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A Review of Dietary Monitoring Applications and Eating Disorder/ Disordered Eating Symptomatology

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A Review of Dietary Monitoring Applications and Eating Disorder/Disordered Eating Symptomatology

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Abstract

Eating disorders are among the deadliest mental illnesses in the United States. Given their high prevalence and low treatment rates, mitigating risk exposure is necessary for prevention. Dietary monitoring applications are highly popular self-monitoring tools that can inform dietary patterns and improve weight loss efficacy. However, they can also serve as a means for those with body preoccupation to restrict and possibly exacerbate disordered symptomatology. A literature search was conducted to identify research regarding the usage of dietary monitoring applications and eating disorder/disordered eating symptomatology. Twelve articles met inclusion criteria and are discussed in the review. An association between the use of apps to self-monitor dietary intake and disordered eating behaviors were consistently reported in observational studies. No impact on the use of these apps and validated assessments of eating disorder/disordered eating symptomatology were indicated in experimental studies on low-risk populations. However, both limitations and qualitative analysis suggest that continued research with improved methodology is necessary. Some principal issues within methodology include sampling issues, minimal risk exposure, and unrealistic use case scenarios. With eating disorder prevalence and dietary monitoring app use rising, future research to investigate the associations and any temporal effects on eating disorder/disordered eating symptomatology is imperative to inform researchers and clinicians.

Chapter I. Introduction

Eating disorders **(**EDs) are highly prevalent and impactful mental disorders, being the second highest cause of death from mental illness in the United States (Arcelus et al., 2011; Harvard T.H. Chan: School of Public Health [HSPH], 2020). EDs involve severe and persistent disturbances in eating behaviors and related emotions, as well as food, body weight, and/or shape preoccupation (American Psychiatric Association [APA], 2013; Hay, 2020). Symptoms may be assessed via validated questionnaires, such as the Eating Disorder Examination-Questionnaire (EDE-Q; Fairburn & Beglin, 1994) or the Eating Attitudes Test (EAT-26; Garner et al., 1982). The three most empirically researched and clinically understood EDs are anorexia nervosa (AN), bulimia nervosa (BN), and binge eating disorder (BED; APA, 2013). Current ED treatment options focus on evidence-based psychological therapies and some pharmacological treatments (Fairburn, 2008; Hilbert et al., 2017; Waller et al., 2007; Zeeck et al., 2018). However, treatment and symptom remission rates are low, and the prevalence of EDs continues to rise (Galmiche et al., 2019; Lilienfeld et al., 2013; Swanson et al., 2011). Moreover, sociocultural pressures to diet, as well as accessibility to and popularity of self-monitoring is highly prevalent, especially amongst young people (Levine & Murnen, 2009, Sidani et al., 2016; Statista, 2021, 2018).

Food journals have been used by people looking to make positive health changes through dietary self-monitoring. While effective in weight loss interventions, overweight and obese individuals in these programs often display symptoms of disordered eating (DE; Burke et al., 2011; Hollis et al., 2008; Konttinen et al., 2019; Linde et al., 2004). While not inherently negative, there may be unintended consequences to dietary self-

monitoring, especially for those with eating disorders/disordered eating symptomatology (ED/DE-S). Individuals with EDs may self-monitor their diet during their recovery/treatment process (Fairburn, 2008). However, more often, dietary self-monitoring is used as an unhealthy coping mechanism to restrict caloric intake outside of clinical treatment, which may exacerbate ED/DE-S (Tchanturia et al., 2013). Obsessive and compulsive monitoring, as well as dieting, are risk and/or maintaining factors for EDs (Pennesi & Wade, 2016; Stice et al., 2017). Given the hereditary nature of liability to EDs (28-83%), minimizing risk exposure is key to prevention (Arcelus, 2011; Le et al., 2017; Stice et al., 2021; Thornton et al., 2011, Wade & Wilksch, 2018). However, the opposite may be occurring with the rise in accessibility to sociocultural and technological influences, which have been linked to increased ED/DE-S (Culbert et al., 2015; Keel & Forney, 2013; Turner & Lefevre, 2017).

The use of smartphones and mobile health (mHealth) applications (apps) is rising (Statista, 2021). Dietary monitoring apps (DMAs) are a particularly popular genre of mHealth apps, that allows users to log and analyze their dietary intake (Ferrara et al., 2019; Statista, 2018). As a result, it has never been easier to self-monitor dietary intake, though it is unclear to what extent this may impact ED/DE-S. As with traditional pen and paper dietary monitoring, DMAs can be effective in weight loss interventions (Farage et al., 2021; Harvey et al., 2019). However, similar, and novel concerns come from DMA logging functionalities that may exacerbate or contribute to ED/DE-S. Some of these functions include notifications, feedback, and encouragement of social sharing, continued app use, and other forms of weight-related self-monitoring (WRSM; Hahn, Linxwiler, et al., 2021; Honary et al., 2019).

Strong, repeated associations have been found between use of dietary self-monitoring applications and increased ED/DE-S ((Eikey et al., 2018; Embacher Martin et al., 2018; Hahn, Sonneville, et al., 2021; Hefner et al., 2016; Levinson et al., 2017; Linardon & Messer, 2019; Messer, McClure, et al., 2021; Plateau et al., 2018; Simpson & Mazzeo, 2017). Few experimental studies have been conducted based on these associations, and those that have been completed, have not yielded a causal relationship (Hahn, Kaciroti, et al., 2021; Jospe et al., 2018). Given the limited experimental research, this review will aim to evaluate the current literature and suggest future research on the investigating of how dietary tracking via DMAs may contribute to ED/DE-S.

Chapter II. Rationale

Eating Disorders

It is estimated that 28.8 million Americans will have an ED within their lifetime (HSPH, 2020). While EDs affect individuals of all ages, genders, races, and sexual orientations, some groups are more likely to be impacted than others. Women are twice as likely to have an ED relative to men, being highly prevalent in young women, with estimates of 13.5% of female college students having an ED (Galmiche et al., 2019; HSPH, 2020). People of color with an ED are half as likely to be diagnosed or receive treatment (Sonneville & Lipson, 2018). Those within the lesbian, gay, bisexual, and transgender (LGBTQIA+) population are at a higher risk for ED/DE-S compared to their heterosexual and cisgender peers (Parker & Harriger, 2020). Individuals with EDs are also at a higher risk for other psychiatric disorders, social impairment, and suicide, with over a quarter of those with EDs attempting suicide (Arcelus et al., 2011; Swanson et al., 2011). Regarding deaths from mental illness, EDs are only second to opioid overdoses, accounting for 10,200 deaths per year (Arcelus et al., 2011; HSPH, 2020). Evaluation of DE and diagnosis of EDs is a complex and highly individual process, requiring mental health and medical professionals. EDs span the age spectrum though onset and diagnosis are most likely to occur in early adolescence through early adulthood (Volpe et al., 2016). While every ED has some unique symptoms and qualifications for diagnosis, EDs can be characterized by persistent and severe disturbances in eating behaviors and related thoughts and emotions. These behaviors and cognitions often involve food, body weight, and shape preoccupation that significantly impair physical health and/or psychosocial function and are highly variable amongst individuals (APA, 2013, Hay, 2020).

While not diagnostic, validated questionnaires for clinical and research purposes have been developed to screen ED/DE-S quickly and cheaply. Two of the more commonly used assessments are the Eating Disorder Examination-Questionnaire (EDE-Q) and the Eating Attitudes Test (EAT-26). The EDE-Q is considered the gold standard, measuring the frequency of common ED/DE attitudes and behaviors across four subscales. The subscales include restraint, eating concern, shape concern, and weight concern, the average of which comprises the EDE-Q Global Score (Fairburn & Beglin, 1994). There are multiple versions, including the 38-item (EDE-Q 4.0), 28-item (EDE-Q 6.0) or 12-item (short-form, EDE-QS), all of which demonstrate strong internal consistency (Cronbach's α = 0.9-95) and strongly correlate with one another (r = 0.82-0.91; Gideon et al., 2016; Peterson et al., 2007; Quick & Byrd-Bredbenner, 2013). The EAT-26 is a refined version of the original EAT-40, measuring ED symptoms on three subscales; bulimia and food preoccupation, dieting, and oral control (Garner et al., 1982). High internal consistency has been demonstrated by the EAT-26 (Cronbach's α = 0.86-0.9), with a score of $\geq$ 20 warranting the consult of a medical professional to determine ED status (Dotti & Lazzari, 1998; Garner et al., 1982). While not a strict ED/DE-S measurement, the Clinical Impairment Assessment (CIA) was developed to assess psychosocial impairment as a result of ED/DE-S. Thereby, the 16-item measure is meant to be used following a current-state ED/DE-S assessment, such as an EDE-Q, to measure the severity of impairment as a result of ED/DE-S (Bohn et al., 2008). Internal consistency of the CIA is high (Cronbach's α = 0.97) and a score > 16 is the cut-off point used as a predictor of ED status (Bohn et al., 2008). It should be noted that any score on

these questionnaires is not a diagnosis of an ED; an official diagnosis requires the consultation of a medical professional.

