EHEALTH INTERVENTIONS TO PROMOTE PHYSICAL ACTIVITY AND WELL-BEING ACTIONS IN ADULTS WITH OBESITY

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PUBLIC ABSTRACT

EHEALTH INTERVENTIONS TO PROMOTE PHYSICAL ACTIVITY AND WELL-BEING ACTIONS IN ADULTS WITH OBESITY

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Use of the Internet to improve health, known as eHealth, is an emerging concept in healthcare that may present opportunities to promote physical activity and other healthy behaviors (e.g., eating a mostly plant-based diet, engaging in positive interactions) in adults with obesity. The purpose of this dissertation (psychosocial aspects of sport and physical activity) was to increase knowledge in the emergent area. Study 1 systematically reviewed previous eHealth intervention studies to promote physical activity in adults with obesity. The study design was a systematic review study guided by relevant guidelines. Five electronic databases were used. Two researchers screened articles, assessed risk of bias, and extracted data independently. A qualitative data synthesis was conducted. Study 2 evaluated the effectiveness of the Fun For Wellness (FFW) eHealth intervention to promote well-being actions in adults with obesity in the United States of America (USA) in a relatively uncontrolled setting. The FFW intervention is based on self-efficacy theory. The study design was a large experimental study across 60 days. Data collection via self-reports occurred at: baseline, 30 days and 60 days after baseline. Participants were recruited through a national healthcare panel recruitment company. A single path model was fit based on the FFW conceptual model.

In Study 1, 2276 articles were identified, and 18 studies met all inclusion criteria. Study quality ranged from poor to good. The included studies varied in intervention technology (e.g., web-based, mobile phone-based, physical activity monitor-based), physical activity assessment (e.g., device-based, self-report based), and control group. Behavioral change techniques used in

the included studies were consistent with some techniques (e.g., self-monitoring, personalized feedback) that were previously known as effective in the majority of face-to-face interventions, but more automatically and efficiently employed in eHealth using information and communication technology. Overall, Study 1 shows that a web-based or physical activity monitor-based eHealth intervention has the potential to be effective in promoting physical activity in adults with obesity. The use of theory and monitor-based physical activity assessment in eHealth seems to be beneficial to the intervention design and study design. In Study 2, participants (N = 667) who were assigned to the FFW group (nFFW = 331) were provided with 30 days of 24 hr access to FFW. There was evidence of validity and reliability in the self-reports. Supportive evidence was provided for the effectiveness of FFW in real-world settings to promote, either directly or indirectly, three dimensions: community, occupational, psychological. Overall, Study 2 shows that the theory-based eHealth intervention has the potential to be effective in promoting well-being actions in adults with obesity.

In conclusion, this dissertation shows that an eHealth intervention has the potential to be effective in promoting physical activity and well-being actions in adults with obesity in a relatively uncontrolled setting, particularly when the intervention is web-based or physical activity monitor-based, using theory. The use of monitor-based physical activity assessment in the field is recommended. This dissertation provides a contemporary and salient research base and identifies gaps in the emergent area, indicating that eHealth is promising for adults with obesity. This dissertation will be useful to develop (or refine), implement, and evaluate an eHealth intervention that effectively and efficiently promotes physical activity and other healthy behaviors in adults with obesity in real-world settings.

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In conclusion, this dissertation shows that an eHealth intervention has the potential to be effective in promoting physical activity and well-being actions in adults with obesity in a relatively uncontrolled setting, particularly when the intervention is web-based or physical activity monitor-based, using theory. The use of monitor-based physical activity assessment in the field is recommended. This dissertation provides a contemporary and salient research base and identifies gaps in the emergent area, indicating that eHealth is promising for adults with obesity. This dissertation will be useful to develop (or refine), implement, and evaluate an eHealth intervention that effectively and efficiently promotes physical activity and well-being actions in adults with obesity in real-world settings.

This dissertation is dedicated to my parents and my wife.
Thank you for always believing in me.

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CHAPTER I: GENERAL INTRODUCTION

EHEALTH INTERVENTIONS TO PROMOTE PHYSICAL ACTIVITY AND WELL-BEING ACTIONS IN ADULTS WITH OBESITY

INTRODUCTION

Use of information and communication technology to improve health, known as eHealth, is an emerging concept in healthcare that may present opportunities to promote physical activity and other healthy behaviors in adults with obesity. The topic of this dissertation is eHealth interventions to promote physical activity and well-being actions in adults with obesity. This dissertation comprises two studies. Study 1 is a systematic review study entitled, *eHealth interventions to promote physical activity in adults with obesity: A systematic review of experimental studies.* In this dissertation, eHealth was defined broadly as the use of information and communication technology, especially the Internet, to improve or enable health and health care. Study 2 is an empirical study entitled, *Effectiveness of the Fun For Wellness online behavioral intervention to promote well-being actions in adults with obesity or overweight: A randomized controlled trial.* The Fun For Wellness (FFW) online intervention is a theory-based multicomponent eHealth intervention designed to promote growth in well-being and physical activity by providing capability-enhancing learning opportunities to participants. In this dissertation, well-being actions were defined as the frequency to which an individual takes behavioral actions (e.g., physical activity, healthy diet) that may improve their status in key domains of their life (e.g., physical domain).

The purpose of Study 1 is to systematically review eHealth intervention studies to promote physical activity in adults with obesity. Physical activity is important to adults with obesity due to multiple reasons: (a) a significant relationship between greater amounts of physical activity and attenuated weight gain in adults, (b) an additive effect on weight loss when

combined with moderate dietary restriction, and (c) some health benefits (e.g., relative reduction in risk of developing a new chronic disease) by being physically active even without weight loss (see the introduction section of Study 1 for full citations and references). Compared to a typical face-to-face intervention, an eHealth intervention may offer several potential advantages: (1) increased access to information and support on demand, (2) improved capability of combining a variety of media to address the particular purposes of the intervention, (3) improved chance to tailor information to the specific needs of a population, and (4) increased possibility for users to remain anonymous while seeking information and support from experts about a sensitive and private health issue (Atkinson & Gold, 2002; Eng & Gustafson, 1999). However, there are potential disadvantages of eHealth interventions, for example, authoritative delivery of health information by eHealth without active consultation (see the discussion section of Study 1 for full citations and references). The aforementioned advantages and downsides may make the question open as to the effectiveness of eHealth for physical activity promotion specifically designed or tested to target adults with obesity.

Study 1 is important because conducting systematic reviews may help researchers and practitioners draw out useful scientific implications from extant literature in the area of eHealth to promote physical activity in adults with obesity, consistent with a recommendation in the physical activity promotion field (USDHHS, 2018). The knowledge identified from Study 1 will be helpful to not only support scientific contributions of Study 2 to the physical activity promotion field but also to address scientific limitations of Study 2 for future eHealth intervention research to promote physical activity in adults with obesity. To my knowledge, few studies systematically reviewed eHealth intervention research, focusing on “promoting physical activity” in “adults with obesity”. There has been a variety of systematic review studies on

eHealth interventions but for different purposes, focusing on either "promoting weight loss or weight maintenance in adults with obesity" or "promoting physical activity in other adult populations such as adults with normal weight" (see the introduction section of Study 1 for full citations and references). In summary, Study 1 is important because systematically reviewing eHealth intervention studies to promote physical activity in adults with obesity is necessary to report recent research status and future research directions in the field.

The purpose of Study 2 is to evaluate the effectiveness of the FFW eHealth intervention to promote well-being actions in adults with obesity in the United States of America in a relatively uncontrolled setting. Study 2 is important because it is recommended to conduct experimental research aimed at testing physical activity interventions combined with other health behavior interventions (e.g., eating a mostly plant-based diet, engaging in positive interactions with people) to promote optimal physical activity change within the context of such multicomponent interventions (USDHHS, 2018). Additionally, Study 2 addressed major research needs identified in the promoting regular physical activity chapter of the 2018 Physical Activity Guidelines Advisory Committee Scientific Report (USDHHS, 2018): (a) targeting a vulnerable and at-risk population (i.e., adults with obesity), (b) developing efficient methods for collecting data (i.e., online data collection), and (c) testing physical activity interventions in real-world settings (i.e., relatively uncontrolled condition). In summary, Study 2 is important because it may provide evidence for the effectiveness of a theory-based multicomponent eHealth intervention to promote well-being actions in adults with obesity in real-world settings.

Together, the studies comprising this dissertation will increase knowledge of eHealth interventions to promote physical activity and well-being actions in adults with obesity, by conducting both a systematic review study and an empirical study. Study 1 in this dissertation

may help (a) adults with obesity understand if eHealth interventions can promote their physical activity, (b) researchers understand how eHealth interventions to promote physical activity in the population should be developed and evaluated, and (c) practitioners understand how eHealth interventions to promote physical activity in the population should be used in real-world settings. Study 2 in this dissertation may help individuals, communities, and governments understand the effects of a theory-based multicomponent eHealth intervention to promote multi-dimensional well-being actions in adults with obesity in a relatively uncontrolled setting. Thus, this dissertation will be useful to develop (or refine), implement, and evaluate an eHealth intervention that effectively and efficiently promotes physical activity and well-being actions in adults with obesity in real-world settings. Background information for this dissertation is briefly described below, with more comprehensive presentations appearing in Study 1 and Study 2.

BACKGROUND INFORMATION

According to the World Health Organization [WHO] (2018), more than 1.9 billion adults were overweight. Of these numbers, over 650 million were obese, and the size of this subgroup has tripled over the past few decades (WHO, 2018). This trend toward an increasing number of adults with obesity is problematic from a public health perspective because obesity is a risk factor for major non-communicable diseases including cardiovascular disease, type II diabetes, and some cancers (Bauer, Briss, Goodman, & Bowman, 2014). To reduce the prevalence of adults with obesity, the WHO (2018) recommends that individuals engage in regular physical activity.

Physical activity is defined as bodily movement produced by skeletal muscles that requires energy expenditure (Caspersen, Powell, & Christenson, 1985). Recent evidence indicated that the benefits from physical activity can be achieved by people who perform in the

range of 500 to 1000 Metabolic Equivalent of Task (MET)-min per week of aerobic physical activity, which is commonly expressed as 150 to 300 min of moderate-intensity physical activity (or 75 to 150 min of vigorous-intensity physical activity) per week (USDHHS, 2018). Previous studies found that moderate amounts of physical activity might be sufficient to reduce overall weight gain in men and women (Moholdt, Wisløff, Lydersen, & Nauman, 2014). People do not have to reach the lower end of the 150 to 300-min target range to benefit from regular physical activity, but people who exceed the target range may get even greater health benefits (Moholdt et al., 2014; USDHHS, 2018).

Physically active individuals generally function better in cognition, sleep better, and feel better, compared to those who are not physically active (see the introduction section of Study 1 for full citations and references). Regular physical activity is equally (or possibly more) important to adults with obesity due to multiple reasons. First, many studies demonstrated a significant relationship between greater amounts of physical activity and reduced weight gain in adults (e.g., Drenowatz et al., 2016; Hamer et al., 2013; Hankinson et al., 2010; Lee, Djoussé, Sesso, Wang, & Buring, 2010). Second, performing moderate-to-vigorous physical activity provides an additive effect on weight loss when combined with dietary restrictions, compared to dietary restrictions only (USDHHS, 2008). Third, even without weight status change in adults with obesity, physically active adults with obesity experience some of the health benefits, for example, the relative reduction in incidence of type 2 diabetes (USDHHS, 2018). Fourth, there is evidence that vigorous physical activity more consistently produces improvements in blood pressure, insulin sensitivity, and body composition in adults with obesity than adults without weight problems (Batacan, Duncan, Dalbo, Tucker, & Fenning, 2017; Jelleyman et al., 2015; Kessler, Sisson, & Short, 2012). Fifth, regular physical activity helps individuals with a chronic

medical condition reduce the risk of developing a new chronic disease (e.g., type 2 diabetes, hypertension) as well as the risk of progression of a chronic disease they already have (USDHHS, 2018). The scientific evidence has shown that physical activity is a best buy for public health, particularly in adults with obesity that are a vulnerable and at-risk population.

In spite of the valuable benefits of physical activity, adults with obesity are more physically inactive and less likely to meet the public health guidelines for physical activity such as 150 min per week of moderate-to-vigorous physical activity, compared to adults with normal weight (Tran, Tran, & Tran, 2020; Tudor-Locke, Brashear, Johnson, & Katzmarzyk, 2010). A possible reason for the problematic issue is that adults with obesity tend to perform physical activity only when trying to lose weight (Leone & Ward, 2013). This would indicate that simply understanding the variety of benefits accompanied by an active lifestyle is not sufficient to make a regularly active lifestyle, particularly in the obese adult population (USDHHS, 2018). Therefore, it is important to develop, implement, and evaluate behavioral interventions (e.g., face-to-face intervention or remote intervention) that are designed to supplement the importance of physical activity (and other healthy behaviors) and reinforce health promotion messages for adults with obesity.

