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Review

Digital Tools for Early Identification and Course Modification in Generalized Anxiety Disorder

Reyouf Abdulsalam Almughamsi[1*], Maram Hussam Hassan[2], Abdullah Mohammed Alsaeed[3], Zahra Zaki Al Mattar[4], Manar Abaas Alhejji[5], Yazeed Abdullah Alasiri[6], Bader Fouad Ablis[7], Raed Ahmad Alhamdan[8]

[1] *Department of Family Medicine, King Fahad General Hospital, Jeddah, Saudi Arabia*
[2] *Department of Psychiatry, Ministry of Health, Al Ahsa, Saudi Arabia*
[3] *College of Medicine, King Faisal University, Al Hofuf, Saudi Arabia*
[4] *Department of Preventive Medicine, Ministry of Health, Dammam, Saudi Arabia*
[5] *College of Medicine, King Faisal University, Dammam, Saudi Arabia*
[6] *Head of Quality and Project Department, AD Diriyah Hospital, Riyadh, Saudi Arabia*
[7] *College of Medicine, Istanbul University, Istanbul, Turkey*
[8] *Department of Clinical Social Work Addiction, Erada Mental Health Complex, Dammam, Saudi Arabia*

Correspondence should be addressed **Reyouf Abdulsalam Almughamsi**, Department of Family Medicine, King Fahad General Hospital, Jeddah, Saudi Arabia. Email: reyouf005@hotmail.com

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Abstract

Generalized anxiety disorder (GAD) is a mental condition with persistent and excessive feelings of worry and fear, leading to significant distress and impairment of daily life and functioning. It is one of the leading causes of mental health disability, with a 12-month prevalence of 1.8% globally. Diagnosis of GAD is usually made through the Generalized Anxiety Disorder 7-item (GAD-7) and 2-item (GAD-2) scales, and symptoms must be persistent for at least 6 months for a confirmed diagnosis of GAD. Management involves medication, mainly antidepressants, in addition to psychotherapy, which is often cognitive behavioral therapy (CBT). However, there are several limitations to accurate diagnosis and treatment of GAD, due to the presence of comorbidities, and the inaccessibility of psychotherapy to many individuals. Passive data collection, behavioral analysis over social media platforms, and machine learning can be implemented for the development of digital biomarkers for GAD and the accurate prediction of the disorder. Digital mental health interventions, such as the internet, virtual reality (VR), and smartphones, can be used to provide CBT and meditation training to individuals with GAD, leading to early and better access to mental health care and tailored management of the disorder. In this narrative review, we aim to investigate current evidence regarding the use of digital tools for early identification and course modification in GAD.

Keywords: *Generalized anxiety disorder, passive data collection, machine learning, digital mental health interventions*

Introduction

Generalized anxiety disorder (GAD) is a mental health condition that is characterized by prolonged and excessive feelings of worry and fear without a reasonable cause. This persistence of anxiety leads to significant distress and impairment of daily life and functioning, and consequently, poor quality of life and healthcare utilization (1). GAD is considered one of the most common anxiety disorders and a leading cause of mental health disability in the world, with a 12-month global prevalence of 1.8%. The prevalence is notably higher and more impairing in high-income countries (5.0%) compared to middle-income (2.8%) and low-income countries (1.6%), despite a negative association between GAD and socioeconomic status within countries (2). Common symptoms include excessive worrying, restlessness, difficulty sleeping, muscle fatigue and tiredness, irritability, sweating, and tremors (1). Symptoms must be present on most days for at least 6 months for a confirmed diagnosis of GAD (3). GAD is often associated with other comorbid conditions. Depressive disorders, especially major depressive disorder, and other anxiety disorders, especially panic disorder, often coexist with GAD. This comorbidity leads to more severe impairment and worse outcomes in GAD patients (4). Moreover, suicidal ideation and suicide attempts are common in patients with GAD, which require immediate intervention (5).