The fifth edition of the American Psychiatric Association's *Diagnostic and Statistical Manual of Mental Disorders* (DSM-V) contains six specific feeding and ED diagnoses: anorexia nervosa (AN), bulimia nervosa (BN), binge eating disorder (BED), avoidant/restrictive food intake disorder (ARFID), pica, and rumination disorder (RD), as well as two more general diagnoses, other specified feeding or eating disorders (OSFED) and unspecified feeding or eating disorders (UFED). As AN, BN, and BED are the most empirically researched and clinically understood, these will be the specific disorders elaborated upon. AN is characterized by the restriction of energy that results in significantly low body weight (less than minimally normal or expected), while patients with BN and BD are typically normal or above normal weight. There are two subtypes of AN: restrictive or binge eating/purging (self-induced vomiting, misuse of laxatives, diuretics, or enemas). The latter overlaps with BN in the use of compensatory behaviors (skipping meals, excessive exercise) and the overevaluation of weight/shape, as well as BN and BED with regards to recurrent BE episodes. Patients with BED do not regularly engage in compensatory behaviors, however, reports of frequent cycles of dieting and BE are common (APA, 2013). AN, BN, and BED diagnosis criteria are as follows (APA, 2013):

Anorexia Nervosa (AN)

A. Restriction of energy intake relative to requirements, leading to a significantly low body weight in the context of age, sex, developmental trajectory, and physical health. *Significantly low weight* is defined as a weight that is less than minimally normal or, for children and adolescents, less than that minimally expected.

B. Intense fear of gaining weight or of becoming fat, or persistent behavior that interferes with weight gain, even though at a significantly low weight.

C. Disturbance in the way in which one's body weight or shape is experienced, undue influence of body weight or shape on self-evaluation, or persistent lack of recognition of the seriousness of the current low body weight.

AN is categorized into non-exclusive subtypes based on current symptoms, criteria specific subtypes are:

Specify whether:

I. *Restricting type*: During the last 3 months, the individual has not engaged in recurrent episodes of binge eating or purging behavior (i.e., self-induced vomiting or the misuse of laxatives, diuretics, or enemas). This subtype describes presentations in which weight loss is accomplished primarily through dieting, fasting, and/or excessive exercise.

II. *Binge-eating/purging type*: During the last 3 months, the individual has engaged in recurrent episodes of binge eating or purging behavior (i.e., self-induced vomiting or the misuse of laxatives, diuretics, or enemas).

Specify if:

I. *In partial remission*: After full criteria for anorexia nervosa were previously met, Criterion A (low body weight) has not been met for a sustained period, but either Criterion B (intense fear of gaining weight or becoming fat or behavior that interferes with weight gain) or Criterion C (disturbances in self-perception of weight and shape) is still met.

II. *In full remission*: After full criteria for anorexia nervosa were previously met, none of the criteria have been met for a sustained period of time.

Specify if: current severity:

I. *Mild*: BMI $\geq$ 17 kg/m^2

II. *Moderate*: BMI 16–16.99 kg/m^2

III. *Severe*: BMI 15–15.99 kg/m^2

IV. *Extreme*: BMI < 15 kg/m^2

Bulimia Nervosa (BN)

A. Recurrent episodes of binge eating. An episode of binge eating is characterized by both of the following:

   I. Eating, in a discrete period of time (e.g., within any 2-hour period), an amount of food that is definitely larger than what most individuals would eat in a similar period of time under similar circumstances.

   II. A sense of lack of control over eating during the episode (e.g., a feeling that one cannot stop eating or control what or how much one is eating).

B. Recurrent inappropriate compensatory behaviors in order to prevent weight gain, such as self-induced vomiting; misuse of laxatives, diuretics, or other medications; fasting; or excessive exercise.

C. The binge eating and inappropriate compensatory behaviors both occur, on average, at least once a week for 3 months.

D. Self-evaluation is unduly influenced by body shape and weight.

E. The disturbance does not occur exclusively during episodes of anorexia nervosa.

Specify if:

   I. In partial remission: After full criteria for bulimia nervosa were previously met, some, but not all, of the criteria have been met for a sustained period of time.

   II. In full remission: After full criteria for bulimia nervosa were previously met, none of the criteria have been met for a sustained period of time.

Specify current severity:

   I. *Mild*: An average of 1–3 episodes of inappropriate compensatory behaviors per week.

   II. *Moderate*: An average of 4–7 episodes of inappropriate compensatory behaviors per week.

   III. *Severe*: An average of 8–13 episodes of inappropriate compensatory behaviors per week.

   IV. *Extreme*: An average of 14 or more episodes of inappropriate compensatory behaviors per week.

Binge Eating Disorder (BED)

A. Recurrent episodes of binge eating. An episode of binge eating is characterized by both of the following:
    I. Eating, in a discrete period of time (e.g., within any 2-hour period), an amount of food that is definitely larger than what most people would eat in a similar period of time under similar circumstances.
    II. A sense of lack of control over eating during the episode (e.g., a feeling that one cannot stop eating or control what or how much one is eating).

B. The binge-eating episodes are associated with three (or more) of the following:
    I. Eating much more rapidly than normal.
    II. Eating until feeling uncomfortably full.
    III. Eating large amounts of food when not feeling physically hungry.
    IV. Eating alone because of feeling embarrassed by how much one is eating.
    V. Feeling disgusted with oneself, depressed, or very guilty afterward.

C. Marked distress regarding binge eating is present.

D. The binge eating occurs, on average, at least once a week for 3 months.

E. The binge eating is not associated with the recurrent use of inappropriate compensatory behavior as in bulimia nervosa and does not occur exclusively during the course of bulimia nervosa or anorexia nervosa.

Specify if:

I. *In partial remission*: After full criteria for binge-eating disorder were previously met, binge eating occurs at an average frequency of less than one episode per week for a sustained period of time.

II. *In full remission*: After full criteria for binge-eating disorder were previously met, none of the criteria have been met for a sustained period of time.

The minimum level of severity is based on the frequency of episodes of binge eating (see below). The level of severity may be increased to reflect other symptoms and the degree of functional disability.

Specify if: current severity:

III. *Mild*: 1–3 binge-eating episodes per week.

IV. *Moderate*: 4–7 binge-eating episodes per week.

V. *Severe*: 8–13 binge-eating episodes per week.

VI. *Extreme*: 14 or more binge-eating episodes per week.

Evidence-based psychological therapies, such as cognitive behavioral therapy (CBT) delivered by an ED clinician may be the most effective ED treatment option (Fairburn, 2008; Hay et al., 2019; Waller et al., 2007). Additionally, given the high rate of other psychiatric disorders, social impairment, and attempted suicides in individuals with EDs, a multi-disciplinary team is likely the best approach (Hay, 2020; Swanson et al., 2011). These teams should at least consist of a psychological therapist and a primary physician. However, in more severe cases, such as those requiring partial/full-time hospitalization, other interdisciplinary specialists should be consulted. Specialists might include a registered dietitian nutritionist, psychiatrist, exercise therapist, and/or occupational therapist (Hay, 2020). There are also pharmacological treatments available for EDs. Antidepressants and antipsychotics have been used in AN but have mixed results and little direct evidence for treatment, possibly just treating a co-occurring disorder (Hilbert et al., 2017; Zeeck et al., 2018). The serotonin reuptake inhibitor, fluoxetine, as well as lisdexamfetamine may also be effective in treating BED and BN, especially when combined with psychological therapies (Hilbert et al., 2017, 2019). Despite advances, treatment is a daunting task complicated by extensive individual, socioeconomic, and systematic barriers, evident by low ED treatment rates (Innes et al., 2017). Approximately 80% of individuals with an ED never receive treatment and those that do have high dropout rates, do not typically receive evidence-based care, and

experience low symptom remission (Fassino et al., 2009; Lilienfeld et al., 2013, Swanson et al., 2011).

The pervasiveness of EDs is rising globally; 2013-2018 estimates placed ED prevalence at 7.8% of the global population, over double the 2000-2006 estimation of 3.5% (Galmiche et al., 2019). Increases have likely been exacerbated by the COVID-19 pandemic, as a third of Americans displayed signs of anxiety or depression as of May 2020, just two months into the pandemic (Fowers & Wan, 2020). Furthermore, those with mental illness may see more significant negative impacts of the pandemic compared to the general population (Galletly, 2020; Kaufman et al., 2020). Specifically, individuals with EDs are reporting higher levels of anxiety, depression, and isolation, as well as increased restriction and binge eating (BE) episodes during the COVID-19 pandemic (Termorshuizen et al., 2020; Vitagliano et al., 2021). While this growing prevalence may be partially attributed to greater awareness and individuals seeking help, other influences, such as technology, social media, and the pervasiveness of diet culture should not be disregarded (Hefner et al., 2016; Levine & Murnen, 2009; McLean et al., 2015, Sidani et al., 2016; Turner & Lefevre, 2017)

Dietary Monitoring

Food journals have been used for decades for self-monitoring of dietary intake. Weight loss is the most cited reason for use, though individuals with conditions such as acid reflux or irritable bowel syndrome (IBS) may track dietary intake to record symptoms associated with foods eaten (Zia et al., 2017). In addition to specific foods consumed; amounts, time, location, caloric and/or macronutrient content may also be recorded. Dietary monitoring via pen and paper food logs has been demonstrated to

increase the effectiveness of weight loss interventions (Burke et al., 2011). These increases are thought to be mediated via improved dietary intake, whereas an individual can record and recognize dietary patterns, plan behavioral changes, implement said changes, then evaluate effectiveness (Burke et al., 2011; Hollis et al., 2008). This approach may help to build self-regulatory behaviors and increase self-efficacy in eating (Anderson et al., 2007; Bandura, 1998). However, baseline BE is associated with improved adherence to dietary monitoring in weight loss interventions; similarly overweight/obese individuals seeking weight loss treatment often display DE-S (Konttinen et al., 2019; Linde et al., 2004; Martinelli et al., 2020). This symptomatology is troubling as among typical dieters, 35% develop DE behaviors and 15% of those come to meet partial or full ED criteria (Shisslak et al., 1995). While dietary monitoring is not inherently negative, problems may arise when it is the result of and/or leads to excessive food, weight, and/or body preoccupation. Therefore, the risk of exacerbating DE behaviors through dietary monitoring may not be relegated to individuals with EDs.

