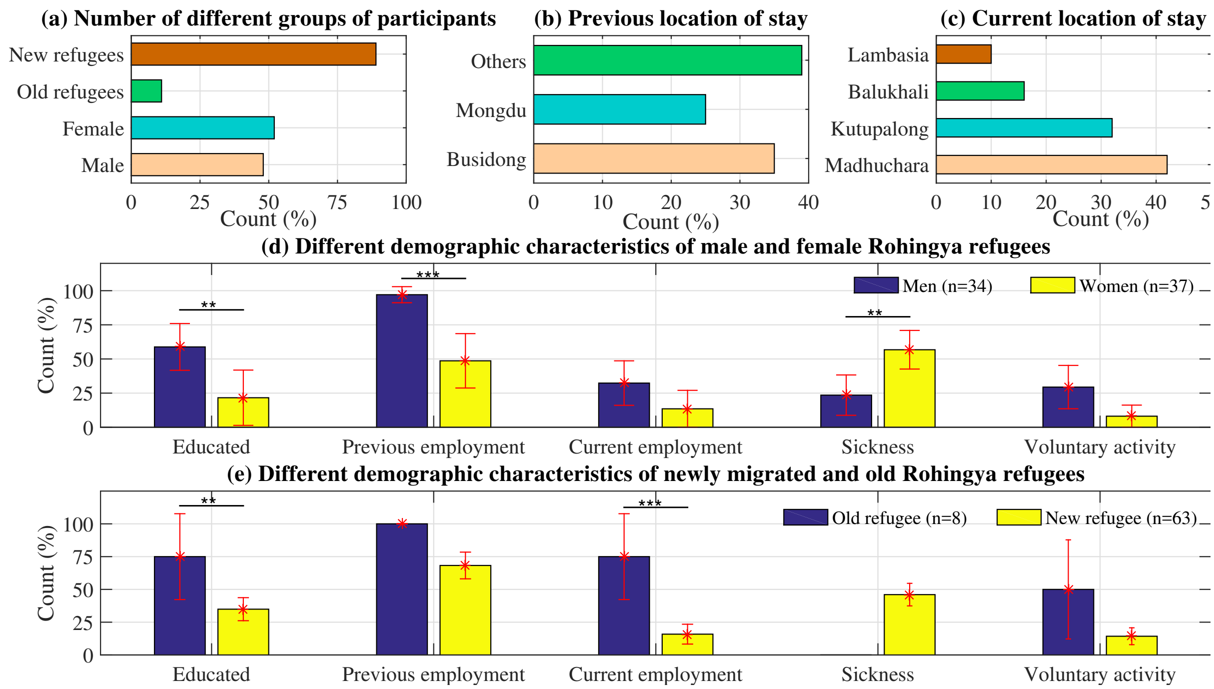


Fig. 2. Demographic and socio-economic characteristics of the participant Rohingya refugees. Bars show mean percentage of participants under different demographic characteristics. Error bars represent 95% confidence interval from the means of the response of the participants for educational status, employment status, post-migration activities, and health condition. Statistically significant difference (Benjamini-Hochberg corrected [103]) between the response of different subgroups of refugees is denoted by asterisks (** indicates $P < 0.01$, *** indicates $P < 0.001$).

Among the 45 Bangladeshi citizens who voluntarily participated in our study, 32 (71.1%) were male and 13 (28.9%) were female. The mean age of these participants was 25.77 years (SD = 10.77 years). Among the 71 Rohingya refugees, 37 (52%) were female and 34 (48%) were male (Figure 2(a)). They migrated to Bangladesh mainly from Busidong (35%) and Mongdu (25%) area of the Rakhaine state of Myanmar (Figure 2(b)). During this study, most of them were living in Madhuchara (42%) and Kutupalong area (32%) of Cox's Bazar, Bangladesh (Figure 2(c)). The mean age of all the participant refugees was 30.15 years (SD = 13.37 years). Illiteracy rate was way too high (60.6%) among this refugee group (Figure 2 (d, e)). Among them, 70% were previously employed in Myanmar, whereas, currently in Bangladesh, their employment rate is only around 23% (Figure 2 (d, e)). More than 800,000 Rohingyas are currently living in Bangladesh and among them only around 30,000 have official UNHCR refugee cards [150]. Without the card, unofficial migrants are not allowed to work or pursue education. Movement restrictions within refugee camp as well as unavailability of legal work permit contributed to their high unemployment rate here in Bangladesh. Besides such socio-economic disadvantages, their lives have been rife with various health risks [70]. About 41% refugees in our sample reported sickness and health-related problems (Figure 2 (d, e)). Most of them reported being injured and suffering from pain owing to pre-migration torture, accidents, and hazards during exodus. Others reported to suffer from stomach problems, gastric pain, fever, jaundice, asthma, hypertension, etc. Despite all these difficulties, the refugees are trying their best to assimilate themselves into their current surroundings. Many refugees are working as volunteers in close cooperation with various humanitarian agencies to help the huge influx of refugees cope with the camp environment [56]. About 18% refugees in our sample reported to have worked as volunteers within the camp area (Figure 2 (d, e)).

When we analyzed different socio-economic characteristics of male and female refugees, we found that educational qualifications ($\chi^2(3) = 12.06$, P = 0.007), previous employment status in Myanmar ($\chi^2(1) = 18.2$, P = 1.99×10^{-5}), and reported status of sickness ($\chi^2(1) = 6.8$, P = 0.009) varied significantly among them (Figure 2(d)). Such differences can be explained from the perspectives of social and cultural practices of Rohingya Muslims. Within their social structure, women are expected to remain inside home and take up traditional gender roles of housework and childcare, whereas, men are more present in public spheres [150]. For instance, among the participant refugees in our sample, illiteracy rate among women was as high as 78% compared to that of men (44%) (Figure 2(d)). Among the participant female refugees, none received higher education while 6% of male refugees continued their study beyond secondary level and one even completed his graduation. As expected within such social structure, men become the breadwinners while women are discouraged to work outside. During this interview, 20 female refugees (54%) reported of being unemployed in Myanmar compared to only one such man (3%) (Figure 2(d)). The male refugees in our sample were associated with farming (41.2%), teaching (11.8%), small businesses (8.8%), or NGO jobs (2.9%) during their stay in Myanmar, whereas, women were found to be less involved in income-generating activities. 46% female refugees reported being involved in housekeeping activities and another 27% reported to help their husbands in farming. Even after migration, participation of women in voluntary (8%) and income-generating activities (14%) was still less compared to that of men (32%) (Figure 2(d)).

Besides, among the participant refugees, there were 63 (88.7%) newly arrived refugees (Figure 2(a)) whose mean staying period in Bangladesh was 4.23 months (SD = 1.35 months). On the contrary, there were 8 (11.3%) participants who migrated to Bangladesh long ago, with mean migration period of 15 years (SD = 8.16 years). When analyzed, we found that the status of newly migrated and old Rohingya refugees varied significantly in terms of educational qualifications ($\chi^2(3) = 13.42$, P = 0.004) and current employment status ($\chi^2(1) = 11.03$, P = 0.0008) in Bangladesh (Figure 2(e)). In our sample, out of 8 old Rohingya refugees, 2 (25%) were uneducated, 4 (50%) received up to some level of primary education, 1 (12.5%) received some level of secondary education, and 1 (12.5%) even completed his graduation. Among the newly migrated 63 refugees, 41 (65%) were uneducated, 11 (17.5%) received some level of primary education, another 11 (17.5%) received some level of secondary education, and none studied beyond secondary level. Now, comparing the age and migration period of the old Rohingya refugees, we found that the one who completed his graduation were born here in Bangladesh and received his education here, whereas, others migrated at an older age and therefore, it is more likely that they received their education over there in Myanmar. This is because the existing education program (both primary and secondary) within camp area in Bangladesh has been extended only for Rohingya children, not for their adults [140]. Same goes for the newly migrated refugees - majority of whom were adults and who came to Bangladesh from Myanmar just a few months ago. The existing racial segregation and barriers to receive education, as part of ethnic cleansing package in Myanmar, have engendered lower literacy rate among these Rohingya Muslims while living in Myanmar [25].

On the other hand, among the 8 old Rohingya refugees in our sample, only 2 (25%) were unemployed and the others were involved in day labor, fishing, farming, tailoring, etc., within the camp area. However, the majority of the newly migrated refugees (84%) were still unemployed. The reason behind current higher employment rate among the old Rohingya refugees is that, since they migrated long ago before the current influx of refugees, they could seek small job opportunities within the camp area under different government and non-government organizations. Findings from an earlier report state that these old Rohingya refugees who migrated to Bangladesh back in 1991 – 92 usually worked as laborers in the forest, salt factories, fishing industry, farm fields, and construction sites [163]. They also worked in restaurants, ran small shops, pulled rickshaw, or worked as porters. Even within the registered camp area, various activities were organized to maintain their livelihood including vocational training in tailoring, knitting floor mats, soap production, carpentry, and repairing mobile phones and rickshaws [163]. However, the recent influx of large numbers of refugees has jeopardized the situation resulting in a handful of job opportunities, unavailability of legal work permit for refugees, hostile attitude towards them from the host community in some cases, and so on.

3.2 Trauma Events

After collecting initial demographic information, we prompted the refugees to talk about their experiences in Myanmar. During our interactive conversation, many of them shared their terrible experiences of violence and abuse in Myanmar. A few of the shared experiences are as follows:

> "My brothers have been slaughtered. I still feel afraid whenever I think of those days. I can hardly sleep now with those thoughts in my mind."
>
> — A 28-year-old female refugee, Kutupalong

> "The military set fire on my house and burnt alive one of my children. Even when I sleep, I still see my house on fire."
>
> — A 40-year-old male refugee, Madhuchara

> "They killed my brother-in-laws. They burnt our house. Whenever I think about my country, I feel sad. Those events haunt me, they frighten me. I cannot but feel angry for whatever happened to us. It feels like there is no justice for us."
>
> — A 40-year-old female refugee, Kutupalong

> "The military did not allow us to visit the bazaar to buy anything. We needed permission from them to go anywhere. They killed my cousins. I feel angry whenever I remember these things. Here, I have no work. I cannot see any future for us."
>
> — A 28-year-old male refugee, Madhuchara

From their responses and using the list of trauma events as mentioned in Harvard Trauma Questionnaire [68], we compiled a list of 12 notable trauma events (Table 2) experienced by the refugees. Among 71 participants, 63 (88.7%) refugees (89% of women and 88% of men) reported experiencing at least one violence during their stay in Myanmar. The mean number of traumatic events directly experienced was 1.94 (SD = 1.37). Analyzing the responses of the individuals, we found that the female refugees experienced significantly more trauma events than the male refugees ($t(68) = 2.162$, $P = 0.017$). This happens as women fall victims to sexual violence, harassment, and other forms of torture more frequently than men [193]. However, it is worth mentioning that the reported status of sexual violence in our sample is too low compared to that of UNHCR report [138]. The underlying reasons of this happening lie with deep-rooted stigma and shame that keep many women from revealing their ordeal. Existence of such stigma and feelings of shame and guilt among refugee women have been addressed in previous literature [76, 115]. Due to persisting stigma within patriarchal and misogynist culture and in the fear of social and gender-shaming, female victims hesitate to open up about their traumas and hardly report the abuses they suffered from.