The exact cause of GAD remains unknown. However, a significant association between traumatic events in childhood and the development of GAD has been discovered. Common childhood adversities that contribute to GAD development include physical abuse, sexual abuse, neglect, family violence, and parental malfunctioning through mental illness, criminal behavior, and substance abuse (6).

Anxiety disorders, including GAD, are mainly detected using the Generalized Anxiety Disorder 7-item (GAD-7) and 2-item (GAD-2) scales, with good diagnostic accuracy for GAD and other anxiety disorders (7). However, self-reported and clinician-administered questionnaires have their own limitations (8). Therefore, there is a need for the development of early and rapid detection methods with high accuracy for GAD. The use of smartphones to passively collect data and the application of machine learning are considered a promising approach for early prediction of several mental health disorders, including depression, GAD, and other anxiety disorders (9-12).

As for management, there are several treatment options available for GAD treatment, including medication and cognitive behavioral therapy. Among the medication treatments, antidepressants, buspirone, benzodiazepines, hydroxyzine, and azapirone have been studied for the management of GAD (13, 14). Cognitive behavioral therapy (CBT) is a well-established psychotherapy approach for the treatment of GAD. However, there are several logistical barriers to accessing in-person CBT. Digital CBT has the potential to overcome these barriers and be used as a digital intervention for the treatment of GAD (15-17).

Digital interventions are software-based therapeutic activities that can be accessed via technology platforms, such as the internet, virtual reality (VR), and mobile phones. According to the World Health Organization (WHO), digital intervention means using technology to achieve health sector objectives (18). Digital mental health interventions are rising in popularity due to their relatively low cost, effectiveness, and convenient diagnostics and treatment for various mental conditions. including anxiety disorders such as GAD and social anxiety disorder (SAD), depression, panic, insomnia, posttraumatic stress disorder (PTSD), and obsessive-compulsive disorder (OCD) in several age groups (19-21). This narrative review aims to provide current evidence regarding the use of digital tools for early prediction and identification of GAD, in addition to the application of digital mental health interventions for course modification in this mental condition, therefore, guiding further research for early and accurate diagnosis and management.

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Methodology

This narrative review is based on a thorough literature search conducted on 7 October 2025 in PubMed, Cochrane, and Web of Science databases. The search aimed to identify studies examining the use of digital tools for early identification and course modification in generalized anxiety disorder (GAD), using medical subject headings (MeSH) and relevant keywords. The review focused on articles that address the use of passive data collection and machine learning for early detection of GAD, in addition to the use of digital interventions for GAD management. No restrictions were applied regarding the type of publication, publication date, or language, to ensure a broad investigation of the available literature.

Discussion

Digital phenotyping of generalized anxiety disorder

A new and innovative approach for diagnosing and monitoring anxiety has emerged, which uses smartphone sensor–based monitoring as a metric for the detection and management of anxiety. This digital phenotyping relies on the collection of passive sensor data for the prediction of GAD. Such data points include GPS location, Bluetooth, call and message logs, audio, and accelerometer. A machine learning-based data mining tool was used to track an individual's daily anxiety levels with a prediction accuracy of 76% using nonintrusive, passively collected smartphone data (12). This demonstrates that passively collected smartphone data augmented with data mining using machine learning can be an effective approach to derive accurate digital biomarkers for mental health conditions such as GAD, allowing for early and rapid detection of this condition.

Data can be collected using not only smartphones. A cohort study investigated the use of passive movement data collected using wearable sensors for estimating symptom severity in 264 individuals with GAD. In the study, movement data were collected over one week, and machine learning techniques were applied for the determination of GAD symptom severity. Results indicate high accuracy for predicting individuals with elevated GAD symptoms with a 70.0% sensitivity, 95.5% specificity, and a Brier score of 0.092 (22). However, a limitation of this study is that it examined the estimation of GAD symptom severity instead of the prediction of GAD symptom severity over time. Hence, more research is needed to investigate the efficacy of sensor-collected movement data for the accurate prediction of GAD development.