Among individuals with EDs, varying degrees of dietary and/or other forms of self-monitoring have been successful tools in treatment. However, the purpose is to garner information regarding the patient's emotions and patterns of disordered behaviors (Fairburn, 2008). Therefore, monitoring should be accompanied by some form of psychological therapy, as well as mediated and overseen by a treatment team (Fairburn, 2008; Hay et al., 2019; Waller et al., 2007). Alternatively, dietary monitoring may be used by individuals with ED to restrict caloric intake, as a means of controlling body shape and/or size, leading to increased ED behaviors and impairment (Tchanturia et al., 2013). Furthermore, unsupervised monitoring may be used as a coping mechanism, as

those with EDs have demonstrated inadequate healthy coping strategies compared to the general population, with poor emotional coping strategies being demonstrated as an ED risk factor (Lobera et al., 2009; Zheng et al., 2020). More insight regarding the risks of dietary monitoring as it relates to ED/DE-S may be garnered based on personality traits. For example, neuroticism can be a direct cause of body dissatisfaction and correlates with behaviors like avoiding food when hungry (Brookings & Wilson, 1994; Roberts & Good, 2010). Furthermore, neurotic individuals experience higher levels of obsessive-compulsive disorder (OCD), as well as health-related anxiety, possibly fueling perfectionist/restrictive eating when monitoring (Lagoe & Atkin, 2015; Samuels et al., 2000).

Attitudes and behaviors, such as obsessive and compulsive perfectionism, especially regarding diet, are common for those with EDs (Boone et al., 2014; Jacobi et al., 2004). These attitudes and behaviors, as well as dieting in general, have been demonstrated as risk and/or maintaining factors for EDs (Pennesi & Wade, 2016; Stice et al., 2017). A varying degree of ED risk is also hereditary; 28-78%, 30-83%, 41-57% for AN, BN, and BED respectively (Thornton et al., 2011). However, psychosocial factors may influence the expression of an individual's genetic risk (Culbert et al., 2015). Therefore, minimizing environmental and lifestyle risk exposure is key in prevention (Arcelus, 2011). Promotion of media literacy, dissonance, and healthy habit modifications may assist in early recognition and addressing of risk factors to prevent later ED onset (Le et al., 2017; Stice et al., 2021; Wade & Wilksch, 2018). However, the opposite may be occurring as sociocultural influences affect body ideals, dissatisfaction, and ED risk (Culbert et al., 2015; Keel & Forney, 2013; Levine & Murnen, 2009).

Internalization of thinness ideals and corresponding body dissatisfaction have been identified as psychosocial risk factors for ED/DE-S (Culbert et al., 2015; Keel & Forney, 2013). Idealization of thinness can be influenced by levels of exposure to mass media and the resulting, both from peers and self-imposed, expectations of thinness (Culbert et al., 2015; Keel & Forney, 2013; Levine & Murnen, 2009). Perpetuation of these influences through social media may be implicit in increased dietary restraint, body dissatisfaction, and overvaluation of weight and shape (McLean et al., 2015; Roberts & Good, 2010, Sidani et al., 2016; Turner & Lefevre, 2017). The prevalence of smartphones and mHealth apps, as well as social sharing within them, may be culpable in the accessibility and engagement with these sociocultural influences, thereby influencing ED/DE-S.

Dietary Monitoring via a Mobile Health Application

The availability of smartphones and mHealth apps is growing, with nearly 54,000 mHealth apps being available on the Apple iOS app store, as of the first quarter of 2021, a 5% increase from the previous quarter (Statista, 2021). While mHealth apps encompass apps ranging from simple meditation to patient portals for healthcare providers, DMAs are a large subsect of the genre. MyFitnessPal (MFP) for example, the most popular DMA, reports 19.1 million unique, monthly users (Statista, 2018). There are a variety of DMAs on the market, with each offering different functions, features, and forms of dietary monitoring, as well as other forms of WRSM, such as physical activity or body weight logging (Ferrara et al., 2019). However, the predominant feature of DMAs is to allow users to record and analyze their dietary intake via large databases of foods, providing both caloric, as well as micronutrient and macronutrient breakdowns. Many

apps require setting a weight goal and subsequently recommends daily caloric and/or macronutrient goals to meet it. The usability of DMAs is generally high, offering features such as barcode scanning, photo entry, frequently entered food items, auto-completion, and food suggestion lists (Ferrara et al., 2019).

DMAs appeal to a wide range of consumers; those looking to improve their health and monitor their diet, physical activity, and/or weight may use mobile apps as a convenient tool. As with dietary monitoring, DMAs can be an effective tool for weight loss, as users may improve adherence to weight loss interventions, as well as maintenance thereafter (Farage et al., 2021; Harvey et al., 2019). Improvements in weight loss from DMA use may be due to goal setting, self-monitoring, and the development of self-efficacy (Anderson et al., 2007; Fakih El Khoury et al., 2019). However, it is unclear whether DMA use results in sustainable behavior change, as apps often focus on caloric restriction, physical activity, and weight monitoring, but offer little with regards to long-term behavior change (Bardus et al., 2016; Briggs et al., 2021; Davis et al., 2016; Ferrara et al., 2019). Users do report increased food choice awareness, as well as feelings of pride and accomplishment when staying within their caloric recommendations. However, these feelings come at the cost of app compliance, such as improved mood when eating within DMA recommendations relative to exceeding (Hahn, Linxwiler, et al., 2021).

Concerns regarding dietary monitoring in general are likely applicable to DMA usage including obsessive, compulsive behaviors, food anxiety and preoccupation, as well as feelings of guilt, worry, anxiety, and increased concern about weight and shape (Hahn, Linxwiler, et al., 2021; Honary et al., 2019; Messer, McClure, et al., 2021). However, certain issues may be exacerbated by logging functionalities within the DMAs. In

contrast to pen and paper logs, DMAs generate feedback, give notifications, encourage social sharing, and often advertise to users. These functions encourage continued use of apps, as well as other types of fitness tracking and WRSM within the apps (Hahn, Linxwiler, et al., 2021; Honary et al., 2019). Moreover, significant amounts of said functions are reported to facilitate negative feelings and/or behaviors (Honary et al., 2019). Some apps generate weight projections based on caloric intake and/or give users greater calorie allotments based on exercise, promoting compensatory behaviors, and encouraging users to eat less than their already restricted caloric budget (Eikey et al., 2017, 2018; Honary et al., 2019, McCaig et al., 2020). DMAs are often misused, both as perceived "recovery" tools, as well as through setting unhealthy or dangerously low weight and/or calorie goals (Eikey et al. 2017, 2018; McCaig et al., 2020). DMAs may also promote negative social reinforcement of maladaptive behaviors through user generated content and communities, as occurs on other social media platforms (Deighton-Smith & Bell, 2018; Tiggemann et al., 2018). Additionally, some DMA users report hiding their app use from friends and family , as well as social isolation due to diet and fitness goals (Honary et al., 2019; McCaig et al., 2020). The latter of which can negatively affect interpersonal relationships, fueling feelings of loneliness and exacerbating ED-S (Levine, 2012).

Cooccurrence of DMA use and ED/DE-S may be the result of consumers, both with and without ED/DE-S, using apps to self-monitor health changes. Alternatively, DMA use may contribute to ED/DE development via functions within these apps facilitating food anxiety, preoccupation, and obsessive, compulsive behaviors, as well as enable rigid dieting as a means of controlling body shape and size (Messer, McClure, et

al., 2021). It is unknown whether these apps can be used responsibly for weight loss, especially when dieting and body dissatisfaction are predictive risk factors for ED development (Levine & Murnen, 2009; Rohde et al., 2015; Stice et al., 2017; Smolak & Levine, 2015.) Given the limited experimental research on DMA use and ED/DE-S, the topic represents a growing area of research interest. This review will aim to identify the current literature and inform future research on DMA use to self-monitor dietary intake as it relates to ED/DE-S.

Chapter III. Methodology

To obtain all relevant articles the databases PubMed and PsycINFO were searched for the terms “eating disorders’ and “disordered eating” placed after each of the following keywords: “mobile health apps”, “dietary monitoring apps”, “calorie tracking apps”, “weight loss apps” and “diet apps”. These terms were narrowed down from a larger list based on the number of search results and the relevance of the first 10 articles of each search. To be eligible for inclusion, articles had to measure dietary monitoring app usage and disordered eating/eating disorder symptomatology, be peer reviewed, and published prior to December 2021.

As detailed in Figure 1, the initial search garnered 170 results, after removing duplicates, 79 remained, of which, 49 articles were deemed relevant, with eight publications meeting the inclusion criteria. To complete an exhaustive search, each included article had the references, as well as the “cited by” feature of PubMed, analyzed to identify any remaining sources. This further analysis resulted in the identification of four additional articles. All included articles were either observational or experimental and are summarized in Tables 1 and 2 respectively.