Table 2. Reported exposure to pre-migration trauma events among the Rohingya refugees.

Index	Trauma categories	Count	%
1	Beating	5	7
2	Physical injury	30	42.3
3	Serious physical injury of family member/ friend	3	4.2
4	Murder of spouse	12	16.9
5	Murder of child	10	14.1
6	Murder of other family member/ friend	48	67.6
7	Forced to betray family member/ friend placing them at risk of death or injury	1	1.4
8	Combat situation	2	2.8
9	Imprisonment	1	1.4
10	Abduction	2	2.8
11	Destruction of personal property	4	5.6
12	Rape	2	4.8

Cases	Men (% of men)	Women (% of women)	Total (% of total refugees)
No trauma	4 (11.8%)	4 (10.2%)	8 (11.2%)
1 − 3 traumas	27 (79.4%)	30 (81.1%)	57 (80.3%)
> 3 traumas	3 (8.8%)	3 (8.1%)	6 (8.5%)
At least one violence	30 (88%)	33 (89.2%)	63 (88.7%)

3.3 Post-traumatic Stress Symptoms

No Bangladeshi participants in our study passed the screening questions of PTSD module of MINI. Therefore, only the responses of participant refugees have been summarized in Figure 3(a). Out of 71 refugees, 64 (90.1%) reported having been exposed to severe traumatic events (Question 1); 69 (97%) refugees reported remembering these events in a distressing way and having nightmares (Question 2); 57 refugees (80%) confirmed that they tried to avoid anything that reminded them of those incidents (Question 3). Among the 54 participants who answered the screening questions positively, 49 were diagnosed with a probable case of PTSD (69% of total 71 refugees). Among this PTSD-diagnosed refugee group, 28 (76% of total women) were women and 21 (62% of total men) were men, 44 were (69.8% of new refugees) newly migrated, and 5 refugees (62.5% of old refugees) migrated long ago (Figure 3(b)). However, we did not find any significant difference in the post-traumatic stress symptoms and prevalence of PTSD among different refugee subgroups, i.e., male vs. female or old vs. new refugees. Even when we performed simultaneous multiple regression, we did not find any significant correlation between the prevalence of PTSD and other demographic factors, such as, age, gender, educational status, current employment status, migration period, voluntary activities, and reported status of sickness. Only trauma history (number of trauma events experienced by the refugees) showed significant association (estimate = 0.123, P = 0.0051) with prevalence of PTSD. This is because the number of trauma events significantly correlates (r = 0.434, P = 0.0002) with the post-traumatic stress symptoms score of the individuals (Figure 4). This score is basically the total number of post-traumatic stress symptoms experienced by each individual. In this figure, the size of the marker at location (x, y) is proportional to the number of people who experienced x trauma events and had a MINI score of y. This correlation conforms to previous findings of dose-effect relationship between trauma history and PTSD symptoms [112, 113]. This indicates that cumulative exposure to trauma is associated with psychiatric symptoms of PTSD. However, when we looked for further association between different types of trauma events (Table 2) and PTSD symptoms, we found that the type of trauma events had no significant influence on the response of post-traumatic stress symptoms. Therefore, we can assume that the effect of trauma exposure is meaningful only when their cumulative effect is considered compared to the effects of individual trauma types.

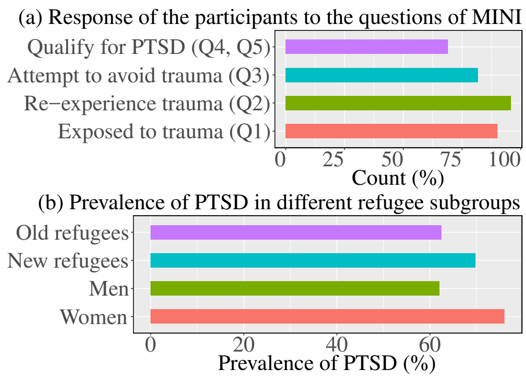


Fig. 3. A measure of prevalence of PTSD within different subgroups of Rohingya refugees based on their responses to MINI questionnaire.

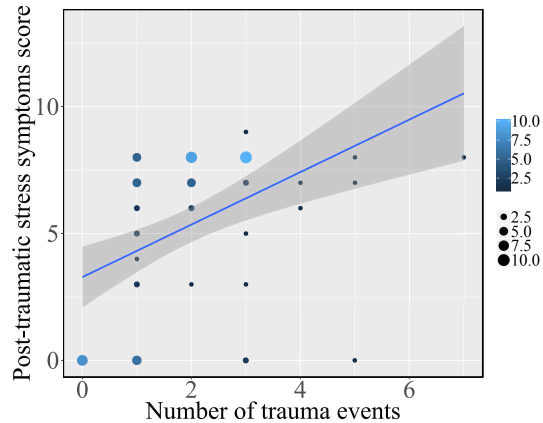


Fig. 4. Association between number of traumatic events and severity of PTSD symptoms.

3.4 PTSD Correlation Network (PTSDCN)

Since the trauma events affect the development of PTSD [31] and the trauma history significantly correlates with post-traumatic stress symptom scores of PTSD (Figure 4), we went further to look into the types of associations between the symptoms and the disorder. Our first approach towards this was to build a PTSD correlation network (PTSDCN) based on significant correlations between the symptoms themselves and their associations with PTSD. We calculated the correlation matrix of PTSD and its symptoms (Table 3), and used it to build a correlation network using qgraph package available in R [46]. This resulted in an undirected graph as shown in Figure 5(a). The edges in this network reflect Benjamini-Hochberg corrected significant correlations between two entities ($r >= 0.25$ and $P < 0.05$), however, they ignore the direction of associations between them. They just imply the mere existence of associations (either direct or indirect) and the magnitudes of those associations. For example, the width and shade of the edges represent the strength of association between two correlated entities. The stronger the correlation between two entities, the wider and darker the edge between them.

As evident from the correlation network (Figure 5(a)), post-traumatic stress symptoms are strongly interconnected among trauma-inflicted Rohingya refugees. It revealed strong positive correlations (green edges) between PTSD and other psychiatric symptoms except for feeling distressed and inability to recall trauma events (Table 3). In fact, the strongest association appeared between ($r = 0.74$) PTSD and avoidance of trauma related stimuli. Besides, the symptoms themselves were interrelated. The only negative correlation (red edge) in this network appeared between nightmare and trouble in recalling trauma events (Figure 5). The associations between sleeping disorder, irritability or outbursts of anger, difficulty in concentrating, and feeling of nervousness conform to clinical observations as embodied in the DSM-V clusters of trauma-related arousal and reactivity [133].

Further, when we looked for maximal cliques in this network, we found two maximal cliques (blue subgraphs in Figure 5(b and c)). One of them consists of six entities: five symptoms and the disorder itself (Figure 5(b)), whereas, the other consists of five entities: PTSD along with four other symptoms (Figure 5(c)). The entities in these groups are completely interconnected, i.e., each component is associated with every other component in the same group. The group consisting of six entities, i.e., PTSD, avoidance, difficulty in sleeping, irritability,

Table 3. Bivariate correlations among PTSD and its various symptoms. Asterisks represent Benjamini-Hochberg corrected [103] statistically significant correlation between two entities (* indicates P < 0.05, ** indicates P < 0.01, and *** indicates P < 0.001).

Category	PTSD	Dst	Avd	Slp	Cnc	Ngh	Rcl	Irr	Nrv
Dst	0.16								
Avd	0.74***	0.248							
Slp	0.68***	0.15	0.39***						
Cnc	0.57***	0.28*	0.36**	0.69***					
Ngh	0.38**	0.31*	0.19	0.33**	0.41***				
Rcl	-0.08	-0.17	-0.19	-0.16	-0.14	-0.38**			
Irr	0.43***	0.25	0.31**	0.44***	0.32**	0.22	-0.11		
Nrv	0.59***	0.04	0.28*	0.61***	0.43***	0.5***	-0.24	0.31**	

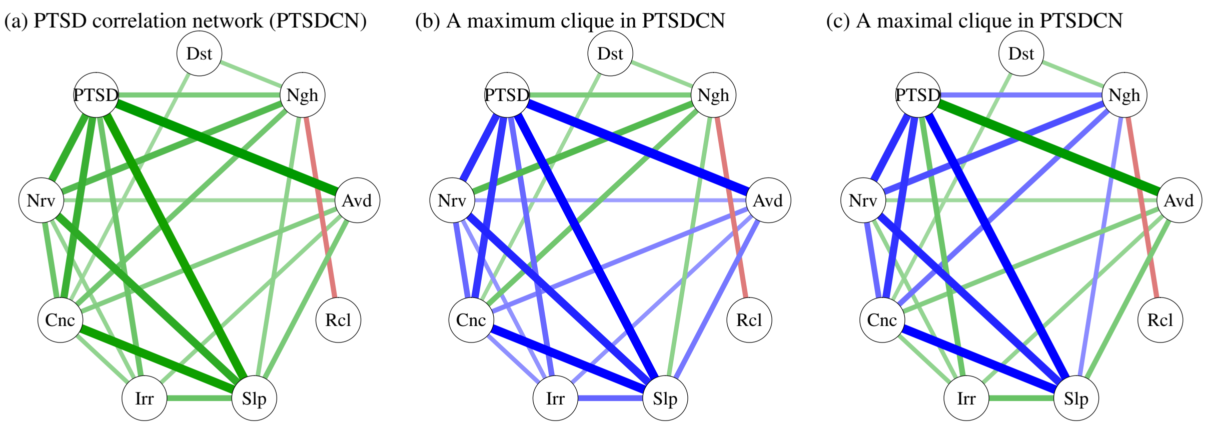


Fig. 5. A simple PTSD correlation network (PTSDCN) based on Benjamini-Hochberg corrected significant (r >= 0.25 and P < 0.05) bivariate correlations between post-traumatic stress symptoms and the disorder. The blue-colored subgraphs in Figure (b) and (c) represent two maximal cliques of completely interconnected and strongly correlated entities within the correlation network. The maximal clique in Figure (b) is also a maximum clique.

difficulty in concentrating, and feeling of nervousness also forms the maximum clique in our developed model of PTSDCN (Figure 5(b)). This maximum clique represents the largest possible chain of interactions among different psychiatric symptoms and PTSD based on empirical data on mental health status of Rohingya refugees. According to DSM-5 criteria of PTSD [133], this maximum clique successfully grouped the symptoms associated with trauma-related arousal and reactivity, and also showed their associations with other post-traumatic stress symptoms and PTSD. This maximum clique reveals the largest possible subset of different psychiatric symptoms that correlate among themselves and also with PTSD. Moreover, it is evident from Figure 5(b) that this group contains some of the strongly correlated entities within the network, such as, correlation between PTSD and other post-traumatic stress symptoms, e.g., avoidance of trauma-related stimuli, sleeping disorder, difficulty in concentrating, and so on. Besides, this maximum clique is also a maximal clique because if we try to include one more symptom within this completely inter-connected subnetwork, we will lose complete interaction among all participating components.

