Review Article

mHealth solutions for early interventions after trauma: improvements and considerations for assessment and intervention throughout the acute post-trauma period

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Abstract: Interventions administered shortly after a traumatic event have the potential to prevent posttraumatic stress disorder (PTSD) and related mental health conditions. A key challenge in delivering such interventions is understanding how PTSD symptoms develop in the acute post-trauma period, defined as the first 30 days after a trauma. Mobile devices have the potential to transform the way symptoms are assessed and how treatment is delivered in that they can capture the dynamic and nuanced nature of symptom progression after trauma. Symptoms can be assessed through active strategies that require user input, such as self-report, or through passive strategies, such as location information. Adaptive mobile interventions can be tailored to target PTSD symptoms as they appear and ultimately prevent more chronic courses of illness. Considerations for how such mobile strategies should be implemented are discussed.

Keywords: posttraumatic stress disorder (PTSD); mobile; mhealth

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The prevalence of mobile devices has markedly changed the way healthcare is delivered (1). Given that 90% of American adults frequently carry a mobile device (2), these tools now permit an unprecedented level of access between patients and providers with the goal of improved care. Trauma-focused mental healthcare specifically can benefit by leveraging these devices (3). Mobile devices allow providers to assess patient progress and intervene outside of face-to-face settings (4). For example, a clinician can assess symptoms between sessions and facilitate homework completion via scheduling tools, digital worksheets, and encouraging reminders (5). Such capabilities are viewed by clinicians as essential to implementing evidence-based treatments (6). Extending the reach of providers and researchers beyond traditional settings has perhaps the greatest implication for early interventions delivered in the acute post-trauma period to prevent PTSD. The acute post-trauma period is defined as the first 30 days after an event.

The dynamics of PTSD after a trauma

Exposure to trauma places individuals at risk for a wide-range of mental health disorders. Within 12 months after a trauma, 23–31% of those exposed will meet criteria for a mental health disorder (7,8). Although posttraumatic stress disorder (PTSD) has received the most attention in the literature, and is the focus of this review, there is ample

evidence that trauma exposure is associated with numerous mental health conditions (7) such as depression, panic disorder, generalized anxiety disorder, and substance use.

PTSD has a chronic course with symptoms that can persist for years in a substantial portion of those affected (9-12). Despite the long-term stability of the disorder, the progression of symptoms after a trauma is fairly dynamic. A 2-year longitudinal study of victims of traumatic injury demonstrated that PTSD diagnostic status fluctuated (13). That is, a portion of those who were diagnosed with PTSD at one of the four assessment points did not meet criteria for PTSD at a subsequent assessment point. The reverse was also found in that a subset of those who did not meet criteria for PTSD at a given time point, met criteria for the disorder later on. The variability in diagnostic status is posited to reflect a complex developmental process in which symptoms interact with one another. Evidence for this process comes from two longitudinal studies. The first assessed symptoms 1, 6, and 12 months after trauma exposure (14). Elevated arousal at each time point was associated with greater re-experiencing and avoidance at subsequent points. This relation was not found between the other clusters, suggesting that elevated arousal after a trauma may lead to the onset of other symptoms. A recent study employed a network analysis on a sample of traumatic injury victims 24 hours after their injury and then again 1 year later (15). In the acute network, intrusive thoughts were a core feature. Other symptoms in the acute network were less central such as emotional numbing and avoidance of trauma reminders. The network of symptoms at 1-year follow-up also suggested that additional symptoms, such as elevated startle response, became more central. The 1-year network also included a sub-network of negative mood symptoms that was not identified in the acute network. Taken together, these data provide evidence as to the dynamic development of PTSD symptoms after a trauma. Understanding these dynamics is key to providing successful early intervention.

Early interventions for PTSD

The dynamic nature of PTSD after a trauma presents an opportunity and challenge for early intervention. The opportunity is that the symptoms may be highly malleable in this early period such that an early intervention can alter their course (13). The challenge is that the dynamic nature of symptoms requires adaptive treatments. There has been considerable effort to address these challenges outside of mobile technologies (16).