As the technical capacity and accessibility of the Internet via electronic (i.e., eHealth) and mobile (i.e., mHealth) devices grow, offering a viable medium for health behavior interventions and research becomes easier (Atkinson & Gold, 2002). The definitions of eHealth and mHealth vary because they have been applied in a variety of contexts along with continuous developments and advancements of information and communication technologies (see Danaher, Brendryen, Seeley, Tyler, & Woolley, 2015; Eysenbach, 2001; Vandelanotte et al., 2016). In this dissertation, eHealth is defined as the use of information and communication technology using

the Internet to enable health care; whereas mHealth is defined as health care supported by a mobile device (e.g., smartphone), consistent with previous literature (Eng, 2001; Vandelanotte et al., 2016; WHO, 2011). In other words, mHealth is conceptualized to be a subdivision of eHealth because the promise of eHealth interventions is not limited to interventions delivered on personal computers using the Internet but also applies to mHealth interventions delivered on mobile devices. An eHealth intervention may offer several potential advantages for promoting healthy behaviors (e.g., increased access to information and support on demand), compared to a typical face-to-face intervention (see the introduction section in Study 1 for full information).

However, there are also some challenges inherent in conducting eHealth interventions and research (Atkinson & Gold, 2002; Enam, Torres-Bonilla, & Eriksson, 2018). A part of the challenge in developing and testing eHealth interventions to promote healthy behaviors is a lack of expertise in technical skills, health contents, or evaluations among eHealth developers and testers (Eng, 2001). For instance, technology experts may develop fun and attractive eHealth programs that are not based on health behavior theories or effective behavioral change techniques. Conversely, health experts may develop theory-based eHealth interventions that do not fully use the advantages of the technology. It is also possible that technology experts or health experts may employ a study design that may have a rating of poor quality (i.e., high risk of bias) to test their eHealth interventions and thus provide misleading scientific knowledge in the field. Due to the aforementioned reasons, there is evidence that the reported effectiveness of eHealth for clinical populations on health outcomes varies hugely (Enam et al., 2018; Nguyen, Carrieri-Kohlman, Rankin, Slaughter, & Stulbarg, 2004).

The purpose of this dissertation was to provide a contemporary and salient research base and identify gaps in the emergent eHealth area to promote physical activity and well-being

actions in adults with obesity, by conducting both a systematic review study (Study 1) and an empirical study (Study 2). The purpose of Study 1 was to systematically review eHealth intervention studies to promote physical activity in adults with obesity. Three research questions were investigated and are listed below.

Research Question 1. What are the characteristics of the study design (e.g., physical activity assessment, control group) used in the eHealth interventions to promote physical activity in adults with obesity?

Research Question 2. What are the characteristics of the eHealth interventions (e.g., intervention technology, theory use) to promote physical activity in adults with obesity?

Research Question 3. Do the findings of the eHealth interventions to promote physical activity in adults with obesity provide support for eHealth as an effective medium?

The purpose of Study 2 was to evaluate the effectiveness of the FFW online intervention to increase well-being actions in adults with obesity in the United States of America in relatively uncontrolled settings. Four hypotheses were investigated and are listed below.

Hypothesis 1. The FFW intervention would exert a positive direct effect on well-being actions self-efficacy.

Hypothesis 2. Well-being actions self-efficacy would exert a positive direct effect on well-being actions.

Hypothesis 3. The FFW intervention would exert a positive direct effect on well-being actions.

Hypothesis 4. The FFW intervention would exert a positive indirect effect on well-being actions through well-being actions self-efficacy.

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CHAPTER II: STUDY 1

EHEALTH INTERVENTIONS TO PROMOTE PHYSICAL ACTIVITY IN ADULTS WITH OBESITY: A SYSTEMATIC REVIEW OF EXPERIMENTAL STUDIES

PREFACE

This study was financially supported, in part, with a Dissertation Completion Fellowship that I was awarded in 2021. Study 1 from this dissertation will be submitted to a peer-reviewed journal such as *Journal of Physical Activity and Health* (or *Obesity Reviews*).

ABSTRACT

Despite a variety of benefits of being physically active, adults with obesity are more physically inactive and less likely to meet the public health guidelines for physical activity, compared to adults with normal weight. Use of information and communication technology to improve health, known as eHealth, is an emerging concept in healthcare that may present opportunities to promote physical activity in adults with obesity. The purpose of this manuscript was to systematically review eHealth intervention studies to promote physical activity in adults with obesity. Five electronic databases were used: PubMed, CINAHL, Cochrane, PsycINFO, and Embase. Two authors screened articles, assessed risk of bias, and extracted data independently. A qualitative data synthesis for summarizing the findings was performed using harvest plots. In the search, 2276 articles were identified, and 18 studies met all inclusion criteria. Study quality ranged from poor to good. The included studies varied in intervention technology (e.g., web-based, mobile phone-based, physical activity monitor-based), physical activity assessment (e.g., device-based, self-report based), and control group. Behavioral change techniques used in the included studies were consistent with some techniques (e.g., self-monitoring, personalized feedback) that were previously known as effective in the majority of face-to-face interventions, but more automatically and efficiently employed in eHealth using information and

communication technology. Overall, this review study shows that a web-based or physical activity monitor-based eHealth intervention has the potential to be effective in promoting physical activity in adults with obesity. Some recommendations for future eHealth interventions to promote physical activity in adults with obesity are provided (e.g., use of theory and monitor-based physical activity assessment).

INTRODUCTION

Physical activity gives a variety of benefits to individuals across the full age spectrum. Compared to those who are not physically active, physically active individuals generally: function better in cognition such as attention and processing speed, executive function, and memory (Smith et al., 2010); sleep better such as reducing the length of time it takes to go to sleep (Kredlow, Capozzoli, Hearon, Calkins, & Otto, 2015); and feel better such as perceiving improved well-being (Bize, Johnson, & Plotnikoff, 2007). There is also strong evidence that greater amounts of physical activity are associated with: reduced risk of developing some cancers (Keimling, Behrens, Schmid, Jochem, & Leitzmann, 2014), reduced risk of developing type 2 diabetes (Aune, Norat, Leitzmann, Tonstad, & Vatten, 2015), and lowering hypertension (Huai, Xun, Reilly, Wang, Ma, & Xi, 2013). Some benefits gained by being physically active even happen immediately. According to the 2018 Physical Activity Guidelines Advisory Committee Scientific Report (United States Department of Health and Human Services [USDHHS], 2018), a single bout of moderate-to-vigorous physical activity can provide some of the aforementioned benefits. With the regular performance of moderate-to-vigorous physical activity, most of these improvements become larger.

Physical activity is equally (or possibly more) important to adults with obesity for at least five reasons. First, a number of previous studies demonstrated a significant relationship between

greater amounts of physical activity and attenuated weight gain in adults (e.g., Drenowatz et al., 2016; Hamer et al., 2013; Hankinson et al., 2010; Lee, Djoussé, Sesso, Wang, & Buring, 2010). Second, moderate-to-vigorous physical activity has an additive effect on weight loss when combined with moderate dietary restriction, compared to the dietary restriction only (USDHHS, 2008). Third, even if weight status of adults with obesity remains the same, physically active adults with obesity experience some of the health benefits such as the relative reduction in incidence of type 2 diabetes (USDHHS, 2018). Fourth, there is evidence that vigorous physical activity more consistently produces improvements in insulin sensitivity, blood pressure, and body composition in adults with obesity than adults with normal weight (Batacan, Duncan, Dalbo, Tucker, & Fenning, 2017; Jelleyman et al., 2015; Kessler, Sisson, & Short, 2012). Fifth, by regular physical activity, individuals with a chronic medical condition can reduce the risk of developing a new chronic disease (e.g., hypertension, type 2 diabetes) as well as the risk of progression of a chronic disease they already have (USDHHS, 2018). The scientific evidence demonstrated that physical activity is a best buy for public health, particularly in vulnerable and at-risk populations such as adults with obesity.

Despite the valuable benefits of physical activity, adults with obesity are more physically inactive and less likely to meet the public health guidelines for physical activity such as 150 min per week of moderate physical activity, compared to adults with normal weight (Tran, Tran, & Tran, 2020; Tudor-Locke, Brashear, Johnson, & Katzmarzyk, 2010). Moreover, there is evidence that adults with obesity tend to be physically active only when trying to lose weight (Leone & Ward, 2013). Simply understanding the variety of benefits accompanying an active lifestyle is, particularly in the obese adult population, insufficient to create a regularly active lifestyle (USDHHS, 2018). Therefore, behavioral interventions, of a typical format (i.e., face-to-face) or

remote format (i.e., eHealth) that are designed to supplement the importance of being physically active and reinforce health promotion messages with effective and efficient approaches and strategies, are important to promote physical activity in adults with obesity.

As the technical capacity and accessibility of the Internet via electronic (eHealth) and mobile (mHealth) devices grow, it becomes easier to offer a viable medium for health behavior interventions and research (Atkinson & Gold, 2002). The definitions of eHealth and mHealth vary because they have been applied in various contexts along with ongoing developments and advancements of information and communication technologies (see Eysenbach, 2001; Danaher, Brendryen, Seeley, Tyler, & Woolley, 2015; Vandelanotte et al., 2016). In this manuscript, eHealth is defined broadly as the use of information and communication technology, especially the Internet, to improve or enable health and health care; whereas mHealth is defined as medical and public health practice supported by a mobile device (e.g., smartphone), consistent with previous literature (Eng, 2001; Vandelanotte et al., 2016; World Health Organization [WHO], 2011). That is, mHealth is considered a subdivision of eHealth because the promise of eHealth interventions is not limited to Internet interventions delivered on personal computers but also applies to mHealth interventions delivered on mobile devices.

Compared to a typical health intervention (e.g., face-to-face), an eHealth intervention may offer several potential advantages for promoting healthy behaviors (Atkinson & Gold, 2002; Eng & Gustafson, 1999): (a) increased access to information and support on demand, (b) improved capability of combining a variety of media to address the particular purposes of the intervention, (c) enhanced ability to update and maintain current scientific knowledge, (d) improved chance to tailor information to the specific needs of a population, and (e) increased possibility for users to remain anonymous while seeking information and support from experts

about a sensitive and private health issue. The "e" in eHealth does not only stand for "*e*lectronic" but implies a number of other "e"s, such as *e*fficiency (i.e., one of the promises of eHealth is … to increase efficiency in health care, thus decreasing costs), *e*nhancing quality of care (i.e., … to use a variety of media as necessary thus enhancing the quality of health care), *e*vidence base (i.e.. … to prove their effectiveness by rigorous scientific evaluation), and *e*thics (i.e., … to increase privacy and equity issues)(Eysenbach, 2001). There are, however, some potential downsides of eHealth interventions such as authoritative delivery of health information by eHealth without active consultation (see the discussion section for more information). The aforementioned advantages and downsides may leave the question open as to the effectiveness of eHealth for physical activity promotion specifically targeting adults with obesity.

Using systematic reviews can help researchers and practitioners draw out useful scientific implications (e.g., maximizing the advantages of eHealth) from extant literature in the area of eHealth to promote physical activity in adults with obesity, consistent with a recommendation in the physical activity promotion field (USDHHS, 2018). Previous literature showed that there are some effective behavioral change techniques used in the majority of face-to-face interventions to promote physical activity in adults with obesity, such as goal-setting, self-monitoring, personalized feedback, and social support (Olander et al., 2013; Samdal, Eide, Barth, Williams, & Meland, 2017). However, the effective behavioral change techniques, used in face-to-face interventions to promote physical activity in adults with obesity, may not be accompanied and used in eHealth interventions. In fact, it was pointed out that one part of the problem in deploying eHealth interventions to promote healthy behaviors is a lack of expertise in technical skills, health contents, or evaluations among eHealth developers and testers (Eng, 2001). For example, technology experts may develop fun and attractive websites that are not based on

health behavior theories and effective behavioral change techniques. On the other hand, health experts may develop theory-based eHealth interventions that do not use the advantages of the technology. It is also even possible that technology experts or health experts may use a study design that may have a rating of poor quality to test their eHealth interventions and thus provide misleading scientific knowledge in the field. Therefore, we believe that systematically reviewing eHealth intervention studies to increase physical activity in adults with obesity is important to report recent research status and future research directions in the field.