Moreover, the correlation network contains another maximal clique (Figure 5(c)), which includes four post-traumatic stress symptoms (i.e., nightmare, difficulty in sleeping, difficulty in concentrating, feeling nervous) and PTSD itself. Like maximum clique, it also captures some of the strongly correlated entities within the network, such as correlation between sleeping disorder and PTSD along with other psychiatric symptoms, e.g., difficulty in concentrating, feeling nervous, etc. Such maximal cliques encode groups of completely interconnected components that have developed a self-contained interaction or feedback system among themselves. Adding any extra component violates this property, i.e., spoils the harmony of self-contained correlations among the entities in the group. Therefore, we can assume that these strongly correlated entities within maximum clique and maximal clique will significantly contribute to our understanding of the underlying hierarchy of PTSD.

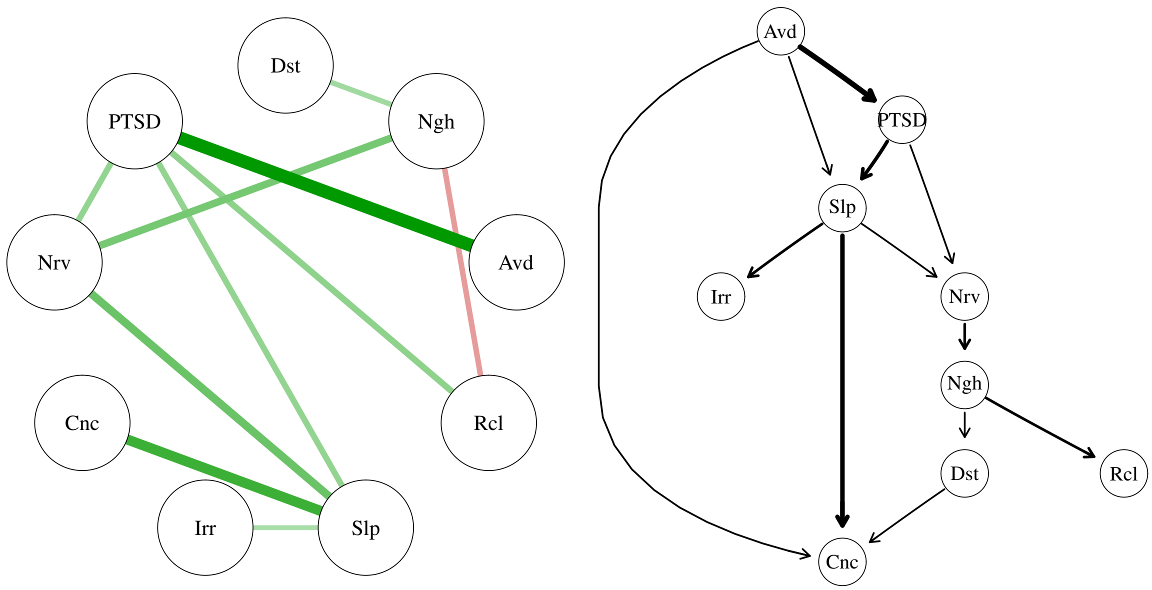
3.5 PTSD Partial Correlation Network (PTSDPCN)

As we have mentioned earlier, PTSDCN does not capture the direction of association between two symptoms. Moreover, in PTSDCN, some associations may arise between two components even if there is no direct interaction between them. This happens when both components are induced by another entity, i.e., their expressions are controlled by a third entity. For example, two entities B and C might appear to be correlated with one another even if there is no direct interaction between them. This happens when a third entity A affects both B and C. Or, it might be the case that A works as a mediator between B and C where B affects A directly which in turn affects C. However, there is no direct interaction between B and C. Here, in any case B and C would correlate with A. If we do not take into account the effect of their correlation with A, then B and C might appear to be correlated with one another even if there exists no direct interaction between them. Therefore, PTSD partial correlation network (PTSDPCN) might be of particular interest where edges reflect direct association between two entities after one has statistically controlled the effects of all other entities in the network. Accordingly, we calculated partial correlation matrix of PTSD and its different symptoms (Table 4) and used it to build PTSDPCN using qgraph package available in R [46]. It is readily observable from the table that PTSD is strongly correlated with symptoms, such as avoidance and difficulty in recalling trauma events, whereas, moderately associated with sleeping disorder and feeling of nervousness.

Table 4. Partial correlations among PTSD and its various symptoms. Asterisks represent statistically significant correlation between two entities where the effects of other entities have been statistically controlled (* indicates $P < 0.05$, ** indicates $P < 0.01$, and *** indicates $P < 0.001$).

Category	PTSD	Dst	Avd	Slp	Cnc	Ngh	Rcl	Irr	Nrv
Dst	-0.14								
Avd	0.74***	0.16							
Slp	0.31*	-0.01	0.13						
Cnc	0.11	0.16	0.1	0.57***					
Ngh	0.22	0.27*	-0.22	-0.19	0.21				
Rcl	0.33**	-0.01	-0.12	-0.12	0.04	-0.28*			
Irr	0.15	0.2	0.13	0.25*	-0.06	-0.02	-0.04		
Nrv	0.31*	-0.14	0.07	0.44***	-0.07	0.4**	-0.15	0.003	

The PTSDPCN derived from the post-traumatic stress symptoms of Rohingya refugees appears in Figure 6(a). The edges in this network reflect statistically significant partial correlations ($r >= 0.25$ and $P < 0.05$) among different entities. The stronger the partial correlations, the wider and darker the edges. Now, it is evident from Figure 6(a) that PTSDPCN is less dense, i.e., contains fewer edges than PTSDCN (Figure 5). This is because the edges in PTSDPCN reflect only direct associations between entities, whereas, the edges in PTSDCN may reflect both direct and indirect associations.



(a) PTSD partial correlation netowrk

(b) PTSD regulatory network

Fig. 6. Different networks depicting the relationship between PTSD and its symptoms. Figure (a) represents PTSD partial correlation network (PTSDPCN) based on Benjamini-Hochberg corrected significant partial correlations (r >= 0.25 and P < 0.05) among different entities. Figure (b) represents PTSD regulatory network (PTSDRN) based on Bayesian Inference of post-traumatic stress symptoms of Rohingya refugees.

Significant positive correlations (green edge) appeared between PTSD and avoidance, sleeping disorder, difficulty in recalling trauma events, and feeling of nervousness. If we compare this structure to that of PTSDCN (Figure 5), we can see that the correlation that appeared between PTSD and other two symptoms, i.e., irritation and nightmares in PTSDCN, are most likely caused by indirect associations. For instance, in case of irritability, sleeping disorder might have worked as an intermediary between PTSD and this symptom, because difficulty in sleeping is directly correlated with both PTSD and irritability or outbursts of anger (Table 4). On the other hand, both trouble in recalling trauma events and feeling of nervousness might have contributed to the indirect association between PTSD and nightmares as observed in PTSDCN (Figure 5). This is because, both trouble in recalling trauma events and feeling of nervousness are directly associated with PTSD and nightmares as evident from their correlation in PTSDPCN. The same applies for the interactions among the symptoms themselves. For example, in PTSDCN, sleeping disorder appears to be significantly correlated with nightmares (Table 3). However, there is no direct association between them as suggested by PTSDPCN. The indirect association between them might have arisen from both of their direct association with feeling of nervousness (Table 4).

To measure the importance of symptoms in this network, we used centrality measurements, such as strength (Figure 7(a)) and betweenness (Figure 7(b)) of the symptoms. In a network, strength quantifies the overall weight of all interactions associated with a particular entity. Now, PTSDPCN is a weighted graph where edges reflect partial correlations among different entities and all the correlations are not of equal strength. Therefore, to account for which symptoms strongly interact with others in PTSDPCN, we took the sum of weights of all interactions associated with a particular symptom. On the other hand, betweenness measures the degree of influence of a particular symptom on the interactions among other entities. Sleeping disorder, feeling of nervousness, avoidance, and nightmare emerged as highly central symptoms. The importance of these symptoms is also evident from PTSDPCN (Figure 6(a)) where strong partial correlations appear among these symptoms and PTSD. Among them, sleeping disorder has the highest strength score (Figure 7(a)), i.e., the sum of correlations (weights) of all interactions (edges) involving sleeping disorder is maximum. Therefore, sleeping disorder appears to be more influential than others. Besides, it is the only post-traumatic stress symptom that is strongly correlated with PTSD and three other different symptoms (Figure 6(a)). It also has the highest betweenness score (Figure 7(b)), i.e., it is most likely to mediate the interactions among other symptoms and PTSD. For example, it connects symptoms, such as irritability or outbursts of anger, difficulty in concentrating, etc., to PTSD. This suggests that these symptoms might provide important prognosis for PTSD.

On the other hand, among the symptoms irritability had lowest positive strength score, as among all the partial correlations in PTSDPCN, it shared the weakest interaction with others (Table 4). Feeling of distress, avoidance, irritability, and difficulty in concentrating had zero betweenness score (Figure 7(b)) because they are correlated with only one entity (Figure 6(a)) and therefore, could not mediate the interaction among other entities. Finally, when we looked for maximum clique in this partial correlation network, we found only one containing PTSD and two highly central symptoms namely sleeping disorder and nervousness. These two symptoms have top two strength and betweenness scores in PTSDPCN (Figure 7(a, b)).

3.6 PTSD Regulatory Network (PTSDRN)

Though PTSDCN and PTSDPCN provide us the strength of association among different PTSD symptoms and the disorder, they fail to provide any account of the direction of these associations. Therefore, we developed a directed regulatory model of PTSD from the response of Rohingya refugees to the questions of MINI using bnlearn package available in R [159]. Figure 6(b) represents the PTSD regulatory network (PTSDRN) built from Bayesian inference of the post-traumatic stress symptoms of Rohingya refugees. This model reveals a complex structure of relationship among various PTSD symptoms and the disorder itself and enables us to infer the direction of several associations more securely. The thickness of the edges signifies the level of confidence that the prediction (and potentially causation) flows in the direction as depicted in the network. Several significant features get evident from this regulatory network, since we combined aspects from both reflective and formative models of PTSD. As we have mentioned earlier, reflective models assume that PTSD works as the underlying cause of all its symptoms which in turn makes the symptoms correlate with one another. While the formative model posits that the symptoms themselves constitute the disorder by working in direct, close interaction with one another. Now, these two contrasting viewpoints often fail to grasp the dynamics of PTSD through their simplistic concepts of purely causal and formative models of PTSD. Therefore, we tried to bridge the gap between two seemingly different concepts of PTSD by developing a hybrid model. Our initial assumption was that some symptoms interact with one another and eventually comprise PTSD while the disorder itself gives rise to some other symptoms. In this model, any symptom that is caused by PTSD is reflective of the underlying disorder (reflective property), whereas, any symptom that leads to PTSD constitute the disorder (formative property). A number of interesting observations followed from this hybrid model of PTSD.