A well-evaluated early intervention approach is "screen-and-treat" in which individuals are monitored for approximately 1 month and then referred to treatment if necessary (17). Shalev and colleagues (18) screened individuals for 3 weeks and randomized those at risk for PTSD to receive Prolonged Exposure, medication, or a waitlist control. Those who received Prolonged Exposure demonstrated a more rapid recovery than the other groups. A related study used a similar methodology with a modular intervention that included cognitive behavioral therapy (CBT) components to address the primary presenting symptoms (19). Treatment lasted 4–10 sessions and began about 1 month after the trauma. Those who received the intervention demonstrated a faster rate of recovery relative to those who were in the treatment as usual comparison group. These data suggest that screen-and-treat approaches are an efficacious way to systematically offer treatment to those at risk for developing PTSD. However, the limitation of this approach includes the substantial resources required for repeated screening (20). Also, not all individuals at high-risk engaged in treatment or were available for assessment. Thus, there is room to improve the efficacy of this model.

Three behaviorally-based early interventions designed to be delivered within days after a trauma have demonstrated efficacy relative to treatment-as-usual (21-23). The first is a modified Prolonged Exposure intervention that occurs over three sessions (21). The first session begins shortly after the trauma and the following sessions occur over the next 2 weeks. Those who received this intervention had reduced PTSD symptoms 1 month later. The second is stepped collaborative care which integrates evidence-based treatment elements to address pressing concerns (24). Treatment progresses over a 12-month period with providers regularly assessing and providing support to the trauma-exposed individual. The number of interactions declines over the 12-month period such that communication is more frequent in the acute post-trauma period. The third involved two sessions and focused on psychoeducation about trauma-related symptoms and motivational interviewing related to discussing the trauma with others. A significant other was involved in the treatment as well and participants engaged in the treatment approximately 10 days after the trauma. Those who received this approach had improved recovery relative to a no-treatment control (23). Of note, the intervention was delivered by trained social workers and nursing staff who received regular supervision. Treatment gains from this intervention were present at a 2-year

follow-up (25). These data suggest that starting treatment after a trauma is beneficial and would reduce the burden of extended monitoring and referrals. The challenges of implementing these approaches, however, include the need for highly-skilled providers and the use of multi-session in-person treatments that recent trauma victims may be unable to complete.

The lack of a gold-standard early intervention is notable given that it has been a goal of the mental health field since the turn of the previous century (26). It is proposed that the key barriers preventing progress in developing early interventions are a limited understanding of the developmental course of symptoms during the acute-post trauma period and the challenges of providing face-to-face treatment. That is, it is difficult to tailor interventions to the needs of an individual at a given time without assigning a dedicated provider. The evolving nature of these symptoms suggests that treatment may need to last for a significant period of time. Mobile devices can address these limitations in that they permit individuals to be reached throughout the acute post-trauma period in a manner that is minimally invasive and minimally burdensome.

Mobile devices as a novel method to assess PTSD after a trauma

Mobile devices are well positioned to conduct repeated assessments during the acute post-trauma period. They are frequently carried and regularly used throughout the day. Individuals are conditioned to respond to prompts on their mobile device. A large portion of adults already use their mobile devices to obtain information about health conditions (27), suggesting that these devices are already viewed as a source of medical information. Mobile devices are able to administer validated self-report instruments (28), gather location-based (29) and biological data (30), and allow for communication with providers via text, video, and phone. Thus, they can efficiently collect a wide range of data during the acute post-trauma period.

Preliminary work has evaluated the willingness of individuals to use their mobile device for early intervention after a trauma. Post and colleagues (31) evaluated the prevalence of mobile device use and ownership among patients in acute care. The results were consistent with broader trends of mobile phone ownership and smartphone use. These data suggest that those in an acute care setting are capable and willing to use such devices for their acute post-trauma care. A subsequent usability study evaluated user preferences for a mobile application to track symptoms in a sample of trauma-exposed individuals (32). This laboratory-based study suggested that using such a mobile phone application was perceived as useful and minimally burdensome. Participants stated they would be willing to complete 2–3 brief assessments every 2–3 days. This sample indicated that that they viewed such an application as a beneficial way to interact with their provider, while also highlighting that it should not replace direct (e.g., messaging, phone calls, in-person) interactions with providers.