To our knowledge, however, few studies systematically reviewed eHealth intervention research, focusing on "promoting physical activity" in "adults with obesity". To be specific, there were only systematic review studies (with or without meta-analyses) on eHealth interventions to promote physical activity in a number of other populations. These systematic reviews targeted: older adults (Kwan et al., 2020; Muellmann et al., 2018), adults with some cancers (Dorri, Asadi, Olfatbakhsh, & Kazemi, 2020; Haberlin et al., 2018), adults with type 2 diabetes who are not necessarily obese (Astrup & Finer, 2000; Connelly, Kirk, Masthoff, & MacRury, 2013), adults with cardiovascular disease (Duff et al., 2017), African American and Hispanic adult women (Joseph, Royse, & Benitez, 2019), adults with normal weight, chronic disease, and obesity all together (Davies, Spence, Vandelanotte, Caperchione, & Mummery, 2012; Kroeze, Werkman, & Brug, 2006; Vandelanotte, Spathonis, Eakin, & Owen, 2007; van den Berg, Schoones, & Vliet Vlieland, 2007), or all ages (LaPlante & Peng, 2011; McIntosh, Jay, Hadden, & Whittaker, 2017; Norman et al., 2007; Stephens & Allen, 2013; Stephens, Cobiac, & Veerman, 2014), but not exclusively for adults with obesity. On the other hand, there were many systematic review studies (with or without meta-analyses) on eHealth interventions to promote weight loss or weight maintenance in adults with obesity (Allen, Stephens, & Patel, 2014;

Bacigalupo et al., 2013; Coons et al., 2012; Hutchesson et al., 2015; Kodama et al., 2012; Lau, Chee, Chow, Cheng, & Wong, 2020; Manzoni, Pagnini, Corti, Molinari, & Castelnuovo, 2011; Neve, Morgan, Jones, & Collins, 2010; Raaijmakers, Pouwels, Berghuis, & Nienhuijs, 2015; Sherrington et al., 2016), but not exclusively for promoting physical activity in adults with obesity. Physical activity does not necessarily result in weight loss. Even without weight loss, however, adults with obesity who perform regular physical activity experience some of the previously mentioned health benefits such as reducing the risk of developing a new chronic disease (USDHHS, 2018).

The purpose of this manuscript was to systematically review eHealth intervention studies to promote physical activity in adults with obesity. Three research questions were investigated and are listed below.

Research Question 1. What are the characteristics of the study design (e.g., physical activity assessment, control group) used in the eHealth interventions to promote physical activity in adults with obesity?

Research Question 2. What are the characteristics of the eHealth interventions (e.g., intervention technology, theory use) to promote physical activity in adults with obesity?

Research Question 3. Do the findings of the eHealth interventions to promote physical activity in adults with obesity provide support for eHealth as an effective medium?

METHODS

This systematic review study followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines (Liberati et al., 2009) and met some criteria (e.g., inclusion criteria, data synthesis) outlined in Institute of Medicine (2011), and Higgins and Thomas (2020). Accordingly, in this manuscript, systematic review refers to a systematic review

without a meta-analysis; whereas, meta-analysis refers to a systematic review that includes a meta-analysis (see the data synthesis section). Before conducting this systematic review study, we searched multiple databases including the PROSPERO international prospective register of systematic reviews to check that no similar ongoing and published systematic reviews existed.

Search Strategy

The search strategy, such as eligibility criteria, information sources, and search terms, was used to search relevant articles for this systematic review study. The search strategy was developed using a list of core terms of the Population, Intervention, Comparison, and Outcome framework (Higgins & Thomas, 2020; Schardt, Adams, Owens, Keitz, & Fontelo, 2007). To be specific, the search strategy considered Population (i.e., adults with obesity), Interventions (i.e., eHealth, mHealth), Comparison (i.e., experimental studies), and Outcome of interest (i.e., physical activity).

Eligibility criteria. There were inclusion/exclusion criteria in the systematic review. Studies were included if they: (a) were peer-reviewed and full text articles published in English, (b) investigated the use of eHealth interventions to promote physical activity, (c) were either pre-post study design or randomized controlled trial (RCT), (d) targeted adults from 18 to 64 years consistent with the USDHHS (2008; 2018), (e) targeted adults who are considered at least overweight (i.e., body mass index [BMI] index ≥ 25.00 kg/m^2) consistent with many physical activity interventions for adults with obesity (de Vries, Kooiman, van Ittersum, van Brussel, & de Groot, 2016; Gourlan, Trouilloud, & Sarrazin, 2011), (f) included physical activity assessment (e.g., device-based, self-report based) as a main outcome, and (g) conducted an analysis for physical activity outcomes. In this systematic review, eHealth interventions encompassed any form of information and communication technology to promote physical

activity (e.g., website, mobile phone application, tablet, text-messaging, social media, interactive exergame), consistent with previous literature (e.g., Eng, 2001; Eysenbach, 2001; USDHHS, 2018). Studies were excluded if they were review studies (e.g., systematic reviews, meta-analyses), observational studies (e.g., case control, case series), and studies without testing the effect of eHealth interventions on physical activity. Grey literature (e.g., conference abstracts, dissertations) was not considered in this systematic review study because of some potential limitations such as interim data and limited access (Gunnell, Poitras, & Tod, 2020).

Information sources. Five databases were used: PubMed, CINAHL, Cochrane, PsycINFO, and Embase. The databases were selected because: (a) PubMed and Embase performed adequately and efficiently in literature searches in systematic review studies, (b) CINAHL and PsycINFO supplemented the search by adding unique results, and (c) Cochrane was used in the 2018 Physical Activity Guidelines Advisory Committee Scientific Report (Bramer, Rethlefsen, Kleijnen, & Franco, 2017; Torres et al., 2018). De-duplication from the databases was conducted through a reference management software.

Search terms. The lead author and a librarian from a major research university worked together in an iterative process to develop comprehensive search terms for the databases. The developed search terms were tested in the databases and refined as needed to ensure relevant scope. The search terms included the developed search keywords, Boolean logic used to combine the search keywords, and limits. Full information about search terms and search results from each database is provided in Table 4 in the appendix section, consistent with the recommendations of reporting systematic reviews (Liberati et al., 2009).

Screening Strategy

The screening strategy, such as study selection, was used in the process of this systematic review study to identify relevant studies for this systematic review study. The scientific literature was screened in a systematic way to enhance transparency and reproducibility while reducing bias.

Study selection. There were two levels of screening for study selection, using the aforementioned eligibility criteria. At the first-level screening, screening titles and abstracts was conducted to remove studies that were obviously irrelevant. At the second-level screening, full texts of potentially relevant articles published between 2010 and 2020 were examined against the eligibility criteria. For each screening, the lead author screened the searched studies, and a co-author independently screened 30% of the total number of the studies to balance efficiency and rigor. Before the beginning of the full screening, calibration exercises (i.e., piloting the screening on ten randomly selected studies) were performed. The amount of agreement between the two authors (i.e., interrater reliability such as observed proportion of agreement, Cohen's Kappa) was quantified to determine the reliability of the study selection, consistent with the relevant guidelines (Liberati et al., 2009). The reasons for any disagreement in the process were carefully explored and resolved (Boutron et al., 2019). The options for dealing with lack of clarity or conflict during the study selection included consultation with other co-authors and contacting the researchers to get more information.

Data Collection Strategy

The data collection strategy, such as risk of bias and data extraction, was used in the process of this systematic review study. Research Question 1 and Research Question 2 were answered by the data collection strategy with descriptive statistics and narrative summaries.

Risk of bias. After the study selection, risk of bias in the included studies was evaluated, consistent with the recommendations of reporting systematic review (Higgins & Thomas, 2020; Institute of Medicine, 2011; Liberati et al., 2009). Specifically, the Study Quality Assessment Tools were used (National Institutes of Health [NIH], 2018). Based on study design, the assessment tools offer tailored questions about the methods of experimental intervention studies to help reviewers focus on the key concepts for evaluating a study's internal validity (e.g., randomization, power analysis). The assessment tool culminates in an overall rating of good, fair, or poor quality. A rating of good quality translates to low risk of bias; whereas, a rating of poor quality translates to high risk of bias. The evaluation of the risk of bias was used in the data synthesis (see the data synthesis section).

The lead author assessed risk of bias from the included studies from the study selection, and a co-author independently assessed 30% of the total number of the included studies. Before the beginning of the full assessment, calibration exercises (i.e., piloting the assessment of risk of bias on two randomly selected studies) were performed. The amount of agreement between the two authors was quantified to determine the reliability of the risk of bias, consistent with the relevant guidelines (Liberati et al., 2009). The reasons for any disagreement were explored and resolved. The options for dealing with lack of clarity or conflict during the assessment of risk of bias were the same as the aforementioned options.

Data extraction. Abstraction forms were developed and used to systematically record the characteristics of the study design, characteristics of the eHealth interventions, and study results from the included studies. Before the beginning of the full data extraction, piloting the abstraction forms on two randomly selected studies was performed, and the logistics were refined when necessary. The lead author extracted the data from the included studies, and a co-

author independently extracted 30% of the total number of the included studies. The reasons for any disagreement were explored and resolved. The options for dealing with lack of clarity or conflict during the data extraction were the same as the aforementioned options. A summary table was made by pulling the relevant data elements from the abstraction forms.

Data Synthesis

A meta-analysis (i.e., quantitative data synthesis) was not feasible and suitable because the included studies were too heterogeneous in regard to intervention technology, physical activity assessment, and control group. "A meta-analysis should not be assumed to always be an appropriate step in a systematic review [SR]. ... Ultimately, it is a subjective judgment that should be made in consultation with the entire SR team, including both clinical and methodological perspectives" (Institute of Medicine, 2011, p. 179). Conducting a systematic review without a meta-analysis is acceptable and consistent with a variety of previous systematic review studies on eHealth interventions to promote physical activity in various populations (e.g., Connelly et al., 2013; Dorri et al., 2020; Duff et al., 2017; Haberlin et al., 2018; Joseph et al., 2019; Kroeze et al., 2006; LaPlante & Peng, 2011; McIntosh et al., 2017; Muellmann et al., 2018; Norman et al., 2007; Stephens & Allen, 2013; Vandelanotte et al., 2007; van den Berg et al., 2007). In this review study, a qualitative data synthesis for summarizing the findings was performed using the harvest plots to make the assessments of the body of evidence. Research question 3 was answered by the data synthesis with narrative summaries.

Harvest plots. The harvest plot is a method for combining intervention studies with different intervention modes and outcome assessments to give an overall visual effect (Crowther, Avenell, MacLennan, & Mowatt, 2011; Ogilvie et al., 2008). The harvest plot provides a graphical representation of the reported eHealth effect, encapsulating the risk of bias assessment

(i.e., study quality) combined with either characteristics of eHealth interventions (i.e., subgroups of intervention technology) or characteristics of study design (i.e., subgroups of physical activity assessment). Narrative synthesis using the harvest plots was provided for the following subgroups: intervention technology, physical activity assessment. Additional subgroup analyses such as age were attempted.

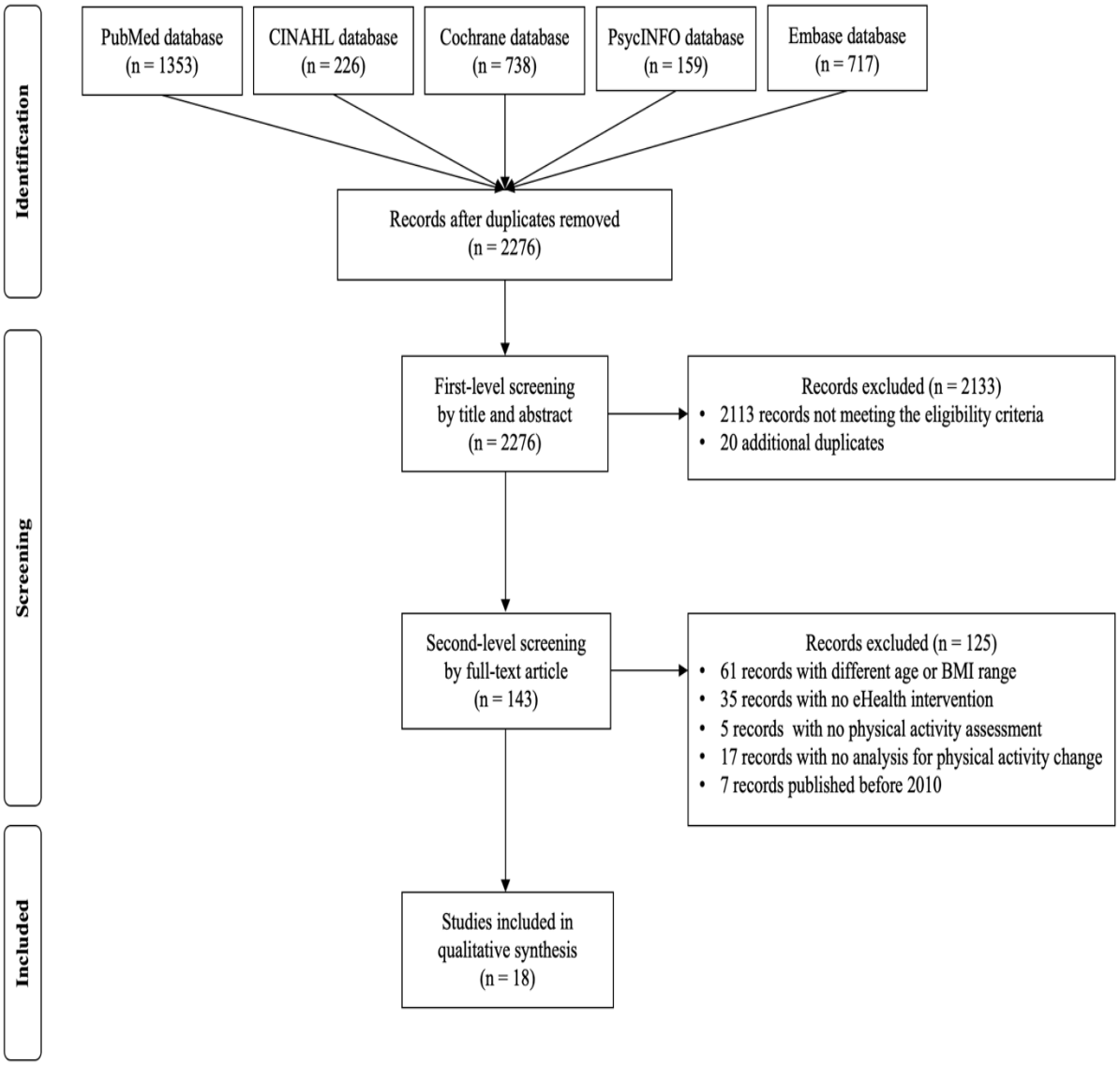
Assessments of the body of evidence. Assessments of the body of evidence in the subgroups (i.e., intervention technology, physical activity assessment) were provided, consistent with the standards recommended by Institute of Medicine (2011). To be specific, all of the co-authors reviewed the risk of bias, data extraction, and harvest plots and then made a consensus of the strength of evidence on the subgroups: strong, moderate, or lack of information.