First, the only symptom that is found to be significant constituent of PTSD is the avoidance of trauma related stimuli. Among the symptoms, sleeping disorder and feeling of nervousness are found to be directly reflective of the underlying disorder. Avoidance of trauma related stimuli also functions as a constituent of sleeping disorder. This network directly predicts that difficulty in concentration is likely to be caused by interactions among several symptoms, such as sleeping disorder, feeling of distress, and tendency to avoid trauma related memories and

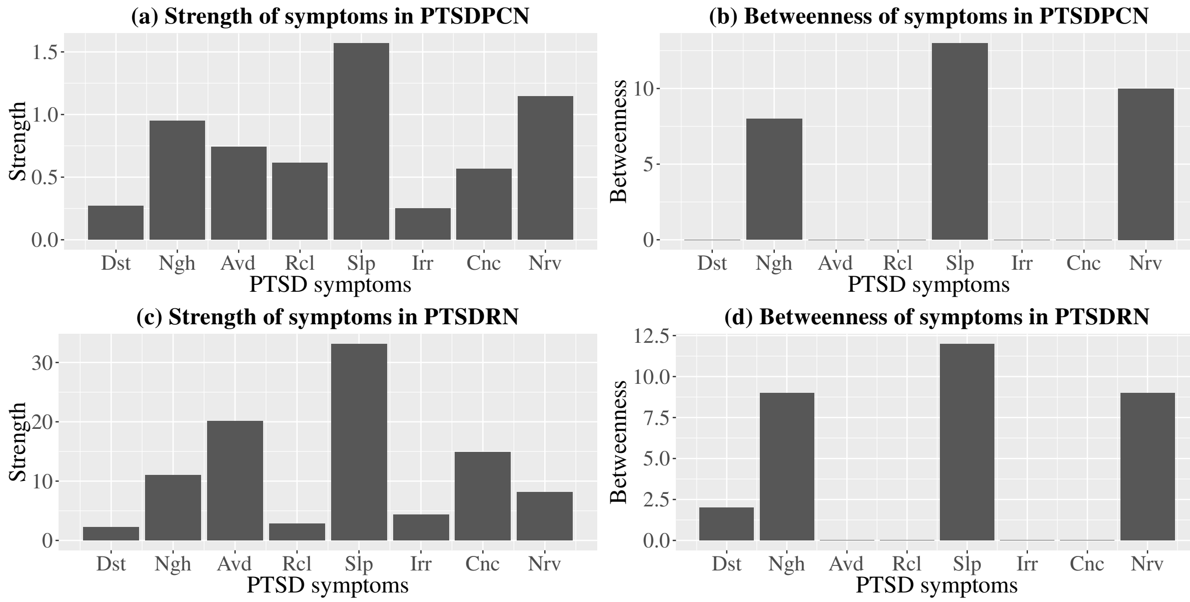


Fig. 7. Measure of centrality (strength and betweeneness) for different post-traumatic stress symptoms in PTSD partial-correlation network (PTSDPCN) and PTSD regulatory network (PTSDRN).

feelings. The network also predicts that difficulty in sleeping directly affects the mood of the refugees along with giving rise to irritability and nervousness. On the other hand, feeling of nervousness leads to nightmares and consequently, the nightmares affect victim's ability to recall trauma related memories and make them feel more distressed.

When we measured the centrality or importance of each symptom in this network, sleeping disorder again emerged as the strongest interacting component within the network (Figure 7(c, d)). This symptom is not only reflective of PTSD but also affects other post-traumatic stress symptoms, such as difficulty in concentrating, feeling of nervousness, and irritability or outbursts of anger. Among other symptoms that emerged as central to the hierarchy of the network are nightmare, tendency to avoid trauma related stimuli, difficulty in concentrating, feeling of nervousness, etc. Among these symptoms, tendency to avoid trauma-related stimuli appeared to be constituent of PTSD while sleeping disorder and nervousness appeared to be reflective of it. Between the other two symptoms, nightmare appeared to be influenced by the feeling of nervousness, whereas, difficulty in concentrating was affected by two other central symptoms, i.e., sleeping disorder and avoidance. Thus, we can see that the influential symptoms in PTSDRN also interact among themselves in an intricate way. On the contrary, symptoms such as avoidance, difficulty in recalling trauma events, irritability, and difficulty in concentrating had zero betweenness score because these symptoms did not lie in between other symptoms to mediate their interaction (Figure 6(b)). These symptoms had either no incoming edges or no outgoing edges to connect symptoms on both ends.

Now, this directed regulatory model of PTSD differed from undirected models of PTSD and its symptoms (PTSDCN and PTSDPCN) in a number of ways. First of all, in this model, PTSD is associated with three post-traumatic stress symptoms, namely, avoidance, sleeping disorder, and feeling of nervousness (Figure 6(b)). However apart from these symptoms, PTSDPCN suggests that difficulty in recalling trauma events is also directly associated with PTSD. Though the regulatory network suggests no such interaction between PTSD and this symptom. This is because Bayesian network connects two entities as cause-effect pairs based on conditional dependency between them, instead of simple correlations. Second, the strength scores of PTSD symptoms in PTSDRN (Figure 7(c)) varied from that of symptoms in PTSDPCN (Figure 7(a)). This is because in PTSDPCN the edge weights are partial correlations (value between 0 to 1) between entities. Therefore, the strength score of each symptom was comparatively small. On the other hand, in PTSDRN the edge weight is a measure of confidence or strength for each edge calculated using Bayesian Dirichlet sparse score [161]. The weight of each edge in this model is the difference between the score of the network including the edge and the score of the network in which the edge is not present. Since these two models adopted different measures to calculate edge weights, the strength scores of the symptoms differed accordingly.

3.7 Relative EEG Power

Since EEG signals from both the comparison group and refugee group were collected while they were talking, i.e., engaged in casual conversation, we used signals during this activity to potentially differentiate between these two groups of people. Our EEG collecting device Neurosky MindWave has only one sensor that needs to be placed at FP1 region. This region constitutes of the left side of frontal lobe and left part of prefrontal cortex, and is responsible for the execution of cognitive tasks [12]. Based on signals collected from this region, the device produces EEG power values for eight different frequency bands. These power values provide a useful indication of whether a particular band is increasing or decreasing over time, and how strong each band is relative to the other bands. Relative power for each band was calculated by expressing absolute power in each frequency band as a percent of total absolute power over the eight frequency bands [69]. Next, we analyzed whether temporal values of different EEG power bands varied significantly among different groups of participants (e.g., participants who suffered from various PTSD symptoms and those who did not). For this purpose, we performed Benjamini-Hochberg corrected [103] F-tests and t-tests on the relative EEG power measures of the participants (Table 5). F-tests reveal whether temporal values of background EEG activity show similar variance (changes) among different groups of people or not. On the other hand, t-tests measure whether the levels of background EEG activity are similar or different (greater or less) among different groups of people or not.

The results from F-tests revealed significant variances in different EEG power bands among different groups of people.

- Firstly, significant variance was observed in low alpha, low beta, and mid gamma waves at FP1 site between PTSD and non-PTSD group (all Bangladeshi citizens in the comparison group and Rohingya refugees who were not diagnosed with PTSD) while talking (Table 5). The first pairs of grouped bars in Figure 8 (a, b, d) demonstrate these significant variances.
- Secondly, we found significant variance over the groups of completely interconnected components that we found from maximal clique analysis of PTSDCN (Figure 5). The maximum clique in our network consists of PTSD, avoidance, sleeping disorder, irritability, difficulty in concentrating, and nervousness (Figure 5(b)). People who were either diagnosed with PTSD or suffered from one of these symptoms showed significant variance and lower relative power in mid gamma band (Figure 8 and Table 5). On the other hand, the maximal clique in our correlation network that comprised of PTSD, nightmare, sleeping disturbance, difficulty in concentrating, and feeling of nervousness (Figure 5(c)) showed significant variance in both low beta (Figure 8(b)) and mid gamma bands (Figure 8(d)) while talking. People who were either diagnosed with a potential case of PTSD or suffered from one of these four symptoms showed greater relative power in their low beta band, whereas, smaller relative power in their mid gamma band activity while talking (Figure 8 and Table 5).
- Besides, relative low alpha, low beta, low gamma, and mid gamma powers showed significant variance (Table 5) in the left part of prefrontal cortex of people suffering from sleeping disorder (Figure 8(a, b, d, f)), which appears to be one of the most highly central symptoms in both PTSDPCN and PTSDRN (Figure 7).

Table 5. Benjamini-Hochberg corrected F-tests and t-tests on the relative EEG power of different frequency bands at FP1 site while talking. F-tests reveal whether there is any statistically significant variance in the temporal values of EEG power among different groups of people. Here, t-tests represent statistical significant difference in the relative EEG power measures of different groups of people. Besides, ** indicates P < 0.01 and *** indicates P < 0.001.

Category	Low alpha	High alpha	Low beta	High beta	Low gamma	Mid gamma	Delta	Theta
PTSD	F(1602)=1.28*** t(2365)=4.16***	F(1602)=1.16 t(2289)=1.03	F(1602)=1.32*** t(2386)=-3.03**	F(1602)=1.19 t(2314)=6.68***	F(1602)=0.86 t(2057)=-4.13***	F(1602)=4.55*** t(2441)=15.78***	F(1602)=1.13 t(2273)=-9.66***	F(1602)=1.06 t(2219)=1.86
Dst	F(1079)=1.22*** t(2110)=3.68***	F(1079)=1.46*** t(2035)=0.98	F(1079)=1.23*** t(2166)=-3.75***	F(1079)=1.15 t(2215)=3.84***	F(1079)=0.54*** t(2617)=-7.55***	F(1079)=2.28*** t(1726)=13.56***	F(1079)=1.06 t(2278)=-8.3***	F(1079)=1.1 t(2253)=0.4
Avd	F(1363)=1.09 t(2620)=2.35*	F(1363)=1.20 t(2622)=-0.91	F(1363)=1.05 t(2614)=-4.22***	F(1363)=1.09 t(2619)=2.83**	F(1363)=0.46*** t(2195)=-8.18***	F(1363)=2.49*** t(2329)=10.52***	F(1363)=1.07 t(2617)=-5.02***	F(1363)=1.1 t(2620)=0.13
Slp	F(1628)=1.27*** t(2294)=3.54***	F(1628)=1.17 t(2227)=1.27	F(1628)=1.36*** t(2348)=-2.99**	F(1628)=1.15 t(2213)=5.5***	F(1628)=0.74*** t(1866)=-5.04***	F(1628)=4.88*** t(2451)=18.42***	F(1628)=1.11 t(2187)=-10.05***	F(1628)=1.1 t(2179)=1.26
Cnc	F(1748)=1.23 t(1923)=1.94	F(1748)=1.01 t(1757)=-0.04	F(1748)=1.25*** t(1937)=-2.44*	F(1748)=1.04 t(1782)=1.71	F(1748)=0.71*** t(1514)=-4.54***	F(1748)=3.34*** t(2603)=12.75***	F(1748)=1.09 t(1816)=-5.25***	F(1748)=1.05 t(1789)=-0.91
Ngh	F(1649)=1.18 t(2180)=2.33*	F(1649)=1.44*** t(2336)=3.36***	F(1649)=1.50*** t(2368)=-0.81	F(1649)=1.21 t(2202)=5***	F(1649)=1.18 t(2179)=-1.92	F(1649)=3.67*** t(2588)=16.25***	F(1649)=1.16 t(2165)=-9.41***	F(1649)=1.07 t(2100)=0.16
Rcl	F(2424)=0.89 t(229)=-1.04	F(2424)=2.41*** t(285)=4.22***	F(2424)=1.95*** t(267)=1.98	F(2424)=3.15*** t(314)=5.91***	F(2424)=4.36*** t(363)=3.61***	F(2424)=0.90 t(229)=0.82	F(2424)=1.18 t(239)=-3.26	F(2424)=1.39 t(247)=2.92**
Irr	F(1831)=1.08 t(1562)=0.58	F(1831)=1.02 t(1519)=-0.12	F(1831)=1.04 t(1530)=-3.43***	F(1831)=0.99 t(1499)=1.89	F(1831)=0.61*** t(1225)=-5.63***	F(1831)=4.27 t(2593)=16.62***	F(1831)=1.04 t(1532)=-5.95***	F(1831)=0.97 t(1483)=-0.81
Nrv	F(1438)=1.23*** t(2602)=4.22***	F(1438)=1.42*** t(2622)=2.97**	F(1438)=1.36*** t(2618)=-2.75**	F(1438)=1.29*** t(2611)=8***	F(1438)=0.75*** t(2361)=-5.5***	F(1438)=5.02*** t(2070)=20.33***	F(1438)=1.14 t(2580)=-13.42***	F(1438)=1.13 t(2576)=2.82**