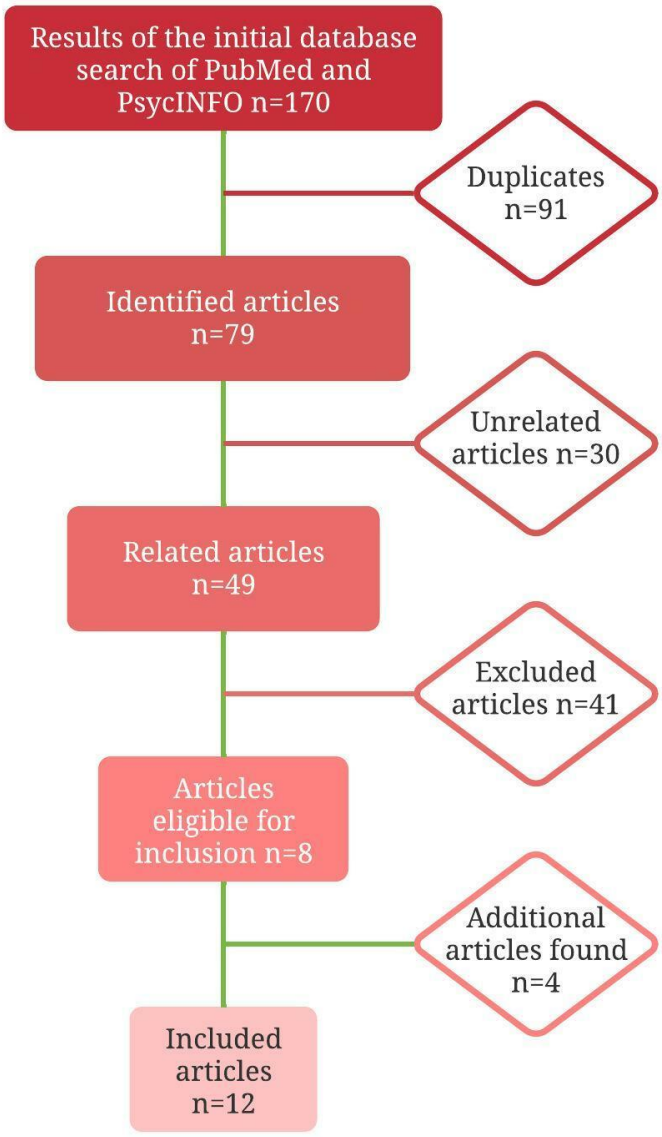

Figure 1. Diagram of Literature Search for Articles Investigating Dietary Monitoring Applications and Eating Disorder/Disordered Eating Symptomatology

Chapter IV. Manuscript

Abstract

Eating disorders are among the deadliest mental illnesses in the United States. Given their high prevalence and low treatment rates, mitigating risk exposure is necessary for prevention. Dietary monitoring applications are highly popular self-monitoring tools that can inform dietary patterns and improve weight loss efficacy. However, they can also serve as a means for those with body preoccupation to restrict and possibly exacerbate disordered symptomatology. A literature search was conducted to identify research regarding the usage of dietary monitoring applications and eating disorder/disordered eating symptomatology. Twelve articles met inclusion criteria and are discussed in the review. An association between the use of apps to self-monitor dietary intake and disordered eating behaviors were consistently reported in observational studies. No impact on the use of these apps and validated assessments of eating disorder/disordered eating symptomatology were indicated in experimental studies on low-risk populations. However, both limitations and qualitative analysis suggest that continued research with improved methodology is necessary. Some principal issues within methodology include sampling issues, minimal risk exposure, and unrealistic use case scenarios. With eating disorder prevalence and dietary monitoring app use rising, future research to investigate the associations and any temporal effects on eating disorder/disordered eating symptomatology is imperative to inform researchers and clinicians.

Introduction

Eating disorders **(**EDs) are highly prevalent and life-threatening mental disorders, being the second highest cause of death from mental illness in the United States (Arcelus et al., 2011; Harvard T.H. Chan: School of Public Health [HSPH], 2020). EDs are characterized by severe and persistent disturbances in eating behaviors and related emotions that significantly impair physical health and/or psychosocial function (American Psychiatric Association [APA], 2013; Hay, 2020). ED prevalence is on the rise, yet treatment rates remain low, with an estimated 80% of individuals with an ED never receiving treatment (Galmiche et al., 2019; Lilienfeld et al., 2013; Swanson et al., 2011).

Dietary self-monitoring is a commonly used and effective tool in weight loss interventions (Burke et al., 2011). While not inherently negative, monitoring may affect individuals with eating disorders/disordered eating symptomatology (ED/DE-S) through increased maladaptive behaviors and resulting impairment (Tchanturia et al., 2013). Furthermore, obese/overweight individuals seeking weight loss treatment often display DE-S, among typical dieters, 35% develop DE behaviors, with 15% of those meeting partial or full ED criteria (Konttinen et al., 2019; Linde et al., 2004; Shisslak et al., 1995). These behaviors may suggest that the risk of exacerbating DE behaviors through dietary monitoring may not be relegated to individuals with an ED. With 28-83% of ED risk being hereditary, minimizing risk exposure is key to prevention (Arcelus, 2011; Le et al., 2017; Stice et al., 2021; Thornton et al., 2011, Wade & Wilksch, 2018). However, the opposite may be occurring with increased accessibility to sociocultural and technological

influences, which have been linked to greater DE symptomatology (Culbert et al., 2015; Keel & Forney, 2013; Turner & Lefevre, 2017).

The use of mobile health (mHealth) applications (apps) is rising, with dietary monitoring apps (DMAs) being a popular subsect (Statista, 2021, 2018). DMAs allow users to log, analyze, and receive feedback on their diet (Ferrara et al., 2019). As a result, it has never been easier to self-monitor dietary intake, though it is unclear to what extent this may impact ED/DE-S. DMAs can also be effective in weight loss interventions, however, there are similar and novel concerns with regards to exacerbating or contributing to ED/DE-S (Farage et al., 2021; Harvey et al., 2019). Logging functionalities provide notifications, feedback, and encourage social sharing, continued app use, and other forms of weight-related self-monitoring (WRSM) within apps (Hahn, Linxwiler, et al., 2021; Honary et al., 2019).

Despite consistent associative evidence, as well as the implication of DMA use as a predictor of ED/DE-S and vice versa, few experiments have been conducted to establish a causal relationship (Eikey et al., 2018; Embacher Martin et al., 2018; Hahn, Sonneville, et al., 2021; Hefner et al., 2016; Levinson et al., 2017; Linardon & Messer, 2019; Messer, McClure, et al., 2021; Plateau et al., 2018; Simpson & Mazzeo, 2017). Those that have been done, did not yield any significant results (Hahn, Kaciroti, et al., 2021; Jospe et al., 2018; Martinelli et al., 2021). Given the minimal amount of experimental research, further investigation is warranted to strengthen the totality of evidence and address limitations within the current body of research. The aim of this review is to identify and evaluate the literature on how dietary tracking via DMAs may contribute to ED/DE-S.

Methods

To obtain all relevant articles the databases PubMed and PsycINFO were searched for the terms “eating disorders’ and “disordered eating” placed after each of the following keywords: “mobile health apps”, “dietary monitoring apps”, “calorie tracking apps”, “weight loss apps” and “diet apps”. These terms were narrowed down from a larger list based on the number of search results and the relevance of the first 10 articles of each search. To be eligible for inclusion, articles had to measure dietary monitoring app usage and disordered eating/eating disorder symptomatology, be peer reviewed, and published prior to December 2021.

As detailed in Figure 1, the initial search garnered 170 results, after removing duplicates, 79 remained, of which, 49 articles were deemed relevant, with eight publications meeting the inclusion criteria. To complete an exhaustive search, each included article had the references, as well as the “cited by” feature of PubMed, analyzed to identify any remaining sources. This further analysis resulted in the identification of four additional articles. All included articles were either observational or experimental and are summarized in Tables 1 and 2 respectively.

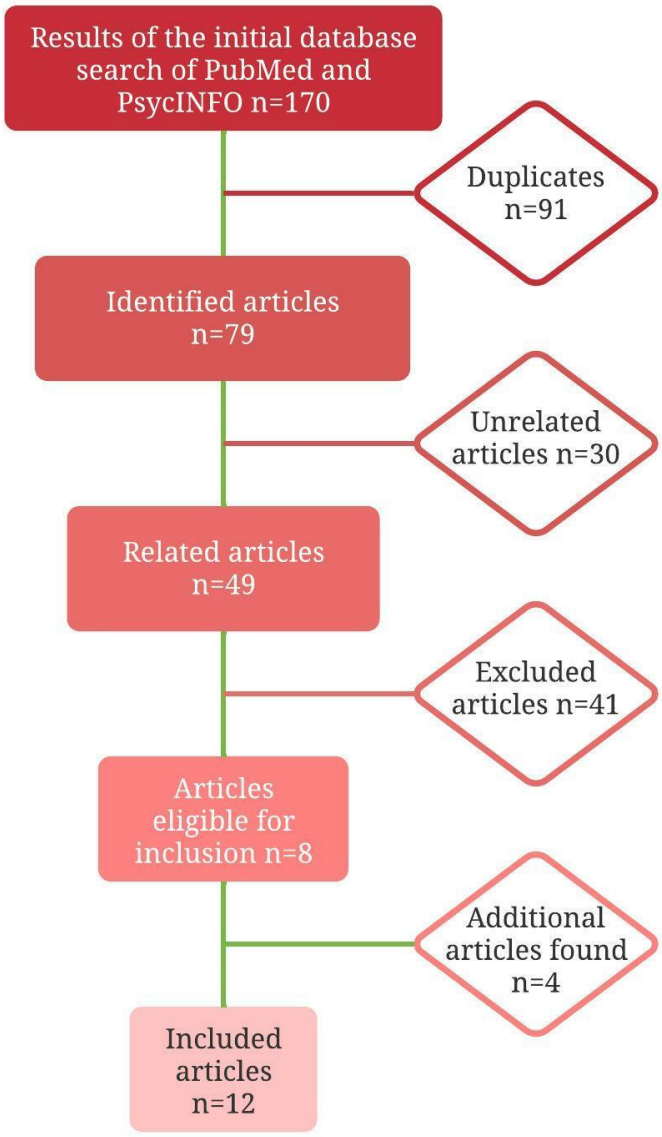

Figure 1. Diagram of Literature Search for Articles Investigating Dietary Monitoring Applications and Eating Disorder/Disordered Eating Symptomatology