Considerations for mobile-based assessments after a trauma

The development of early interventions using mobile devices requires thoughtful consideration of a range of issues (33). A principle consideration is response burden. Those who recently experienced a traumatic event are faced with a range of social, financial, employment, physical health, and mental health related challenges (34). Despite the ease with which data can be collected via a mobile device relative to traditional methods, active data collection imposes a burden if done without proper implementation. Active data collection requires user input and includes responding to self-report items and is the most common type of data collection via mobile devices (35). The following considerations and recommendations to manage response burden are drawn from the existing empirical literature and the authors' experiences using mobile devices as a data collection tool data during this period (4,32,36,37).

An initial consideration for mobile data collection is the frequency of interactions, which are typically assessments of symptoms, within a given period. The typical time scale that is used for this work is 24 hours. Multiple assessments per day afford examinations of within-day change and comparisons of symptoms across contexts. For example, it would be possible to determine how symptoms differ when the individual is near a reminder of their trauma relative to when they are not. However, this level of interaction may prove overly burdensome. Prior work using mobile devices after a trauma has used one assessment per day with response rates ranging from 44.93% to 88.00% (36-38). Qualitative data obtained in these studies suggested that participants found one assessment per day to be adequate and were unwilling to complete multiple assessments per day (36,37). Thus, it is recommended that a single assessment per day be used if the primary goal is to monitor

symptom changes over a 30-day period. More frequent assessments should be considered if there is a need to examine contextual differences, such as the presence or absence of particular stimuli (e.g., trauma cues, support individuals, or a particular location).

A second consideration is the length of time that assessment data will be collected in order to make a diagnosis, take clinical action, or determine that continuous monitoring is no longer needed. The DSM 5 requires symptoms to be present for at least 30 days from the time of the traumatic event to diagnose PTSD (39). Although the acute post-trauma period is defined as this 30-day period, it is unclear how much of this period needs to be monitored. One study used a 15-day assessment window and reported a response rate of 63.1% (37). Two others used a 30-day period and had different response rates (44.93%:36,88%) (38). It is recommended that mobile assessments carry on for 30 days to gather sufficient information about symptom dynamics. As a consensus for appropriate stopping points are developed, the length of this period can be adjusted. A key research question is the point when assessment can stop because an individual is characterized as sufficiently low-risk.

A third consideration is the length of each assessment. Many self-report assessments of PTSD include one item for each of the 20 symptoms of the disorder [e.g., PCL-5 (40)]. The resulting 20-item instrument is appropriate for a dedicated research or clinical setting. A mobile device, however, alters how this measure is presented such that a survey of this length is cumbersome. For example, administration of these measures on a mobile device involves providing one item per screen (32,41). Variations in screen sizes across devices may require scrolling to view the entire question and corresponding choices. Advancing to the next screen requires using a next button. Also, the instructions for a measure cannot be displayed continuously and may need to be presented again for complex measures. Taken together, these additional elements place a greater burden on the user relative to paper-and-pencil administration. Thus, it is necessary to design assessments that can be completed quickly and provide an incentive for their completion (e.g., a "thank you" screen or reward animation). It is recommended that assessments take no longer than 5 minutes. This limitation places an imposing constraint on researchers and clinicians. To address this, abbreviated forms of PTSD assessments have been created that assess the domains of PTSD with 4 to 8 items and provide a total score that can scale to the full measure (42). Measures of such length can be completed within 30 seconds (32). Future work is required to determine what variables should be monitored and with what frequency. For example, a rotating schedule of assessments may improve response rates because each assessment is somewhat novel.

Additionally, it is recommended that short answer items be included. Short answer items allow participants to provide information that is relevant to their experience that may not be adequately captured in standardized assessments. Indeed, feedback from participants has highlighted their desire to provide additional information about their recovery that is not assessed in established measures (32). For example, an individual may want to indicate that although they have many symptoms of PTSD, they are most concerned about their inability to sleep and would want intervention specifically for sleep. In a recent study that used free text response questions as part of a mobile assessment, 90.1% of these questions received a response (36). This response rate suggests that individuals are highly likely to provide such information when given the opportunity. The length of responses varied from a single word (e.g., "pain") to longer descriptions of current problems. The qualitative information obtained from these questions can help explain potential mechanisms for recovery. For example, an increase in avoidance of talking about the event may have stemmed from a recent negative social interaction. A short answer response that describes this interaction would provide clinically relevant information for this change in the quantitative responses.