- Significant variance was also observed in relative low gamma and mid gamma powers among people who tended to avoid trauma-related stimuli (Figure 8(d, f) and Table 5). This symptom showed high strength score in both PTSDPCN and PTSDRN (Figure 7).
- On the other hand, significant variance was observed in alpha, beta, and gamma frequency bands (Figure 8) among people who reported about feeling nervous (Table 5), which is another highly central symptom in both PTSDPCN and PTSDRN (Figure 7).
- Apart from these, significant variance was also observed in the relative power of low beta, high alpha, and mid gamma bands among refugees who reported about having nightmares (Figure 8(b, c, d) and Table 5). This is also one of the most influential symptoms in both PTSDPCN and PTSDRN (Figure 7).
- Moreover, refugees who suffered from difficulties in concentrating, another symptom of high strength in both PTSDPCN and PTSDRN (Figure 7(a, c)), showed significant variance in relative powers of low beta, low gamma, and mid gamma bands (Table 5). They exhibited significantly lower mean relative power in mid gamma band than those without such problem (Figure 8(b, d, f)).
- On the contrary, no significant variance was observed in the relative powers of delta and theta frequency bands among different groups of participants while talking. However, refugees suffering from PTSD and various post-traumatic stress symptoms showed significantly increased delta activity than those without any such complications (Table 5).

Table 6 provides a brief summary of the relative EEG power analysis among different groups of participants. From the table, it is evident that relative powers in delta and theta frequency bands did not account for any neurobiological abnormalities associated with PTSD and its symptoms. Relative power in mid gamma frequency

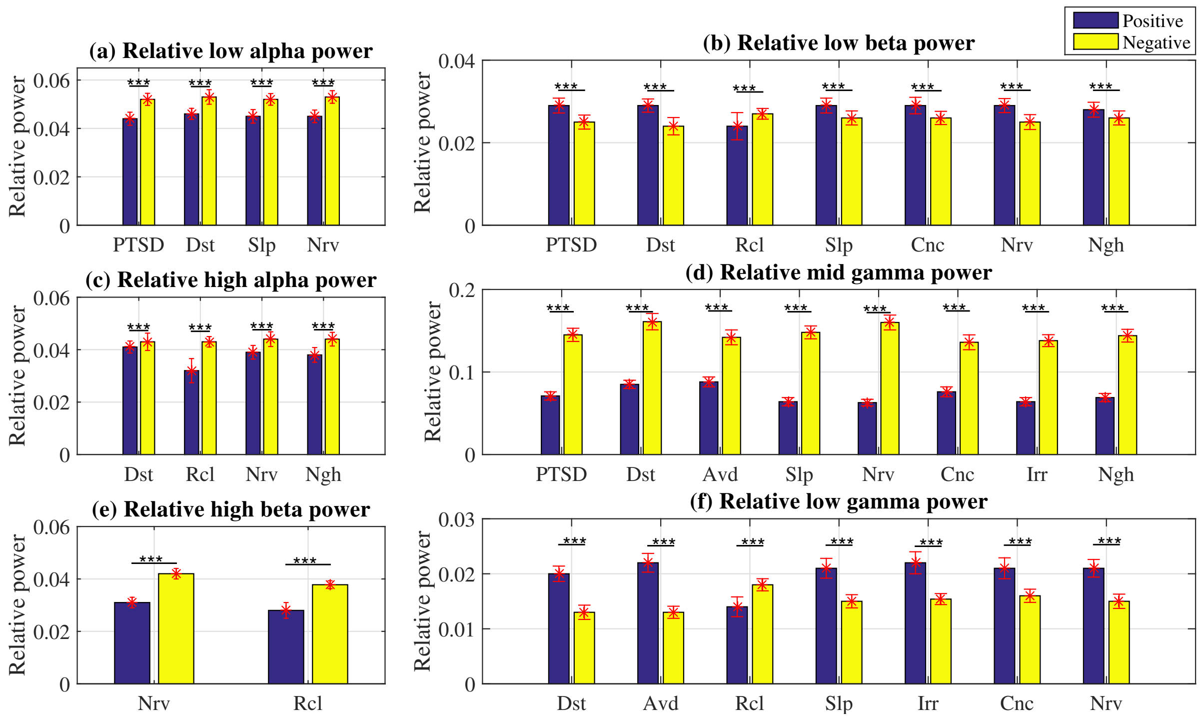


Fig. 8. Comparison of relative band powers of different EEG signals (1) between the participants who were diagnosed with PTSD and those who were not diagnosed with PTSD, and (2) between the participants who positively reported about facing different PTSD symptoms and those who reported negatively about facing those symptoms. Asterisks (*** indicates P<0.001) represent that Benjamini-Hochberg corrected statistically significant variance exists in the relative band powers of different groups of participants with positive and negative response to PTSD and different post-traumatic stress symptoms.

Table 6. An overview of relative EEG power analysis (1) between the participants who were diagnosed with PTSD and those who were not, and (2) between the participants who reported positively about various PTSD symptoms and the ones who did not report facing any such symptom. Checkmark in a cell indicates that statistically significant variance exists in the relative power of that particular EEG signal between the participants who positively reported about a particular effect and those who reported negatively about that effect.

Effects	Relative EEG power							
	Low alpha	High alpha	Low beta	High beta	Low gamma	Mid gamma	Delta	Theta
PTSD	✓		✓			✓		
Dst	✓	✓	✓		✓	✓		
Ngh		✓	✓			✓		
Avd					✓	✓		
Rcl		✓	✓	✓	✓			
Slp	✓		✓		✓	✓		
Irr					✓	✓		
Cnc			✓		✓	✓		
Nrv	✓	✓	✓	✓	✓	✓		

band showed significant variance among people with PTSD and almost all post-traumatic stress symptoms except difficulty in recalling trauma events. On the other hand, people suffering from nervousness or constantly feeling on guard showed significant variance in the relative power across a wide range of EEG signals, from low alpha to mid gamma (7.5 – 49.75 Hz).

3.8 Attention and Relaxation Values

Besides EEG signals, the NeuroSky MindWave mobile device also produces attention values that indicate the intensity of user's mental focus. Therefore, we compared the attention values of refugees who reported difficulty in concentrating with those who did not face any such difficulty for three different activities (talking, recalling trauma events, and drawing) (Table 7 and 8). We found that the refugees who faced difficulty in concentrating showed significantly lower mean attention values (Table 7) while talking (casual conversation) than those who reported no such attention deficit (Figure 9(a)). However, no significant difference was observed between these two groups (Table 7) while discussing trauma events (Figure 9(b)) and drawing (Figure 9(c)). We also found that the refugees who reported difficulty in concentrating showed significantly greater mean attention values while drawing than talking (casual conversation) and recalling trauma events (Figure 9(d) and Table 8). In case of refugees without any attention deficit, mean attention values while drawing were significantly greater than talking and recalling trauma events (Figure 9(e) and Table 8).

Table 7. Difference in attention and relaxation values of the participants who faced difficulty in concentrating and felt nervous compared to those who did not face these problems while doing a particular task. Asterisks represent Benjamini-Hochberg corrected [103] statistical significant difference in the attention as well as relaxation values of the participants, who faced problems in these mental states compared to those who did not (*** represents $P < 0.001$).

Category	Talking	Recalling trauma events	Drawing
Difficulty in concentrating	t(1430)=-3.46***	t(1659)=0.8	t(1533)=-1.23
Feeling nervous	t(960)=-0.52	t(911)=-3.95***	t(1133)=-6.03***

Table 8. Difference in attention and relaxation values while doing different tasks among people who reported similar mental states (i.e., either faced difficulty while concentrating/ relaxing or did not face any such difficulty). Asterisks represent that Benjamini-Hochberg corrected [103] statistically significant difference exists in the attention and relaxation values of the participants while performing different types of tasks (*** represents $P < 0.001$).

Category	Talking vs Recalling trauma events	Recalling trauma events vs Drawing	Drawing vs Talking
People who reported attention deficiency	t(1901)=-2.04	t(1618)=7.43***	t(1563)=9.06***
People who did not report attention deficiency	t(1447)=0.53	t(1425)=5.36***	t(1352)=4.76***
People who reported feeling nervous	t(2399)=0.89	t(2188)=0.27	t(2172)=1.07
People who did not report feeling nervous	t(917)=4.58***	t(1021)=-3.58	t(916)=7.02***

On the other hand, NeuroSky MindWave mobile device produces relaxation values that indicate the level of mental calmness or relaxation. Therefore, we also compared the relaxation values of the refugees who felt nervous or on guard against those who felt no such problem. We found that the refugees feeling constantly nervous or on guard were significantly less calm and less relaxed while discussing their traumatic experiences and drawing than those without such problems (Figure 9(f, g) and Table 7). The relaxation levels of the refugees who reported to be nervous or on guard did not show significant difference across three different activities (Figure

9(h) and Table 8). However, the refugees who did not report any case of nervousness showed significantly greater mean relaxation values while drawing and recalling trauma events than talking (Figure 9(i) and Table 8).

