# From Ecological Momentary Assessment (EMA) to Ecological Momentary Intervention (EMI): Past and Future Directions for Ambulatory Assessment and Interventions in Eating Disorders

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## Abstract

**Purpose of Review** Ambulatory assessment methods, including ecological momentary assessment (EMA), have often been used in eating disorders (EDs) to assess the type, frequency, and temporal sequencing of ED symptoms occurring in naturalistic environments. Relatedly, growing research in EDs has explored the utility of ecological momentary interventions (EMIs) to target ED symptoms. The aims of the present review were to (1) synthesize recent literature pertaining to ambulatory assessment/EMA and EMI in EDs, and (2) identify relevant limitations and future directions in these domains.

**Recent Findings** With respect to ambulatory assessment and EMA, there has been substantial growth in the expansion of constructs assessed with EMA, the exploration of state- vs. trait-level processes, integration of objective and passive assessment approaches, and consideration of methodological issues. The EMI literature in EDs also continues to grow, though most of the recent research focuses on mobile health (mHealth) technologies with relatively minimal EMI components that adapt to momentary contextual information.

**Summary** Despite these encouraging advances, there remain several promising areas of ambulatory assessment research and clinical applications in EDs going forward. These include integration of passive data collection, use of EMA in treatment evaluation and design, evaluation of dynamic system processes, inclusion of diverse samples, and development and evaluation of adaptive, tailored EMIs such as just-in-time adaptive interventions. While much remains to be learned in each of these domains, the continual growth in mobile technology has potential to facilitate and refine our understanding of the nature of ED psychopathology and ultimately improve intervention approaches.

**Keywords** Eating disorders · Ambulatory assessment · Ecological momentary assessment · mHealth · Ecological momentary intervention

## Introduction

Although earlier literature in eating disorders (EDs) relied heavily on trait-level measurements to inform our understanding of etiology, maintenance, and intervention development, there is increasing consensus that EDs, like other psychiatric conditions, are highly heterogeneous, dynamic constructs that vary *between* individuals and fluctuate over time *within* individuals. Accordingly, understanding and effectively targeting ED symptoms requires a methodology that can capture dynamic momentary processes, account for meaningful individual differences in such processes, and ultimately harness such information to refine and improve intervention approaches. Ambulatory assessment methods, including ecological momentary assessment (EMA), have emerged as a popular methodology in the study of EDs in recent years [1], and there is growing evidence to support the potential of ecological momentary intervention (EMI) approaches [2, 3]. While these methods show much promise in advancing ED research and treatment by identifying and intervening upon momentary processes, there remain important gaps in the literature to address. Therefore, the purpose

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of the present review is to (1) summarize ambulatory assessment/EMA and EMI research in EDs in recent years and (2) highlight key future directions in each of these domains.

## Ambulatory Assessment Studies in EDs

Ambulatory assessment refers to monitoring of experiences in the natural environment, including EMA or experiencing sampling approaches that assess individuals at periodic intervals [4]. Such methodology offers a range of advantages over traditional self-report or laboratory-based measures, including enhanced ecological validity, reduced retrospective recall biases, and, perhaps most importantly, examination of micro-temporal relationships between variables of interest [5]. Over the past decades, numerous studies in EDs have utilized EMA to provide enhanced understanding of theoretical models, antecedents and consequences of ED behaviors, the frequency and patterns of ED symptoms, and evaluation of psychometric properties of EMA measures (see Engel and colleagues [1] for a review). This literature has continued to grow in EDs, with dozens of EMA studies published within the last 3 years alone. Here, we highlight developments in four broad areas over the previous 3 years: (1) emerging constructs assessed via EMA; (2) the interplay of state- and trait-level processes; (3) integration of objective assessments of physiological, neurocognitive, and neurobiological functioning; and (4) methodological issues.