Machine learning approaches for the identification of GAD and course prediction

As previously shown, machine learning is an important approach for mining passively collected data for early prediction of GAD and detection of symptom severity. Deep learning models offer the tool to analyze smartphone sensor and wearable sensor data to accurately predict the development of GAD symptoms, which can aid clinicians in their GAD diagnosis and lead to early and personalized management of the disorder.

Another use of machine learning for the identification of GAD involved the analysis of user-generated content and users' activities on social media platforms for characteristics of GAD. Several studies used natural language processing (NLP) in addition to machine learning for the prediction of various mental health conditions, including anxiety, depression, PTSD, and eating disorders, via popular social networks (23-27). The use of machine learning and deep learning models for behavioral analysis of users over social media offer an opportunity for large-scale assessment of GAD and understanding the mechanisms underlying this mental health condition.

For instance, a study investigated social media posts and behavioral patterns of people with GAD over X (formerly Twitter) to identify digital markers of GAD. NLP and machine learning tools that focused on language use, emotional expression, topics discussed, and engagement were used. Results of the linguistic analysis revealed significant differences between individuals with GAD and the control group. GAD individuals showed significantly higher values ($p < 0.001$) in the

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assessment of cognitive style than the control group, including insight and memory. There were also significant differences regarding personal needs. Individuals with GAD used fewer reward words ($p = 0.003$) and fewer communication words ($p < 0.001$) than the control group. Regarding emotional expressiveness, individuals with GAD significantly expressed more negativity ($p < 0.001$), such as anxiety, anger, sadness, and swear words (28). These findings highlight the potential of applying machine learning for the analysis of social media posts and engagement as an early predictor of GAD development. Further research is needed for the development of suitable assessment tools that can aid clinicians in the diagnosis process.

Another remarkable application of machine learning in GAD research is the prediction of GAD clinical course. A recent study investigated GAD outcomes in 126 participants over a nine-year follow-up. Social, biological, psychological, sociodemographic, and health variables were studied as predictors for GAD clinical course. Machine learning models were used to predict GAD outcomes, and results indicated that higher depressive symptoms, daily discrimination, more mental health care visits, and more medical care visits were highly predictive of nonrecovery. On the other hand, more friends support, being older, having some college education, and having a higher waist-to-hip ratio were all predictors for recovery (29).

Digital therapeutics and their role in modifying the GAD course

The use of digital therapeutics for management and course modification in GAD has been investigated. A meta-analysis of 20 randomized controlled trials studied the effectiveness of internet-delivered interventions for the treatment of GAD symptoms. Results show a significant effect for the treatment on symptoms of anxiety ($p < 0.0001$) and worry ($p < 0.0001$). Furthermore, a large effect in favor of the treatment on depressive outcomes ($p < 0.0001$) and functional impairment ($p < 0.0001$) was observed, in addition to a small-to-moderate effect on quality of life outcomes ($p = 0.024$) (30). These findings highlight the potential of internet-delivered interventions as digital therapeutics for alleviating anxiety symptoms and improving quality of life in GAD treatment, leading to better and tailored management of the disorder.

Moreover, in a randomized controlled trial to test the efficacy of an app-delivered mindfulness training for GAD, a significant anxiety reduction (GAD-7 score) was observed in the mindfulness training group compared with the control group at 2 months (67% vs 14%, $p < 0.001$). This anxiety reduction was a result of increasing mindfulness, which consequently led to a reduction in worry. The study included 63 participants with GAD with moderate to severe anxiety (31). These findings prove that mindfulness training can be beneficial as a digital therapeutic for anxiety management in individuals with GAD.

Another randomized controlled trial investigated the efficacy of a digital cognitive behavioral therapy (CBT) program for participants with GAD with moderate to severe symptoms. Results showed a significant decrease in anxiety symptoms (GAD-7 score) in the digital CBT group compared with the waitlist control at three time points: mid-intervention ($p < 0.001$), post-intervention ($p < 0.001$), and at follow-up ($p < 0.001$). Moreover, significant improvements were observed for worry, depressive symptoms, sleep difficulty, and mental well-being at all the assessment time points. The study included 242 participants (16). These findings highlight the effectiveness of digital CBT for alleviating symptoms of anxiety over time and overall improvement of quality of life in individuals with GAD. Digital CBT can be a potential solution that avoids the limitations of in-person CBT.