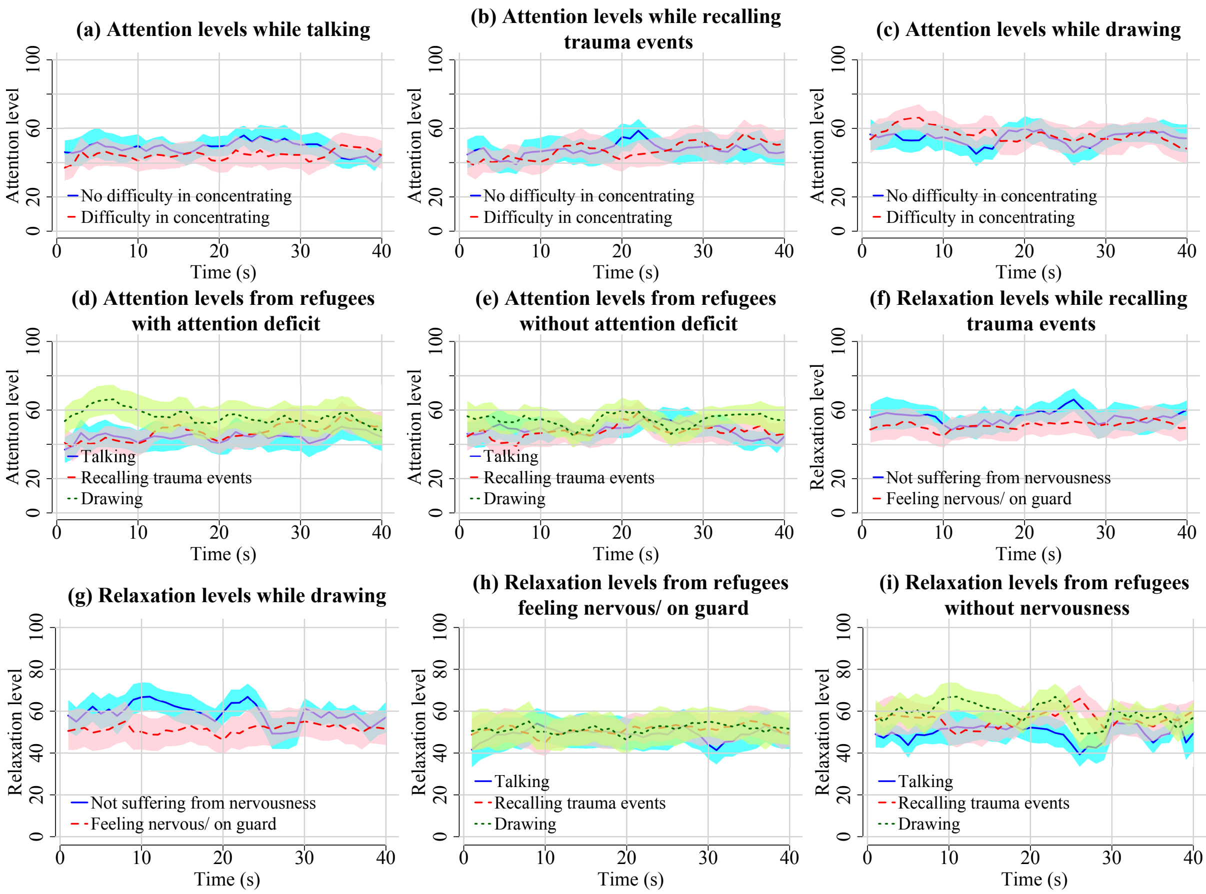


Fig. 9. Attention and relaxation values of Rohingya refugees from NeuroSky MindWave mobile device.

4 DISCUSSION

This study was designed to examine the effects of forced migration and pre-migration torture on psychiatric morbidity of Rohingya refugees living in Bangladesh. In our study, around 69% participant refugees in our sample screened positive for PTSD. This percentage is greater than the previously reported moderate diagnostic rate of PTSD (36%) among this population [149]. Earlier study identified several factors to be associated with higher prevalence of PTSD, such as reported torture, cumulative exposure to trauma, shorter time since traumatic experiences, etc,. [174] The latest exodus that began on August 25, 2017 drove more than 700 thousand Rohingyas to seek refuge in Bangladesh when violence broke out in Rakhaine state of Myanmar [184]. Most of the refugees in our sample (88.7%) have mean migration period of about 4 months, and therefore, they are the latest survivors and witnesses of violence, ethical cleansing, and criminal abuses that took place in Myanmar. Besides, a number of studies have shown that multiple exposure to trauma is associated with higher levels of psychiatric symptoms of PTSD [49, 102, 112, 113]. This is also evident from our demonstration of dose-effect relationship between cumulative torture experience and psychiatric symptoms of PTSD as shown in Figure 4. This suggests that pre-migration trauma is an important risk factor for developing PTSD. On the other hand, the diagnostic tool (MINI) we used is highly sensitive and particularly suitable for detecting high proportion of patients with PTSD than the proportion detected in previous under-diagnosed cases [164]. Earlier use of MINI among US veterans who served in Iraq also revealed higher (60%) prevalence of PTSD [173]. In addition to all these factors, the major participation of female interviewers with occasional presence of male interviewers in our study made the interview session more friendly and comfortable, particularly for female refugees. As a result, the participants got spontaneously engaged in a discussion on their sorrows and sufferings.

Now, this high prevalence of PTSD was also observed among the old Rohingya refugees (62.5%) in our sample (Figure 3(b)) who migrated to Bangladesh almost 15 years ago. Earlier studies suggest that psychiatric symptoms caused by trauma improve over time for the majority [175], yet in the long run, they still pose a significant threat to the minority. A study on World War II survivors who were imprisoned by the Japanese showed that these individuals suffered from a manifestation of PTSD even after 40 years of the war experiences [10]. Another study on Vietnamese refugees showed that, being disadvantaged by post-migration hardships and lack of social resources, this group continued to be more depressed than others even after 2 years of the initial investigation [59]. Though the number of old refugees is small in our sample, we may attribute their high prevalence of PTSD to the ongoing daily stressors and hardships in makeshift camps, as it has been already pointed out in previous literature.

On the other hand, the newly migrated ones were at no less risk of suffering from PTSD than that of the old Rohingya refugees (Figure 3 (b)). The recent influx of large numbers of refugees along with their exposure to trauma, scarcity of resources, and lack of proper health-care and sanitation facilities have put the newly migrated ones at the risk of developing various physical and mental health hazards. Many studies have pointed out that pre-migration trauma as well as post-migration hardships, such as lack of social support within refugee camps, restrictions on free movement, restrictions to access of services (health-care, education, etc.,), restrictions to employment opportunities, and emerging resettlement risk factors have significant impact on psychiatric morbidity over time [10, 65, 149]. During our period of interview, more than 880 thousand Rohingyas were living in Kutupalong refugee camp, Bangladesh [145]. For the two decades of staying period of Rohingya refugees in Bangladesh, there have been very minimal psycho-social services along with constant lack of specialized mental health interventions [149]. Therefore, we need some efficient and cost-effective measure to diagnose this huge influx of refugees to provide them with primary mental health care as soon as possible. However, as we have already pointed out, traditional questionnaire based diagnostic tools often suffer from various human-centered design issues owing to differences in language and cultural components. This happens as the effect of trauma is expressed and evaluated differently across different socio-cultural contexts. Therefore, we must be careful in just assuming PTSD symptoms as per American Diagnostic and Statistical Manual of Mental Disorders [4]. Besides, we would require humanitarian intervention to assess and understand how people experience and respond to different social and personal sufferings from their point of view. Psychiatric and humanitarian interventions undertaken to understand and improve the conditions of the refugees must take into account their unique cultural, social, and personal perspectives. For instance, the recent encounter of the refugees with traumatic experiences followed by the uncertainty and hardships of refugee life deterred many of them initially to take part in the interview. However, some of the refugees, who agreed to participate in our interview described their experiences of violence and abuses with unexpected vividity, giving away the innate psychological need to share their stories. In such cases, the interviewers need to direct the flow of the conversation deftly so that the original course of the interview is maintained without the participants feeling unheard of or being neglected. On the other hand, some of the refugees, in our study, expressed their initial uneasiness to use the EEG headset, whereas, none of the participants in our comparison group expressed any kind of uneasiness. This might be attributed to the prevalence of lower academic and technical literacy among the refugees. Therefore, the researchers need to take special care while dealing with such marginalized group of people. They need to carefully design their studies to introduce and integrate new technologies in such a way that is consistent with the cultural beliefs and expectations of the people in critical needs.

4.1 Neurobiological Signatures of PTSD

In this work, we tried to reach beyond the qualitative measure of PTSD and looked for alternatives to words/ languages/ conversations as expression media as well as quantification tools for the purpose of diagnosing different post-traumatic stress symptoms. This study, to the best of our knowledge, is the first to look for potential neurobiological markers of post-traumatic stress symptoms and PTSD via low-cost, consumer-grade, and portable brain-computer interface in the scarce-resource settings of refugees. The motivation behind this work is to go beyond the qualitative measure of PTSD and look for alternatives to human-human interaction within the traditional settings of interview or questionnaire-based diagnostic tools. Here, we hope to find means to reduce long administrative time and overcome language as well as cultural barriers associated with human interaction while using traditional screening tools of PTSD. For example, in our case, even though we used a brief comprehensive diagnostic tool like MINI and had interviewers among us who could fluently speak in Chittagonian dialect, we still faced problems to communicate some questions to the participant refugees. Most of the refugees in our sample faced difficulty in understanding questions about avoiding situations pertinent to their traumatic pasts. Therefore, it is likely that more confusions would follow with long questionnaires, whereas, EEG signals of a few minutes exhibit the potential to differentiate between the neurobiological status of healthy individuals from that of disordered patients [51, 197].

When we compared EEG signals of the participants who faced different post-traumatic stress symptoms with that of individuals who experienced no such psychiatric complications, we found substantial variance in relative power of different brainwaves at FP1 site while talking (Table 5). An overall summary of our findings is given in the following.

4.1.1 Alpha Activity. From Table 6, it is evident that the participants who reported positively about suffering from sleeping disorder, nervousness, and distress, and those who were diagnosed with PTSD showed significant variance in their relative low alpha power. Therefore, when we compared EEG signals of the participants who screened positive for PTSD with that of participants who screened negative, we found that PTSD is associated with significant decrease in relative low alpha power (Figure 8(a)). Even earlier study on PTSD patients identified abnormal pattern of electroencephalogrpahic alpha asymmetry, i.e., decrease in alpha power at FP1 site during eye-opening state [143]. Besides, low level of alpha power has been associated with anxiety, high stress, and insomnia [123]. Accordingly, participants in our study who reported sleeping disorder, feeling distressed as well as nervous, exhibited a decrease in their relative low alpha power compared to those who experienced none of these intrusions (Figure 8(a)).

On the other hand, the participants in our sample, who reported feeling nervous and distressed, suffered from nightmares, and faced difficulties in recalling trauma events showed significant variance in their high alpha power (Table 6). First of all, the participants in our sample, who reported feeling nervous or on guard showed significantly lower relative power in their high alpha band (Figure 8(c)). Even findings from earlier study indicate that increases in alpha power are associated with lower levels of anxiety and increased levels of calmness [23]. This suggests that abnormality in relative high alpha power reveals underlying anxiety and qualms. Next, people who reported about having nightmares showed significantly decreased relative power in high alpha band at FP1 site than those not facing such problem (Figure 8(c)). This finding is corroborated by earlier study where lower relative power in high alpha band was observed at O1 site among nightmare recallers [100]. Besides these implications, earlier study associated increase in upper alpha band with good cognitive and memory performance [87]. Therefore, a decrease in relative power of high alpha band suggests poor memory performance. This is evident from significantly lower mean relative power of high alpha band among the participant refugees who reported about facing difficulties in recalling trauma events (Figure 8(c)).

4.1.2 Beta Activity. PTSD along with four post-traumatic stress symptoms namely sleeping disturbance, nightmare, nervousness, and difficulty in concentrating formed one of the maximal cliques in our PTSDCN (Figure 5(c)). Participants in our sample, who reported positively about at least one of these completely interconnected components exhibited significant variance in their relative low beta power (Table 6). This frequency band also accounted for neurobiological abnormality in low beta activity among refugees who felt distressed and faced difficulty in recalling trauma events (Table 5, 6).