## Emerging Momentary Constructs

While EMA has been most commonly employed to study affective states prior to and following ED symptoms [6], EMA research in recent years has seen a growth in other relevant domains, as well as expansion and refinement of emotion-related assessments. For instance, EMAs of affective states have broadened to include momentary indices of affect instability in bulimia nervosa (BN) [7], momentary emotion identification in anorexia nervosa (AN) [8], emotion switching in BN [9, 10], and fluctuations in momentary emotion regulation [11, 12]. There has also been increasing interest in the study of momentary cognitive processes (e.g., meal-related cognitions [13]; cognitive dissociation [14]), including repetitive negative thinking and cognitive rumination, the latter of which is theorized to exacerbate and maintain negative affect and psychopathology [15, 16]. For example, recent ED research found that momentary repetitive negative thinking predicted weighing and body checking, as well as ED symptoms at a 1-month follow-up [17]. Other findings have indicated EMA-measured rumination was related to negative affect in AN [9, 18] and that food-related rumination decreased during weight restoration [9]. Such findings are consistent with state- and trait theories of rumination and emotion regulation, which broadly suggest the repetitive nature of cognitions, in addition to specific content, is a key predisposing factor for affective disturbances and maladaptive behaviors [16, 19, 20].

## State and Trait Factors

Given the high degree of heterogeneity seen across and within ED diagnoses [21], another important area that has expanded with EMA research is the differentiation and interactions between state- and trait-level processes. As a result, this body of research has elucidated meaningful individual differences in momentary processes contributing to ED symptoms. In particular, several studies have examined the moderating influences of trait-level facets of impulsivity on momentary relationships between affect and ED behaviors across diagnoses and ages [22–26]. For instance, in BN, Fischer and colleagues [23] found that those with high negative urgency (i.e., the tendency to act impulsively when distressed) showed lesser increases in negative affect prior to binge eating; similarly, in an AN sample, the change in negative affect prior to and following binge eating and purging episodes was less for those with higher negative urgency [22]. Together, these results suggest that relatively smaller shifts in momentary negative affect may trigger ED behaviors among those high in negative urgency compared with those low in negative urgency.

In addition to interactive effects of state and trait variables, other studies have examined similarities and distinctions between state- and trait-level measures of constructs. Fuller and colleagues [27] found that both trait levels and state (i.e., EMA-measured) mean levels of body dissatisfaction were associated with ED pathology, while other momentary indices of body dissatisfaction (i.e., inertia and instability) were not correlated with trait body satisfaction or ED symptoms. On the other hand, among individuals with obesity, differential relationships between affective valence (i.e., positive vs. negative) and stability (i.e., trait vs. state) emerged with binge eating and cognitive restraint measured via EMA, indicating that trait-level positive affect was related to restraint, while both trait- and state-level negative affects predicted binge eating [28].

## Integration of Objective and Passive Assessments

There has also been growth in the use of objective ambulatory assessments. For example, Ranzenhofer and colleagues [29••] found that lower momentary heart rate variability (an indicator of autonomic functioning and self-regulatory capacity

measured via an ambulatory Holter monitor) was related to subsequent loss-of-control eating in adolescents. Another study utilizing an ambulatory measurement of sleep (i.e., wrist-worn accelerometer) found that participants with full or subthreshold BN and binge eating disorder (BED) had lower subjective sleep quality compared with those without EDs, though ED symptoms were only related to subjective but not accelerometer-based sleep parameters [30]. However, given that this study employed aggregated measures of ED symptoms and sleep, it is not clear whether there were in fact time-varying effects of sleep and eating symptoms.