A concern about short answer responses is the increased risk that individuals will disclose high-risk behaviors in these messages, which has ethical and legal consequences for providers. In past work, participants were explicitly told that the short answer questions were a way for them to share more information with the research team and not to be used as an alternative emergency service. Across all of the short answer messages, none contained information about high-risk behaviors. Continued work on the risks associated with free-text responses is needed to determine how to best use this approach, however.

Passive data collection methods

The previously discussed considerations are for active data collection, which requires actions and thus imposes a burden. An alternative that poses less burden is passive data collection. Passive data collection involves gathering data from a mobile device's native and connected

sensors (43). Examples of passively collected data include physical activity such as step counts, GPS location, voice data, and social media usage. There is evidence to suggest that each of these elements is associated with mental health outcomes. Increased physical activity is associated with reduced depressive (44,45) and anxiety symptoms (46). Mobile devices can assess physical activity, primarily in the form of pedometer. Wearable sensors that can communicate with a native mobile device may provide additional information such as heart rate, stairs climbed, and related activity metrics (30,47). A recent study demonstrated that the locations to which individuals traveled, as determined by the GPS on their mobile device, were correlated with depression symptoms (29). Voice information obtained from mobile phone calls has been shown to identify depressed and manic states in those with bipolar disorder (48). Voice information includes abstract data collected from voice calls as opposed to the actual content of the conversation. When this information was combined with other data obtained from mobile devices, such as the frequency with which text messages were sent, detection of affective states improved. Finally, recent work using machine learning has found that analyzing posts to social media can identify an individual's affective state (49). Each of these streams of data are collected automatically by a mobile phone with no user input, or the input is associated with another use, as in the case of social media. These data are collected continuously, which reduces the amount of missing information and thus improves its quality. There are, however, ethical considerations such as privacy concerns given that passive data is collected continuously (50). Individuals should be made aware of what data is collected, how often it is collected, and where it is stored. Furthermore, individuals should be allowed to opt out of ongoing passive data collection. Continuous consent processes that require an individual to re-authorize data collection at regular intervals may be necessary.

Passively collected streams of data, when combined with self-report data, can provide a rich set of information on recovery after a trauma and, if necessary, how best to intervene (43). The increase in quality of assessments is associated with an increase in the quantity of data collected. There is a concern that providers will be unable to make use of the large amount of data that is collected, termed a 'data tsunami' (51). Indeed, having a clinician review a spreadsheet of GPS coordinates is of limited utility in assessing psychopathology. This concern is addressed with algorithms that take the large quantity of data generated by mobile devices and translate it into a usable metric for the provider. Similar to how tests of cognitive functioning use data across subtests to create a score profile for individuals, algorithms are needed to utilize the large amount of data collected from mobile devices to create similar indices that have clinical utility. Such algorithms will require careful validation and updating to become effective. Once these methods are established, however, they are likely to have tremendous utility in improving the quality of clinical care shortly after a trauma (52).

Early intervention for PTSD with mobile technologies

Mobile devices have the potential to significantly enhance the delivery of early interventions for PTSD as "just-in-time-adaptive" interventions (JITAIs). JITAIs are defined as interventions that are delivered at a time that is most helpful and is appropriate for a given context and need. For example, the acute post trauma period is marked by social withdrawal that is driven by elevated physiological arousal and depressed mood (15). Improved social support is thought to counteract social withdrawal, which may also reduce other symptoms (53). A JITAI during the acute post-trauma period could provide encouragement for a trauma victim to reach out to their social support network. This encouragement could involve an established technique, such as motivational interviewing, or use information gathered from the mobile device itself, such as identifying a frequently messaged phone contact. Understanding the specific challenges a given individual experiences and when they experience them is likely critical for a successful early intervention for PTSD.

JITAIs best fit within a stepped-care framework. Stepped care is a framework for interventions that is delivered across steps that increase in intensity (54). The first step involves a minimally intensive intervention. If this approach is unsuccessful, the patient advances to the next step that is more intense. The number of steps depends on the availability of interventions and the needs of a given patient. Stepped care approaches are more effective and economical than a having standard treatment for all cases (55). The model hinges on two guiding principles (56): (I) that the initial intervention is the least restrictive for the patient and provider while also being effective and (II) there is a validated monitoring method by which an individual can be advanced to the next step of care. The stepped collaborative care approach developed by

Zatzick and colleagues is an example of a stepped care early intervention (22,57). The progress of each individual patient is monitored by their case worker who determines when to progress to the next step. Early steps involve psychoeducation and case management whereas future steps involve CBT or medications.