Firstly, the refugees in our sample, who were diagnosed with a potential case of PTSD showed significantly increased relative low beta power at FP1 site while talking (Figure 8(b)). This is consistent with findings from previous studies, where increase in beta power at FP1 site was observed among PTSD patients during rest [51] and card-sorting test [151]. Even combat veterans suffering from PTSD showed increased beta power [9, 73]. Secondly, this band also showed significantly increased relative power among refugees who were suffering from sleeping disorder (Figure 8(b)). Even earlier study associated increased beta activity with insomnia [137]. Thirdly, the refugees who reported about having nightmares showed significant variance in their relative low beta power at FP1 site (Figure 8(b)). Earlier study reported that higher beta power was observed in waking state at C3, C4, F3, F4, and O1 regions of scalp among PTSD patients and nightmare recallers [100]. Though the nightmare recallers in our sample did not show any significant change in their level of low beta activity at FP1 site, they showed significantly less relative power in their high beta activity (Table 5) from that of people who did not suffer from trauma related nightmares. On the other hand, high level of beta power has been previously identified with anxiety, stress, and hyper arousal [123]. Even the refugees in our sample, who reported feeling distressed, nervous, or constantly on guard showed significant increase in their relative low beta power (Figure 8(b)). Besides, the refugees who reported difficulty in concentrating showed significant increase in relative power of low beta activity (Figure 8(b)). This coincides with findings from earlier study where significantly increased low beta power was observed among people who suffered from inattention and were victims of childhood traumatic experiences [93]. Finally, the refugees who reported difficulty in recalling trauma events exhibited significantly lower relative power in low beta bands (Figure 8(b)). Even findings from earlier study suggest that increased low beta activity reflects memory promoting state [157]. Therefore, decreased power in this frequency band might be associated with PTSD related memory impairment.

On the contrary, high beta frequency band accounted for neurobiological abnormality associated with post-traumatic stress symptoms, such as nervousness and difficulty in recalling trauma events (Table 5, 6). First of all, the refugees who reported being nervous or on guard showed significantly less relative power in their high beta frequency band (Figure 8(e)). This is contradicting from earlier studies, where increased levels of high beta activity were observed during anxiety or periods of emotional intensity [166, 179]. Therefore, neurobiological abnormality connecting high beta activity with nervousness and hyper arousal requires further attention. On the other hand, refugees who faced difficulty in recalling trauma events also showed significantly decreased relative high beta power (Figure 8(e)). This is consistent with findings from previous study where increase in frontal high beta activity has been found to be associated with better memory outcome [75]. This suggests that decrease in relative power of high beta frequency band might be associated with reported memory impairment of Rohingya refugees.

4.1.3 Gamma Activity. Relative power from low gamma ($31 - 39.75$ Hz) and mid gamma ($41 - 49.75$ Hz) frequency bands exhibited significant variance across a wide range of post-traumatic stress symptoms (Table 6). First of all, the refugees who were diagnosed positive with a probable case of PTSD, showed significantly decreased relative power in mid gamma band at FP1 region while talking (Figure 8(d)). This is contrary to findings from previous studies where increased gamma band (30 − 50 Hz) activity was observed at frontal region among PTSD diagnosed women [151] and PTSD patients during resting state [30].

Besides, reflecting neurobiological abnormality associated with underlying disorder, this frequency band also accounts for electroencephalographic abnormality related to different post-traumatic stress symptoms. Gamma-band activity has been marked as hallmark of sensory processing in the forebrain [57]. It has been observed that gamma power is modulated by attention in prefrontal, parietal, and sensory cortical areas [45]. Even recent findings have associated decrease in low gamma band activity at antero-frontal region and decrease in mid gamma band activity at centro-parietal region with attention deficiency [181]. Similarly, participants in our study, who reported difficulty in concentrating exhibited decreased relative power in mid gamma band at FP1 region while talking (Figure 8(d)). However, this group exhibited increased relative power in low gamma band activity at FP1 region (Figure 8(f)).

Moreover, prominence of this frequency band has been associated with anxiety, stress, and hyper arousal [1]. Power spectrum analysis of gamma frequency band (40 − 70 Hz) revealed that increased power in this frequency band is associated with anxiety [198]. Analogously, we found that refugees in our sample, who reported about feeling distressed or nervous showed significant increase in their relative low gamma power (Figure 8(f)). However, this group of people who suffered from distress or nervousness showed significant decrease in their relative mid gamma power (Figure 8(d)).

On the other hand, this is the only frequency band that accounted for neurobiological abnormality associated with avoidance of trauma related memory among Rohingya refugees. Refugees in our sample, who tried to avoid trauma related stimuli showed significant increase in relative low gamma power (Figure 8(f)) but significant decrease in relative mid gamma power (Figure 8(d)) at FP1 site while talking. Even it has been observed in earlier study that increase in gamma (30 − 55 Hz) power is associated with fear-motivated memory avoidance related to PTSD [144]. Also, it has been identified that increase in frontal gamma (20 − 60 Hz) power is associated with recalling memory [21]. Therefore, decrease in this frequency band might be associated with poor capability to recall events. This is evident from the neurobiological characteristics of the participants in our study, who reported about facing difficulty in recalling traume events and exhibited significantly decreased relative power in low gamma band (Figure 8(f)).

Besides all these, a recently developed rodent model has identified sustained increase in low gamma power and decrease in high gamma power to be associated with PTSD-related sleeping disturbances [119]. Even in our sample, we observed a decrease in relative mid gamma power (Figure 8(d)) and increase in relative low gamma power (Figure 8(f)) among refugees with sleeping disorder. On the other hand, people who reported about having nightmares showed decreased relative power in mid gamma band at FP1 region (Figure 8(d)). Though elevated gamma band activity has been observed among nightmare recallers in earlier study [100], decreased gamma band activity among refugees in our sample might be associated with their difficulties in recalling trauma related events and memories because gamma waves might be associated with the ability to recall dreams [48].

Finally, irritability or outbursts of anger is a frequent comorbidity of PTSD with most serious consequences. The refugees in our sample, who felt irritation or outbursts of anger showed significant decrease in relative mid gamma power (Figure 8(d)) and increase in relative low gamma power (Figure 8(f)). Though we could not find any association of relative gamma power with irritability and outbursts of anger in previous literature, there were lots of evidence that gamma oscillations associated with cognitive processes are modulated in various psychiatric diseases, such as schizophrenia [6], bipolar disorder [6], autism spectrum disorder [176], Alzheimer's disease [6], ADHD [78], and so on. Moreover, the group of completely interconnected post-traumatic stress symptoms (avoidance, sleeping disorder, irritability, difficulty in concentrating, feeling of nervousness) and PTSD, from maximum clique analysis of PTSDCN (Figure 5(b)), showed significant variance and decreased relative power in mid gamma band (Figure 8(d)) while people with these symptoms showed significant variance and increased relative power in low gamma band (Figure 8(f)). So, we can see that these two sub regions of gamma signal vary in terms of their neurobiological characteristics associated with different post-traumatic stress symptoms. Moreover, from previous studies, we can see that the frequency range of observed gamma activity influence our interpretation of neurobiological characteristics associated with this region. Therefore, we need to be careful about the scope of gamma band activity before associating psychiatric morbidity related to PTSD with neurobiological abnormalities of this frequency band.

4.1.4 Delta Activity. Though none of the refugees suffering from PTSD and other psychiatric symptoms showed significant variance in their delta activity, they showed significantly greater relative power in this frequency band (Table 5). Even earlier study identified increased delta power as potential neurophysiological correlate to differentiate PTSD from other psychiatric disorders [114].

4.1.5 Attention and Relaxation Values. In our study, participants who reported difficulty in concentrating showed significantly lower mean attention values while talking than those without such problems (Figure 9(a)). However, these two groups exhibited similar levels of attention while recalling trauma events (Figure 9(b)) and drawing (Figure 9(c)). The reason behind this could be that the evocation of traumatic experiences was so strong enough for both groups of participants that they ended up exhibiting similar levels of attention. On the other hand, activities such as, drawing require some level of concerted attention and from our observation, we can see that the participants suffering from attention deficit were able to engage themselves in drawing as well as those without such problems. Moreover, all the refugees, with or without attention deficit, showed significantly greater mean attention values while drawing than during conversations (Figure 9(d, e)). Higher level of attention while drawing asserts the usefulness of impromptu drawing activity in facilitating self-expression and creating awareness of self and others. Even, in many studies, art therapy was found to be highly effective in reinforcing positive behavior among people with attention deficit [80, 162].

On the other hand, the refugees who constantly felt nervous or on guard showed significantly lower mean relaxation values while recalling their traumatic experiences and drawing than those who did not report being distressed or feeling nervous (Figure 9(f, g)). Among the refugees, who did not report any case of nervousness showed significantly greater mean relaxation values while drawing than talking or recalling trauma events (Figure 9(i)). Previously, many studies have suggested that art therapy is particularly suitable to treat trauma effects [88, 99] by utilizing different sensory triggers as part of therapeutic techniques. It helps to modify emotional and physiological responses, which assist in desensitizing physiological reactions. Therefore, as a part of our study, we engaged some of the randomly selected Rohingya refugees to draw their past and expected future homes to see whether this activity has any impact on their psychological or physiological bearings. The increased relaxed state of the refugees while drawing indicates that this activity helped them to divert their mind off the stress and direct their flow of meditation in something creative. Therefore, our findings suggest that incorporation of such art activities into various treatment program of PTSD patients is likely to improve their cognitive performance. However, the refugees who reported feeling nervous or on guard did not show any improvement in their relaxation state while drawing (Figure 9(h)). The reason behind this could be that the extent of their psychiatric morbidity was too severe to benefit from a single session of drawing activity. Though in our work we tried to explore the usefulness of art therapy in small scale, a larger setting within the context of refugee crisis might reveal important findings in this regard.

4.2 The Underlying Structure of the Disorder

Besides analyzing neurobiological signatures, the hybrid models we developed to explore the dynamic interactions among different post-traumatic stress symptoms and PTSD, are the first to take into account both the reflective and formative models of PTSD. Collectively, our models provide clues to both the causal symptoms that are constitutive of PTSD and the symptoms that are reflective of it, at least in the context of trauma-induced Rohingya refugees. The findings from PTSDCN comport well with clinical observations of PTSD patients, as embodied in the DSM-V clusters of PTSD symptoms. Other key findings from these models are summarized in the following.

First, sleeping disorder emerged as the most highly central symptom in both PTSDPCN and PTSDRN (Figure 7). This symptom is also included in all the maximum and maximal cliques derived from PTSDCN (Figure 5 (b, c)) and PTSDPCN (Figure 6(a)). It is also one of the symptoms in PTSDRN that reflect the presence of PTSD (Figure 6(b)). According to PTSDPCN, this symptom is significantly correlated with PTSD, nervousness, difficulty in concentration, and irritability or outbursts of anger (Figure 6(a)). Again according to PTSDRN, among the correlated symptoms, sleeping disorder reflects PTSD and leads to nervousness, concentration problem, and irritability or anger. The correlations among sleeping disorder, irritability/ anger, and concentration problem are consistent with previous findings from the research studies done by McNally and Bryant et al., [20, 106, 107]. This supports earlier evidence that when people are sleep deprived, they feel more irritable and angry [41]. In addition, their reasoning and concentration abilities are affected negatively due to mood changes [42, 95]. These findings illustrate how our hybrid models are close to earlier findings regarding trauma-related arousal and reactivity.