In line with the emergence of state- and trait-level interactions in EMA research, several studies have used laboratory-based measures of neurocognitive, neurobiological, and physiological functioning as predictors or moderators of momentary variables assessed via EMA. Both Goldschmidt and colleagues [24] and Smith and colleagues [26] found that task-based measures of executive functioning strengthened momentary relationships between affect and binge eating symptoms, indicating that individual differences in neurocognitive functioning are meaningful factors contributing to symptoms at the momentary level. In addition, baseline plasma leptin levels (used as a biomarker of undernutrition) were related to EMA-measured rumination about food but not body weight/shape in an AN sample, which may suggest physiological factors related to undernutrition contribute to food-related rumination [9]. Lastly, several studies have integrated fMRI-based measures of neurobiological functioning and EMA. Specifically, neural responses to food cues after an acute stressor have been found to moderate momentary affect, stress, and craving trajectories surrounding binge eating in a BN sample [31, 32, 33••]. In addition, ventral striatum activity measured during regulation of positive affect was associated with EMA-measured body-related rumination and negative affect among individuals with AN but not controls, and this neural response during emotion regulation was also related to poorer treatment outcome in the AN group [34]. While this body of research remains limited, findings broadly indicate the potential utility of neurocognitive, physiological, and neurobiological measures in predicting real-life affect, behaviors, and treatment response.

## Methodological Issues

Another area of EMA research in EDs has emerged focusing on measurement and methodological issues. Kockler and colleagues [35••] discussed the importance of sampling frequency in EMA research to capture highly dynamic processes in EDs. Whereas most EMA research has sampled individuals every few hours, the authors provided an illustrative example of how meaningful micro-temporal cognitive, affective, and behavioral processes may unfold on a much shorter time scale surrounding binge eating. Thus, the validity of EMA results is dependent on the appropriate selection of assessment schedules that allow for accurate characterization of dynamic processes of interest. Recent research has also highlighted how statistical techniques used to analyze EMA data have a meaningful impact on findings. In order to address discrepancies in the EMA literature regarding post-binge affect trajectories, Berg and colleagues compared two analytic techniques to assess affect surrounding binge eating in AN and BN samples. Results indicated that the proximal post-binge negative affect ratings were higher than proximal pre-binge negative affect ratings (which is seemingly contrary to affect regulation theories). However, when accounting for the timing of the ratings (with post-binge ratings made more proximally to the episode), these findings mapped closely onto trajectory analyses that indicated negative affect generally increased prior to and decreased following binge eating in these samples [36••].

EMA has also been used in several recent studies examining the ecological validity and correlates of trait-level measures. For instance, Goldschmidt and colleagues [37] assessed the validity of the Diagnostic and Statistical Manual (DSM-5) binge eating indicators using EMA ratings, and EMA-measured overeating and binge eating assessments were used to validate the Positive-Negative Emotional Eating Scale [38]. Momentary correlates of ED measures were also examined recently by Mason and colleagues [39, 40]. Together, this research has illustrated the additive value of EMA in measurement development and validation.

## Future Directions in Ambulatory Assessment

The literature reviewed in the preceding sections has demonstrated the continuing utility and advancement in the use of ambulatory assessment in EDs. There also remain gaps and limitations that highlight a number of fruitful areas for further study, particularly with regard to objective and passive data collection, utilization of EMA in treatment, applications for dynamic systems approaches, and the need for EMA research to extend to more diverse samples.

Progress has certainly been made in the use and integration of objective measures of constructs relevant to EDs (i.e., HRV, sleep, neurobiology, neurocognition, and neuroendocrine functioning). Such multimethod approaches could meaningfully enhance our understanding of biobehavioral mechanisms that precipitate and maintain ED symptomatology and potentially identify novel targets of interventions. However, most of this research in EDs has nevertheless been limited to small sample sizes and cross-sectional designs, and all but one study [29••] have employed single or aggregated measures of objective data (e.g., baseline measures used as moderators of momentary relationships or predictors of EMA variables). This precludes a more nuanced understanding of time-varying relationships between biobehavioral constructs and momentary ED symptoms,

or the extent to which relationships between EMA variables and such objective measures (e.g., neural responses) change over time or during interventions. In addition, advances in other fields are rapidly being made with a range of other ambulatory data collection methods that do not rely on self-report (e.g., stress [41], geolocation [42], nutrition/dietary intake assessment [43], and physical activity [44]), all of which are relevant constructs in EDs and could be integrated in future studies. Relatedly, increased use of continuous, passive data collection methods could have potential in reducing some of the burden associated with traditional self-report EMA methods and decrease the possibility of missing meaningful fluctuations in constructs, as noted by Kockler and colleagues [35••].