Results

Cross-Sectional Associations

The nine identified observational articles show repeated association between DMA use and increased ED/DE-S (Table 1), with higher ED risk being consistently reported in individuals who use DMAs (Eikey et al., 2018; Embacher Martin et al., 2018; Hahn, Sonneville, et al., 2021; Hefner et al., 2016; Levinson et al., 2017; Linardon & Messer, 2019; Messer, McClure, et al., 2021; Plateau et al., 2018; Simpson & Mazzeo, 2017). Hefner et al. (2016) is rarely cited by other studies, aiming to investigate the relationship between multiple types of social media use and DE, with frequency of mobile application use as a category of their social media use assessment (e.g., nutritional apps or exercise apps). Unfortunately, they did not distinguish between use of DMAs and exercise apps but were the first to find mobile app use as a predictor of ED/DE-S and compulsive exercise, with increased frequency of mobile app use positively correlating with higher Eating Attitudes Test (EAT-26) and Compulsive Exercise Test (CET) scores (Hefner et al., 2016). Alternatively, Simpson and Mazzeo (2017) specifically asked about regular use of a "calorie tracking device or application (e.g., MyFitnessPal)". Among their sample of college students, they found that 13.8% regularly used DMAs. Compared to non-users, users scored higher on Eating Disorder Examination-Questionnaire (EDE-Q) subscales, eating concern and dietary restraint, but not shape concern and weight concern. Researchers also inquired about regular "fitness tracking device or application use (e.g., Fitbit, pedometer)", which did not yield any significant differences in EDE-Q scores between users and non-users. Ultimately, fitness tracking, but not DMA use, was shown to be a unique indicator of ED/DE-S (Simpson & Mazzeo, 2017).

Both Levinson et al. (2017) and Linardon and Messer (2019) attempted to garner a better understanding of prior associations by following up their DMA usage assessment with a rating of how much subjects felt usage contributed to their ED or patterns of DE. However, both studies relegated DMA use to only MyFitnessPal (MFP), rather than offering MFP as an example of a DMA. Levinson et al. (2017) found that 74.3% of subjects reported MFP use, while only 56.6% of subjects reported MFP use in Linardon and Messer (2019). Disparities in results are likely attributable to the sample population, as Levinson et al. (2017) recruited through an ED clinic, where subjects were mostly female (96.2%), and had previously been discharged from a residential/partial hospitalization ED treatment center, while all the subjects in Linardon and Messer (2019) were male, and none had reported an ED diagnosis. These sampling differences may explain the variance between studies in how much users thought MFP contributed to their ED or DE patterns. In the Levinson et al. (2017) study 62.9% of subjects reported MFP at least moderately contributing to their ED, with higher reports of contribution being associated with higher EDE-Q scores on all subscales except eating concerns (Levinson et al., 2017). In the Linardon and Messer (2019) study 52.7% of MFP users that responded reported that MFP did not contribute to any pattern of DE. However, they found that, compared to non-users, MFP users had significantly higher EDE-Q (global and subscales), Dichotomous Thinking in Eating Disorder Scale (DTES), and Clinical Impairment Assessment (CIA) scores, as well as higher objective binge eating (BE) frequency, but not compensatory behavior frequency. Furthermore, after controlling for the variance of all other significant predictors (BMI, compensatory behaviors, CIA, and

DTES scores), MFP predicted a small, but significant amount of unique variance in EDE-Q global scores (Linardon & Messer, 2019).

Messer, McClure, et al. (2021) built upon previous literature with the largest cross-sectional sample size to date (N = 1357), attempting to address some of the limitations and expand the understanding of prior associations. Researchers returned to inquiring about DMAs generally, rather than specifically MFP, while still having users rate the extent to which they felt that engaging with apps contributed to common ED symptoms. Novel measures included asking current users about duration of app usage (months), how helpful they thought the app was for goal achievement, the extent that immediate stoppage of app use would concern them, and their primary motivation for app use. Almost three-quarters (71%) of the subjects reported having used a DMA, over half (55%) of which were current users. Compared to non-users, app users had higher EDE-Q and Muscularly-Oriented Eating Test (MOET) scores, as well as reported greater compensatory behavior frequency, but not BE frequency. Furthermore, duration of app use and concern with ceasing app usage was significantly correlated with most ED symptoms. Over 90% of current users reported using apps primarily for weight/shape reasons. Compared to those citing health, those motivated by weight/shape reasons reported significantly higher levels of ED symptoms, as well as perceived impact of app usage on said symptoms (Messer, McClure, et al., 2021).

Similar to the Simpson and Mazzeo (2017) study, Plateau et al. (2018) and Hahn, Sonneville, et al. (2021) were designed to measure both DMA and fitness tracking use. Plateau et al. (2018) recorded other measures more consistent with Messer, McClure, et al. (2021), with subjects reporting the following information about both food intake

monitoring tools and activity monitoring tools; use of a device, the type of device, frequency of use, subject's primary reason for use, perceived helpfulness, extent of concern if denied access, and the impact of the device on their behaviors. Out of all subjects (N = 352), 25 reported using only food intake monitoring tools, 117 reported using only activity monitoring tools, and 87 reported the use of both. Due to the low number of subjects solely using food intake monitoring tools, the authors performed most of their statistical analysis by those who monitored food intake and/or fitness, and those who did not. However, some meaningful analysis was performed on all food intake monitoring tool users. Among DMA users, 85% perceived the tools as very/somewhat helpful in achieving their desired goals and 56.3% reported that they used food intake monitoring tools either daily or multiple times per week, yet there were no significant differences in frequency of use and any ED behaviors. Seventy percent of users reported mainly using food intake monitoring tools for weight and/or shape management, while the remaining thirty percent reported health-related reasons as their primary motivation. Consistent with Messer, McClure, et al. (2021), compared to those citing health reasons, users motivated by weight/shape reasons reported significantly higher scores on shape concern and weight concern subscales of the EDE-Q, as well as the weight control subscale of the CET. Although, there were no significant differences in BE or purging prevalence (Plateau et al., 2018).

Hahn, Sonneville, et al. (2021) also measured multiple forms of technology-based WRSM, as well as common ED behaviors amongst a sample of first year university students. Researchers inquired about app or technology (e.g., Fitbit or MFP) use within the last year to self-monitor diet, exercise, or weight. If respondents had monitored, they

were asked to indicate which apps and/or technology they used and how they used them. Nearly a third (31.3%) of subjects reported DMA use within the last year, common ED behaviors reported were skipping meals (58.3%), excessive exercise (52%), supplement use (31.2%), fasting (15.4%), and purging/appetite suppressant use (11.5%). Given that technology-based WRSM was the primary focus of the study, fit statistics and interpretability were used to break subjects into monitoring patterns for statistical analysis. Higher predicted probability of ED behaviors were consistently reported with greater patterns of WRSM (Hahn, Sonneville, et al., 2021).

Body dissatisfaction is both an important risk factor and clinical characteristic of ED/DE-S (Rohde et al., 2015; Smolak & Levine, 2015; Stice et al., 2017). Therefore, the study by Embacher Martin et al. (2018) was included as researchers investigated biological sex, neuroticism, and body dissatisfaction as predictors of DMA usage in college students. Subjects were only asked about current use of a smartphone application to count calories and/or track their diet (e.g., MFP, MyNetDiary, Livestrong Calorie Counter, Lose It!, My Diet Coach). Twenty-six percent of the sample reported current use of a DMA. Compared to non-users, DMA users reported significantly higher levels of body dissatisfaction and neuroticism, which highly correlated with one another. Researchers performed a serial mediation statistical analysis, which implicated body dissatisfaction and female sex, but not neuroticism, as significant predictors of DMA usage (Embacher Martin et al., 2018).

Eikey et al. (2018) used an exploratory study design to investigate why college women with DE adopt and use DMAs. However, researchers inquired about DMA usage, as well as administered the EDE-Q, EAT-26, and CIA, thus, meeting review inclusion

criteria. DMA usage was assessed broadly, asking “participants to list all health apps they use or have used”. MFP was the primary app reported, as 21 of the 24 subjects listed it, six other DMAs and nine exercise/fitness apps were also listed but each twice or less. Twenty-two subjects reported losing weight as the objective/motivation for app usage. Of the 19 women who completed the EDE-Q, EAT-26, and CIA, 16 of them answered two or more questionnaires in a manner that suggests DE. Specifically, the mean EDE-Q global scores of subjects were extremely significantly higher than norms (Quick & Byrd-Bredbenner, 2013). Five participants scored higher than 20 on the EAT-26, warranting the consultation of a specialist to determine ED status (Dotti & Lazzari, 1998). Lastly, on the CIA, nine subjects scored higher than 16, a predictor of ED status (Bohn et al., 2008; Eikey et al., 2018).