Second, nervousness also emerged as a symptom of high importance to the networks we built. Both in PTSDCN and PTSDPCN, this symptom is significantly correlated with PTSD (Figure 5(a), 6(a)). In PTSDRN, this symptom emerged as reflective of PTSD and another highly central symptom sleeping disorder (Figure 6(b)). The association between PTSD and feeling nervous/ on guard is consistent with previously developed acute stress symptoms network of PTSD [61]. Besides, our models identified strong correlation between nightmare and feeling nervous/ on guard (Figure 6). Nightmare itself was another highly central symptom in our hybrid models. The positive association between these two symptoms (nightmare and nervousness) emerged earlier in the network analysis of acute and chronic post-traumatic stress symptoms of PTSD [20], even though not all network models of PTSD have been able to identify this phenomena [106, 107]. Earlier study among PTSD diagnosed rape victims and veterans identified positive association between nightmare and exaggerated startle response [22, 178]. Therefore, our Bayesian network of PTSD was robust enough not to miss this crucial association. On the other hand, both PTSDCN and PTSDPCN showed negative correlation between nightmare and difficulty in recalling trauma events and memories (Figure 5, 6(a)). This can be explained from the fact that PTSD patients very often re-experience nightmares again and again [195] and have a feeling as if the trauma events were recurring. This might be responsible for the negative correlation with difficulty in recalling trauma events. Besides, our PTSDRN suggests that nightmare is responsible for the feeling of distress among Rohingya refugees. This is consistent with earlier studies, which identified frequent nightmares to be associated with psychological distress [11, 94].

Third, avoidance was another highly central symptom with respect to the networks we built (Figure 7). This symptom showed the strongest positive correlation with PTSD in both PTSDCN and PTSDPCN (Figure 5, 6(a)). In PTSDRN, this was the only symptom that emerged as constitutive of PTSD (Figure 6(b)). Earlier study also reported avoidance as a distinct PTSD symptom cluster [3]. Apart from this, our study also suggests that avoidance leads to sleeping disorder and concentration problem. These associations have not been reported in previously developed network models of PTSD. However, research studies on patients suffering from major psychiatric depression have showed that intrusive thoughts and avoidance cause sleep disturbances among them [62]. This illustrates how Bayesian inference might be useful in disclosing association among various post-traumatic stress symptoms that are not immediately obvious.

Fourth, attention deficit emerged as one of the highly central symptoms in PTSDRN (Figure 7(c)). According to our PTSDRN, difficulty in concentrating is engendered by avoidance, sleeping disorder, and distress. Though we did not find any direct evidence of how avoidance might influence attention deficit, earlier study suggested that tendency to avoid unbearable feelings or trauma related memories due to hyperarousal may indirectly impair attention [38]. Besides, it has been observed that children with attention deficit have heightened risk of suffering from psychological distress than others [108]. As in our model (Figure 6(b)), the direction of association between attention deficit and psychological distress was reversed, further analysis might be required to validate this association.

Nonetheless, we can see that our hybrid regulatory model of PTSD was able to correctly hypothesise most of the directions of associations between different post-traumatic stress symptoms and PTSD as presented in the previous studies conducted among assault survivors [61], traumatic injury survivors within Western population [20], as well as survivors of natural disasters within Asian population [107]. Moreover, when we compared our hybrid regulatory model of PTSD among Rohingya refugees with post-traumatic stress symptoms network of U.S. military veterans [139], we found that the findings from our model are well-consistent with the findings from U.S. veterans. For instance, both models successfully encoded the interactions between nightmares and feeling of distress, sleeping disorder and irritability, sleeping disorder and feeling of nervousness, and so on. Therefore, we may conclude that our hybrid regulatory model of PTSD can be extended and well-adapted to the diverse settings of post-traumatic stress disorder.

4.3 Potential Interventions for the Diagnosis and Treatment of PTSD

Apart from the potential diagnostic implication of EEG signals and PTSD regulatory networks, they can also provide us useful directions for the treatment of PTSD. Targeting the highly central symptoms within PTSDPCN and PTSDRN may help us in this regard. For example, according to our models, targeting the most central symptom, i.e., sleeping disorder may help alleviate problems. This is because, as per our maximum clique analysis, sleeping disturbance is closely associated with many other chronic post-traumatic stress symptoms and PTSD. Therefore, it emerges as a potential risk factor for the development and course of PTSD. Previously conducted cohort studies on treating PTSD patients through targeting trauma-specific sleep disturbance provide support in favor of our argument [89, 183, 190]. These studies found that such target-specific interventions produce large short-term effects, including substantial reductions in PTSD symptoms, and thereby improve functional outcomes [89, 183, 190]. Besides, it has been observed that many individuals with post-traumatic stress symptoms, prefer to address their sleeping disturbances (insomnia and nightmares) first, and then PTSD, as applicable [91]. Hence, targeting this particular neurobiological mechanism might be helpful in addressing the etiology of the disease. In this regard, we may address the neurobiological abnormalities associated with sleeping disorder through EEG biofeedback [64]. EEG biofeedback or neurofeedback is a specific protocol to improve brainwave activity and is particularly useful for treating various neurological conditions. It has been used as an adjunct therapy for specialized chronic refugee trauma experiences to make their treatment more effective [2, 120]. Recent findings have showed that EEG biofeedback is particularly capable of being used in reducing post-traumatic stress symptoms [54, 189]. For example, decrease in mid gamma band activity associated with attention deficit among the Rohingya refugees in our sample (Figure 8(d)) might be addressed by using neurofeedback training designed to increase local gamma band activity. Earlier study has showed that enhancing gamma band activity via neurofeedback has led to greater flexibility in episodic bindings and improved recollection of memory [81]. On the other hand, as we have already mentioned that lower relative power in high alpha frequency band is associated with poor memory performance among Rohingya refugees, cognitive performance might be improved by enhancing this frequency band as a neurofeedback parameter [199]. Therefore, we can say that targeting particular chronic symptoms within PTSD regulatory network might not only reduce the intrusion of that symptom but is also capable to affect other symptoms that are related to it via direct or indirect causal association. This would result in cumulative remission of post-traumatic stress symptoms and the disorder. All of these are potential interventions that could be attempted in future based on findings of our study.

5 SCOPE FOR FURTHER RESEARCH

The use of DAGs is very informative to understand the underlying hierarchy of PTSD, as it is capable of inferring both the strength and direction of possible associations between PTSD and its different symptoms. However, caution is still required because the DAG models depend a lot on the quality of data. Besides, a potential limitation of DAGs is that they do not allow any cycle. As a result, they cannot encode the feedback loops among symptoms. For example, a symptom affects other symptoms which, in turn, affect others. Thus, the feedback often loops back to influence the very first symptom. Now, such cycles cannot be encoded into DAGs though they play an important role in the self-reinforcing nature of PTSD networks [107]. Therefore, in future, it will be especially valuable to explore techniques for developing directed cyclic graphs, which are capable of encoding feedback loops among symptoms.

On the other hand, in our study, we used a consumer-grade portable EEG headset. Multi-electrode and medical grade EEG devices have long been used in hospitals and laboratories. However, the recent availability of inexpensive, single-channel, dry-electrode, and easy-to-use EEG devices has made it feasible to take this technology outside the formal environment of laboratories into the real world in an ubiquitous manner. Though such single-electrode devices are more affordable and easier to use, the quality of the produced data is not as good as that of the devices with large numbers of electrodes or sensors. Besides, one of the biggest challenges in using BCI devices (such as EEG devices) is to understand and resolve the issue of "BCI illiteracy" [191]. This concept is used for explaining difficulties that users generally face while operating BCI systems. There exists a methodologically weak concept that BCI users possess physiological or functional traits, which prevent their efficient performance while using BCI devices [180]. In existing studies involving BCI systems, it has been observed that BCI control does not work for a significant portion ($20 - 30\%$) of users [40]. However, this concept still remains under rigorous research and a clear understanding of the BCI illiteracy or a solution to this problem is yet to be reported. Besides, there are many biological and technical artifacts that influence the quality of recorded EEG signals [187]. Therefore, before adopting BCI devices to the mass diagnosis of PTSD, we need to properly take care of these factors.

In addition, further research is required to measure the ease of use and acceptability of the device among the users. This is of particular interest, as we have observed that participants in our study reacted differently to the use of EEG headsets. Some participants readily agreed to use the device, whereas, few felt afraid and confused about the use of the device. They were worried mainly because they felt that the device might do harm to them. However, after being ensured of no harm, they agreed to co-operate through the rest of the interview session. Therefore, before integrating BCI based neurotechnology into main-stream diagnostic system of PTSD, we need to think of ways to familiarize this technology to enable users to overcome the initial stigma and fear associated with its use. We can hope to elicit the full potential of this neurotechnology in the field of ubiquitous computing by assimilating refugee experience and expectations in refugee crisis response plan in a meaningful way.

Besides, findings from our study can be well adapted to pervasive mental health care and diagnostic systems. EEG headsets can be used to measure neurobiological abnormalities associated with PTSD even outside the refugee settings, particularly in the case of war veterans, victims of physical or sexual assault, abuse, accident, or other disasters. Even in recent times, potentials of EEG signals in telling PTSD apart from other trauma related brain injuries and in providing better diagnostic techniques have been of particular interest in veteran affairs [51, 182]. Moreover, measure of disturbed EEG sleep physiology has been used as an indicator of PTSD among war veterans [32, 110]. On the other hand, our experience while conducting the interview sessions show that the literate group of people in comparison group were more accepting of the use of EEG headset. Hence, we can easily extend this technology to identify potential cases of PTSD among people where where patients are literate enough not to misinterpret the use of such device. Therefore, UbiComp community needs to think of ways to redesign PTSD diagnostic system, which will foray this technology into the front line of pervasive mental health care and diagnostic system to trigger the next wave of ubiquitous health computing systems.

6 CONCLUSION

PTSD is a multifaceted psychiatric disorder where various social, psychological, and neurobiological factors play important role in the progress and maintenance of the disorder. It is highly prevalent in most of the refugee settings. A critical first step to address PTSD is to figure out the hierarchy of relationships among various symptoms of PTSD that can enable effective diagnosis of PTSD in refugee contexts. Therefore, in this work, we have introduced a radically different conceptualization of PTSD and its symptoms through a hybrid model, which incorporates aspects from both latent variable and network models of PTSD. Our work subsumes both survey-based and EEG-based real data collection on PTSD from Rohingya refugees, analyzing the data based on graph theoretic approaches as well as statistical methods, and correlating PTSD with its symptoms based on the analyses. The findings from our models can help to improve existing diagnostic and treatment methods, as well as, aid in detection of vulnerability and resilience factors associated with PTSD. Moreover, we have also shown the performance of consumer-grade, low-cost, portable, and easy-to-use EEG devices in measuring neurobiological abnormalities of PTSD in emergency humanitarian settings of refugee crisis response plan. Our findings reveal that even the low-cost EEG devices are capable of producing consistent outcomes and thereby, particularly suitable for investigations of larger populations. Thus, EEG can be a promising technology to address the challenges and issues involved with large-scale diagnosis of distressed population. Therefore, we envision that usability, acceptability, cost, and performance of EEG technologies could be focused for effective diagnosis and treatment of PTSD in a ubiquitous manner aiming the refugee crisis in future.

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