RESULTS

Study Selection

A total of 2276 articles were identified using the search terms from the five databases. Following the first-level screening of titles and abstracts, 143 articles remained. After the second-level screening of the full-text versions of these articles, 18 articles remained and were included in the review. The excluded eHealth studies often did not have physical activity assessment or conduct an analysis for physical activity outcomes. Interrater reliability of the first-level of screening was strong, with the observed proportion of agreement, P = 0.97, and Cohen's Kappa, K = 0.82. Interrater reliability of the second-level of screening was strong, with the observed proportion of agreement, P = 1.00, and Cohen's Kappa, K = 1.00. The two authors resolved all the initial disagreements through discussion. The flow of the literature search and study selection is provided in Figure 1.

Figure 1. *The flow of the literature search and study selection*



Risk of Bias

Based on the Study Quality Assessment Tools (NIH, 2018), the included studies were rated as: poor quality (2 out of 18, 11%); fair quality (10 out of 18, 56%); or good quality (6 out of 18, 33%). To be specific, the majority of studies (17 out of 18, 94%) randomly assigned participants to intervention group(s) or control group, achieving demographic similarity (e.g., age, height, weights) between the groups at baseline. Regarding the randomization procedure,

however, only a little more than half of the randomized studies (10 out of 17, 59%) reported that they achieved adequate randomization and allocation concealment (e.g., computer-generated randomization). None of the included studies (0 out of 18, 0%) were able to blind both participants and intervention providers or sufficiently explain the blinding procedure. The majority of studies (14 out of 18, 78%) had low to moderate dropout rate (e.g., ~20% dropout rate in intervention group), but the other studies (4 out of 18, 22%) had high dropout rate or did not report the relevant data. Only a little more than half of the included studies (10 out of 18, 56%) reported that their participants adhered to the protocols of their assigned intervention (e.g., daily self-monitoring of physical activity), but the other studies (8 out of 18, 44%) did not report the relevant data. The majority of studies (16 out of 18, 89%) reported that they used reliable and valid physical activity assessment tools that were previously tested, but the other studies (2 out of 18, 11%) did not report what assessment tools they used. Finally, the majority of studies (16 out of 18, 89%) used intention-to-treat analysis, but only half of the included studies (9 out of 18, 50%) conducted power analysis. Interrater reliability of the risk of bias assessment of the included studies was moderate, with the observed proportion of agreement, $P = 0.86$, and Cohen's Kappa, $K = 0.70$. The two authors resolved all the initial disagreements through discussion. A summary of the risk of bias assessment is provided in Table 1.

Table 1. *Summary of risk of bias assessment*

Study	Adequately randomized	Blind	Baseline similarity	Low dropout	Adherence	Other factors Avoided	Reliable measure	Power	Specified outcome	Intent -to- treat	Rating
#1 Adams et al., (2017)	±	–	+	+	?	?	+	+	+	+	good
#2 Ainscough et al., (2020)	+	?	+	+	+	?	+	–	+	+	fair
#3 Apiñaniz et al., (2019)	+	–	+	±	?	?	?	+	+	+	fair
#4 Beleigoli et al., (2020)	+	?	+	–	+	?	+	+	+	+	good
#5 Garcia et al., (2014)*	±	?	+	±	?	?	+	–	+	+	fair
#6 Hersey et al., (2012)	+	–	+	±	?	?	?	+	+	+	fair
#7 Jakicic et al., (2016)	+	–	+	±	?	?	+	+	+	+	good
#8 Joseph et al., (2016)*†	NA	NA	NA	+	+	?	+	+	+	NA	fair
#9 Nazari et al., (2020)	±	?	+	?	?	?	+	–	+	+	poor
#10 Nakata et al., (2019)	+	?	+	+	?	?	+	+	+	+	good

Table 1 (cont'd)

Study	Adequately randomized	Blind	Baseline similarity	Low dropout	Adherence	Other factors Avoided	Reliable measure	Power	Specified outcome	Intent -to- treat	Rating
#11 Navarro et al., (2020)	+	?	+	±	+	?	+	–	+	–	fair
#12 Patrick et al., (2011)	+	?	+	±	+	?	+	+	+	+	good
#13 Pellegrini et al., (2012)*	±	–	+	–	+	?	+	–	+	+	fair
#14 Roesch et al., (2010)	±	–	+	?	?	?	+	–	+	+	poor
#15 Rogers et al., (2016)	±	?	+	±	+	?	+	–	+	+	fair
#16 Rollo et al., (2020)*	+	?	+	–	+	?	+	–	+	+	fair
#17 Steinberg et al., (2013)	±	–	+	+	+	?	+	–	+	+	fair
#18 Watson et al., (2012)	+	–	+	+	+	?	+	+	+	+	good

Note. + = low risk of bias; ± = moderate risk of bias; – = high risk of bias; ? = unclear risk of bias; NA = not applicable; * = feasibility or pilot study; † = pre-post study with no control group; Items for same topic from the Study Quality Assessment Tools are collapsed for simplicity.

Characteristics of Study Design

The included studies were conducted across the world including the United States of America, Australia, Spain, Iran, Ireland, and Japan. The majority of studies (17 out of 18, 94%) were RCT, and one study (1 out of 18, 6%) was pre-post study without any control group. Across the RCTs, different types of control groups were used: (a) *wait-list* where participants received an intervention after data collection is completed (5 out of 17, 29%); (b) *standard care* where participants received a typical face-to-face intervention (6 out of 17, 35%); and (c) *standard eHealth* where participants received a typical eHealth intervention without enhanced technology such as computer-generated feedback (6 out of 17, 35%). The number of sample sizes ranged from 26 to 1755 across the studies, and more specifically: < 50 (5 out of 18, 28%); 50-100 (6 out of 18, 33%); 100-700 (4 out of 18, 22%); and > 800 (3 out of 18, 17%). Participants with somewhat arbitrary age ranges were recruited and can be categorized by: 19-55 years (11 out of 18, 61%); 18-64 years (5 out of 18, 28%); and 30-64 years (2 out of 18, 11%). The majority of studies (17 out of 18, 94%) recruited adult participants with at least overweight (i.e., ≥ 25.00 kg/m^2), and one study (1 out of 18, 6%) recruited adult participants with at least obesity (i.e., ≥ 30.00 kg/m^2). A number of different study lengths were employed and can be categorized by: < 6 months (6 out of 18, 33%); 6-12 months (9 out of 18, 50%); and > 12 months (3 out of 18, 17%). Regarding physical activity assessment, more than half of the included studies (13 out of 18, 72%) used self-report based assessment, and the other studies (5 out of 18, 28%) used device-based assessment (sometimes combined with self-report based assessment). The characteristics of study design are more fully described in Table 2. The results are relevant to Research Question 1.

Characteristics of eHealth Interventions

All of the eHealth interventions from the included studies intended to increase physical activity in adults with obesity; however, they were originally developed for a particular purpose that can be categorized by: weight loss (9 out of 18, 50%); physical activity promotion (5 out of 18, 28%); and healthy lifestyle (4 out of 18, 22%). At least half of each type of the eHealth interventions statistically increased physical activity in adults with obesity: weight loss intervention (7 out of 9, 78%); physical activity intervention (4 out of 5, 80%); and healthy lifestyle intervention (2 out of 4, 50%). A variety of intervention technology were employed in the included studies and can be categorized by: web-based (11 out of 18, 61%); mobile phone-based (3 out of 18, 17%); and physical activity monitor-based (4 out of 18, 22%). To be specific, a web-based eHealth intervention was generally delivered through a website. A mobile phone-based eHealth intervention was generally delivered through mobile application or text-message. A physical activity monitor-based eHealth intervention was generally provided with a commercial-graded accelerometer (e.g., Fitbit) combined with a small screen, email, website, or mobile application using the Internet. A number of different intervention lengths were employed and can be categorized by: < 6 months (6 out of 18, 33%); 6-12 months (8 out of 18, 44%); > 12 months (2 out of 18, 11%); and not reported (2 out of 18, 11%).

Regarding theory use, less than half of the included studies (8 out of 18, 44%) explicitly reported the use of theory to develop their interventions. More specifically, the majority of interventions with theory use (7 out of 8, 88%) were based on social cognitive theory (sometimes combined with other theory), and one intervention (1 out of 8, 13%) was based on self-regulation theory. Only a little more than half of the studies with theory use (5 out of 8, 63%) measured and evaluated the relevant theoretical constructs that were expected to affect physical activity level.

In general, there was agreement between theoretical construct change and physical activity change (4 out of 5, 80%) in the studies. Regarding behavioral change techniques, a number of different techniques were employed and can be categorized by: self-monitoring, feedback (6 out of 18, 33%); social cognitive theory-based techniques (5 out of 18, 28%); personalized feedback (3 out of 18, 17%); information and advice on health (2 out of 18, 11%); coaching (1 out of 18, 6%); and a combination of the aforementioned techniques (1 out of 18, 6%). The characteristics of eHealth interventions are more fully described in Table 2. The results are relevant to Research Question 2.

Table 2. *Summary of study design, eHealth interventions, and study results*

Study	Study Design	Assessment	eHealth Intervention	Study Results
#1 **Author:** *Adams et al., 2017* **Country:** *USA*	**Design:** *RCT;* **N:** *96* **Age:** *18-60* **BMI:** *25-55* **Gender:** *male, female* **Study Length:** *4 months* **Control Group:** *standard eHealth (static goal)*	**Type:** *accelerometers (Fitbit)* **Measurement:** *steps/day, MVPA mins/day*	**Purpose:** *PA promotion* **Technology:** *mobile phone-based (adaptive goal)* **Intervention Length:** *4 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *personalized feedback (adaptive goal)*	*statistically higher PA in intervention group, compared to control group*
#2 **Author:** *Ainscough et al., 2020* **Country:** *Ireland*	**Design:** *RCT;* **N:** *565* **Age:** *18-45* **BMI:** *25-39.99* **Gender:** *pregnant female* **Study Length:** *7 months* **Control Group:** *standard care*	**Type:** *self-reports (SLÁN 2002 survey)* **Measurement:** *MET-mins/week, frequency of 30 mins MVPA per week*	**Purpose:** *healthy lifestyle* **Technology:** *mobile phone-based (app)* **Intervention Length:** *NR* **Theory Use:** *SCT, control theory (measured and evaluated, no mediation analysis)* **Behavioral Change Techniques:** *information and advice on health*	*statistically higher PA in intervention group, compared to control group (no significant increase in theoretical constructs)*
#3 **Author:** *Apiñaniz et al., 2019* **Country:** *Spain*	**Design:** *RCT;* **N:** *110* **Age:** *18-45* **BMI:** *≥ 25* **Gender:** *male, female* **Study Length:** *6 months* **Control Group:** *standard care*	**Type:** *self-reports (NR)* **Measurement:** *adherence of PA recommendation*	**Purpose:** *healthy lifestyle* **Technology:** *mobile phone-based (app)* **Intervention Length:** *6 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *information and advice on health*	*no statistical difference in adherence of PA recommendation between intervention group and control group*