While each observational article contained unique limitations, highlighted in Table 1., there were consistent limitations across methodology. Assessments of ED/DE-S were primarily done through validated questionnaires. However, there are no valid measurements of DMA use, thus, all articles relied on author generated questions to assess usage. Still, similar associations were reported despite unique measurement tools. Given the prevalence of EDs, smartphone use, and DMA use, especially among younger individuals, the development of a validated questionnaire to assess DMA usage may improve further consistency between studies (Lipson & Sonneville, 2017; Statista, 2018). Few studies assessed duration of app use with Messer, McClure, et al. (2021) being the only one to inquire, asking how many months users had been engaging with the DMA. Another limitation present in all articles, sans Hefner et al. (2016) and Plateau et al. (2018), is a failure to measure frequency/level of engagement with DMAs. That being

said, frequency of use had no significant intergroup effect on DMA users' EDE-Q and CET scores (Plateau et al., 2018). However, among those with neurotic and/or perfectionist tendencies or at a high risk of ED/DE-S, consistent engagement with apps may exacerbate obsessive attention to food and tracking (Boone et al., 2014; Eikey et al., 2017; Embacher Martin et al., 2018; McCaig et al., 2020).

Experimental Evidence

Three experimental studies were included in this review, two being secondary analysis of weight loss randomized control trials (RCTs) and the other a recent short study of DMA use in college women (Table 2; Hahn, Kaciroti, et al., 2021; Jospe et al., 2018; Martinelli et al., 2021). Within the two secondary analyses (Jospe et al., 2018; Martinelli et al., 2021), data came from weight loss interventions that did not focus on DMA usage and its impact on ED/DE-S (Butryn et al., 2020; Taylor et al., 2015). However, use of DMAs for weight loss purposes aligns with the primary reported motivation for app use (Eikey et al., 2018; Messer, McClure, et al., 2021; Plateau et al., 2018). During a 12-month weight loss treatment, Jospe et al. (2018) provided 250 overweight/obese adults (*M* BMI = 33 kg/m^2) a 30–45 minute diet and exercise presentation before randomly dividing them into a control (no monitoring support) or one of four self-monitoring groups (daily weighing, MFP use, hunger/blood glucose monitoring, and monthly weight/progress consults). Only 67.6% of subjects completed a follow-up EDE-Q, lower than mean retention rates reported in other prolonged weight loss trials (*M* = 82% at one year; Delahanty et al., 2016). Researchers found no significant differences between any group in EDE-Q scores (global or subscale) or DE behaviors at 12-months (Jospe et al., 2018). In contrast to prior research demonstrating

the effectiveness of DMA use in weight loss interventions, there were no significant differences in weight or body composition change between all five groups (Farage et al., 2021; Harvey et al., 2019). The lack of differences between groups may also suggest a low rate of adherence to self-monitoring in Jospe et al. (2018). Martinelli et al. (2021) focused on DE behaviors as a predictor for adherence to self-monitoring during a 12-week weight loss intervention. DE behaviors were only assessed at baseline using the Binge Eating Scale (BES) and Three-Factor Eating Questionnaire (TFEQ-R18), excluding any participant that met binge eating disorder (BED) diagnosis criteria. Subjects were instructed to self-monitor diet, physical activity, and weight in the Fitbit app. Adherence was high (M = 82.51%), assessed via the proportion of days subjects logged at least 800 calories into the Fitbit DMA. The analysis revealed greater subclinical BE severity, but not uncontrolled or emotional eating, at baseline predicted greater adherence to dietary and weight self-monitoring (Martinelli et al., 2021). Jospe et al. (2018) and Martinelli et al. (2021) contained two sampling limitations, first, the mean age for subjects, 43.7 and 50.77 respectively, is drastically higher than the typical development and onset age of EDs (Volpe et al., 2016). Additionally, the mean BMI for subjects (33 and 34.86 kg/m^2) was much higher than usual for those with the highest risk for development of, and impairment from ED/DE-S (APA, 2013; Stice et al., 2017). Combined with the exclusion of clinical BE, and the heavy emphasis on digital self-monitoring that could have resulted in recruitment bias, these limitations may have contributed to the high adherence levels across all subjects in Martinelli et al. (2021). While in Jospe et al. (2018), those sampling issues may have excluded individuals that

are typically at the highest risk for ED/DE-S development via risk exposure (APA, 2013; Stice et al., 2017).

Most recently conducted, Hahn, Kaciroti, et al. (2021) performed an intervention on female undergraduate students (N = 200), more consistent with the age and sex of individuals likely to both use DMAs and/or experience ED/DE-S (Embacher Martin et al., 2018; Simpson & Mazzeo, 2017). Researchers evenly divided the sample into two groups, the intervention group was instructed to use MFP to self-monitor their diet at maintenance calories, while the other group was a control, receiving no intervention. Adherence to the intervention was measured via the percentage of days subjects logged at least 500 calories into MFP (M = 89.1%). After 30 days, there were no significant differences in ED behaviors, EDE-QS (short form) or Body Image States Scale (BISS) scores between study groups, yet there was a reduction in self-weighing frequency within the intervention group. These results contradicted those of a pilot study conducted by researchers (N = 12), where one month of MFP use resulted in increased EDE-QS scores (Hahn, Kaciroti, et al., 2021). In Jospe et al. (2018) and Hahn, Kaciroti, et al. (2021), no associations were found between DMA use and health behavior change compared to control groups, reinforcing that DMAs may be missing key aspects for sustainable behavior change (Bardus et al., 2016; Briggs et al., 2021; Davis et al., 2016; Ferrara et al., 2019). As stated by Hahn, Kaciroti, et al. (2021), several limitations may have affected their findings. Prior research suggests that DMA users often utilize multiple forms of WRSM, which could have a compounding effect on ED/DE-S that was not accounted for or was nullified through the reduction in self-weighing (Hahn, Sonneville, et al., 2021; Plateau et al., 2018; Simpson & Mazzeo, 2017). Women who had monitored their diet

within the last year, had an ED diagnosis, or scored ≥ 2 on the EDE-QS were excluded (Hahn, Kaciroti, et al., 2021). While these exclusion criteria may be appropriate for an investigation into a causal relationship, it underrepresents the high prevalence of EDs (13.5%), and DE amongst college women (Galmiche et al., 2019; Lipson & Sonneville, 2017). Additionally, the predominantly reported motivation for DMA use is weight loss (Eikey et al., 2018; Messer, McClure, et al., 2021; Plateau et al., 2018), yet MFP was set to maintenance calories, and studies that have shown DMA use to improve weight loss are usually ≥ 24 weeks (Farage et al., 2021; Harvey et al., 2019). Therefore, given the exclusion criteria, MFP being set to maintenance calories by researchers, and exposure being limited to 30 days, results could be interpreted as null with regards to practical application. Lastly, DMA use within each experiment was accompanied by some level of researcher support, such as nutritional education (Jospe et al., 2018), or DMA direction and assistance prior to use (Hahn, Kaciroti, et al., 2021; Martinelli et al., 2021). Guidance is contrary to the typical user experience, as highlighted by Eikey et al. (2018), app adoption is fueled by the motivation or goal of DMA use, primarily being weight loss. Furthermore, researcher assistance mitigates the learning curve often experienced by DMA users, which may lessen DMA misuse compared to the typical DMA experience.

Discussion

Despite consistent associative evidence linking DMA use to ED/DE-S, no experimental design has demonstrated a significant effect on ED/DE-S from DMA use in low-risk populations. However, given the minimal body of experimental research and limitations within, further investigation is imperative. This is further supported by the body of qualitative research on DMA use and ED/DE-S. During the follow-up

assessments for Hahn, Kaciroti, et al. (2021), the first 20 subjects from the intervention group were recruited to conduct semi-structured qualitative interviews on their experience. Amongst subjects, users reported both positive (feeling physically and emotionally better, more prideful when eating within DMA recommendations) and negative (guilt, worry/anxiety, increased self-consciousness around food choice, weight, and body shape) feelings around app use (Hahn, Linxwiler, et al., 2021). These findings align with previous qualitative research and are consistent with regards to positive emotions being relegated to DMA adherence, while DMA functionalities mostly elicited negative feelings (Eikey, 2021; Eikey et al., 2018, 2017; Honary et al., 2019, McCaig et al., 2020). Functions such as notifications, feedback, and weight projections, all aim to encourage continued use of apps, as well as other forms of WRSM, yet may elicit negative feelings, and promote maladaptive compensatory behaviors (Eikey, 2021; Eikey et al., 2018, 2017; Ferrara et al., 2019; Honary et al., 2019, McCaig et al., 2020).

A large analysis of DMA user profiles (N = 18601) found that nearly 12% of the DMA (DropPounds), users either began, were currently, or desired to be underweight. Furthermore, not one user began with a weight gain goal, all users who began underweight, had underweight goals, and most users with underweight goals, already had a healthy BMI (Eikey et al., 2017). These data are consistent with an analysis of popular ED forums, where DMA users discuss setting apps to unhealthy or dangerously low weight and/or calorie goals (McCaig et al., 2020). Additionally, individuals with EDs may misuse DMAs as a perceived “recovery” tool or to mitigate DE behaviors (Eikey et al. 2018; McCaig et al., 2020). Certain DMAs, like MFP have ostensibly taken steps to reduce misuse, such as not allowing extremely low calorie/weight goals and prompting

users with notifications when their caloric intake is too low (McCaig et al., 2020). However, users provide one another advice on circumnavigating restrictions, such as underreporting height/weight and/or deliberately overestimating food intake (McCaig et al., 2020).