Mobile devices are the ideal way to deliver the initial steps of a stepped care approach. The first step may be exclusively automated in that data is collected and feedback is generated based on the mobile-collected data. For example, patients would enter daily self-report data on reactivity to trauma cues and pain as these symptoms are proposed to be early indicators of problematic recovery (58). GPS-based location data can offer insights into the extent that the individual is engaging in regular activities or avoiding specific locations. These data could then be used to provide feedback to the patient such as information about the course of their symptoms and potential interventions. For example, a patient with elevated pain could be presented with a graph of their pain ratings over several days to show that although their pain is elevated, it has decreased since the initial trauma. They may be recommended to engage in evidence-based interventions for pain such as a mindful meditation or restorative yoga (59). The second step can involve messaging or video conferencing with a provider via their mobile device. The messaging system could be personalized via their local provider or use a centralized system. If neither are effective, formal in-person care can be started that is supplemented by the mobile device. This progression is similar to the screen-and-treat strategies, but is likely to have a much lower burden on the care system at its initial stages. An advantage of this process is that the mobile device is used throughout and information obtained in the first step is available for providers involved in subsequent steps. This information can help providers efficiently determine how PTSD symptoms have progressed, the effect of interventions administered thus far, and personalize the next intervention for the individual. For example, a JITAI that collected data on sleep during the initial mobile-only step could inform a provider that became involved at a subsequent step about the participant's sleep habits. Mobile devices serve as the backbone for this system as they are capable of collecting such data and ultimately delivering frontline treatments.

The stepped care model should adapt to the needs of the patient population. The algorithm for determining advancement to the next step of care must be able to take in new information so that it can better refine its recommendations. Thus, stepped care works best as a dynamic approach for intervention as opposed to a static set of rules. The data gathered by mobile technologies can provide the information necessary for such revisions. Mental health researchers are encouraged to collaborate with computer and data scientists who have expertise in developing adaptive systems as this is likely to result in a more robust intervention.

Conclusions and future directions

The use of mobile devices for early intervention to treat post-trauma psychopathology holds considerable promise. Mobile devices allow the dynamic nature of recovery—the understanding of which is critical to create effective interventions to prevent PTSD—to be evaluated in real time. They offer a way to provide engaging and interactive strategies that build upon current state of the art treatments. That is, mobile devices can offer interactive games, video conferencing, and on-demand messaging systems that break the mold of what is used in current approaches. The development of such interventions should be done collaboratively with colleagues from disciplines outside of mental health. These colleagues may come from a variety of areas including computer science, human-factors, and complex systems science. Researchers should also consider partnering with private industry to facilitate application development. Small businesses often have the range of expertise necessary to develop a prototype of an early intervention or complete distributed system (e.g., frontend and backend for providers and patients). Federal agencies such as the National Institutes of Health and the National Science Foundation offer specific funding mechanisms to support such collaboration (60).

Beyond development, there is a great deal of research that is needed to realize the full benefit of mobile devices as an early intervention. Investigators are encouraged to explore the utility of each data stream (e.g., self-report, location, etc.) that is available from a mobile device for determining recovery and treatment response. This systematic approach is necessary to develop optimized assessment and intervention strategies. Traditional randomized controlled trials and related experimental methodologies may be inefficient in this line of inquiry. Study designs from the field of engineering, such as the multiphase optimization strategy (MOST) and sequential multiple assignment randomized trial (SMART), are ideal for these types of questions because they allow for

investigating the efficacy of multiple components in a single study (61). The quantity of data collected also requires the use of analytic methods not commonly used in the mental health field such as machine learning and network analysis (62,63). Collaboration with those who have expertise in data science is again key to determining how best to use these data (64,65).

The search for an early intervention to prevent the maladaptive outcomes that result from trauma has lasted for decades (26). Despite this motivation, there has been surprisingly little advancement in this area relative to other domains of healthcare. The limited progress is attributed to challenges in accurately understanding the dynamics of recovery in the acute post-trauma period. Mobile devices provide a means by which to efficiently and appropriately assess symptom progression and administer treatments during this period. Through using the many capabilities of mobile devices, we will have a better understanding of how trauma-related psychopathology develops and the best methods by which to intervene.

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Footnote

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