In the context of treatment, ambulatory assessment and EMA methods could also be used in a variety of ways. ED treatment outcomes have historically been measured via the use of trait-level measurements, but "bursts" of EMA could also be used to assess relative changes in daily symptom levels, as well as momentary decoupling of relevant constructs (e.g., relationships between momentary affect and binge eating) using techniques such as time-varying effect modeling (TVEM). At the individual level, "N-of-1" or single-subject trials could also be employed to tailor treatment, consistent with the recent precision medicine initiative across areas of healthcare [45]. Such designs, which involve repeated measurements to identify and intervene upon intra-individual mechanisms, have shown promise for other health-related behaviors (see McDonald and colleagues [46] for a review). The use of ambulatory assessments would therefore have significant utility in such approaches, yet this also raises important issues regarding feasibility, accessibility, and EMA data management in routine clinical care for EDs.

In and outside of EDs, there has been a rapidly growing body of literature using network analysis to understand symptom-level "building blocks" of psychopathology (see Borsboom [47] for a review), as well as how psychiatric disorders can be understood as complex dynamical systems of symptoms (see Nelson and colleagues [48] for a review). Ambulatory assessment methods are very well suited to be integrated in these approaches. For instance, while existing ED network studies have relied heavily on cross-sectional data, applying multilevel vector auto-regressive (mlVAR) models to intensive longitudinal data can provide a nuanced understanding of within- and between-person network structures [49]. In addition, using repeated EMA "bursts" could yield important information regarding how micro-level symptom dynamics evolve over time to predict macro-level outcomes. The early warning signs embedded in EMA data (e.g., increasing temporal auto-correlations or network density) could also investigated as signals of approaching "tipping points" between healthy and disordered states [48, 50].

Finally, it is important to note the relative lack of diversity in samples across the EMA studies reviewed, which consisted of primarily Caucasian women and relatively few adolescent samples [24, 29••, 51]. Given that EDs present in a wide range of demographic groups, going forward, it will be imperative for researchers to make concerted effects to recruit samples including a wider range of ages, genders, ethnicities, and sexual orientations in ambulatory assessment studies. Furthermore, this may require careful consideration of population-specific issues and decisions regarding ambulatory assessment questions and platforms. For example, one recent study reported on the iterative development of an EMA application to assess ED symptoms that was designed specifically for a low-literacy population, in which the authors noted important design considerations that were taken into account based on user feedback [52].

## Ecological Momentary Interventions in EDs

The use of mobile health (mHealth) technologies, and particularly the use of EMIs (interventions delivered to people in real-time, most often through smartphone apps [53]), to augment or extend the reach of existing treatments for EDs continues to remain an underexplored area. Since 2016, only one study has evaluated a non-adaptive text messaging intervention in a single-case series [54], and three other studies [55–57] were published evaluating the acceptability of Recovery Record, a self-monitoring app that includes a non-adaptive EMI component of pre-set meal and/or goal reminders. Additionally, one systematic review of mHealth interventions for eating pathology was published, of which a small number of the included interventions contained an EMI component. Since 2016, no study has evaluated the impact of an adaptive EMI that can adjust the content or timing of interventions based on user data. Below, we will briefly review and evaluate the recent literature related to EMI for EDs and will discuss future directions.