Given DMA misuse, as well as the associations of ED/DE-S among users, the development of a validated pre-screening tool could assist in the recognition of high-risk individuals. Jospe et al. (2018) suggests that their findings "should provide reassurance to clinicians that recommending common tools like MFP or daily self-weighing appears safe for adults who are trying to lose weight but are otherwise healthy." However, with the high heritability of ED risk (28-83%), and prevalence of certain DE behaviors in dieters and overweight/obese individuals, clinicians could use questionnaires to screen patients looking to lose weight before recommending DMAs (Konttinen et al., 2019; Linde et al., 2004; Shisslak et al., 1995, Thornton et al., 2011). This practice would increase ED and DE recognition, diagnosis, and treatment, as well as prevent exposure to susceptible individuals. Furthermore, while not consistent with engaging a larger user base, prefacing DMA use with an EDE-Q or EAT-26 within the app could inform at-risk users, or even limit app accessibility. Additionally, there are ED applications that employ empirically based principles, such as Recovery Record, which may assist in successful treatment (Juarascio, et al., 2015). Developers of popular DMAs could even produce an evidence-based recovery app to direct their current users with ED/DE-S towards, better aligning with public health and profit motives, as well as their customers' best interests.

A principal limitation within all included articles is the relatively low generalizability of sample populations, as the majority of subjects are white and

predominantly female. Amalgamating the participants in Tables 1. and 2. (N = 4380), females made up 75.5% of subjects (n = 3305), and white individuals accounted for 73.7% of the participants (n = 3229). While the former may be more justifiable, given the higher rates of EDs among women, the latter is not (HSPH, 2020). Despite EDs stereotypically being associated with smaller, affluent, white women, there is little evidence to suggest that there is ED/DE-S variance by either race or socioeconomic status (Cheng et al., 2019; Huryk et al., 2021; Quick & Byrd-Bredbenner, 2014; Sala et al., 2013; Solmi et al., 2016). As it is, people of color are significantly less likely to be diagnosed and/or receive treatment for an ED (Sonneville & Lipson, 2018). Additionally, all articles either excluded or contained no gender non-conforming or transgender individuals, limiting the applications of their findings to those individuals who are at a higher risk for ED/DE-S compared to their cisgender peers (Parker & Harriger, 2020). While only two articles inquired about parental education, 50% of subjects had a parent with a graduate degree and ≥ 75% had a parent with at least a bachelor's degree (Hahn, Kaciroti, et al., 2021; Hahn, Sonneville, et al., 2021). These education levels far exceed the general population, among adults aged ≥ 25 in the U.S., only 13.1% and 37% hold graduate and/or bachelor's degrees respectively (U.S. Census Bureau, 2018). Highlighting gaps that can be generated through university sampling, the primary recruitment strategy for 7 of the 12 included articles. Research going forward would benefit from improved sampling techniques, such as using stratified or non-probability quota sampling to garner a more representative study population.

Prospective, experimental research, with superior methodology, should be conducted to further investigate a temporal effect of DMA use on ED/DE-S. A sufficient

exposure/duration of use should be tested within practical, representative, and diverse sample populations. During which app use should be set to a caloric deficit to mirror predominant use cases (Eikey et al., 2018; Messer, McClure, et al., 2021; Plateau et al., 2018). Nutrition education, as well as instruction on DMA use should be limited, as app adoption is an independent user process. Researchers should use multiple intervention groups, utilizing various independent and synchronist forms of technology-based WRSM, given that DMA users tend to perform multiple types of self-monitoring (Hahn, Sonneville, et al., 2021; Plateau et al., 2018; Simpson & Mazzeo, 2017). Conduction of pilot studies would ensure appropriate methodology and highlight additional limitations to address.

Provided further experimentation continues to suggest no causal effect, research on DMA use as a predictive risk factor of ED/DE-S may be useful for preventative and/or clinical applications. Additionally, continued development and validation of recovery applications for those with ED/DE-S should be explored. As mobile recovery options would provide alternatives to DMA use, rather than individuals possibly misusing DMAs as “recovery” tools (Eikey et al. 2018). Furthermore, said recovery applications could ease some of the barriers to evidence-based recovery information for underdiagnosed and/or underserved populations. This review contains several limitations, first, while thorough, it is not systematic in nature, and thus, does not report with due rigor and may be open to apertures if omitting relevant sources. Second, the lack of experimental studies limits the reliability of results. Third, the summary of evidence is only as valid as the methodology used in each study, those limitations are discussed above.

Conclusion

While experimental evidence is limited, the current research suggests that DMA use has no effect on ED/DE-S among low-risk populations (Hahn, Kaciroti, et al., 2021; Jospe et al., 2018). This outcome contradicts associative and predictive research, and thus, may be the result of methodological limitations, as users often have negative experiences with DMAs that may exacerbate or contribute to ED/DE-S (Eikey et al., 2018; Embacher Martin et al., 2018; Hahn, Sonneville, et al., 2021; Hefner et al., 2016; Levinson et al., 2017; Linardon & Messer, 2019; Messer, McClure, et al., 2021; Plateau et al., 2018; Simpson & Mazzeo, 2017). Alternatively, DMA use in individuals with ED/DE-S may simply be a co-occurrence with those looking to improve health, diet, weight, and/or shape through dietary self-monitoring. Regardless, given the limited empirical evidence, any effect DMA use may have on ED/DE-S is a necessary area for future research, as both the prevalence and pervasiveness of EDs continues to rise alongside the increased popularity of DMAs and other WRSM tools (Galmiche et al., 2019; Statista, 2021, 2018).

Table 1. Summary of Included Observational Studies Investigating Dietary Monitoring Application use and Eating Disorder/Disordered Eating Symptomatology

Author	Subjects	ED/DE-S Measure	DMA Measure	Results	Limitations
Messer, McClure, et al., 2021	*N* = 1357 from parent study (Messer, Anderson, et al., 2021). Recruited through health and wellness social media and online forums. 86% female (*n* = 1168). 87.8% white (*n* = 1191). *M* age = 30.28 (*SD* = 13.48). *M* BMI = 26.08 (*SD* = 6.21).	EDE-Q 6.0, Muscularly-Oriented Eating Test (MOET).	Had they ever used a calorie tracking app to monitor their diet? Were they currently using one? Rate the extent calorie tracking app usage contributed to common ED symptoms. How many months they had been using the app? How helpful they thought the app was towards goal achievement? How concerned they would be if they stopped using the app, what was their primary motivation for app use?	71% (*n* = 964) used a DMA. 55% (*n* = 531) of users were current users. CB frequency, EDE-Q and MOET scores were higher in users compared to non-users. Perceived helpfulness was negatively correlated with most symptoms. 93% of current user's primary motivation was weight/shape reasons. Weight/shape motivated users had significantly higher CB frequency, EDE-Q and MOET scores compared to health motivated users. Duration of and concern with stopping use was positively correlated with most symptoms. All ED symptoms were positively correlated.	No measure of reasoning for discontinued use or why they felt apps contributed to ED symptoms.
Hahn, Sonneville, et al., 2021	*N* = 647 first year college students from a large midwestern state university recruited via email. 68.9% female (*n* = 446). 66% white (*n* = 427). 63.4% 18 y/o. *M* BMI = 23.3 (*SD* = 4.4).	Modified Project Eat questions (frequency of common ED/DE behaviors).	"In the past year, have you used any apps or other technology, such as a Fitbit or MFP, to monitor what you are eating, your exercise, or your weight?" "Please indicate which apps and/or technology you used in the past year and how you used them". "How often do you weigh yourself?"	31.3% used a DMA. 43.2% of females and 21.4% of males used multiple forms of technology-based WRSM. Females engaging in multiple forms of WRSM were more likely to report most ED/DE behaviors compared to subjects that did not WRSM. Males with greater patterns of WRSM were associated with higher probability of reporting most ED/DE behaviors.	No measure of motivation. Modified non-validated ED measurement. No statistical analysis of behaviors between DMA users and non-users. Statistical categorization could group incorrectly.
Linardon & Messer, 2019	*N* = 122 men recruited through health and fitness social media and online forums. No subjects self-reported an ED diagnosis. 77.9% white (*n* = 95). *M* age = 28.41 (*SD* = 8.93). *M* BMI = 26.41 (*SD* = 4.35).	EDE-Q 6.0, CIA, Dichotomous Thinking in ED scale (DTES; eating subscale).	"Have you used MFP to track your calories?" "Did you feel that MFP contributed to any pattern of DE in any way?"	56.6% (*n* = 69) used MFP. Compared to non-users, MFP users had significantly higher EDE-Q (global and all subscales), DTES, CIA scores, as well as higher objective BE frequencies. Among app users, 42% (*n* = 29) reported no use contribution to any pattern of DE; 14.5% (*n* =10) moderately, 13% (*n* = 9) somewhat, 10.1% (*n* = 7) very much. After controlling other significant predictors (BMI, CB, CIA, and DTES scores), MFP predicted a significant amount of unique variance in EDE-Q global scores ($\beta = -0.15$, $p = .001$).	Only assessed MFP use. No statistical analysis of ED behaviors and feelings of MFP contribution. No measure of motivation or reasoning why they felt MFP contributed to DE.