Furthermore, artificial intelligence (AI)-based CBT has been investigated. AI-based CBT is a novel approach that delivers CBT as a mental health intervention through AI-powered CBT chatbots. Several chatbots have been developed as digital therapeutic tools for the treatment of depression, anxiety, and other mental health disorders. A systematic review of 10 trials that studied 3 chatbots, namely, Woebot, Wysa, and Youper, reported a significant reduction in symptoms of

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anxiety and depression in users of these chatbots (32). These findings highlight the advantages of the use of such chatbots, including low cost, self-guided treatment, and availability of treatment to individuals who may not have access to mental health care. However, there were limitations regarding these trials, and further research is needed to investigate the efficacy of AI-driven CBT chatbots in individuals with GAD.

Virtual reality (VR) is a valuable technology that can be used as a digital mental health intervention. A systematic review investigated the efficacy of VR-based interventions on several mental health disorders and showed promising results in anxiety disorders, including GAD. Currently, VR research in GAD focuses primarily on VR-based relaxation and mindfulness training as a digital therapeutic tool to reduce anxiety (33). VR exposure therapy might indeed be a promising alternative for traditional anxiety therapies; however, further research is necessary to prove the efficacy of these VR trainings over classical relaxation and mindfulness approaches.

Current challenges and limitations

Although the use of social media content for digital phenotyping of GAD is a promising approach for early diagnosis of the disorder, individuals with various mental illnesses report their concerns about privacy on social media, regarding risks related to relationships, employment, and stigma (34). Moreover, data collected over social media may lack demographic representation, which is considered a limitation for mental health assessment (28). Another concern regarding the use of machine learning predictive models is the accuracy of prediction and the lack of consensus on the sufficiency of predictive power to justify the consequences of false-positive and false-negative predictions in disorder prediction. Moreover, there is a need to understand the used algorithms and ensure the transparency of the predictive models (35).

One of the main limitations of digital mental health interventions is the uncertainty regarding their effectiveness (36). Further research is needed to investigate the long-term efficacy of various digital therapeutics in comparison with medication and in-person psychotherapy for alleviating symptoms of GAD and other associated comorbidities, such as depression disorders. More studies are needed for the validation of digital therapeutics, their reproducibility, and their cost-effectiveness. Other challenges that face digital interventions include digital literacy, many people lacking access to smartphones or the internet, especially in rural areas, and a lack of evidence that supports the use of digital therapeutics for people with severe mental illness, perhaps due to their poor quality of life (37). These challenges can be addressed through collaboration with governments to provide technology in rural areas and provide educational resources to help individuals learn and understand how to use digital therapeutic tools. More research is needed to investigate the integration of digital therapeutics with classical therapy for individuals with severe mental illness.

Conclusion

Anxiety disorders, including GAD, are associated with functional impairment, poor quality of life, and inadequate utilization of medical resources. Many individuals with GAD do not have access to mental health care and thus often go undiagnosed and untreated. Moreover, there is a risk of misdiagnosis due to association with other comorbidities and symptom overlap. Digital interventions that can be delivered using the internet or smartphones have the advantage of better accessibility, leading to early and accurate prediction of the disorder and tailored, effective management. Moreover, the implementation of artificial intelligence and machine learning has the potential to notably expand the accuracy of GAD identification, leading to early and accurate diagnosis. Further research is needed to develop suitable assessment tools that can aid clinicians in the diagnosis process and investigate the efficacy of digital interventions for alleviating symptom severity in individuals with GAD for tailored management of the disorder. Addressing current challenges and limitations to the use of digital therapeutics for GAD management

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will lead to better accessibility and efficient utilization of health care resources.

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Conflict of interest

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Data availability

Data that support the findings of this study are embedded within the manuscript.

Author contribution

All authors contributed to conceptualizing, data drafting, collection and final writing of the manuscript.

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