In 2016, Shingleton and Palfai [54] used a single-case alternating treatment design to test the feasibility and efficacy of motivational text messages on both self-reporting motivation and eating behaviors in 12 individuals with either anorexia nervosa or bulimia nervosa. The text messages were designed as an adjunct to cognitive behavioral treatment (CBT), and all patients received CBT during the course of the trial. Results suggested that the intervention was well accepted and feasible within the context of an 8-week treatment protocol, though the authors note that individuals received monetary compensation for compliance with daily monitoring. Overall, text messages were not found to impact either dietary restraint or caloric intake. However, there was some evidence to suggest that the text messages may have impacted self-reported motivation to reduce dietary restraint, though only in those with bulimia. Individuals with anorexia showed the opposite pattern such that text messages were associated with increased desire to restrict their dietary intake. The pattern of results observed

suggests that text messages could be an effective way to increase motivation for change in some individuals with eating pathology, although it is not clear that this increase in reported motivation to change will lead to actual changes in eating behavior. The findings overall support the potential for text message–based interventions to be a beneficial augmentation to CBT for some individuals, though research with larger sample sizes is clearly needed to confirm and extend these results.

A growing number of studies are investigating the feasibility and acceptability of Recovery Record, the most widely used publicly available self-monitoring app for EDs. Recovery Record contains minimal EMI features, though users can (but do not have to) set meal time reminders or goal reminders. One of the three studies published since 2016 primarily focused on the clinician's perspective of Recovery Record, and little information specific to meal or goal reminders was included in the report, limiting the ability to understand the clinician's perspectives on the use of EMI as an adjunct to treatment [55]. A study by Kim and colleagues [57] tested the use of Recovery Record over an 8-day time period among 200 individuals who downloaded the app and indicated that they did not intend to use the app in conjunction with a clinician. A total of 133 individuals used the app for at least 7 days, and 64 completed an acceptability survey at the end of the trial period. Of the users who participated in the assessments, Recovery Record was found to be feasible and acceptable and was perceived as helpful by users with ED symptoms. In this study, 73% of users opted to have a once a day reminder, which suggests a relatively high number of individuals who selected to receive an EMI component. However, the study only lasted for 8 days total, so it is unclear whether users would have continued requesting daily reminders over longer durations. Daily goal reminders were associated with an increased number of app entries made (31 logs on average/8 days when reminders were daily, 27.7 logs on average/8 days when reminders were every 2 or 3 days), suggesting that the reminder feature may be beneficial in increasing app use.

Another study of Recovery Record, published by Lindgreen and colleagues in 2018 [56] found less positive results. This study followed 41 individuals who used Recovery Record as they received treatment in a Danish ED treatment facility. Twenty-six individuals were interviewed about their experiences with using the app in treatment. While the study is primarily qualitative in nature, the authors found that patients' experiences with Recovery Record were highly variable as was use of various Recovery Record features. Specific to the EMI components, many patients reported that meal reminders were inconvenient, obstructive, or burdensome. Others found that the meal reminders were condescending as the specific content of the reminders was felt to suggest that patients were incapable of structuring their

own meals or remembering to eat on their own. Some patients noted that meal reminders felt overwhelming, and others found the reminders to be invalidating as they reported that they were intentionally choosing not to eat, not simply forgetting to eat. These results demonstrate the challenges and limitations associated with non-personalized or adaptive EMIs, suggesting that one-size-fits-all messages are often perceived as at best, unhelpful, and at worst, invalidating.