Table 2 (cont'd)

Study	Study Design	Assessment	eHealth Intervention	Study Results
#4 **Author:** *Beleigoli et al., 2020* **Country:** *Australia*	**Design:** *RCT;* **N:** *1298* **Age:** *18-60* **BMI:** *≥ 25* **Gender:** *male, female* **Study Length:** *7 months* **Control Group:** *standard eHealth*	**Type:** *self-reports (Brief PA Questionnaire)* **Measurement:** *MVPA days/week*	**Purpose:** *weight loss* **Technology:** *web-based (enhanced eHealth)* **Intervention Length:** *7 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *personalized feedback (computerized or human-delivered)*	*no statistical difference in PA between intervention groups and control group*
#5 **Author:** *Garcia et al., 2014* **Country:** *USA*	**Design:** *FP, RCT;* **N:** *26* **Age:** *18-55* **BMI:** *25-45* **Gender:** *male, non-pregnant female* **Study Length:** *3 months* **Control Group:** *standard care*	**Type:** *self-reports (Paffenbarger PA Questionnaire)* **Measurement:** *PA mins/week*	**Purpose:** *weight loss* **Technology:** *web-based (email)* **Intervention Length:** *3 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *self-monitoring, feedback*	*(1) statistically higher PA in intervention and control groups at postbaseline, compared to baseline; (2) no statistical difference in PA between intervention and control group*
#6 **Author:** *Hersey et al., 2012* **Country:** *USA*	**Design:** *RCT;* **N:** *1755* **Age:** *18-64* **BMI:** *25-50* **Gender:** *male, female* **Study Length:** *18 months* **Control Group:** *standard eHealth*	**Type:** *self-reports (NR)* **Measurement:** *adherence of PA recommendation*	**Purpose:** *weight loss* **Technology:** *web-based (enhanced eHealth)* **Intervention Length:** *NR* **Theory Use:** *NR* **Behavioral Change Techniques:** *personalized feedback (computerized)*	*higher adherence of PA recommendation in all groups at postbaseline, compared to baseline*

Table 2 (cont'd)

Study	Study Design	Assessment	eHealth Intervention	Study Results
#7 **Author:** *Jakicic et al., 2016* **Country:** *USA*	**Design:** *RCT;* **N:** *471* **Age:** *18-35* **BMI:** *25-40* **Gender:** *male, female* **Study Length:** *2 years* **Control Group:** *standard eHealth*	**Type:** *accelerometers (BodyMedia FIT)* **Measurement:** *MET-mins/week*	**Purpose:** *weight loss* **Technology:** *PA monitor-based* **Intervention Length:** *2 years* **Theory Use:** *SCT, health belief model (not measured)* **Behavioral Change Techniques:** *self-monitoring, feedback*	*(1) statistically higher PA in intervention and control groups at postbaseline, compared to baseline; (2) no statistical difference in PA between intervention and control group*
#8 **Author:** *Joseph et al., 2016* **Country:** *USA*	**Design:** *FP, pre-post study* **N:** *33;* **Age:** *19-30* **BMI:** *>25* **Gender:** *African American female* **Study Length:** *3 months* **Control Group:** *NA*	**Type:** *self-reports (7-Day PA Recall), accelerometers (ActiGraph)* **Measurement:** *PA mins/week*	**Purpose:** *PA promotion* **Technology:** *web-based* **Intervention Length:** *3 months* **Theory Use:** *SCT (measured and evaluated, no mediation analysis)* **Behavioral Change Techniques:** *SCT-based techniques (+ cultural relevant information)*	*no statistically higher PA in the group at postbaseline, compared to baseline (no significant increase in theoretical constructs)*
#9 **Author:** *Nazari et al., 2020* **Country:** *Iran*	**Design:** *RCT;* **N:** *91* **Age:** *30-59* **BMI:** *≥ 25* **Gender:** *female* **Study Length:** *3 months* **Control Group:** *wait-list*	**Type:** *self-reports (developed by Dr. Sallis)* **Measurement:** *MET*	**Purpose:** *PA promotion* **Technology:** *web-based* **Intervention Length:** *2 weeks* **Theory Use:** *SCT (measured and evaluated, no mediation analysis)* **Behavioral Change Techniques:** *SCT-based techniques*	*(1) statistically higher PA in intervention and control groups at postbaseline, compared to baseline; (2) statistical difference in PA between intervention and control group (significant increase in theoretical constructs)*

Table 2 (cont'd)

Study	Study Design	Assessment	eHealth Intervention	Study Results
#10 **Author:** *Nakata et al., 2019* **Country:** *Japan*	**Design:** *RCT;* **N:** *95* **Age:** *40-64* **BMI:** *25-40* **Gender:** *male, female* **Study Length:** *27 months* **Control Group:** *standard care*	**Type:** *accelerometers (Active style Pro)* **Measurement:** *steps/day, MVPA mins/day*	**Purpose:** *weight loss* **Technology:** *PA monitor-based* **Intervention Length:** *27 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *self-monitoring, feedback*	*(1) statistically higher PA in intervention and control groups at postbaseline compared to baseline; (2) no statistical difference in PA between intervention and control group*
#11 **Author:** *Navarro et al., 2020* **Country:** *Spain*	**Design:** *RCT;* **N:** *48* **Age:** *18-64* **BMI:** *> 25* **Gender:** *female* **Study Length:** *21 days* **Control Group:** *standard eHealth*	**Type:** *self-reports (IPAQ), weekly PA goal registration* **Measurement:** *PA levels/weeks, weekly achievement of PA goal*	**Purpose:** *PA promotion* **Technology:** *web-based (virtual avatar)* **Intervention Length:** *14 days* **Theory Use:** *SCT, transtheoretical model (measured and evaluated, mediation analysis used)* **Behavioral Change Techniques:** *SCT-based techniques*	*(1) statistically higher PA in intervention and control groups at postbaseline, compared to baseline, with small effect size (significant increase in theoretical constructs); (2) no statistically significant indirect effect of interventions on PA via self-efficacy*
#12 **Author:** *Patrick et al., 2011* **Country:** *USA*	**Design:** *RCT;* **N:** *441* **Age:** *25-55* **BMI:** *≥ 25* **Gender:** *male* **Study Length:** *1 year* **Control Group:** *wait-list*	**Type:** *self-reports (IPAQ)* **Measurement:** *walking-mins/day, MET-mins/week*	**Purpose:** *weight loss* **Technology:** *web-based* **Intervention Length:** *1 year* **Theory Use:** *SCT (not measured)* **Behavioral Change Techniques:** *SCT-based techniques*	*statistically significant difference in PA by group-by-time interaction*

Table 2 (cont'd)

Study	Study Design	Assessment	eHealth Intervention	Study Results
#13 **Author:** *Pellegrini et al., 2012* **Country:** *USA*	**Design:** *FP, RCT;* **N:** *51* **Age:** *21-55* **BMI:** *25-39.99* **Gender:** *male, female* **Study Length:** *6 months* **Control Group:** *standard care*	**Type:** *self-reports (Paffenbarger PA Questionnaire)* **Measurement:** *kcal/week*	**Purpose:** *weight loss* **Technology:** *PA monitor-based* **Intervention Length:** *6 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *self-monitoring, feedback*	*(1) statistically higher PA in intervention and control groups at postbaseline, compared to baseline; (2) no statistical difference in PA between intervention and control group*
#14 **Author:** *Roesch et al., 2010* **Country:** *USA*	**Design:** *RCT;* **N:** *842* **Age:** *18-55* **BMI:** *25-40* **Gender:** *male, female* **Study Length:** *1 year* **Control Group:** *wait-list*	**Type:** *self-reports (IPAQ)* **Measurement:** *MET-mins/week*	**Purpose:** *healthy lifestyle* **Technology:** *web-based* **Intervention Length:** *1 year* **Theory Use:** *SCT, transtheoretical model (measured and evaluated, mediation analysis used)* **Behavioral Change Techniques:** *SCT-based techniques*	*(1) statistically higher PA in intervention group, compared to control group, with small effect size (significant increase in theoretical constructs); (2) statistically significant indirect effect of interventions on PA via self-efficacy or behavior strategies*
#15 **Author:** *Rogers et al., 2016* **Country:** *USA*	**Design:** *RCT;* **N:** *39* **Age:** *21-55* **BMI:** *35-45* **Gender:** *male, female* **Study Length:** *6 months* **Control Group:** *standard care*	**Type:** *self-reports (Paffenbarger PA Questionnaire)* **Measurement:** *kcal/week*	**Purpose:** *weight loss* **Technology:** *PA monitor-based* **Intervention Length:** *6 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *self-monitoring, feedback*	*(1) statistically higher PA in intervention and control groups at postbaseline, compared to baseline; (2) no statistical difference in PA between intervention groups and control group*

Table 2 (cont'd)

Study	Study Design	Assessment	eHealth Intervention	Study Results
#16 **Author:** *Rollo et al., 2020* **Country:** *Australia*	**Design:** *FP, RCT;* **N:** *42* **Age:** *18-45* **BMI:** *25-50* **Gender:** *female* **Study Length:** *6 months* **Control Group:** *wait-list*	**Type:** *self-reports (Godin Leisure-time Exercise Questionnaire)* **Measurement:** *MVPA mins/week*	**Purpose:** *healthy lifestyle* **Technology:** *web-based* **Intervention Length:** *6 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *personalized feedback + information and advice on health + coaching (human-delivered)*	*no statistically significant difference in PA by time, group, and group-by-time interaction*
#17 **Author:** *Steinberg et al., 2013* **Country:** *USA*	**Design:** *RCT;* **N:** *91* **Age:** *18-60* **BMI:** *25-40* **Gender:** *male, female* **Study Length:** *9 months* **Control Group:** *wait-list*	**Type:** *self-reports (Paffenbarger PA Questionnaire)* **Measurement:** *energy expenditure per week*	**Purpose:** *weight loss* **Technology:** *web-based* **Intervention Length:** *6 months* **Theory Use:** *self-regulation theory (not measured)* **Behavioral Change Techniques:** *self-monitoring, feedback*	*no statistically significant difference in PA by time, group, and group-by-time interaction*
#18 **Author:** *Watson et al., 2012* **Country:** *USA*	**Design:** *RCT;* **N:** *70* **Age:** *20-55* **BMI:** *25-35* **Gender:** *male, female* **Study Length:** *3 months* **Control Group:** *standard eHealth*	**Type:** *accelerometers (ActiPed), self-reports (7-day physical activity recall)* **Measurement:** *steps/day, kcal/day*	**Purpose:** *PA promotion* **Technology:** *web-based (virtual coach)* **Intervention Length:** *3 months* **Theory Use:** *NR* **Behavioral Change Techniques:** *coaching (virtual reality)*	*(1) statistically higher PA (percentage changes in step over time) in intervention group, compared to control group; (2) no statistically significant difference in PA by group-by-time interaction*

Note. FP = feasibility or pilot study; RCT = randomized controlled trial; BMI = body mass index; PA = physical activity; MVPA = moderate-to-vigorous physical activity; MET = metabolic equivalent of task; SCT = social cognitive theory; IPAQ = international physical activity questionnaire; NR = not reported; NA = not applicable.