Eikey et al., 2018	*N* = 24 young women with DE behaviors who used/have used DMAs recruited from a large public university in Pennsylvania. 75% white (*n* = 18). *M* age = 20.63.	EAT-26, EDE-Q 6.0, CIA.	Listed all "health apps" they use, showing researchers any DMAs they used, how and why they use them, perceptions, and motivations of use. Asked specifically about ED recovery app use.	16 of 19 respondents answered ≥2 questionnaires in a manner that suggests DE behaviors. MFP was the primary app listed (*n* = 21). 6 other DMAs listed, all ≤2. 22 subjects reported losing weight as their motivation for use. Under exercise/fitness apps, Fitbit was the primary app listed (*n* = 4), 8 other apps listed, all ≤2.	Small sample. Only 19 completed valid ED/DE-S measures. No statistical analysis of ED behaviors and DMA use.
Plateau et al., 2018	*N* = 352 recruited via a course credit incentive at a U.K. university and through social media. 65% female (*n* = 228). 82% white British (*n* = 290). *M* age = 21.9 (*SD* = 3.24). *M* BMI = 22.87 (*SD* = 3.74).	EDE-Q 6.0, CET.	Reported use of an activity or food intake monitoring tools/device, the type used, frequency of use, main reasons for use, perceived helpfulness, level of concern if denied access, and the impact of use on their activity or eating behaviors.	25 subjects currently used only DMAs, 117 used only activity monitoring tools, 87 used both. 56.3% of DMA users used devices daily/a few times per week. 85% of DMA users perceived the tools to be very/somewhat helpful in goal achievement. 70% (*n* = 73) used DMAs for weight and/or shape management. 30% (*n* = 31) used DMAs for health-related reasons. Compared to health motivations, weight/shape management motivated users reported significantly higher CET weight control ($Z = 4.03$; $p \leq .01$; $r = .40$), and EDE-Q shape concern and weight concern scores ($Z \geq 2.90$; $p \leq .01$; $r \geq .28$).	No statistical analysis of ED behaviors between DMA users and non- users. Most statistical analysis done with all self-monitoring tools. Author reported sampling bias concerns.
Embacher Martin et al., 2018	*N* = 491 recruited via a course credit incentive for an introductory course at a large northeastern university. 52% female (*n* = 255). 64% white (*n* = 314). *M* age = 19 (*SD* = 1.26).	Frost's revised Body Esteem Scale (BES; body size, weight, and shape subscale) to measure BD.	Reported current smartphone app use to counts calories and/or tracks their dietary intake (e.g. MFP, MyNetDiary, Livestrong Calorie Counter, Lost It!, My Diet Coach).	26% (*n* = 124) currently used a DMA. Users reported significantly higher levels of BD, $t(474) = -4.06$, $p < .001$, and neuroticism $t(473) = -2.06$, $p < .05$). BD and neuroticism were significantly correlated ($r = .26$, $p < .001$).	Only assessed current DMA use. No measure of motivation. Only measured BD. Vague BD measured (weight, scarring, stretch marks).
Levinson et al., 2017	*N* = 105 recruited from an ED clinic. All previously discharged from a residential/partial hospitalization ED treatment center. 96.2% female (*n* = 102). 92.1% white (*n* = 94). *M* age = 25.58 (*SD* = 7.59).	EDE-Q 4.0, Eating Disorder Diagnostic Scale (EDDS).	"Have you used MFP to track your calories?" "Did you feel that MFP contributed to your ED in any way?"	74.3% (*n* = 78) MFP use. 73.1% (*n* = 57) of users reported MFP use at least somewhat contributed to their ED; 62.9% (*n* = 49) moderately, 30.3% (*n* = 23) very much, 17.9% (*n* = 14) did not. Greater feelings that MFP contributed to their ED was associated with higher EDE-Q scores on all subscales except eating concern.	Only assessed MFP use. No statistical analysis of ED behaviors and MFP use. No measure of motivation or reasoning why they felt MFP contributed to their ED.

Simpson & Mazzeo, 2017	*N* = 493 recruited via a course credit incentive for an undergraduate psychology course at a large, public university in the mid-Atlantic U.S. 69.7% female (*n* = 345). 49.6% white (*n* = 171). *M* age = 20.3 (*SD* = 3.52). *M* BMI = 24.19 (*SD* = 5.37). 29.9% male (*n* = 148). 51.4% white (*n* = 76). *M* age = 21.04 (*SD* = 3.93). *M* BMI = 24.89 (*SD* = 6.02).	EDE-Q 6.0.	Reported regular use of a calorie tracking device or application (e.g., MyFitnessPal) and fitness tracking device or application (e.g., Fitbit, pedometer).	13.8% (*n* = 68) regularly used DMAs. 19.6% (*n* = 98) regularly used fitness tracking devices. 8.9% (*n* = 44) regularly used both. DMA and fitness tracking device use were positively correlated ($r = 0.45$; $p < 0.001$). DMA users had higher EDE-Q eating concern ($p = .047$) and dietary restraint scores ($p < .001$), but not shape or weight concern. Fitness tracking was a significant predictor of EDE-Q Global scores ($p = 0.013$), but DMA use was not.	Only assessed current DMA use. No measure of motivation.
Hefner et al., 2016	*N* = 262 recruited via social media and flyers posted at a private university and in public places around Orange County, California. 76% female (*n* = 198). 68% white (*n* = 191). *M* age = 20.48 (*SD* = 1.75). *M* BMI = 22.63 (*SD* = 3.75).	EAT-26, CET.	Reported use of mobile phone apps (i.e., those that keep track of meals or exercise routines). E.g., "About how many times a week do you use nutritional apps?" and "About how many times a week do you use exercising apps?" Reported use of other social media (traditional blogs and microblogs).	Mobile app use was a significant predictor of EAT-26 (β = .34, $p = .00$) and CET scores (β = .31, $p = .000$). Greater mobile app use and microblog with fitspiration content was associated with higher DE symptomology. .	No distinction between DMAs and fitness apps. No measure of motivation. Vague frequency measure.

Key: Dietary monitoring application (DMA), eating disorder/disordered eating symptomatology (ED/DE-S), Eating Disorder Examination-Questionnaire (EDE-Q), eating disorder (ED), disordered eating (DE), compensatory behaviors (CB), MyFitnessPal (MFP), weight-related self-monitoring (WRSM), Clinical Impairment Assessment (CIA), binge eating (BE), Eating Attitudes Test (EAT-26), Compulsive Exercise Test (CET), body dissatisfaction (BD).

Table 2. Summary of Included Experimental Studies Investigating Dietary Monitoring Application use and Eating Disorder/Disordered Eating Symptomatology

Author	Subjects	ED/DE-S Measure	Intervention	Timeframe	Results	Limitations
Hahn, Kaciroti, et al., 2021	*N* = 200 female undergraduate students.Excluded for dietary self-monitoring within the past year, having an ED diagnosis, and/or scoring ≥2 on the EDE-QS. 51% white (*n* = 101). *M* age = 20.2 (*SD* = 2.4). *M* BMI = 21.3 (*SD* = 4.8).	EDE-QS, Body Image States Scale (BISS), Project EAT questions (self-weighing frequency). Mental health and health behavior questions.	Half the subjects assigned to self-monitor diet via MFP set to maintenance calories for 30 days. The other half received no intervention. Adherence assessed via percentage of days with ≥500 calories logged(*M* = 89.1%, *SD* = 16.9%).	1 month	No changes in EDE-QS (β = -.04, *p* = .17) or BISS (β = -.03, *p* = .81) scores. Self-weighing frequency lowered in the intervention group (β = -.35, *p* = .02). No changes in the mental health or health behaviors measured.	Tracking at maintenance. Insufficient exposure. DMA use seldom in isolation. Loss to follow up exclusive to intervention group.
Martinelli et al., 2020	*N* = 77 from parent study (Butryn et al., 2020). Recruited for digital data sharing focused weight loss treatment. Excluded if met BED diagnosis criteria. 80.52% female (*n* = 62). 53.25% white (*n* = 41). *M* age = 50.77 (*SD* = 13.39). *M* BMI = 34.86 (*SD* = 4.75).	Binge Eating Scale (BES), Three-Factor Eating Questionnaire (TFEQ-R18).	Orientation and 12-week group-based behavioral weight loss treatment. Subjects instructed to self-monitor their diet, physical activity, and weight through the FitBit app via provided digital devices. Adherence assessed via percentage of days ≥800 calories logged.	12 weeks	Greater BE severity at baseline predicted greater adherence to dietary (ρ = 0.25, *p* = .03) and weight (ρ = 0.25, *p* = .03) self-monitoring, but not physical activity (ρ = 0.08, *p* =.50) self-monitoring. UE and EE did not predict adherence to any form of self-monitoring.	Data limited to first 12 weeks of intervention. Subjects may restrict below adherence threshold. Monitoring emphasis may bias subject recruitment towards those more likely to adhere.
Jospe et al., 2018	*N* = 250 from parent study (Taylor et al., 2015). Recruited via advertisements. Had to be ≥18 y/o and have a BMI ≥ 27. 62% female (*n* = 155). 88% white (*n* = 220). *M* age = 43.7. *M* BMI = 33.	EDE-Q 6.0 Depression Anxiety Stress scale (DASS), Dieting and Weight History Questionnaire (DWHQ).	12-month weight loss intervention. Comprehensive diet and exercise advice session before random assignment to a control group or 1 of 4 monitoring groups; daily self-weighing, dietary self- monitoring via MFP, brief monthly consults, and hunger self-monitoring.	1 year	No significant differences in EDE-Q scores or DE behaviors across all groups. BE prevalence and regular BE lowered from baseline to 12 months, with no significant differences between groups (*p* = 0.458 and *p* = 0.202 respectively).	Subjects well above typical ED development age. Secondary outcome data analysis. High dropout rate (32.4%).

Key: Dietary monitoring application (DMA), eating disorder/disordered eating symptomatology (ED/DE-S), eating disorder (ED), Eating Disorder Examination-Questionnaire Short (EDE-QS), MyFitnessPal (MFP), Binge Eating Disorder (BED), Binge Eating (BE), disordered eating (DE). uncontrolled Eating (UE), emotional Eating (EE).

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