In 2018, Anastasiadou and colleagues published a systematic review of mHealth tools for the treatment of EDs, four of which including a text message–based EMI component [58••]. The studies ($n = 15$) included a diverse mix of text message–based interventions, smartphone applications without an EMI component, and vodcasts (i.e., video podcasts), which limited the ability to draw conclusions about the efficacy of specific types of mHealth tools. Similarly, the way in which the mHealth tool was employed was diverse, with some studies testing the mHealth tool as a stand-alone intervention, others testing the mHealth tool as a complement to face-to-face treatment, and still others testing the value of mHealth tools for relapse prevention. Of note, several studies were included in the review that only tested the use of mHealth tools as a self-monitoring augmentation [59, 60] and others included only the use of focus groups to test the perceived acceptability and feasibility of an app augmentation to treatment [61••]. The authors found that the majority of studies that used mHealth tools as the sole means of intervention found no effect of treatment. However, more promising results were found for adjunctive treatments, and improvements at post-treatment were observed in several vodcasts, smartphone application, and text messaging interventions. The results of text messaging–based interventions were not reviewed separately from the other mHealth tools in the systematic review, though an examination of the tables provided in the review suggests considerable variability in outcomes for these interventions. Overall, Anastasiadou and colleagues concluded in their review that the effect of mHealth interventions designed to reduce ED symptoms is limited at present but that many methodological limitations and an overall dearth of research in this area limit the ability to draw firm conclusions.

## Current and Future Directions in Ecological Momentary Intervention

Of note, Anastasiadou and colleagues report that as of summer 2018, five research trials were included on clinicaltrials.gov (NCT02503098, NCT02484794, NCT02130037, NCT02978742, and NCT03197519) that are presently evaluating smartphone applications for the support of EDs. Of these, two are testing versions of Recovery Record that include adaptive and tailored EMIs (NCT02503098, NCT02978742). Between summer 2018 and spring 2019,

one additional study has been added (NCT03673540) that will evaluate the use of an adaptive EMI-based smartphone app (CBT+) that is designed to increase skill acquisition and utilization when used in conjunction with CBT for BN. The existence of several clinical trials that are underway is promising given the overall lack of EMI research on eating pathology within the last several years.

In sum, despite the fact that EMI systems have shown promise in the treatment of numerous physical [62] and mental health concerns [63], there remains a lack of research on EMI for EDs. The existing studies that have been completed in since 2016 have relatively minimal EMI components, and no study has tested a more sophisticated type of EMI that is adapted and tailored in response to user data (e.g., delivering momentary emotion regulation interventions to prevent binge eating at the particular moments when users endorse high levels of negative affect or stress). However, as noted above, several studies are underway that are testing more sophisticated EMI systems. All of the existing trials that are in progress are testing a form of EMI known as a just-in-time adaptive interventions (JITAIs). JITAIs have the capability to deliver tailored interventions to individuals in naturalistic settings based on momentary assessment data of individuals' endogenous and environmental circumstances. Specifically, JITAIs are designed to (1) provide interventions at moments when individuals are vulnerable to engaging in symptoms and in contexts when they are receptive to making changes and (2) tailor the nature of interventions (e.g., type, timing, and dosage) according to time-varying information (e.g., mood, location) [64]. Given the ability of JITAIs to provide highly tailored, real-time interventions at the particular moments when individuals most need support, such methodology could have potential to advance EMI approaches in EDs [3].

## Conclusions

Collectively, the present literature reviewed indicates that ambulatory assessment methods continue to be widely used in EDs, and in recent years, these studies have significantly increased our knowledge of within- and between-person variability in cognitive, affective, and behavioral functioning from multiple units of analysis. With the ever-growing capacities of mobile technologies and novel statistical approaches, ambulatory assessment in EDs going forward has unique potential to advance our understanding of biobehavioral mechanisms that underlie ED symptoms and to characterize the micro-temporal dynamics that influence macro-level outcomes and symptom course. Furthermore, while the ED field has seen substantial growth in EMI, and though many studies are underway, there remain no published studies that have harnessed ambulatory assessment data to provide adaptive momentary interventions such as JITAIs. This is a particularly exciting area of research on the horizon that illustrates the potential clinical utility of ambulatory assessment methods. As a field, such developments will certainly bring about new questions and issues to engage researchers and clinicians in collaborative discussions, including those related to feasibility of implementing such interventions, issues of data security and ownership, and how to optimize EMIs/JITAIs to be maximally effective in clinical populations.

## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

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