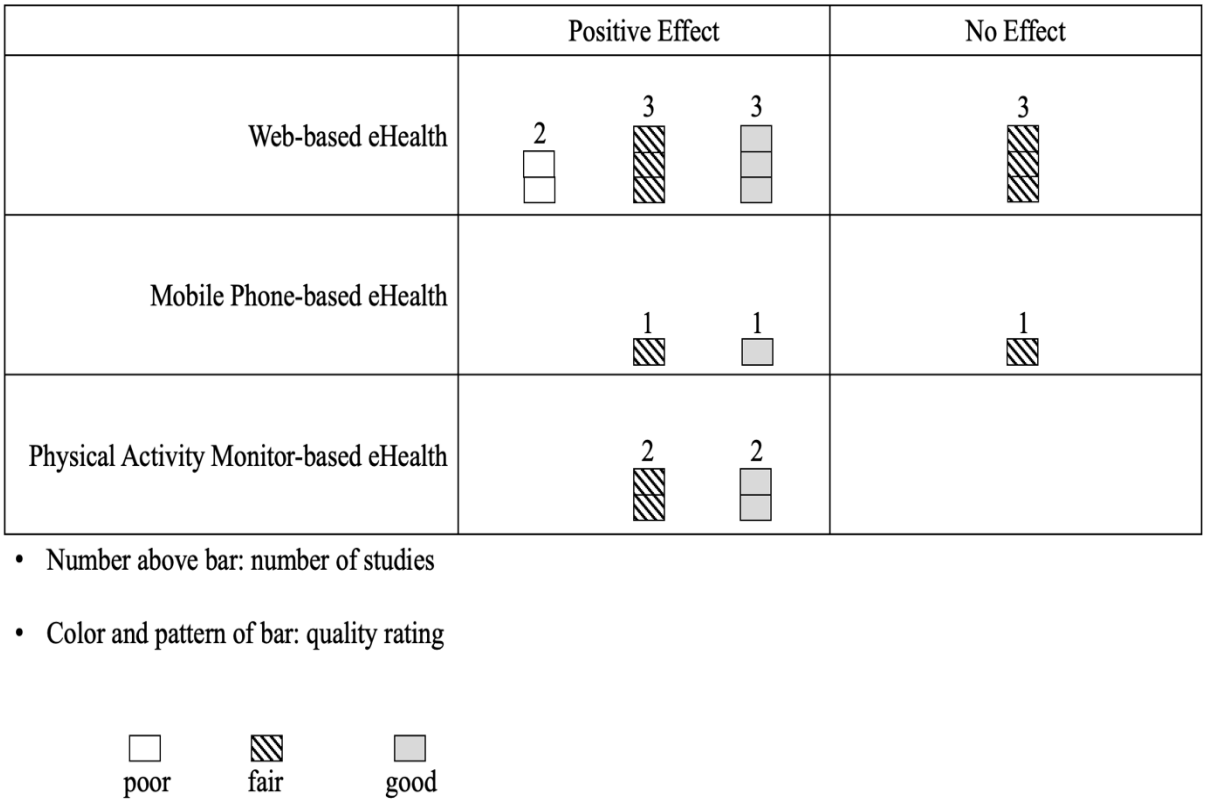
Assessments of the Body of Evidence

Regardless of the risk of bias, characteristics of study design, and characteristics of eHealth interventions, more than half of the included studies (13 out of 18, 72%) found that their eHealth interventions had a positive effect on physical activity in adults with obesity. In the following sections, the harvest plots were narratively described for encapsulating the risk of bias assessment (i.e., study quality) combined with either characteristics of eHealth interventions (i.e., subgroups of intervention technology) or characteristics of study design (i.e., subgroups of physical activity assessment). Then, the assessments of the body of evidence for each subgroup were provided. Additional subgroup analyses (e.g., age-related) were not provided in this manuscript because the relevant data were not available. The results are relevant to Research Question 3.

Intervention technology. Figure 2 illustrated the evidence regarding eHealth effectiveness by three aforementioned subgroups of the intervention technology: web-based, mobile phone-based, and physical activity monitor-based. The subgroup results were consistent with a systematic review (regarding web-based, mobile phone-based) and previous meta-analysis (regarding physical activity monitor-based) on an eHealth intervention to promote physical activity in adult populations (de Vries et al., 2016; Muellmann et al., 2018). Web-based eHealth interventions from the included studies (11 out of 18, 61%) had either positive (8 out of 11, 73%) or no effect (3 out of 11, 27%) on physical activity in adults with obesity. To be specific, the subgroup with a positive effect consisted of: good quality (3 out of 8, 38%); fair quality (3 out of 8, 38%); and poor quality (2 out of 8, 25%). The subgroup with no effect consisted of fair quality only (3 out of 3, 100%). Mobile phone-based eHealth interventions from the included studies (3 out of 18, 17%) had either positive (2 out of 3, 67%) or no effect (1 out of 3, 33%) on physical

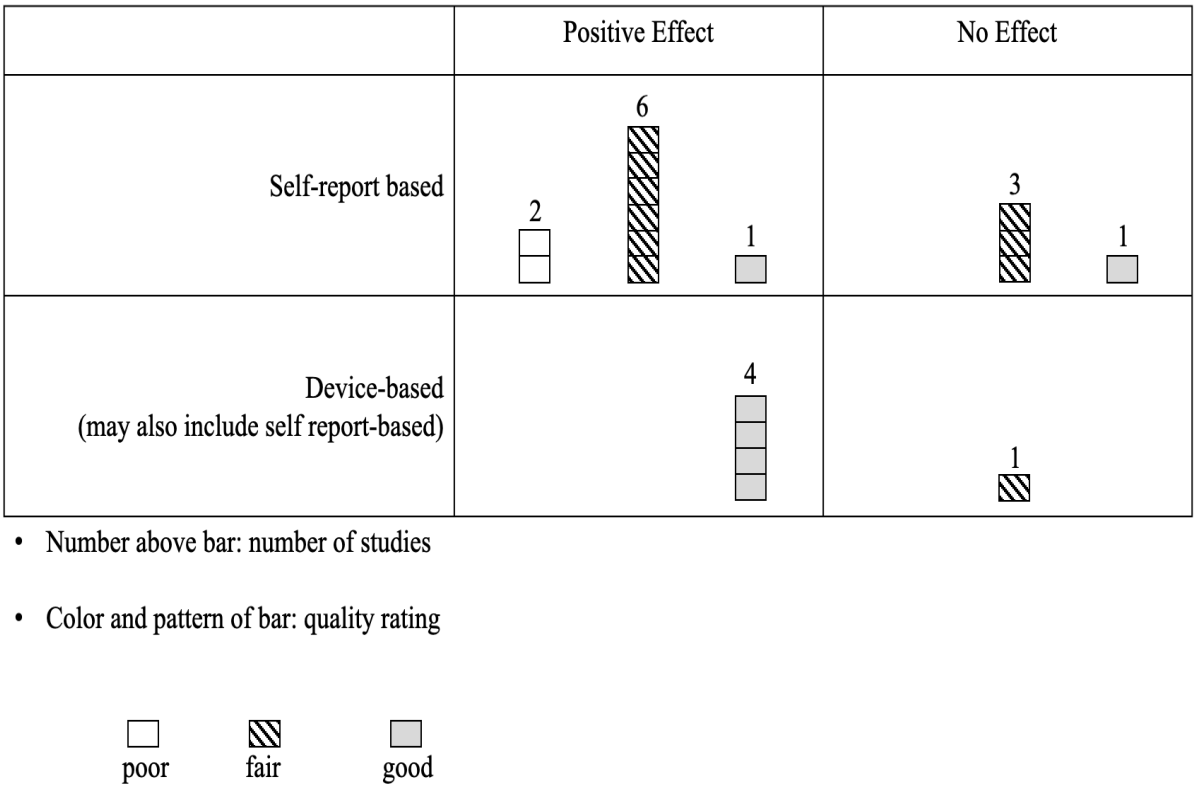
activity in adults with obesity. To be specific, the subgroup with a positive effect consisted of: good quality (1 out of 2, 50%) and fair quality (1 out of 2, 50%). The subgroup with no effect consisted of fair quality (1 out of 1, 100%). Physical activity monitor-based eHealth interventions from the included studies (4 out of 18, 22%) only had a positive effect (4 out of 4, 100%) on physical activity in adults with obesity. To be specific, the subgroup with a positive effect consisted of: good quality (2 out of 4, 50%) and fair quality (2 out of 4, 50%). In the harvest plot (see Figure 2), there was moderate strength of evidence that a web-based or physical activity monitor-based eHealth intervention is an effective medium to promote physical activity in adults with obesity. However, there was a lack of information indicating that a mobile phone-based eHealth intervention is an effective medium to promote physical activity in adults with obesity.

Figure 2. *Harvest plot of evidence for eHealth effectiveness by intervention technology*



Physical activity assessment. Figure 3 illustrated the evidence regarding eHealth effectiveness by two aforementioned subgroups of the physical activity assessment: device-based, self-report based. The subgroup results were consistent with a previous systematic review on an eHealth intervention to promote physical activity in adult populations (Muellmann et al., 2018). Studies with self-report based assessment (13 out of 18, 72%) found that their eHealth interventions had either positive (9 out of 13, 69%) or no effect (4 out of 13, 31%) on physical activity in adults with obesity. To be specific, the subgroup with a positive effect consisted of: good quality (1 out of 9, 11%); fair quality (6 out of 9, 67%); and poor quality (2 out of 9, 22%). The subgroup with no effect consisted of: good quality (1 out of 4, 25%) and fair quality (3 out of 4, 75%). Studies with device-based assessment (5 out of 18, 28%) found that their eHealth interventions had either positive (4 out of 5, 80%) or no effect (1 out of 5, 20%) on physical activity in adults with obesity. To be specific, the subgroup with a positive effect consisted of good quality only (4 out of 4, 100%). The subgroup with no effect consisted of fair quality (1 out of 1, 100%). In the harvest plot (see Figure 3), there was moderate strength of evidence that studies with device-based assessment may find that their eHealth interventions have a positive effect on physical activity in adults with obesity. However, there was a lack of information indicating that studies with self-report based assessment may find that their eHealth interventions have a positive effect on physical activity in adults with obesity.

Figure 3. *Harvest plot of evidence for eHealth effectiveness by physical activity assessment*



DISCUSSION

The purpose of this manuscript was to systematically review eHealth intervention studies to promote physical activity in adults with obesity. The findings will be discussed in terms of the research questions in this review study: characteristics of the study design (e.g., physical activity assessment), characteristics of the eHealth interventions (e.g., theory, behavioral change techniques), and support for eHealth as an effective medium (e.g., web-based, mobile phone-based).

In this review study, there was moderate strength of evidence that web-based eHealth intervention is an effective medium to promote physical activity in adults with obesity. Related to the findings, the Physical Activity Guidelines Advisory Committee concludes that there is strong evidence for web-based eHealth interventions to increase physical activity in adults

(USDHHS, 2018). Further, effective multicomponent behavioral interventions for adults with obesity often include web-based technology (The Community Guide, 2017; United States Preventive Services Task Force, 2018). In this review study, however, there was lack of information that indicated that a mobile phone-based eHealth intervention is an effective medium to promote physical activity in adults with obesity. The scientific reasons for the finding cannot be drawn from this systematic review. However, a previous study showed that a web-based intervention may outperform a mobile phone-based intervention for adult populations (Gomez Quiñonez, Walthouwer, Schulz, & de Vries, 2016). An explanation is that participants with a mobile phone-based intervention may be more prone to distractions than participants with a web-based intervention. For example, participants with a mobile phone-based intervention may feel obligated to check their phone regardless of time, place, and readiness (e.g., receiving their intervention tasks at a grocery store or restaurant). The obligation may decrease their intrinsic motivation, leading to skipping activities or ignoring messages. On the other hand, participants with a web-based intervention may be committed to take the time to complete their intervention tasks (e.g., consciously start their computer). The feeling of autonomously choosing when and how to engage may create more intrinsic motivation on a web-based intervention than a mobile phone-based intervention, in the perspective of self-determination theory (Ryan & Deci, 2000). The explanation, however, requires more research to demonstrate its applicability to adults with obesity. This systematic review study supports the previous reports that web-based eHealth interventions are effective in promoting physical activity in adults with obesity.

In this review study, there was moderate strength of evidence that physical activity monitor-based eHealth intervention is an effective medium to promote physical activity in adults with obesity. Physical activity monitors in behavioral interventions (either eHealth or face-to-

face) for adults with obesity are recommended based on two findings from a recent meta-analysis of 11 RCTs (de Vries et al., 2016). First, behavioral interventions with physical activity monitors increase physical activity in adults with obesity. Second, adding physical activity monitors to an existing behavioral intervention (previously without the monitors) may slightly increase physical activity in adults with obesity. An explanation is that physical activity monitors may serve as a tool to increase self-awareness of daily physical activity and to support behavioral physical activity interventions (de Vries et al., 2016). These findings led the Community Preventive Services Task Force to recommend that physical activity interventions for adults with obesity include physical activity monitors and behavioral instructions (The Community Guide, 2017). Along with the previous literature, this review study indicates that eHealth interventions equipped with physical activity monitors are expected to be beneficial because physical activity monitor-based eHealth interventions provide easy access to effective behavioral change techniques such as self-monitoring.

In this review study, there was moderate strength of evidence that studies with device-based assessment may find that their eHealth interventions have a positive effect on physical activity in adults with obesity, but not with self-report based assessment. An explanation is that the use of device-based assessment may affect statistical power to detect the effect of eHealth interventions on physical activity in adults with obesity. A systematic review study showed that the majority of studies with comparable data exclusively on overweight and obese populations reported higher levels of physical activity by self-report, compared to accelerometry (Prince et al., 2008). The scientific importance is reinforced by troubling findings that suggest only small to moderate relative agreement and large absolute disagreement between estimates of physical activity based on self-report versus accelerometry (Cerin et al., 2016). The use of device-based

assessment seems to be related to the statistical power to detect the effect of the eHealth interventions in the included studies.

The measurement method can have a significant impact on the observed levels of physical activity (Prince et al., 2008). Accelerometers and self-reports may measure different constructs due to their different physical activity assessment criteria (Ham, Reis, Strath, Dubose, & Ainsworth, 2007). According to previous literature, possible factors explaining this divergence are: (a) a response bias due to social desirability particularly in obese populations (Prince et al., 2008), (b) a possibility that vigorous physical activity is easier to remember due to their association with the feeling of exhaustion and could be overestimated if warm-up and cool-down are included (Dyrstad, Hansen, Holme, & Anderssen, 2014), (c) the inability of accelerometers to measure activities involving no vertical acceleration such as cycling and upper-body movement (Hagstromer, Ainsworth, Oja, & Sjostrom, 2010), and (d) the choice of accelerometer cut points (Ham et al., 2007). This systematic review study serves as a note of caution that great care should be taken when interpreting device-based assessment and self-report based assessment in the field. Increased use of device-based assessment may help ameliorate some of the challenges that self-report based assessment has particularly for eHealth interventions to promote physical activity in adults with obesity (e.g., little group difference due to self-report response bias by social desirability in the control group).

With respect to theory use, only five studies out of the included studies reported the use of theory (e.g., social cognitive theory) to develop their eHealth interventions and also conducted the evaluation of relevant theoretical constructs (e.g., self-efficacy) in their study design. Among the five studies, only two studies conducted mediation analysis that tests indirect effect of intervention on physical activity via relevant theoretical construct. This would indicate that a

theory application approach is not yet prevalent in the field. However, theory application is an integral component in the design and evaluation of behavioral interventions (Glanz & Bishop, 2010), and the current evidence base supports the application of behavioral theories in developing individual-level interventions to promote physical activity in adult populations (USDHHS, 2018). We acknowledge that effectiveness is often the focus of arguments for or against theory (Dalgetty, Miller, & Dombrowski, 2019; Hagger & Weed, 2019) but believe that the benefits of theory extend beyond effectiveness. An important benefit of theory-based interventions is that researchers can both measure and evaluate specified variables that are expected to lead to the change in behavioral outcomes, providing a unifying framework from which behavior changes are understood (Glasgow & Linnan, 2008). The theoretical understanding of behavior change in a particular population will advance science and develop better eHealth interventions for that population (Michie, Yardley, West, Patrick, & Greaves, 2017). Thus, it is arguable that a theory application approach in developing and evaluating eHealth interventions should be more frequently and carefully adopted in the field.

With respect to behavioral change techniques, the techniques used in the included studies are consistent with some effective techniques used in the majority of face-to-face interventions but used more efficiently to promote physical activity in adults with obesity (Olander et al., 2013; Samdal et al., 2017). Regarding self-monitoring and feedback, participants were asked to self-monitor their physical activity with a physical activity monitor and get feedback via a website or mobile device that is linked to the activity monitor (Jakicic et al., 2016; Nakata, Sasai, Tsujimoto, Hashimoto, & Kobayashi, 2019; Pellegrini et al., 2012; Rogers et al., 2016). Regarding personalized feedback, participants received their feedback generated by a computational algorithm via a website or mobile device (Adams et al., 2017; Beleigoli, Andrade,

Diniz, & Ribeiro, 2020; Hersey et al., 2012). Similarly, participants received their feedback generated by a software-generated coach via their computer (Watson, Bickmore, Cange, Kulshreshtha, & Kvedar, 2012). Regarding social cognitive theory-based techniques, participants were asked to do a variety of activities (e.g., goal-setting, modeling, watching a video, having vicarious experiences, etc.) for behavior change conceptualized by social cognitive theory via a website or mobile device (Joseph et al., 2016; Navarro, Cebolla, Llorens, Borrego, & Baños, 2020; Nazari, Reisi, Tahmasebi, & Javadzade, 2020; Patrick et al., 2011; Roesch, Norman, Villodas, Sallis, & Patrick, 2010). Some effective behavioral techniques delivered in-person are also used in the eHealth interventions but more automatically and efficiently employed using information and communication technology.

Despite the benefits of eHealth (e.g., increased access to information and support on demand), there are at least two challenges that are relevant to eHealth interventions to promote physical activity in adults with obesity. First, eHealth developers may be enamored with the technical elegance and innovation of new information and communication technologies than its contents or utility (Kreps & Neuhauser, 2010). Second, some may perceive authoritative delivery of health information by eHealth without active consultation or consideration of unique issues/barriers in a population as off-putting (Neuhauser & Kreps, 2003), which may lead to less positive behavioral outcomes (e.g., physical activity) and psychological outcomes (e.g., satisfaction) in patients compared to face-to-face interventions. Unfortunately, only a few of the included studies in this review provided sufficient information on how to address the aforementioned challenges (e.g., conceptual or theoretical bases for eHealth, personalized approach).

Researchers and practitioners should be deliberate in developing, implementing, and evaluating eHealth to promote physical activity in adults with obesity. The key recommendations for future eHealth interventions are summarized in Table 3. The recommendations are based on this systematic review study and previous literature and briefly described below.

Table 3. *Summary of key recommendations*

eHealth & Behavioral Change Techniques	Study Design & Evaluation
Consider web-based and physical activity monitor-based eHealth	Interpret device-based and self-report based physical activity assessment carefully
Test more mobile phone-based eHealth	Increase the use of device-based assessment
Consider theory use	Conduct power analysis
Use self-monitoring, personalized feedback, and theory-based techniques	Report randomization procedure
Consider unique barriers in adults with obesity	Measure and evaluate theoretical constructs using mediation analysis
Use technology to meet specific needs of adults with obesity efficiently	Report participant adherence
Combine other health behavior change techniques	Test effectiveness of eHealth in relatively uncontrolled settings

eHealth & Behavioral Change Techniques

According to this systematic review study, using web-based and physical activity monitor-based eHealth should be considered to promote physical activity in adults with obesity in the future. Mobile phone-based eHealth in the field should be tested more in the future. A theory application approach in developing eHealth interventions should be more frequently and carefully adopted in future research. Future research may use the effective behavioral change techniques: self-monitoring and feedback, personalized feedback, social cognitive theory-based techniques. According to previous literature, future research may consider unique barriers to

physical activity in adults with obesity. Previous research has found that adults with obesity may encounter unique barriers (e.g., feeling too fat to exercise, being embarrassed to exercise) in seeking physical activity (Atlantis, Barnes, & Ball, 2008; Ball, Crawford, & Owen, 2000; Leone & Ward, 2013). Information and communication technology can be used to meet specific needs of the population efficiently. Finally, future research is recommended to test physical activity interventions combined with other health behavior interventions (e.g., engaging in positive interactions with people, taking steps to experience peace of mind) to promote optimal physical activity change within the context of such multicomponent interventions (USDHHS, 2018). The aforementioned eHealth and behavioral change techniques will increase the effectiveness of eHealth interventions in the research field, contributing to promoting population-level physical activity change in adults with obesity.

Study Design & Evaluation

According to this systematic review study, great care should be taken when interpreting device-based assessment and self-report based assessment in future research. Increased use of device-based assessment may help ameliorate some of the challenges that self-report based assessment has particularly for adults with obesity. Power analysis should be conducted in future research. The lack of power analysis was observed in previous literature that reviewed eHealth interventions to promote physical activity in broader populations including youth, adolescents, and adults (LaPlante & Peng, 2011). Unfortunately, this issue seems to continue and occur in the field. Future research should report if an adequate randomization procedure (e.g., computer-generated randomization) is employed. If a theory application approach is used, future research may measure and evaluate the relevant theoretical constructs, preferably using mediation analysis (Michie & Abraham, 2004). Future research should report participant adherence to the

protocols for the intervention group because low adherence to the protocol may lead to misleading results on specific clinical outcomes (NIH, 2018). According to previous literature, future research is recommended to test physical activity interventions in relatively uncontrolled settings such as recruiting participants through a national healthcare panel recruitment company (USDHHS, 2018). The aforementioned rigorous methods in study design and evaluation will reduce the risk of bias in the research field, resulting in more accurately evaluating the effect of the eHealth interventions on physical activity in adults with obesity. It is recommended for eHealth researchers to consult available guidelines such as Consolidated Standards of Reporting Trials-EHEALTH checklist (Eysenbach & CONSORT-EHEALTH Group, 2011). The checklist may help researchers: (a) plan stages and design of their studies, (b) propose modifications or enhancements to these standards in the study design and evaluation, and (c) provide sufficient information about study results.

We are aware of at least four limitations of this systematic review. First, the assessment of risk of bias was not easy and possibly subjective. The limitation, however, was partially addressed by the two independent raters (e.g., carefully exploring and resolving any disagreement). Second, some researchers may use a different age range for adult populations such as 19-64 years in the United Kingdom or 18-65 in Germany, rather than 18-64 years. The age break between adults and older adults is not clear-cut but may generally center on retirement (USDHHS, 2018). Third, a variety of intervention technology used in the included studies were categorized by reviewing their research questions (or hypotheses) and main technology, but we acknowledge that some of the included studies used more than one medium (i.e., not 100% exclusive). For example, a physical activity monitor-based eHealth intervention was sometimes combined with a website or mobile application using the Internet to allow participants to check

their activity level. This limitation appeared in previous literature reviews on eHealth interventions to promote physical activity in adult populations (e.g., de Vries et al., 2016; Muellmann et al., 2018). Fourth, this review study was largely narrative because of the nature of qualitative data synthesis.

As indicated in this review study, interventions with information and communication technology are promising. This potential is supported by the RE-AIM perspective that eHealth can be rated as an intervention with relatively: high *R*each, low *E*fficacy, moderate *A*doption, moderate *I*mplementation, and moderate *M*aintenance (Glasgow, Vogt, & Boles, 1999). Low-cost eHealth interventions that work in real-world environment have the potential to make population-level progress in health promotion and to be worth sustained investment. Thus, it is recommended to measure and evaluate physical activity (not only weight) in adults with obesity in eHealth research (e.g., eHealth interventions for weight loss) because, even without weight loss, adults with obesity who increase physical activity experience some of the health benefits (e.g., relative reduction in incidence of type 2 diabetes). Behavioral interventions with information and communication technology may have the potential to become useful in some small (i.e., meaningful effect size) but important ways (i.e., online intervention delivery for dissemination) to increase physical activity in adults with obesity.

In conclusion, this review study shows that a web-based or physical activity monitor-based eHealth intervention has the potential to be effective in promoting physical activity in adults with obesity. It is noted that some effective behavioral techniques delivered in-person are also employed in the eHealth interventions but more automatically and efficiently using information and communication technology. For future studies, a theory application approach (e.g., theory use, mediation analysis), monitor-based assessment (e.g., accelerometers), and

rigorous methods (e.g., power analysis) are recommended. To our knowledge, this systematic review is the first to review the effectiveness of eHealth interventions to promote physical activity in adults with obesity. The findings provide a contemporary and salient research base and identify gaps in this emergent area to help researchers and practitioners who develop, implement, and evaluate eHealth interventions to promote physical activity in adults with obesity.

APPENDIX

Table 4. *Search terms and search results*

Database	Search Keywords	Additional Limits	Results
PubMed	#1: ((((((((((physical activity) OR (physical training)) OR (exercis*)) OR (aerobic)) OR (walk)) OR (running)) OR (bicycle)) OR (cycling)) OR (swim)) OR (yoga)) OR (danc*)) OR (gardening) #2: ((((((((((((((eHealth) OR (mHelath)) OR (digital)) OR (computer)) OR (web)) OR (online)) OR (internet)) OR (mobile application)) OR (phone)) OR (text messag*)) OR (email)) OR (electronic mail)) OR (multimedia)) OR (exergame*)) OR (acceleromet*)) OR (pedometer) #3: (((adults with obesity) OR (adults with overweight)) OR (obese adult)) OR (obese patient) #4: #1 AND #2 AND #3	Clinical Trial, Randomized Controlled Trial	1353 results (11/25/2020)
CINAHL	S1: physical activity OR physical training OR exercis* OR aerobic OR walk OR running OR bicycle OR cycling OR swim OR yoga OR danc* OR gardening S2: eHealth OR mHelath OR digital OR computer OR web OR online OR internet OR mobile application OR phone OR email OR exergame* OR acceleromet* S3: adults with obesity OR adults with overweight OR obese adult OR obese patient S4: S1 AND S2 AND S3	Limiters - English Language; Research Article; Peer Reviewed; Human; Randomized Controlled Trials	226 results (11/25/2020)

Table 4 (cont'd)

Database	Search Keywords	Additional Limits	Results
Cochrane	#1: (physical activity):ti,ab,kw OR (physical training):ti,ab,kw OR (exercis*):ti,ab,kw OR (aerobic):ti,ab,kw AND (walk):ti,ab,kw #2: (digital):ti,ab,kw OR (online):ti,ab,kw OR (internet):ti,ab,kw OR (web):ti,ab,kw OR (app):ti,ab,kw #3: (adults with obesity):ti,ab,kw OR (adults with overweight):ti,ab,kw OR (obese adult):ti,ab,kw OR (obese patient):ti,ab,kw #4: #1 AND #2 AND #3		738 results (11/25/2020)
PsycINFO	S1: (noft(physical activity) OR noft(physical training) OR noft(exercis*) OR noft(aerobic) OR noft(walk) OR noft(running) OR noft(bicycle) OR noft(cycling) OR noft(swim) OR noft(yoga)) AND PEER(yes) S2: (noft(eHealth) OR noft(mHelath) OR noft(digital) OR noft(computer) OR noft(web) OR noft(online) OR noft(internet) OR noft(app) OR noft(phone) OR noft(email)) AND PEER(yes) S3: ((adults with obesity) OR (adults with overweight) OR (obese adult) OR (obese patient)) AND PEER(yes) S4: (S1 AND S2 AND S3) AND me.exact("Empirical Study" NOT ("Meta Analysis" OR "Literature Review" OR "Systematic Review" OR "Brain Imaging" OR "Mathematical Model"))		159 results (11/25/2020)

Table 4 (cont'd)

Database	Search Keywords	Additional Limits	Results
Embase	#1: ('physical activity':ti,ab,kw OR 'physical training':ti,ab,kw OR exercis*:ti,ab,kw OR aerobic:ti,ab,kw OR walk:ti,ab,kw OR running:ti,ab,kw OR bicycle:ti,ab,kw OR cycling:ti,ab,kw OR swim:ti,ab,kw OR yoga:ti,ab,kw OR danc*:ti,ab,kw OR gardening:ti,ab,kw) AND ([controlled clinical trial]/lim OR [randomized controlled trial]/lim) #2: (ehealth:ti,ab,kw OR mhelath:ti,ab,kw OR digital:ti,ab,kw OR computer:ti,ab,kw OR web:ti,ab,kw OR online:ti,ab,kw OR internet:ti,ab,kw OR 'mobile application':ti,ab,kw OR phone:ti,ab,kw OR 'text messag*':ti,ab,kw OR email:ti,ab,kw OR 'electronic mail':ti,ab,kw OR multimedia:ti,ab,kw OR exergame*:ti,ab,kw OR acceleromet*:ti,ab,kw OR pedometer:ti,ab,kw) AND ([controlled clinical trial]/lim OR [randomized controlled trial]/lim) #3: ('adults with obesity' OR (('adults'/exp OR adults) AND with AND ('obesity'/exp OR obesity)) OR 'adults with overweight' OR (('adults'/exp OR adults) AND with AND ('overweight'/exp OR overweight)) OR 'obese adult' OR (obese AND ('adult'/exp OR adult)) OR 'obese patient'/exp OR 'obese patient' OR (obese AND ('patient'/exp OR patient))) AND ([controlled clinical trial]/lim OR [randomized controlled trial]/lim) #4: #1 AND #2 AND #3		717 results (11/25/2020)

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CHAPTER III: STUDY 2

EFFECTIVENESS OF THE FUN FOR WELLNESS ONLINE BEHAVIORAL INTERVENTION TO PROMOTE WELL-BEING ACTIONS IN ADULTS WITH OBESITY OR OVERWEIGHT: A RANDOMIZED CONTROLLED TRIAL

PREFACE

This study was financially supported, in part, with a Summer Research Renewable Fellowship that I was awarded in 2020. Study 2 from this dissertation is published in a peer-reviewed journal, *Journal of Sport and Exercise Psychology* (see reference below). Study 2 is provided as supplemental material in PDF format, consistent with the Copyright and Permissions of Human Kinetics (see https://journals.humankinetics.com/page/copyright/copyright-and-permissions).

Lee, S., McMahon, A., Prilleltensky, I., Myers, N. D., Dietz, S., Prilleltensky, O., . . . Brincks, A. M. (2020). Effectiveness of the fun for wellness online behavioral intervention to promote well-being actions in adults with obesity or overweight: A randomized controlled trial. *Journal of Sport & Exercise Psychology, 43,* 83-96. doi:10.1123/jsep.2020-0049

CHAPTER IV: SUMMARY/DISCUSSION

EHEALTH INTERVENTIONS TO PROMOTE PHYSICAL ACTIVITY AND WELL-BEING ACTIONS IN ADULTS WITH OBESITY

The topic of this dissertation is eHealth interventions to promote physical activity and well-being actions in adults with obesity. This dissertation intends to increase knowledge in the emergent area, by conducting both a systematic review study (Study 1) and an empirical study (Study 2). The findings are summarized and discussed in the following sections.

SUMMARY

Study 1

The purpose of Study 1 was to systematically review eHealth intervention studies to promote physical activity in adults with obesity. The main findings are as follows.

1. In the search, 2276 articles were identified, and 18 studies met all inclusion criteria. The included studies were rated as poor quality, fair quality, or good quality
2. The included studies varied in intervention technology: web-based, mobile phone-based, and physical activity monitor-based. In the harvest plot, there was moderate strength of evidence that a web-based or physical activity monitor-based eHealth intervention is an effective medium to promote physical activity in adults with obesity. However, there was a lack of information indicating that a mobile phone-based eHealth intervention is an effective medium to promote physical activity in adults with obesity.
3. The included studies varied in physical activity assessment: device-based assessment, self-report based assessment. In the harvest plot, there was moderate strength of evidence that studies with device-based assessment may find that their eHealth interventions have a positive effect on physical activity in adults with obesity. However, there was a lack of

information indicating that studies with self-report based assessment may find that their eHealth interventions have a positive effect on physical activity in adults with obesity.

4. Regarding theory use, less than half of the included studies explicitly reported the use of theory to develop their interventions, for example, social cognitive theory. Only a little more than half of the studies with theory use measured and evaluated the relevant theoretical constructs that were expected to affect physical activity level. In general, there was agreement between theoretical construct change and physical activity change in the studies.
5. Regarding behavioral change techniques, a number of different techniques were employed and can be categorized by: self-monitoring and feedback, social cognitive theory-based techniques, personalized feedback, information and advice on health, coaching, and a combination of the aforementioned techniques.

Overall, Study 1 shows that a web-based or physical activity monitor-based eHealth intervention has the potential to be effective in promoting physical activity in adults with obesity. The use of theory and monitor-based physical activity assessment in eHealth seems to be beneficial to the intervention design and study design.

Study 2

The purpose of Study 2 was to evaluate the effectiveness of the Fun For Wellness (FFW) online intervention to increase well-being actions in adults with obesity in the United States of America (USA) in relatively uncontrolled settings. The main findings are as follows.

1. In Study 2, participants (N = 667) who were assigned to the FFW group (nFFW = 331) were provided with 30 days of 24 hr access to FFW.

2. There was evidence of internal structure validity (confirmatory factor analysis) and test-retest reliability (intraclass correlation) in the well-being action scale and well-being action self-efficacy scale.
3. The single path model provided evidence for adequate fit of the path model to the observed data. The unstandardized estimate of each focal parameter from the path model is described below.
    a. The adjusted mean difference on well-being actions self-efficacy at T2 for the FFW group as compared to the usual care (UC) group was statistically significant and approximately small in size for two dimensions: community, psychological.
    b. The path coefficient from well-being actions self-efficacy at T2 to well-being actions at T3 was statistically significant for every dimension: interpersonal, community, occupational, physical, psychological, and economic.
    c. The adjusted mean difference on well-being actions at T3 for the FFW group as compared to the UC group was statistically significant and approximately small in size for two dimensions: community, occupational.
    d. The 95% CI for the product of path coefficients from FFW to well-being actions at T3 through well-being actions self-efficacy at T2 did not include 0.00 for two dimensions: community, psychological.

Overall, Study 2 provides at least partial supportive evidence to the four construct-level hypotheses tested.

DISCUSSION

In recent years with the emergence of information and communication technology and widespread use of technology by societies, the way individuals interact and get information has

changed. Compared to a typical face-to-face intervention, an eHealth intervention may offer several potential advantages for promoting healthy behaviors in individuals such as increased access to information and support on demand (see the introduction section of Study 1 for full information). The advantages of eHealth interventions are equally (or even possibly more) important to adults with obesity due to at least two noteworthy reasons. First, previous research has reported that behavioral interventions for adults with obesity are typically intensive and require in-person sessions, often occurring for about 6 months or a little less (Sharma, 2007). This intensive approach may not be appealing to adults with obesity who are unable or unwilling to participate in the in-person sessions for the period. In this case, eHealth interventions can be an alternative program to replace or complement face-to-face interventions while retaining key behavioral change techniques. Second, previous research has reported that adults with obesity may encounter unique barriers (e.g., feeling too fat to exercise, being embarrassed to exercise) in seeking healthy behaviors (Atlantis, Barnes, & Ball, 2008; Ball, Crawford, & Owen, 2000; Leone & Ward, 2013). Using information and communication technology, eHealth interventions can tailor their treatment to the specific needs of the population efficiently and also increase possibility for users to remain anonymous while seeking information and support from experts about a sensitive and private health issue. As shown by Study 1 and Study 2 in this dissertation, eHealth interventions have the potential to be effective in promoting physical activity and well-being actions in adults with obesity.

This dissertation reviewed and tested intervention technology in the eHealth field. In Study 1, there was moderate strength of evidence that web-based eHealth intervention is an effective medium to promote physical activity in adults with obesity. In Study 2, supportive evidence was provided for the effectiveness of FFW as a web-based eHealth intervention.

Related to the findings, there is strong evidence that web-based eHealth interventions are effective to increase physical activity in adults (United States Department of Health and Human Services [USDHHS], 2018). Further, effective multicomponent behavioral interventions for adults with obesity are often delivered via web-based technology (The Community Guide, 2017; United States Preventive Services Task Force, 2018). This dissertation supports the previous reports that web-based eHealth interventions are effective in promoting physical activity and well-being actions in adults with obesity.

This dissertation reviewed the use of theory in the eHealth field and tested the effectiveness of the FFW intervention that is based on a theory. In Study 1, only five studies out of the reviewed studies reported the use of theory (e.g., social cognitive theory) to develop their eHealth interventions and also conducted the evaluation of relevant theoretical constructs (e.g., self-efficacy). This would indicate that a theory application approach for developing and evaluating eHealth to promote physical activity in adults with obesity is not yet prevalent. However, theory application is important in the design and evaluation of behavioral interventions (Glanz & Bishop, 2010), and the current evidence supports the application of behavioral theories in developing individual-level interventions to increase physical activity in adults (USDHHS, 2018). In Study 2, the effectiveness of the FFW eHealth intervention that was based on self-efficacy theory (more broadly social cognitive theory) to promote well-being actions in adults with obesity was evaluated. Accordingly, self-efficacy was specified as a mediating variable in the FFW conceptual model for the promotion of well-being actions. Supportive evidence was provided for the effectiveness of FFW in real-world settings to promote, either directly or indirectly, three dimensions of well-being actions. With respect to behavioral change techniques, both Study 1 and Study 2 support that social cognitive theory-based techniques are effective in

eHealth interventions to promote physical activity and well-being actions in adults with obesity. This dissertation will contribute to a theory application approach in the eHealth field.

This dissertation suggests that future research should utilize rigorous methods in evaluating eHealth interventions to promote physical activity and well-being actions in adults with obesity. In Study 1, the majority of the included studies rated as fair or poor quality did not report: (a) power analysis, (b) participant adherence to the protocols for intervention group, or (c) randomization procedure if study design is RCT. In Study 2, the issues were addressed by using or reporting: (1) sample size determination, (2) compliance data, and (3) computer-generated randomization. The study design and reporting issues should be addressed in future research because rigorous methods in study design will reduce the risk of bias in the research field, resulting in more accurately evaluating and comparing the effect of the eHealth interventions on physical activity and well-being actions in adults with obesity.

This dissertation has at least two limitations. For each limitation, a possible solution is provided as follows. First, Study 1 was largely narrative because of the nature of qualitative data synthesis. In the future, a possibility of meta-analysis on the included studies will be carefully checked by an expert in the quantitative data synthesis. Second, Study 2 did not use device-based physical activity assessment. As indicated by Study 1, the use of device-based assessment may help ameliorate some of the challenges that self-report based assessment has for eHealth interventions to increase physical activity in adults with obesity (e.g., no group difference due to self-report response bias by social desirability in the control group). To address the limitation, a feasibility study using both self-reported and accelerometer-measured physical activity in adults with obesity is currently underway in the FFW context (Myers et al., 2019).

In conclusion, this dissertation shows that an eHealth intervention has the potential to be effective in promoting physical activity and well-being actions in adults with obesity in a relatively uncontrolled setting, particularly when the intervention is web-based or physical activity monitor-based, using theory. The use of monitor-based physical activity assessment in the field is recommended. The eHealth intervention area is relatively new, particularly for adults with obesity. This dissertation provides a contemporary and salient research base and identifies gaps in the emergent area, indicating that eHealth interventions are promising for adults with obesity. However, researchers and practitioners should be deliberate in using eHealth to ensure that they maximize the benefits of eHealth. This dissertation will be useful to develop, implement, and evaluate an eHealth intervention that effectively and efficiently promotes physical activity and well-being actions in adults with obesity in real-world settings.

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